Wahleach Project Water Use Plan

Wahleach Reservoir Fertilization Program

Implementation Year 16

Reference: WAHWORKS-2

WAHLEACH RESERVOIR NUTRIENT RESTORATION PROJECT REPORT, 2020 - Fisheries Project Report No. RD 175

Study Period: 2020

**Province of British Columbia, Ministry of Environment,
Ecosystems Protection & Sustainability Branch**

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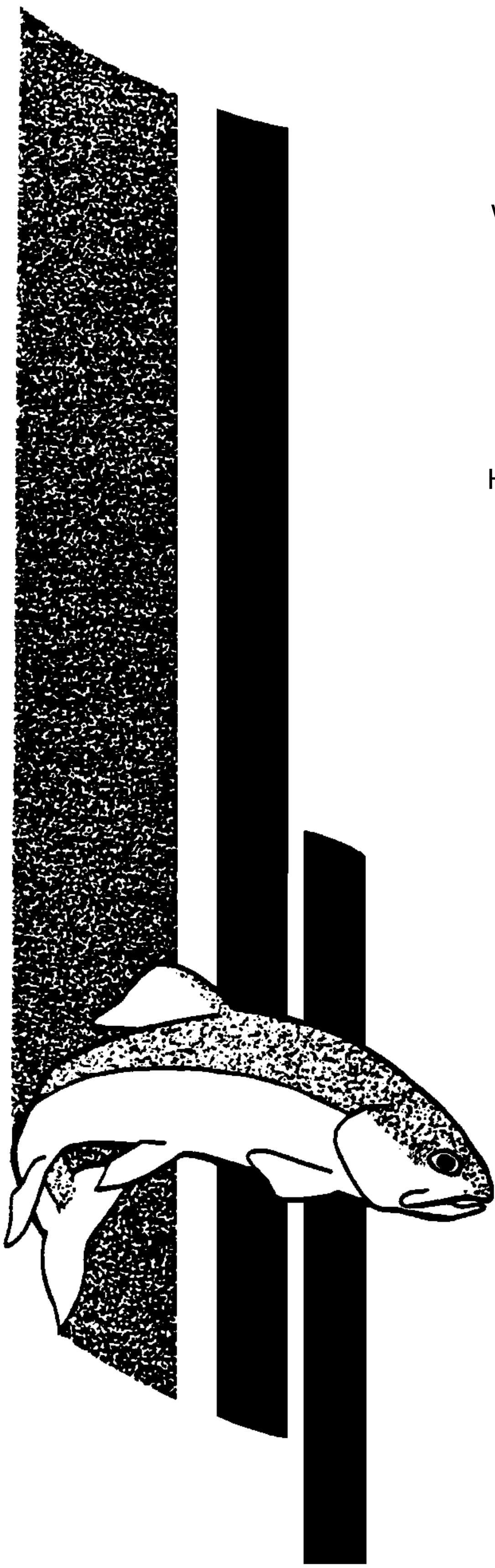

WAHLEACH RESERVOIR NUTRIENT RESTORATION PROJECT REPORT, 2020

by

H.E. Vainionpaa, J.A. Sarchuk, T. Weir, and S.L. Harris

Fisheries Project Report No. RD 175
2022

Province of British Columbia
Ministry of Environment and Climate Change Strategy
Ecosystems Branch

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Executive Summary

The restoration of the Wahleach Reservoir Kokanee population continued in 2020 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 2020 monitoring year.

In 2020, 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 present throughout the season, while abundance of inedible species was high in 2020 samples, with peaks in July in both basins due to blooms of an inedible blue-green algae. Small blooms of blue-green algae are common in Wahleach during the summer as water temperatures increase and have not been observed to negatively impact higher trophic levels. The seasonal mean phytoplankton abundance was 23,371 cells·mL^{-1} (SD = 21,467), while biovolume was 0.34 $mm^3 \cdot L^{-1}$ (SD = 0.23). At the secondary trophic level, *Daphnia* densities averaged 2.1 individuals·L^{-1} and biomass averaged 47.5 µg·L^{-1}; *Daphnia* accounted for 38% of the total zooplankton density and 53% 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. Threespine Stickleback abundance based on hydroacoustic estimates remained low at 31,799, 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 2020, the age 0 and age ≥1 Kokanee populations were both higher than the previous year at 105,978 and 24,049 individuals, respectively. The escapement estimate for Kokanee was 4,996 spawners; however, it should be noted that this is an underestimate as the peak of the run on Flat Creek was not captured. Cutthroat Trout catch from fall 2020 gillnetting included ages 1+ to age 2+, with a mean length of 282 ± 61 mm (range 225 to 325 mm) and mean condition factor of 0.95 ± 0.07. Two larger Cutthroat Trout were released alive, as such, weights and ages were not recorded; these likely represented older age classes.

Overall, data from Wahleach Reservoir have demonstrated that seasonal nutrient additions are associated with 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.

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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*). 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*), 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, trawl, 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 Ministry of Environment 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 second three-year Memorandum of Understanding (for 2018, 2019, 2020) was signed by BC Hydro and the Province.

This summary report presents data from the 2020 monitoring season.

2. Study Area

Wahleach Reservoir is located at 49°13'N, 121°36'W, approximately 100 km east of Vancouver, British Columbia within the traditional territory of the S'ólh Téméxw (Stó:lō) people (Figure 1). 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 a 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.

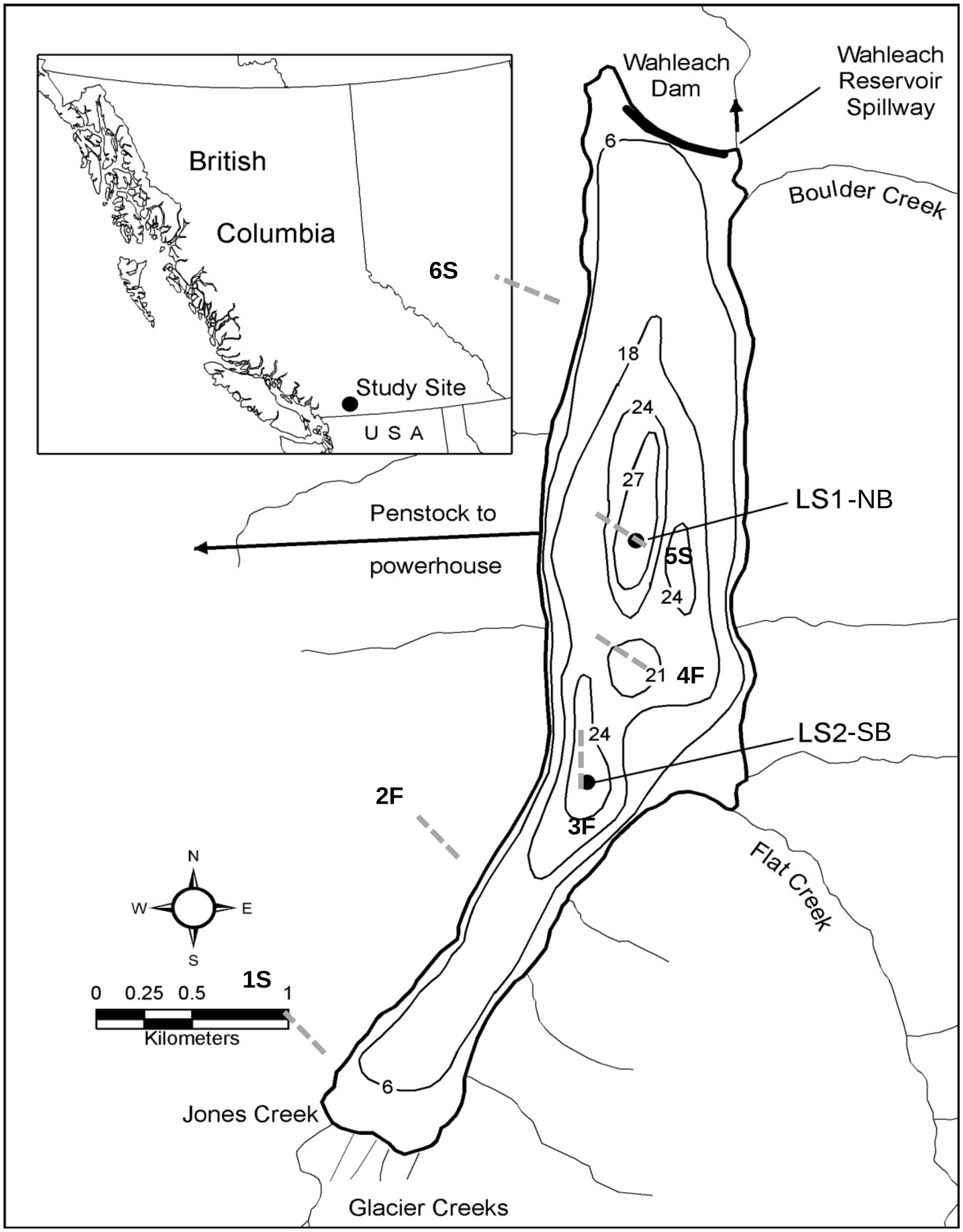


Figure 1. Map of Wahleach Reservoir, BC, including sampling locations. LS2-SB and LS1-NB are limnological sample locations and 1S, 2F, 3F, 4F, 5S, and 6S are gillnetting locations, with S=sinking net and F=floating net. Bathymetric contour depths (m) represent the reservoir at full pool.

3. Methodology

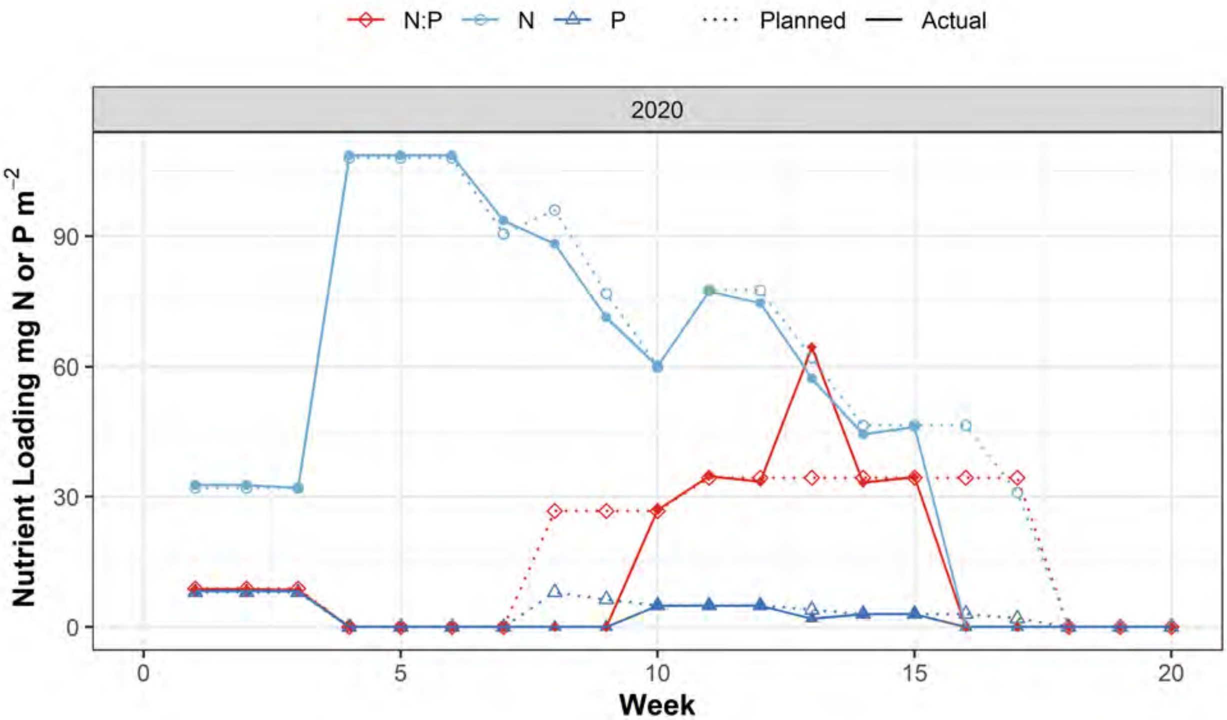
All figures and analyses contained in this report were completed using R version 3.6.1 (R Core Team, 2019). Supporting R packages included doBy and tidyverse. The reported long-term mean values were calculated for the duration of the Wahleach Reservoir Nutrient Restoration Project from 1993-2020. Values used in a comparative context represent baseline conditions from 1993-1994, and nutrient restoration conditions from 1995-2020. 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 first week of June (after thermal stratification) for a period of 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 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 2020 included nitrogen-only applications from weeks 4 to 9 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. At Wahleach Reservoir in 2020, despite challenges associated with the COVID-19 pandemic, a communicable disease prevention plan was successfully implemented, and nutrient additions began as planned at the start of June. Actual nutrient loading rates were modified in weeks 8 and 9 by omitting phosphorus loading after assessment of *in situ* conditions (Figure 2, Table 1). During week 13, phosphorus loading was reduced by half, again based on *in situ* conditions. Overall, weekly areal loading rates for phosphorus were greatest at the start of the season with a maximum of 8.3 mg $P\cdot m^{-2}$, with a total of 68.4 mg $P\cdot m^{-2}$ for the season. Nitrogen loading increased rapidly during the first five weeks of the season with a maximum of 108.5 mg $N\cdot m^{-2}$ (Figure 2). Total nitrogen loading for the season from both the ammonium polyphosphate and urea-ammonium nitrate was 1130.9 mg $N\cdot m^{-2}$. The weekly molar nitrogen to phosphorus ratio peaked at 64.4 during the latter half of the season when both phosphorus and nitrogen loading rates were being ramped down (Figure 2).



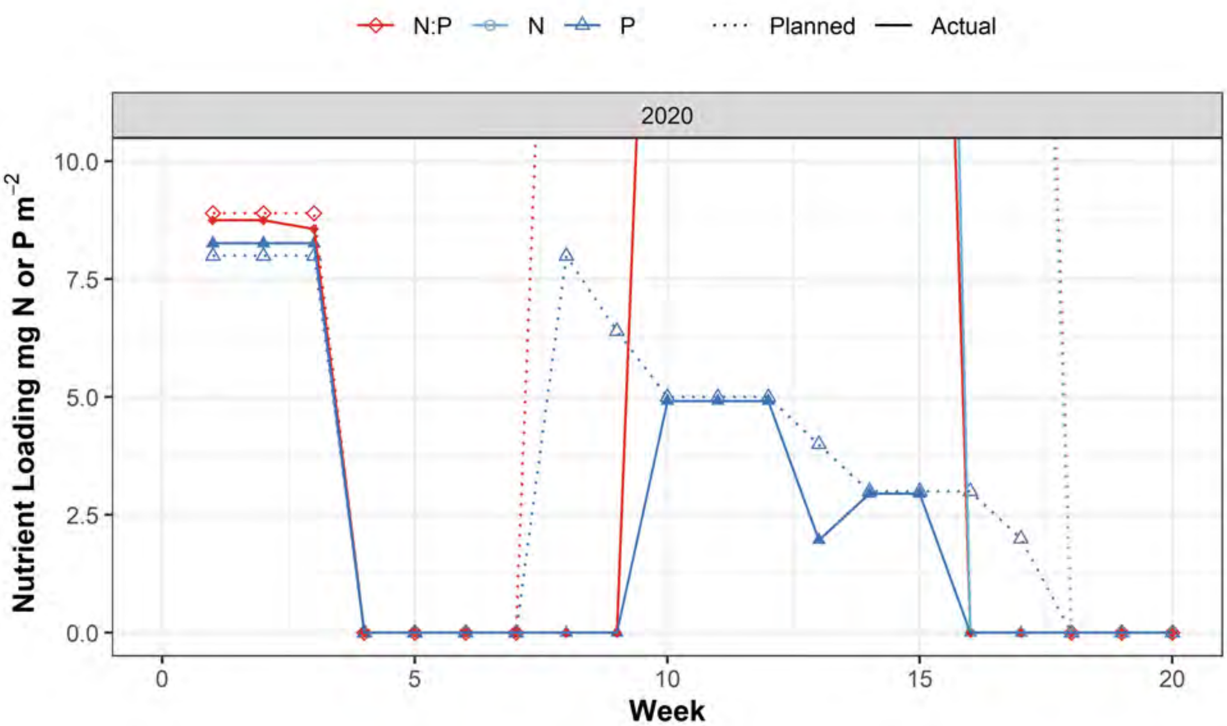


Figure 2. Upper figure shows seasonal planned and actual nutrient additions for Wahleach Reservoir, including areal nitrogen and phosphorus loading as well as molar N:P ratios, 2020; planned values are represented by hollow points and dashed line, while actual values are represented by solid points and solid line. Lower figure is zoomed in to better show phosphorus loading values.

Table 1. Annual nutrient additions by weight and areal loading, 2020, 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	$mg \cdot m^{-2}$
2020	3-Jun to 9-Sep	1.28	14.3	434	47.4	4,142	1035

3.1.2 Fish Stocking

Stocking of (sterile) triploid Cutthroat Trout was continued to maintain top-down pressure on the Threespine Stickleback population. In 2020, a total of 2,000 triploid Cutthroat Trout (average weight 76.94 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 acoustic 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 to a downstream project through the penstock). Analysis methods followed Sarchuk et al. (2019).

3.2.2 Climate

Data were provided by BC Hydro. Analysis methods followed Sarchuk et al. (2019).

3.2.3 Physical and Chemical Limnology

Two sites were sampled monthly from May to October: 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).

3.2.4 Phytoplankton

Depth-integrated samples of the epilimnion were collected monthly from May to October. 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 previous reports, phytoplankton analysis was conducted by John Stockner, Eco-Logic Ltd. Starting in 2019, analysis was 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 October 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 2020 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, 2020, Wahleach Reservoir, BC.

Gear	Station	Latitude	Longitude	Station	Latitude	Longitude
GN	1S	49°12.474 N	121°38.015 W	4F	49°13.429 N	121°36.244 W
GN	2F	49°13.215 N	121°37.181 W	5S	49°14.167 N	121°36.220 W
GN	3F	49°13.060 N	121°36.673 W	6S	49°14.625 N	121°36.878 W
MT	1M	49°14.042 N	121°37.127 W	4M	49°13.323 N	121°37.147 W
MT	2M	49°13.771 N	121°37.158 W	5M	49°12.183 N	121°37.999 W
MT	3M	49°13.402 N	121°37.146 W	6M	49°12.143 N	121°37.977 W

Standardized annual nearshore gillnet sampling was completed from October 21 to 22, 2020, 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 2020, 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 4 to October 7, 2020. For additional field sampling and analysis methods, refer to Sarchuk et al. (2019).

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 2020 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, 2020, Wahleach Reservoir, BC.

Year	Survey Date	Sounder	Reservoir Elevation[1] (m)	Avg Transect Start/End Depth (m)
2020	August 19	EK60	638.92	8

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

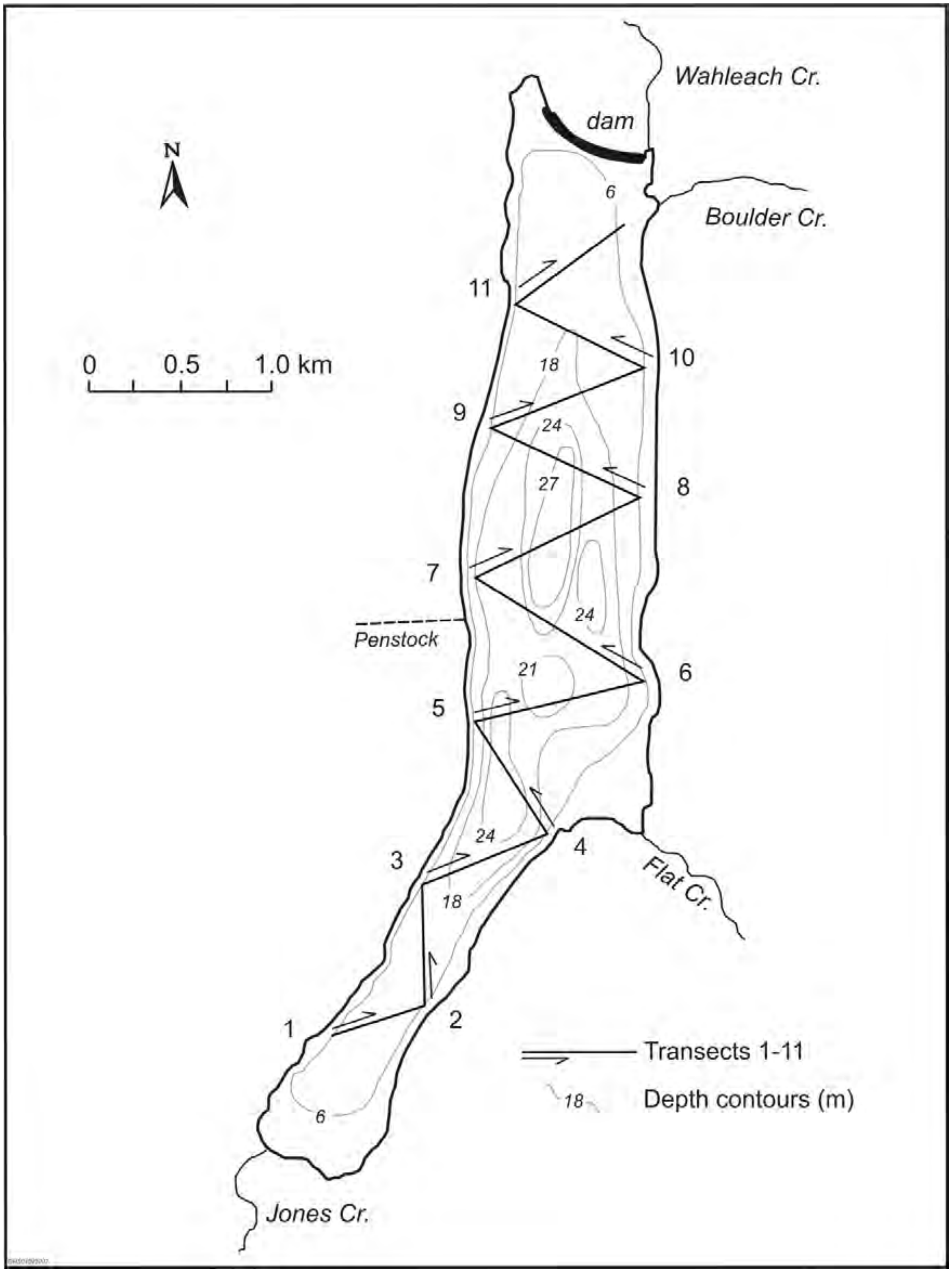


Figure 3. Locations of standardized hydroacoustic transects, Wahleach Reservoir, BC.

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; accordingly, the 'All Fish' population was defined as all targets >-66 dB from 2-30 m. The 'All Fish' 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 2020 the inflection point was -46 dB (Table 4). Within the 'All Fish' group, the small fish component (-66 to -47 dB) included age 0 Kokanee (i.e., fry) and Threespine Stickleback while the larger size group (≥ -46 dB) represented age ≥1 Kokanee, as well as lesser numbers of Cutthroat Trout and Rainbow Trout.

Acoustic data were then partitioned by depth and again by size 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 2020, the depth range that met these criteria was 6-30 m. Table 4 summarizes the depth and size criteria applied. In this report, the 6-30 m estimates are referred to as Kokanee populations, specifically Kokanee fry (age 0; depth-partitioned targets within the small size group decibel range), adult Kokanee (age ≥1; depth-partitioned targets within the large size group decibel range), and all Kokanee (fry and adult Kokanee combined).

Table 4. Summary of analysis parameters for hydroacoustic data, 2020, Wahleach Reservoir, BC.

Groups	Analysis Depth Range (m)	Small Fish dB Thresholds	Large Fish dB Thresholds
All Fish	2-30	-66 to -47	≥ -46
Kokanee	6-30	-66 to -47	≥ -46

Fish populations were estimated with confidence intervals using a stochastic simulation approach (a Monte Carlo method). Simulations were done in R (R Core Team, 2019), producing estimates for all fish size categories within the reservoir, as well as within the Kokanee depth range. Additional details can be found in Sarchuk et al. (2019).

Initial biomass (kg) estimates for Wahleach Reservoir were presented in detail in Sarchuk et al. (2019); methods were based on a novel approach developed specifically for Wahleach Reservoir and vary from typical biomass estimates reported by the Province for other large lakes and reservoirs in BC. Biomass densities (kg/ha) were not reported for this reason for Wahleach Reservoir. Methods for this report were consistent with the approach taken in Sarchuk et al. (2019).

4. Results

4.1 Hydrometrics and Reservoir Operations

4.1.1 Inflow

Mean daily inflow into Wahleach Reservoir during 2020 was 6.4 ± 5.2 $m^3 \cdot s^{-1}$ (range 0.9 to 60.0 m^3 s^{-1}), which was similar to the long-term mean of 6.2 ± 5.4 $m^3 \cdot s^{-1}$ (range 0 to 96.1 $m^3 \cdot s^{-1}$). During the nutrient addition period (June to September, inclusive), mean daily inflow was 6.0 ± 3.9 $m^3 \cdot s^{-1}$ (range 0.9 to 17.9 $m^3 \cdot s^{-1}$) which was also similar to 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 flows were observed in February, while consistently high flows were also observed during spring freshet and the fall and winter storm season (Figure 4).

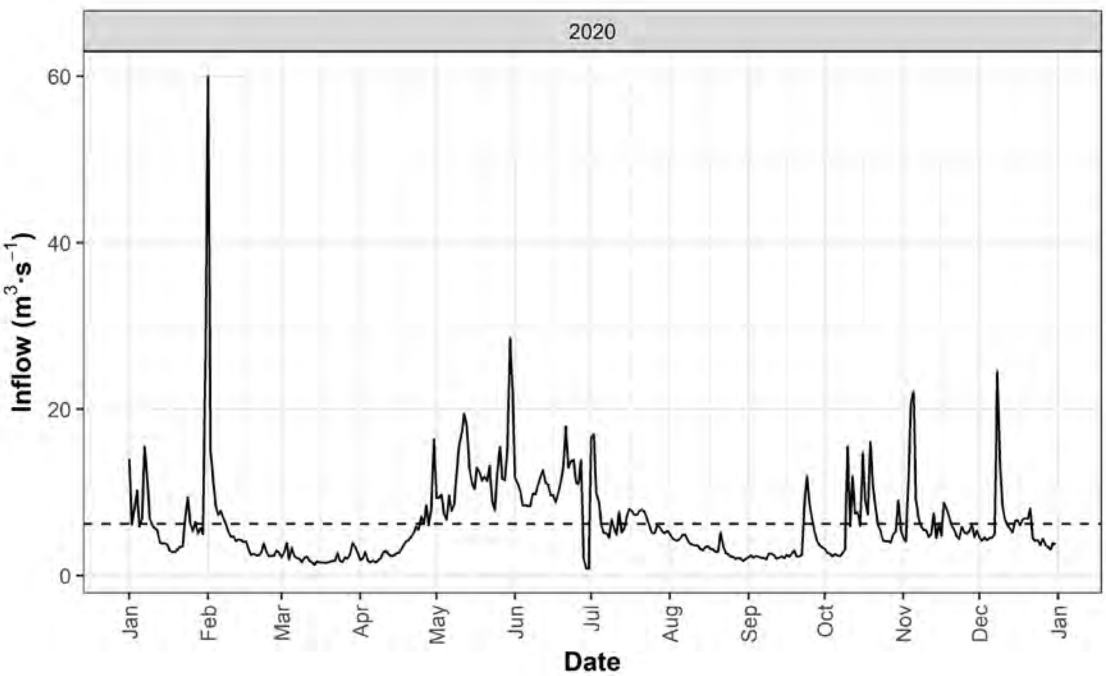


Figure 4. Daily inflow ($m^3 \cdot s^{-1}$), 2020, Wahleach Reservoir, BC. Dashed line is the long-term mean from 1993-2020 for daily inflows.

4.1.2 Discharge

Mean daily discharge from Wahleach Reservoir in 2020 was 5.6 ± 5.3 $m^3 \cdot s^{-1}$ (range 0 to 16.9 $m^3 \cdot s^{-1}$), which was lower than the long-term mean of 6.2 ± 4.7 $m^3 \cdot s^{-1}$ (range 0 to 78.6 $m^3 \cdot s^{-1}$). During the nutrient addition period, mean daily discharge was 6.6 ± 4.5 $m^3 \cdot s^{-1}$ (range 0.8 to 16.9 $m^3 \cdot s^{-1}$), which was higher than the long-term mean of 5.3 ± 4.5 $m^3 \cdot s^{-1}$ (range 0 to 28.1 $m^3 \cdot s^{-1}$). Figure 5 shows the annual pattern in discharge, which was highly variable. Generally, discharge was the greatest during high inflow periods associated with fall and winter storms, as well as during spring freshet. No outflow occurred from late January to late April.

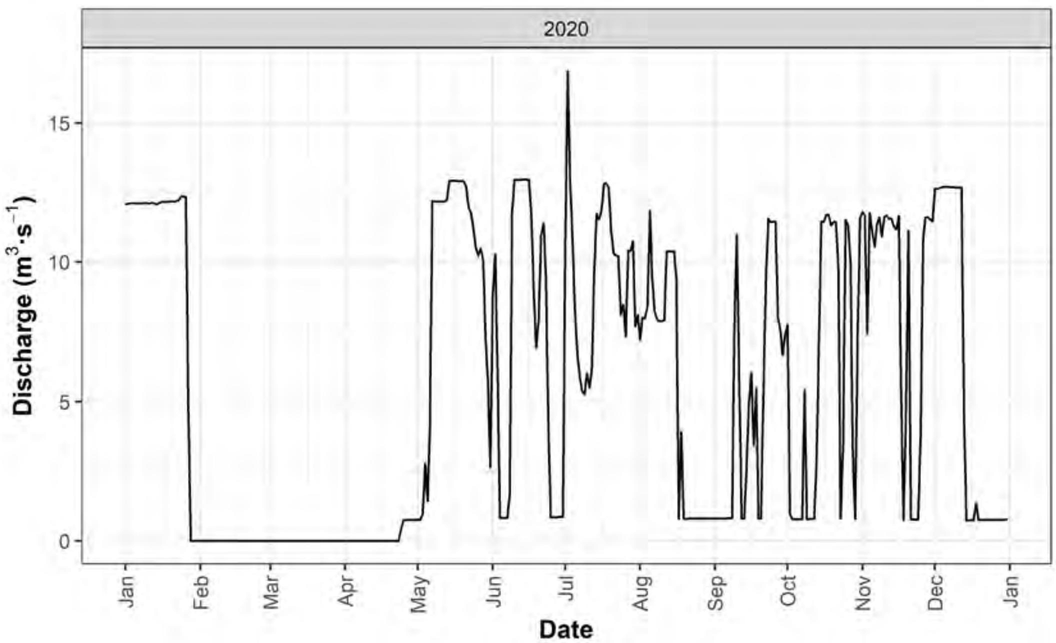


Figure 5. Daily discharge ($m^3 \cdot s^{-1}$), 2020, Wahleach Reservoir, BC.

4.1.3 Reservoir Elevation

The minimum water elevation is typically observed during the month of April or May, and 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 2020, the minimum elevation was observed in late January which is about one month earlier than in 2019. During this month the reservoir reached the minimum standard operating level of 628 m. After this, reservoir levels steadily increased until reaching maximum elevation in July. The drawdown was 14.0 m in 2020, which was higher than the long-term (1993-2020) mean of 12.2 m (Figure 6).

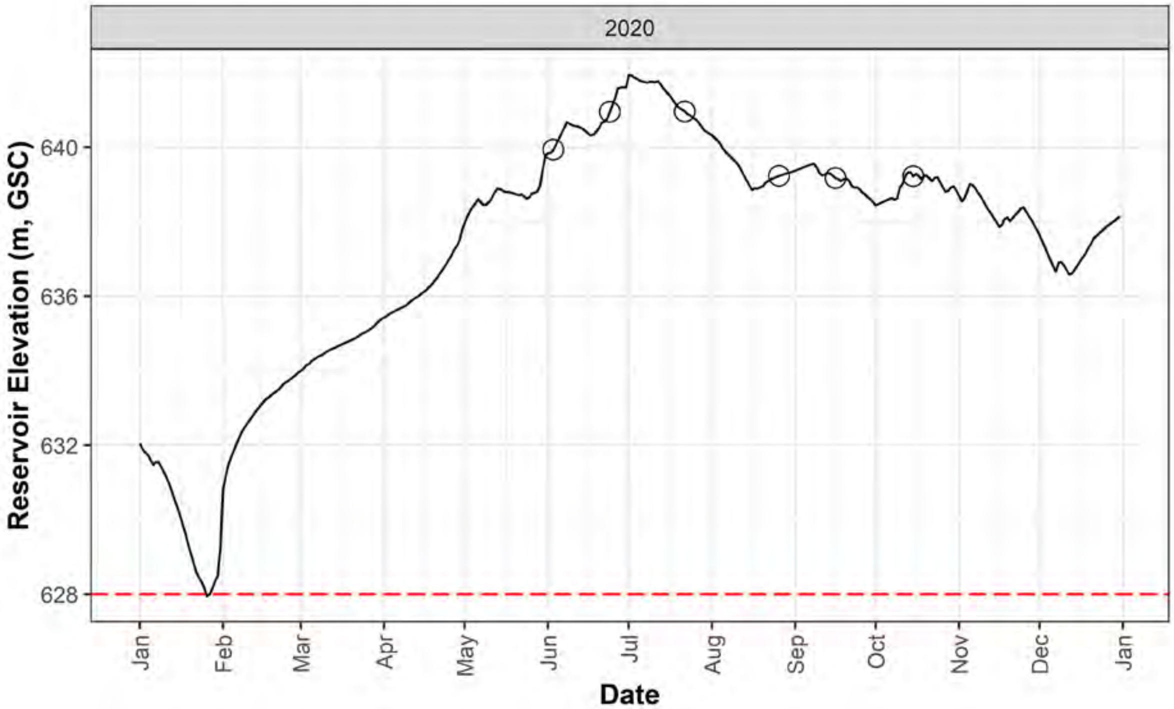


Figure 6. Daily reservoir surface elevation (m, Geodetic Survey of Canada), 2020, Wahleach Reservoir, BC. Open circles represent limnology sampling dates. The red dashed line represents minimum operating level of 628 m.

4.2 Climate

4.2.1 Air Temperature

Seasonal air temperatures in 2020 were highest in July and August and lowest in January (Figure 7). Overall, the mean daily temperature in 2020 (7.0 ± 6.8°C, range -17.8 to 31.4°C) was similar to the long-term mean (7.1 ± 6.8°C, range -22.3 to 33.9°C). During the nutrient addition period (June through September), mean daily temperature was 14.1 ± 3.7°C (range 3.9 to 31.4°C), which was similar to the long-term mean (14.2 ± 3.9°C, range 0.8 to 33.9 °C).

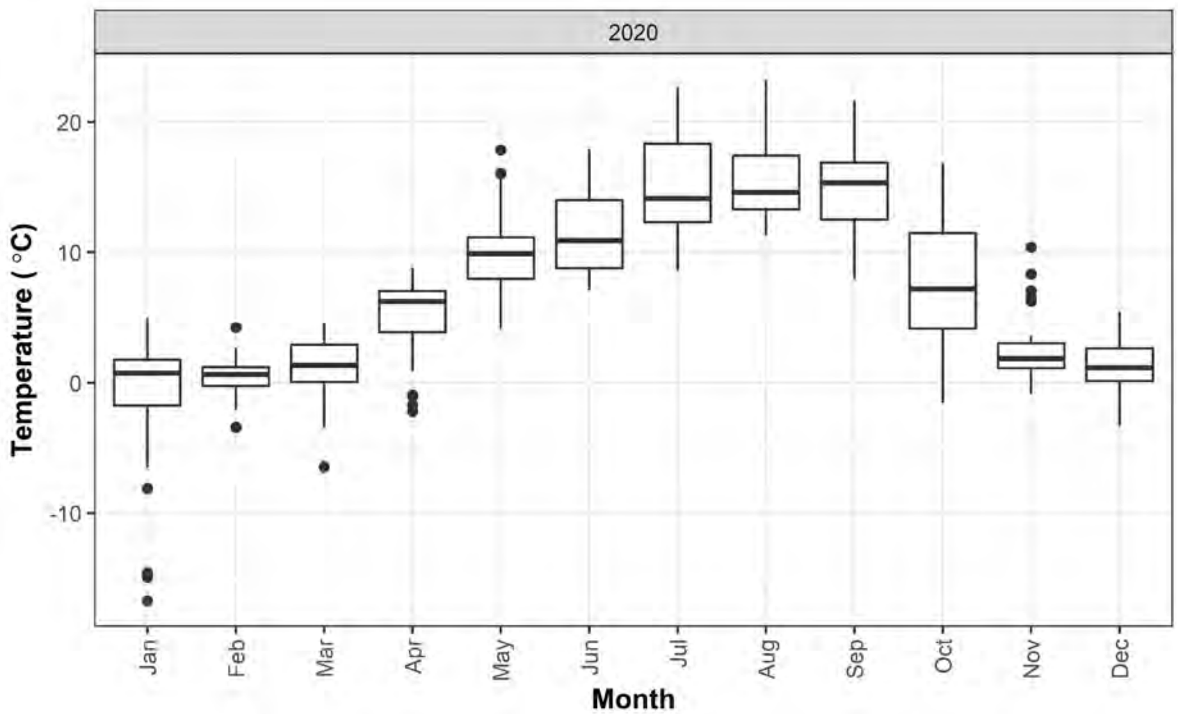


Figure 7. Boxplot of daily mean air temperatures (°C) during each month, 2020, Wahleach Reservoir, BC. Black dots represent outliers.

4.2.2 Precipitation

The seasonal precipitation pattern generally followed the inverse trend of air temperature; precipitation was low in the summer months while in the fall and winter months generally precipitation was high (Figure 8). Precipitation was highest in January during winter storms. In 2020, mean daily (8 ± 13 mm, range 0 to 100 mm) precipitation was similar to the long-term mean (7 ± 13 mm, range 0 to 130 mm), while mean monthly precipitation was higher at 241 ± 136 mm (range 56 to 526 mm) compared to the long-term mean of 218 ± 124 mm (range 7 to 733 mm). A total of 2,894 mm of precipitation fell in 2020, which was greater than the long-term mean of 2,616 ± 283 mm (range 2,084 to 3,124 mm). During the nutrient addition period (June through September), the daily and monthly means for precipitation in 2020 were 4 ± 9 mm (0 to 52 mm) and 118 ± 49 mm (56 to 174 mm), respectively, which were similar to the long-term means of 4 ± 9 mm (0 to 114 mm), and 124 ± 75 mm (8 to 335 mm), respectively. Total seasonal precipitation during the nutrient addition period in 2020 was 472 mm, which was also similar to the long-term mean (494 ± 123 mm, range 202 to 746 mm).

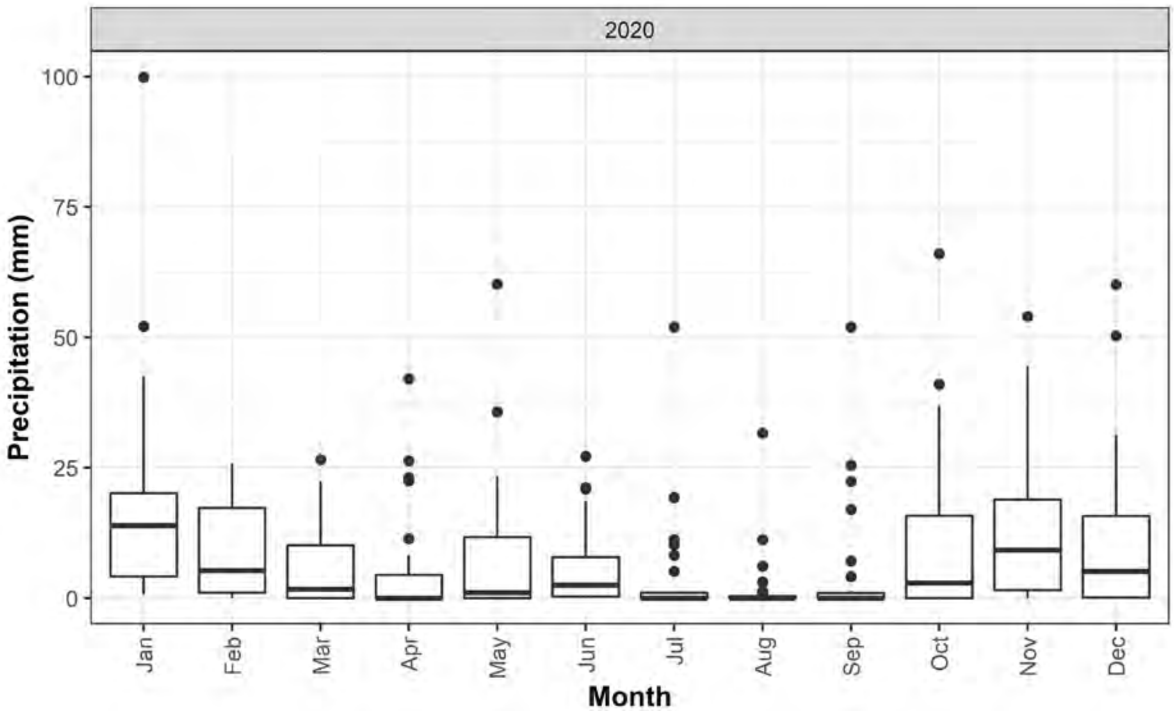


Figure 8. Boxplot of daily total precipitation (mm) during each month, 2020, Wahleach Reservoir, BC. Black dots represent outliers.

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 9. A thermocline begins to develop in June with strong thermal stratification in July and August, and then stratification begins to weaken in September. Generally, the water column is well-mixed (isothermal) in the spring (May) and fall (October). In 2020, the thermocline ranged between 3-6 m (Figure 9). Water temperatures were similar between the north basin and the south basin with a combined mean temperature of 11.6 ± 3.4°C (range 7.0 to 19.7°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 2020 for both basins combined was 9.2 ± 0.9 $mg \cdot L^{-1}$ (range 7.0 to 10.6 $mg \cdot L^{-1}$) 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 $mg \cdot L^{-1}$ and 6.5 $mg \cdot L^{-1}$, respectively (CCME, 1999). Throughout the growing season dissolved oxygen concentrations in the hypolimnion remained above 6.5 $mg \cdot L^{-1}$ (Figure 9).

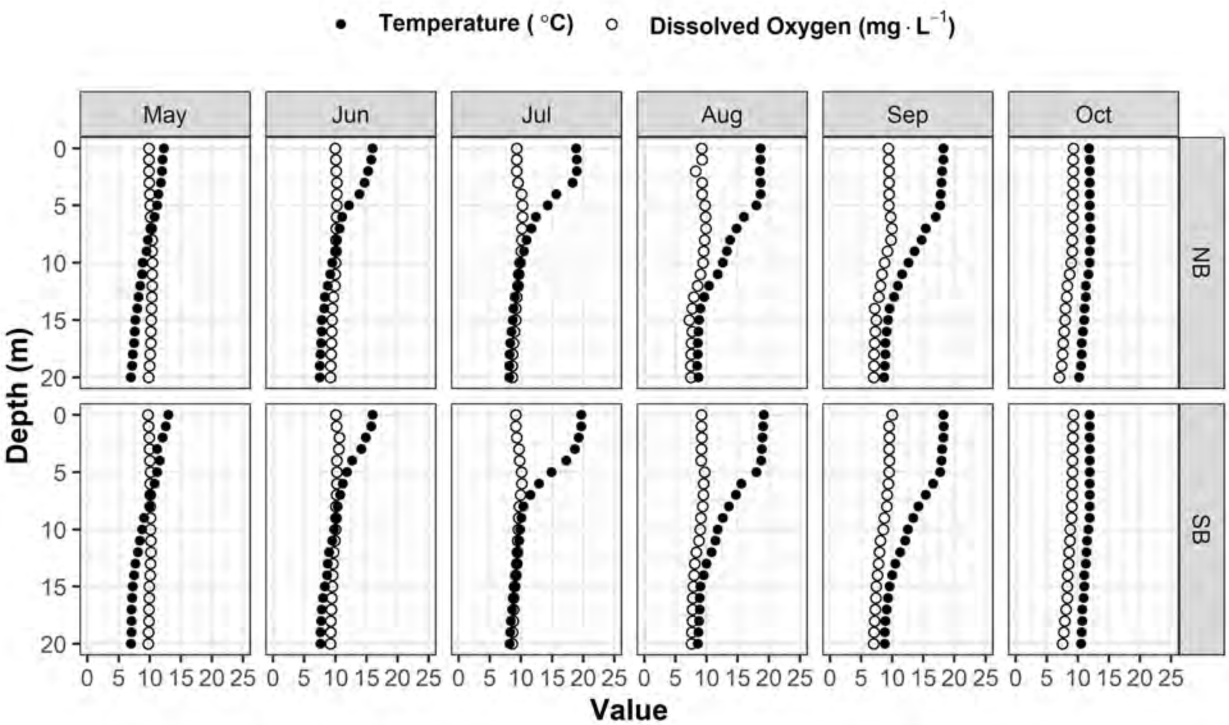


Figure 9. Water temperature (°C) and dissolved oxygen (mg·L^{-1}) profiles at the north basin (NB-LS1) and south basin (SB-LS2) limnology sampling stations May to October, 2020, Wahleach Reservoir, BC.

The pH in Wahleach Reservoir, as taken from 1-m water samples, was neutral with a mean of 7.2 ± 0.1 (range 7.0 to 7.4; Figure 10), 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 8.7 and 11.5 mg $CaCO_3 \cdot L^{-1}$ with a mean of 9.9 ± 0.8 mg $CaCO_3 \cdot L^{-1}$ in 2020 (Figure 11). 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 2020 averaged 5.5 ± 0.8 m (range 4.7 to 7.0 m) and were similar between the two basins (Figure 12). 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).

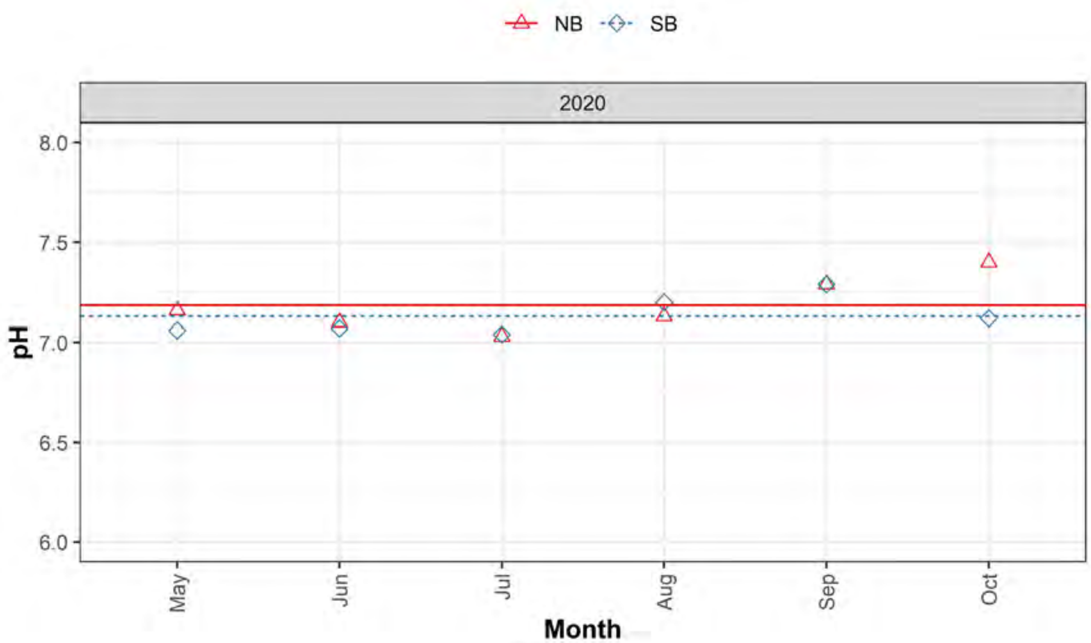


Figure 10. pH values from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to October 2020, Wahleach Reservoir, BC. Horizontal bars represent seasonal mean for each station.

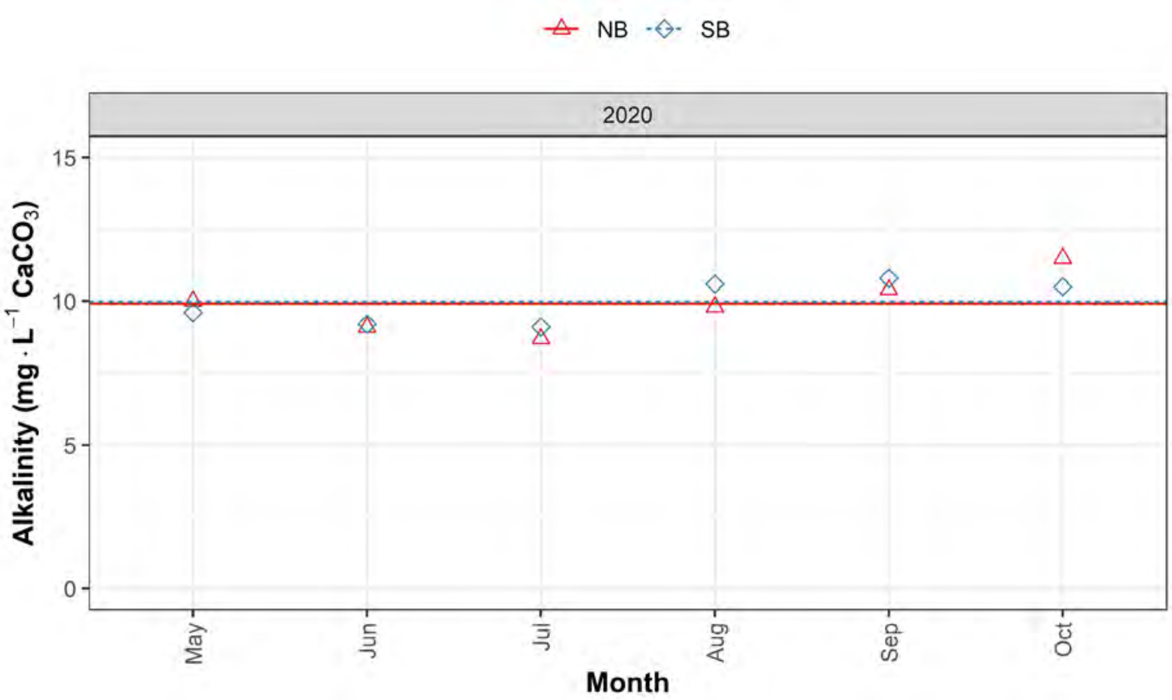


Figure 11. Alkalinity (mg $CaCO_3 \cdot L^{-1}$) values from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to October 2020, Wahleach Reservoir, BC. Horizontal bars represent seasonal mean for each station.

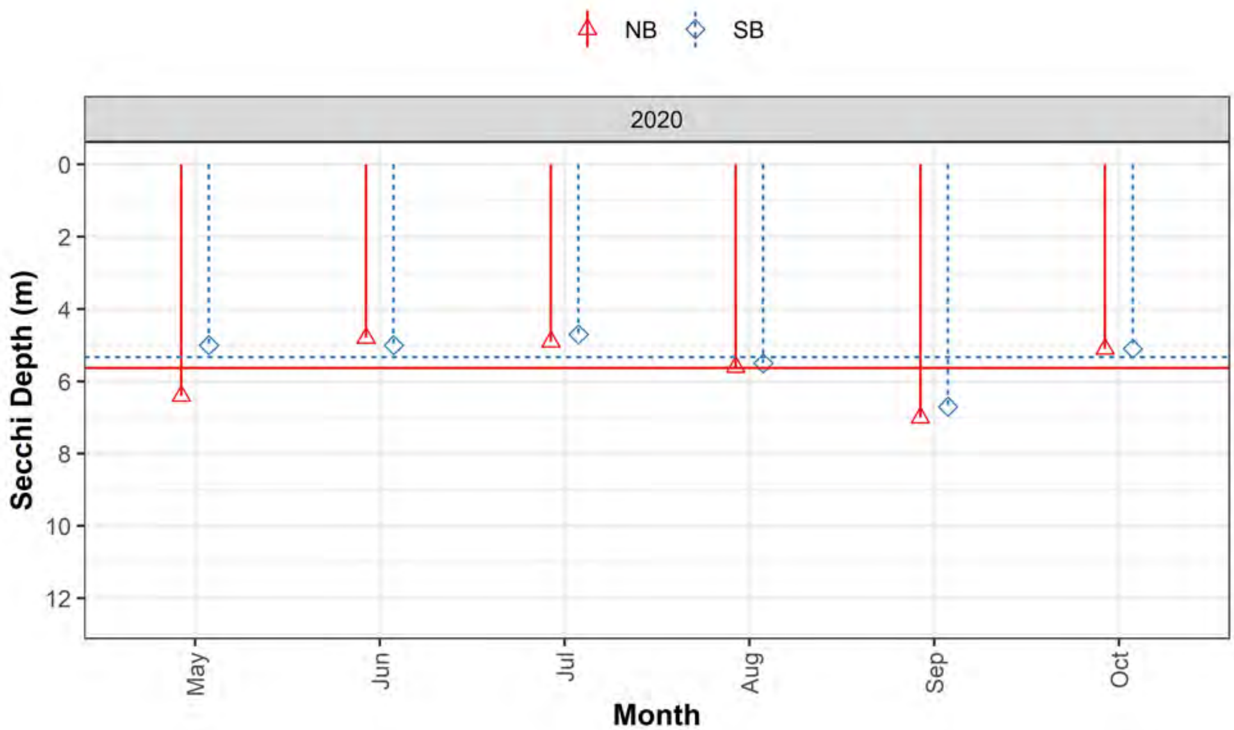


Figure 12. Secchi depths (m) at the north basin (NB) and south basin (SB) limnology sampling stations May to October 2020, Wahleach Reservoir, BC. Horizontal bars represent seasonal means for each station.

Vollenweider (1968) found total phosphorus (TP) concentrations below 5 $\mu g \cdot L^{-1}$ were indicative of ultra-oligotrophic productivity, while TP concentrations between 5-10 $\mu g \cdot L^{-1}$ were indicative of oligotrophic productivity. Prior to nutrient restoration, seasonal mean epilimnetic TP was 4.3 ± 2.0 $\mu g \cdot L^{-1}$ and ranged from 2.9 to 12.0 $\mu g \cdot L^{-1}$, which was representative of ultra-oligotrophic productivity nearing oligotrophic productivity. In 2020, TP values ranged from 2.2 to 5.5 $\mu g \cdot L^{-1}$ with a seasonal mean of 3.8 ± 1.1 $\mu g \cdot L^{-1}$ indicating phosphorus concentrations remained primarily in the ultra-oligotrophic productivity range (Figure 13).

Soluble reactive phosphorous (SRP), a measurement of low-level orthophosphate, is the form of phosphorous readily available to phytoplankton. The SRP concentration during the baseline era was 1.1 ± 0.3 $\mu g \cdot L^{-1}$ with a range of 1 to 2 $\mu g \cdot L^{-1}$. In 2020, SRP values ranged from below detection limits (<1 $\mu g \cdot L^{-1}$) to 1.1 $\mu g \cdot L^{-1}$ with a seasonal mean of 0.6 ± 0.2 $\mu g \cdot L^{-1}$ (Figure 14). This suggests rapid uptake and assimilation of useable phosphorus by phytoplankton.

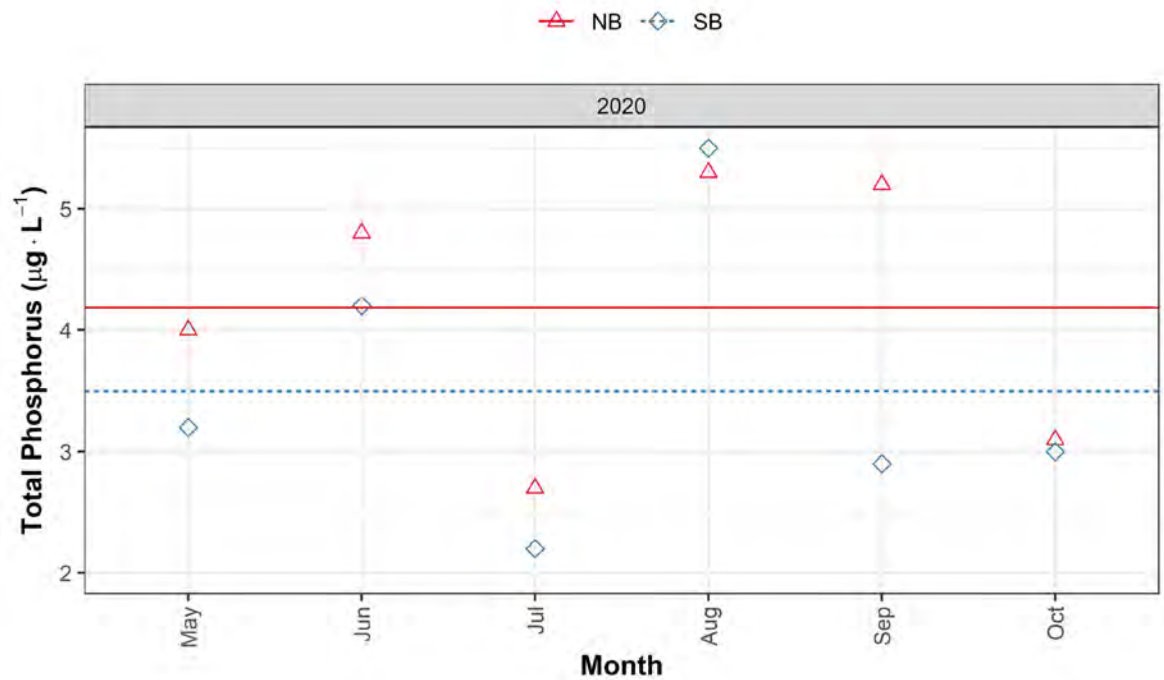


Figure 13. Total phosphorus concentration (µg·L^{-1}) from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to October 2020, Wahleach Reservoir, BC.

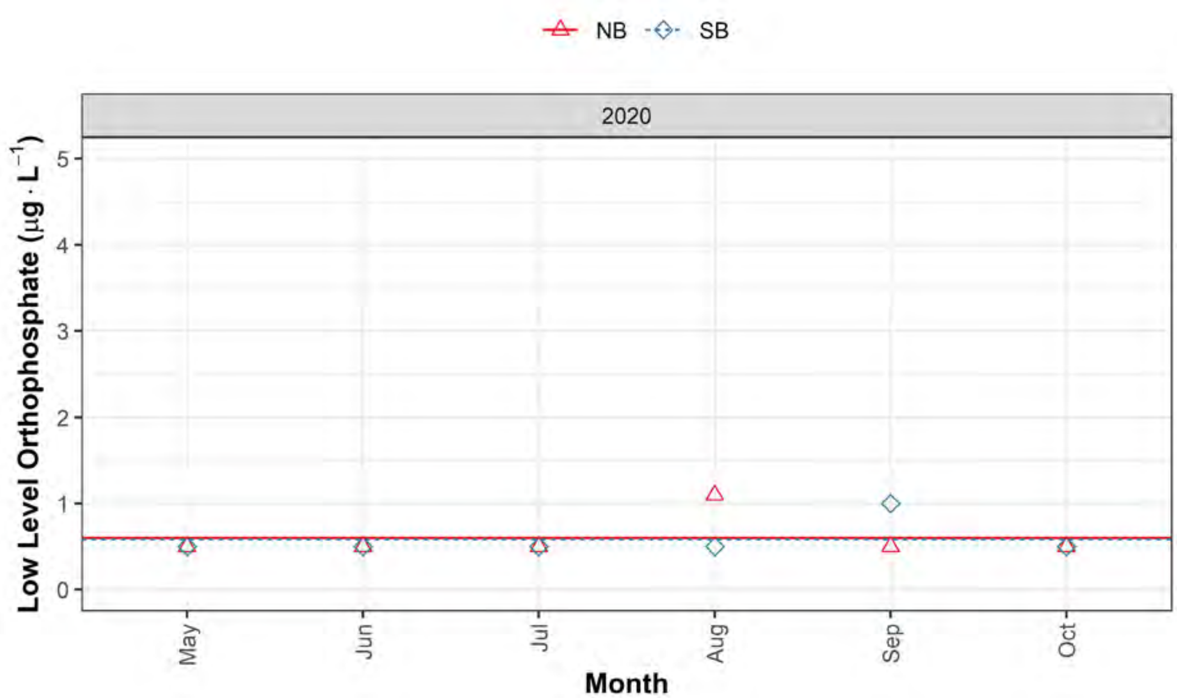


Figure 14. Low level orthophosphate concentrations (µg·L^{-1}) from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to October 2020, Wahleach Reservoir, BC.

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 2020, TN was highest in early spring and followed a slight decreasing trend through to the fall (Figure 15). The TN sample collected in August at the north basin was reported with a value of 401 $\mu g \cdot L^{-1}$; being anomalously high, it was considered contaminated and was discarded. Given the close similarity between the results of the two basins in August the TN value for the south basin was also used for the north basin. The mean TN concentration in 2020 was 149 ± 18 $\mu g \cdot L^{-1}$ (range 123 to 181 $\mu g \cdot L^{-1}$), which was higher than the baseline of 107 ± 47 $\mu g \cdot L^{-1}$ (range 9 to 220 $\mu g \cdot L^{-1}$; Figure 15).

Nitrate and nitrite-N (NO_3+NO_2-N) are important forms of dissolved nitrogen supporting algal growth (Wetzel 2001). In 2020, the highest concentrations of NO_3+NO_2 were observed during spring when the reservoir was completely mixed, NO_3+NO_2 decreased throughout summer and began to rise again in October. In August NO_3+NO_2 concentrations dipped just below the level considered limiting for phytoplankton growth (<20 $\mu g \cdot L^{-1}$), while in September NO_3+NO_2 concentrations were below detection limits (<3.2 $\mu g \cdot L^{-1}$) — a pattern suggestive of strong biological utilization of NO_3+NO_2, occurring after the cessation of nutrient additions in early September. The seasonal mean NO_3+NO_2 concentration in 2020 was 44 ± 34 $\mu g \cdot L^{-1}$ (range 1.6 to 100 $\mu g \cdot L^{-1}$; Figure 16), which was lower than baseline conditions of 66 ± 69 $\mu g \cdot L^{-1}$ (range 0.9 to 426 $\mu g \cdot L^{-1}$).

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 2020, TN:TP varied seasonally ranging between 26 to 75 with a mean of 43 ± 15 (Figure 17). The TN:TP in 2020 had a smaller range and higher mean than during baseline years, when TN:TP ranged between 3 to 67 with a mean of 27 ± 14.

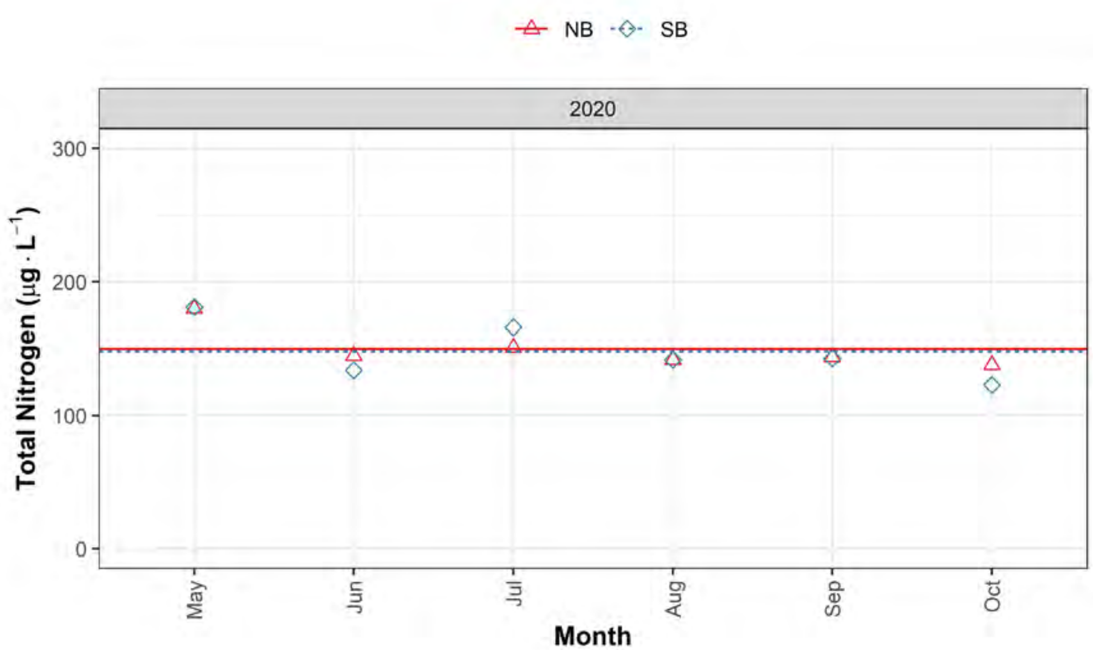


Figure 15. Total nitrogen concentrations ($\mu g \cdot L^{-1}$) from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to October 2020, Wahleach Reservoir, BC; horizontal lines represent seasonal means for each station.

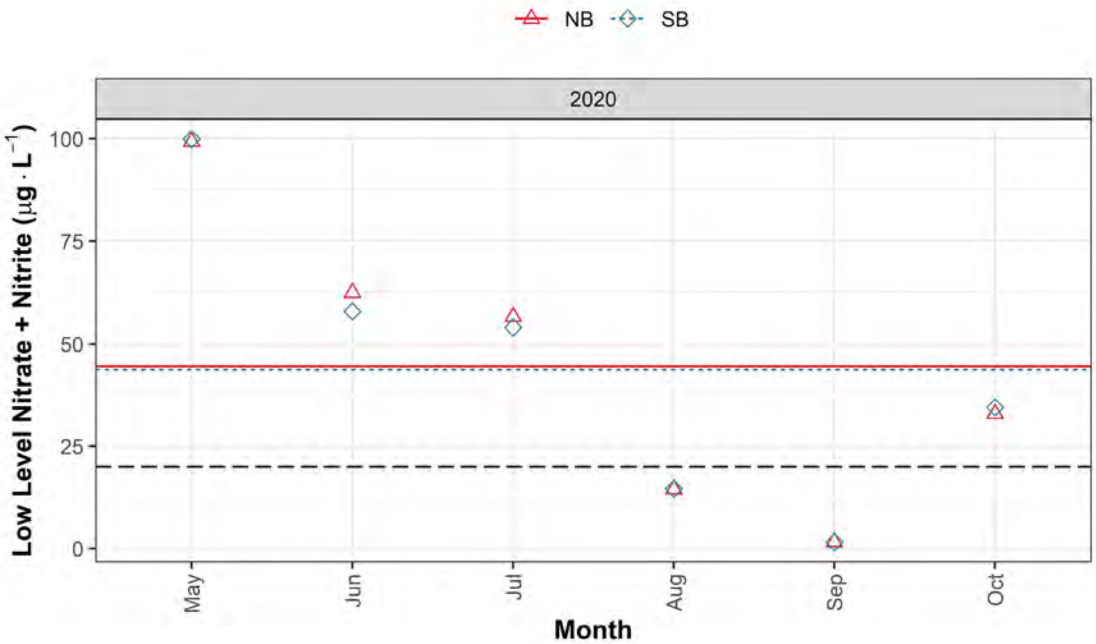


Figure 16. Low level nitrate + nitrite nitrogen concentrations (µg·L^{-1}) from 1 m discrete water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to October 2020, Wahleach Reservoir, BC; black dashed line at 20 µg·L^{-1} represents the limiting concentration for phytoplankton growth.

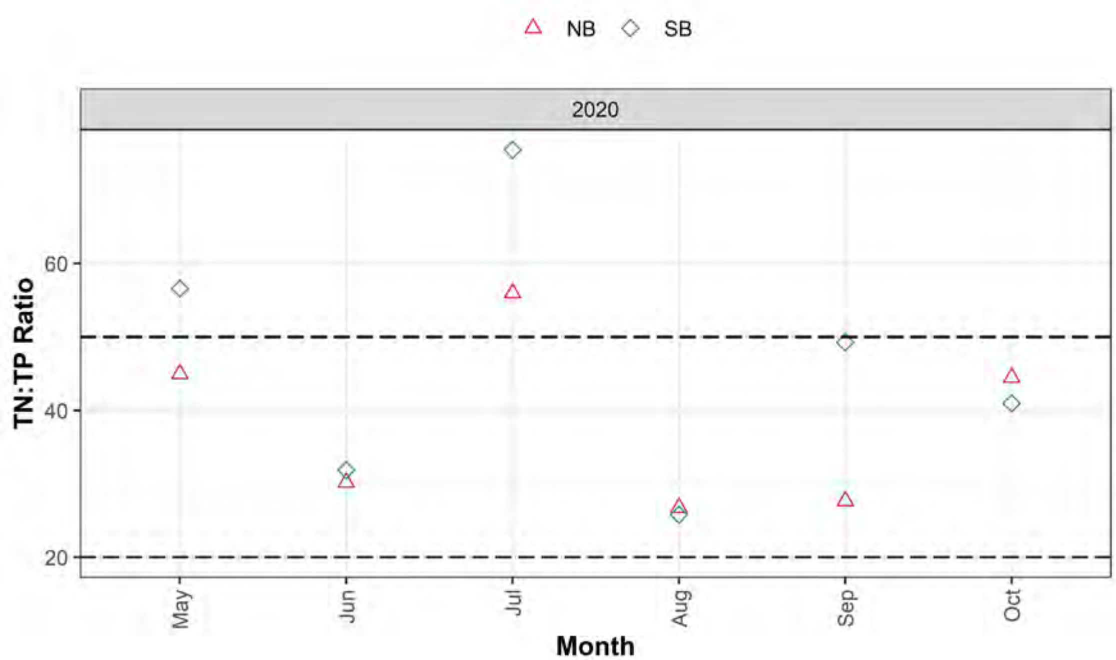


Figure 17. Total nitrogen (TN) to total phosphorus (TP) ratios based on 1 m water chemistry samples from the north basin (NB) and the south basin (SB) limnology stations May to October 2020, Wahleach Reservoir, BC. Points above dashed line at 50 were likely in a state of P limitation, while points below dashed line at 20 were likely in a state of N limitation (Guildford and Hecky 2000).

4.4 Phytoplankton

A total of 44 phytoplankton species were detected in Wahleach Reservoir during 2020 (Appendix A), which was higher than the 1994 baseline year, when 38 phytoplankton species were detected. Mean phytoplankton abundance in 2020 was 23,371 ± 21,467 cells·mL^{-1} (range 5,830 to 65,637 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 2020 was driven largely by growth of blue-green algae (class *Cyanophyceae*) and to a lesser extent flagellates (class *Chryso-* & *Cryptophyceae*; Figure 18). The phytoplankton community consisted of edible species and forms found throughout the season (6,413 ± 5,018 cells·mL^{-1}; range 1,683 to 21,050 cells·mL^{-1}; Figure 19). Inedible fractions (16,899 ± 19,568 cells·mL^{-1}; range 98 to 60,417 cells·mL^{-1}) were high in 2020 samples, peaking in July in both basins with a bloom of *Aphanothece minutissimus*, a non-toxin-producing blue-green algae. In past years this species was identified as *Microcystis* sp., a type of blue-green algae that produces toxins. During the 2021 growing season toxicology samples will be tested for microcystins to help determine which of these visually similar species is present. Small blooms of blue-green algae are not uncommon in Wahleach at this time of year and negative impacts to the fish population have not been observed.

Phytoplankton biovolume in 2020 was 0.34 ± 0.23 mm^3·L^{-1} (range 0.07 to 0.92 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}). This was likely related to the laboratory switch (slight differences in taxonomic identification and calculations) and is being investigated further; we are unable to comment at the time of writing this report. Early in the season, biovolume was largely driven by flagellates, while mid-season biovolume was predominantly blue-green algae. In September and October biovolume was a fairly balanced mix of flagellates, blue-green algae and chlorophytes (class *Chlorophyceae*; Figure 20). Though inedible species were dominant when examining abundance, the opposite was found when looking at biovolume. Edible biovolume (0.20 ± 0.10 mm^3·L^{-1}; range 0.05 to 0.36 mm^3·L^{-1}) was predominantly driven by flagellates, followed by chlorophytes and dinoflagellates (class *Dinophyceae*), while inedible biovolume (0.13 ± 0.16 mm^3·L^{-1}; range 0.006 to 0.59 mm^3·L^{-1}) was largely a result of blue-green algal growth (Figure 21).

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.

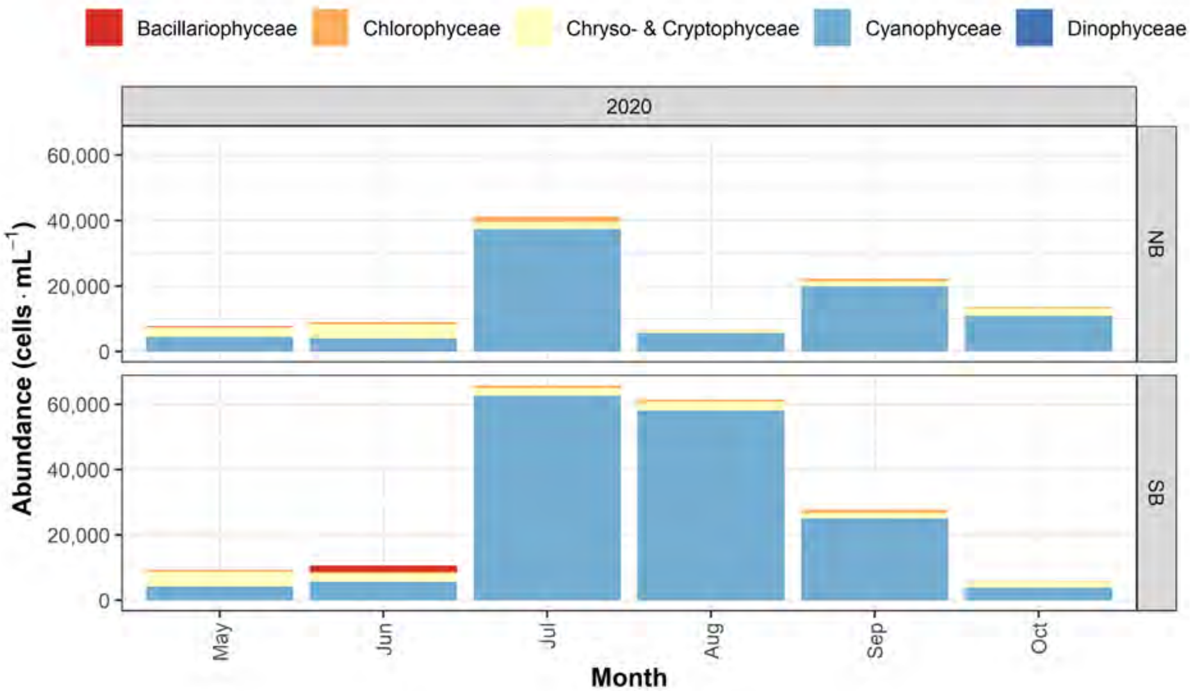


Figure 18. Seasonal phytoplankton abundance (cells·mL^{-1}) by class at the north basin (NB) and south basin (SB) limnology stations May to October 2020, Wahleach Reservoir BC.

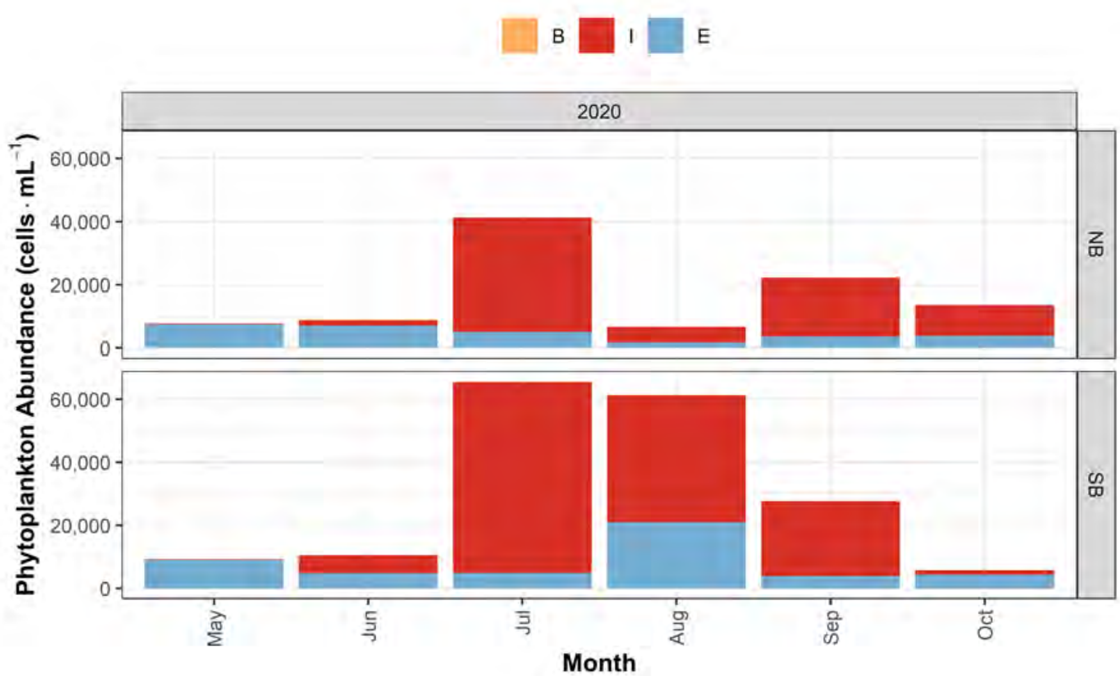


Figure 19. Seasonal phytoplankton abundance (cells·mL^{-1}) by edibility (E=edible, I=inedible, B= both edible and inedible forms) at the north basin (NB) and south basin (SB) limnology station May to October 2020, Wahleach Reservoir, BC.

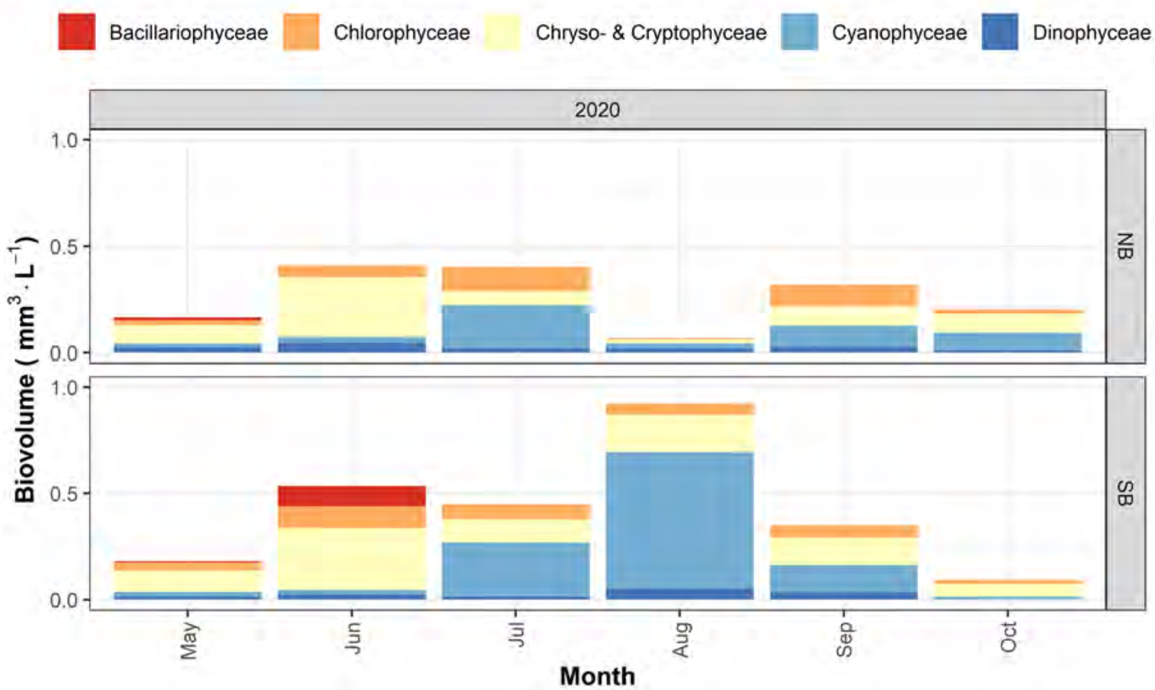


Figure 20. Seasonal phytoplankton biovolume (mm^3·L^{-1}) by class at the north basin (NB) and south basin (SB) limnology stations May to October 2020, Wahleach Reservoir, BC.

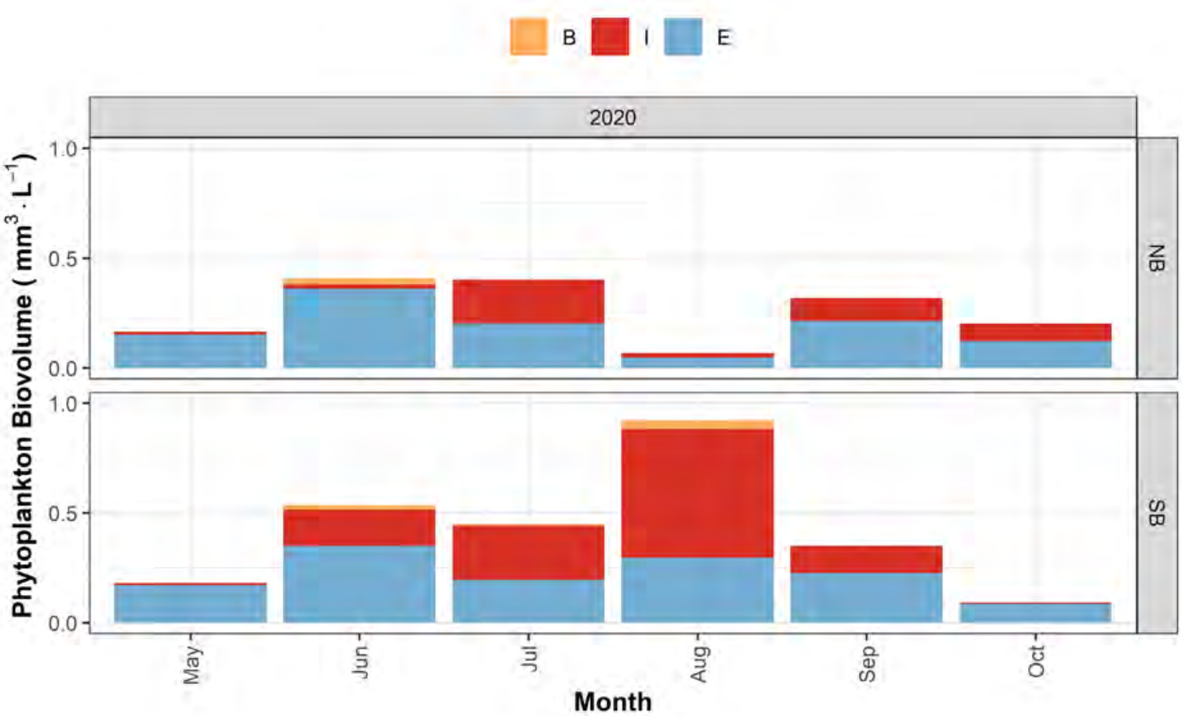


Figure 21. Seasonal phytoplankton biovolume (mm^3·L^{-1}) by edibility (E=edible, I=inedible, B=both edible and inedible forms) at the north basin (NB) and south basin (SB) limnology station May to October 2020, Wahleach Reservoir, BC.

4.5 Zooplankton

Seven *Cladocera* species and two *Copepoda* species were identified in Wahleach Reservoir in 2020 (Appendix B). Species such as *Bosmina longirostris* (O.F.M.), *Daphnia rosea* (Sars), *Cyclops vernalis* (Fischer) and *Holopedium gibberum* (Zaddach) were common, while others such as *Chydorus sphaericus* (O.F.M.), *Daphnia galeata mendotae (Birge), Leptodiaptomus ashlandi* (Marsh), *Leptodora kindtii* (Focke) and *Scapholeberis mucronata* (O.F.M.) were present at low densities. *Scapholeberis mucronata* 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. The species *Daphnia galeata mendotae* was present in 2020 samples for the first time on record.

Seasonal zooplankton density in 2020 was 5.5 ± 2.2 individuals·L^{-1} (range 2.3 to 11.8 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 90.4 ± 44.5 µg·L^{-1} (range 42.3 to 259.9 µg·L^{-1}). Early in the season, zooplankton density was largely driven by cladocerans other than *Daphnia*. From July through to October, *Daphnia* were the dominant driver of both density and biomass (Figure 22, Figure 23). Copepod densities peaked in August and again in October (Figure 22). Seasonal densities and biomass of each major zooplankton group are detailed in Table 5. Overall, in 2020, *Daphnia* made up 38% of the seasonal zooplankton density and 53% of biomass, while other cladocerans made up 49% of density and 46% of biomass (majority of which were *Holopedium*).

Table 5. Summary statistics for seasonal zooplankton density and biomass of each major group (Copepoda, *Daphnia* and other Cladocera), 2020, Wahleach Reservoir, BC.

Taxonomic Group	Density (individuals·L^{-1})				Biomass (µg·L^{-1})			
	Mean	SD	Max	Min	Mean	SD	Max	Min
Copepoda	0.7	0.5	1.7	0.1	1.1	0.8	2.9	0.2
Daphnia	2.1	2.0	9.1	0.04	47.5	49.8	232.7	0.9
Other Cladocera	2.7	2.5	10.6	0.6	41.7	36.1	129.4	6.4

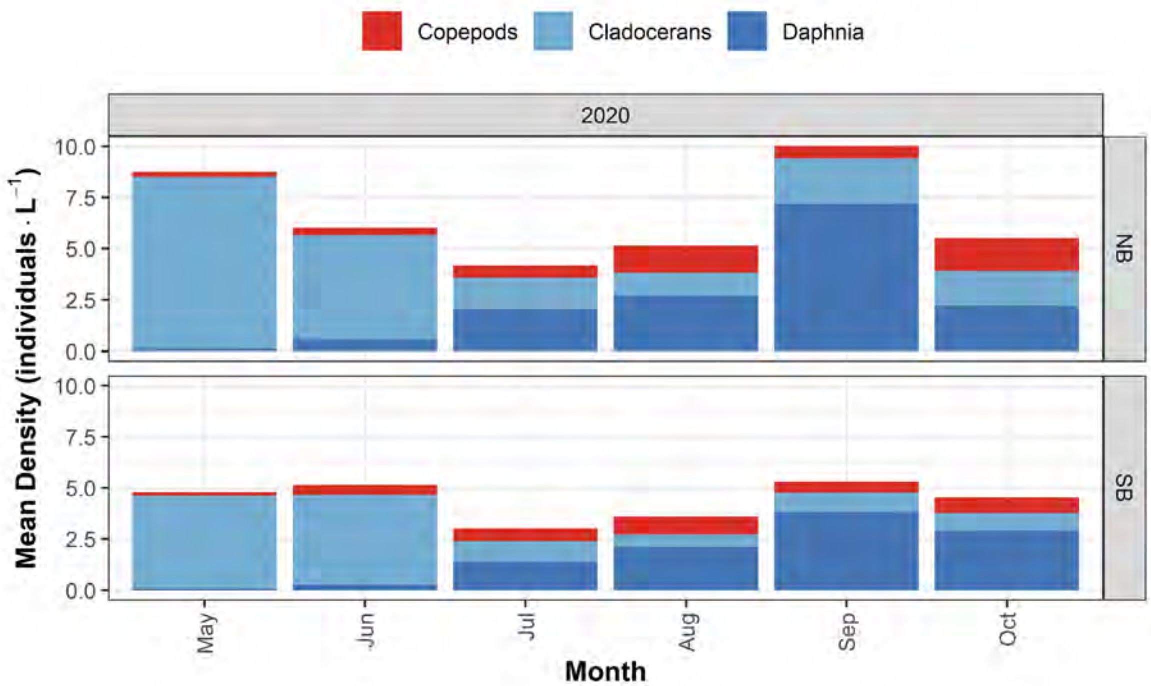


Figure 22. Monthly zooplankton density (individuals·L-1) by major group (Copepoda, *Daphnia* and other Cladocera) at the north basin (NB) and south basin (SB) limnology stations, 2020, Wahleach Reservoir, BC.

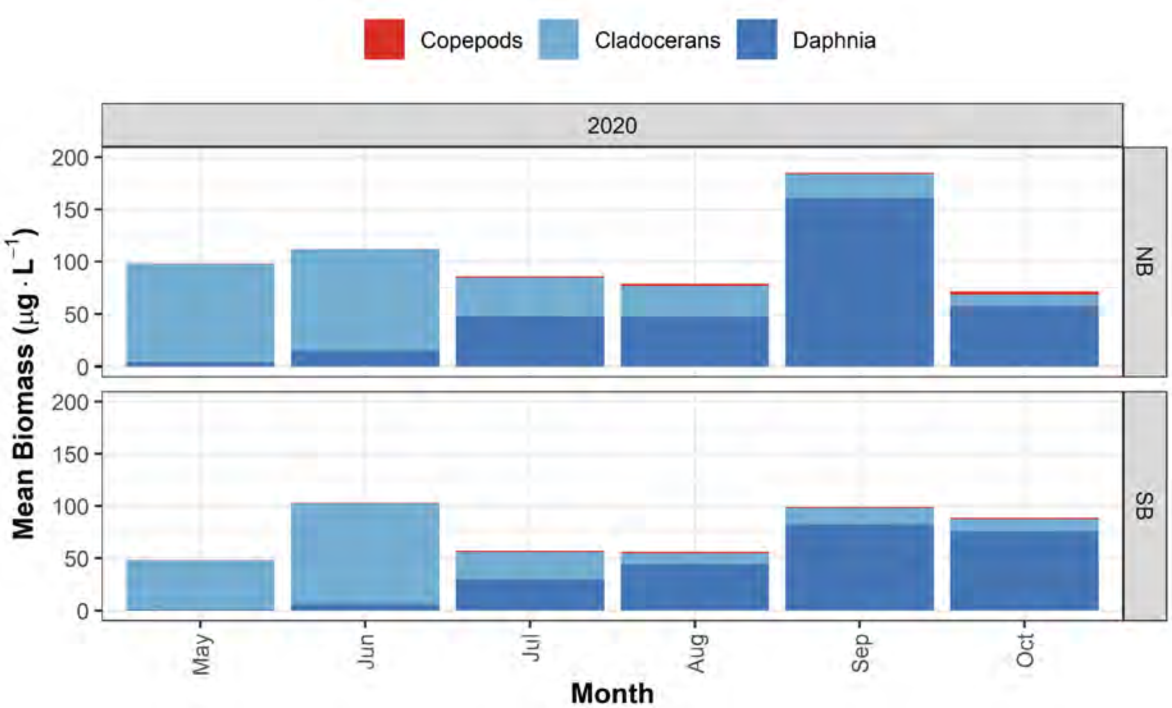


Figure 23. Monthly zooplankton biomass (µg·L^{-1}) by major group (Copepoda, *Daphnia* and other Cladocera) at the north basin (NB) and south basin (SB) limnology stations, 2020, Wahleach Reservoir, BC.

4.6 Fish

4.6.1 Catch & CPUE

Total catch during the nearshore gillnet sampling in 2020 was 106 fish (Table 6). The majority of the catch were Rainbow Trout at 55% while 18% were Kokanee (Table 6). Of the total catch, 25% were caught in the 1.25” mesh panels (Table 7). Catch-per-unit-effort (CPUE) for all species combined in the nearshore gillnetting was 0.06 fish·100 $m^{-2}\cdot hr^{-1}$. Catch from the minnow trap sampling was 12 Threespine Stickleback and 1 juvenile Rainbow Trout; total soak time in 2020 was 115 trap hours with CPUE at 0.1 fish per trap hour.

Table 6. Summary of fall nearshore gillnetting catch and percentage (%), 2020, Wahleach Reservoir, BC. Species include Cutthroat Trout (CT), Rainbow Trout (RB), hybridized Cutthroat/Rainbow Trout (CT/RB), Kokanee (KO), and unknown Trout (TR) which could not be clearly identified due to consumption by Crayfish (*Pacifastacus leniusculus*).

Species	2020[1]	%
CT	22	21
RB	58	55
CT/RB	1	1
KO	19	18
TR	6	6
Total	106	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, 2020, Wahleach Reservoir, BC. The 1.25” panel was added in 2014.

Species	2020 - Standard	2020 - 1.25”
CT	21	1
RB	37	21
CT/RB	1	0
KO	17	2
TR	4	2
Total	80	26

4.6.2 Kokanee

A total of 19 Kokanee were captured during fall nearshore gillnetting, ranging in length from 171 to 234 mm and in weight from 53.0 to 137.0 g (Table 8). All were immature, either age 1+ or age 2+ fish (Table 9, Figure 24) which is expected given the netting program occurred after the Kokanee spawning window. Age 1+ was the dominate age class caught in 2020. When comparing summary statistics of Kokanee size by age class, individuals caught in 2020 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 2020 were larger than the age 2+ Kokanee from baseline years (Table 9). Most natural salmonid populations have a calculated b value between 2.5 and

3.5 (Carlander, 1969). Kokanee length-weight regressions based on the 2020 fall nearshore gillnetting data (Figure 25, Table 10), had a slope or b value of 2.75; 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 biometric data, including length, weight, and condition factor (K), 2020, Wahleach Reservoir, BC.

Year	n	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)	Mean K	SD K
2020	19	198	15	90.6	19.2	1.2	0.08

Table 9. Summary of Kokanee biometrics by age, 2020, 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+	194	11	209	171	85.4	15.1	103.5	53.0	1.2	0.08	1.25	1.01	15
2+	221	12	234	212	116.7	18.2	137.0	102.0	1.1	0.01	1.09	1.07	3

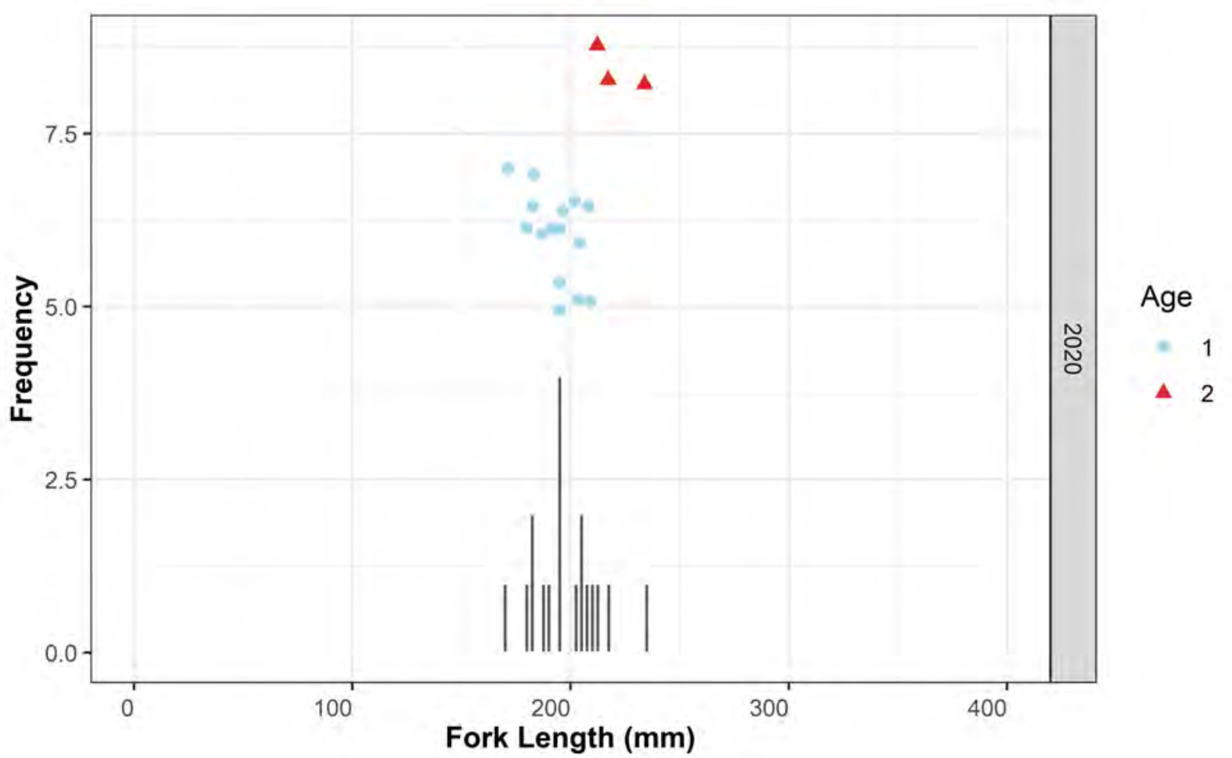


Figure 24. Length frequency distribution by age class of Kokanee, 2020, Wahleach Reservoir, BC.

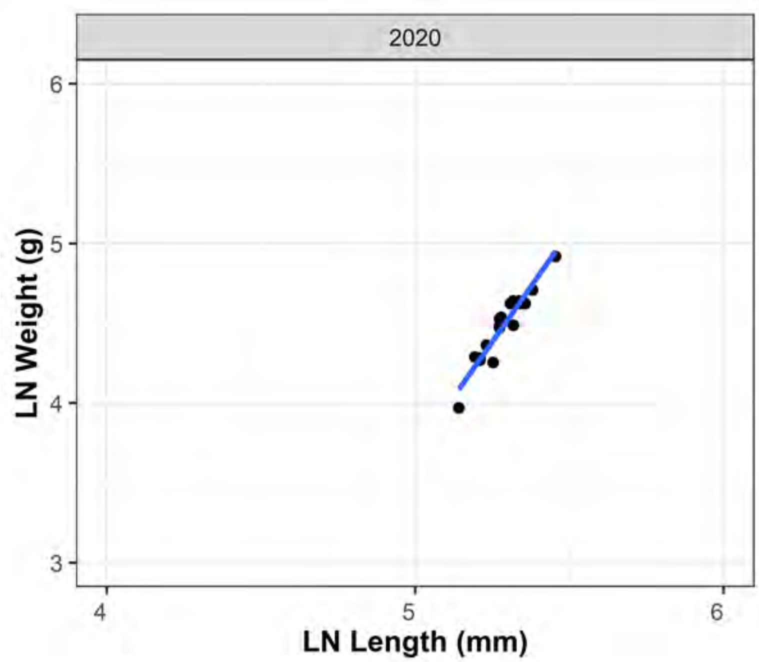


Figure 25. Natural logarithm of length weight linear regression (LN W = LN a * LN Lb) of Kokanee, 2020, Wahleach Reservoir, BC.

Table 10. Summary of variables in R for Kokanee length weight relationships (Ln W = b · Ln L + Ln a), 2020, Wahleach Reservoir, BC.

Year	Equation	R^2
2020	LN.weight.g = 2.75 * LN.length.mm -10.1	0.9088

4.6.2.1 Spawners

Timing of Kokanee spawning in 2020 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 early October (Figure 26). Kokanee escapement in 2020 was 4,996. Flat Creek had the most spawners (4,513), followed by Jones Creek (461), and then Boulder Creek (22); this pattern has been observed since 2009 (data on file; Sarchuk et al., 2019). In pre-treatment years, 1993-1994, Kokanee spawning had largely collapsed with only 953 and 568 individuals observed, respectively (data on file). Due to unsafe bear activity on Flat Creek in 2020, the September 16th survey was only partially completed and therefore not included in final calculations. This appears to have been the peak of the run and as such, escapement numbers are largely underestimated.

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 250 ± 18 mm (range 200 to 280 mm) and ages ranged from age 1+ to 3+, with the majority of spawners aged at 2+ years (Table 11, Figure 27). Length frequency and associated age-at-length data show substantial overlap in the lengths between each of the age classes (Table 12, Figure 28).

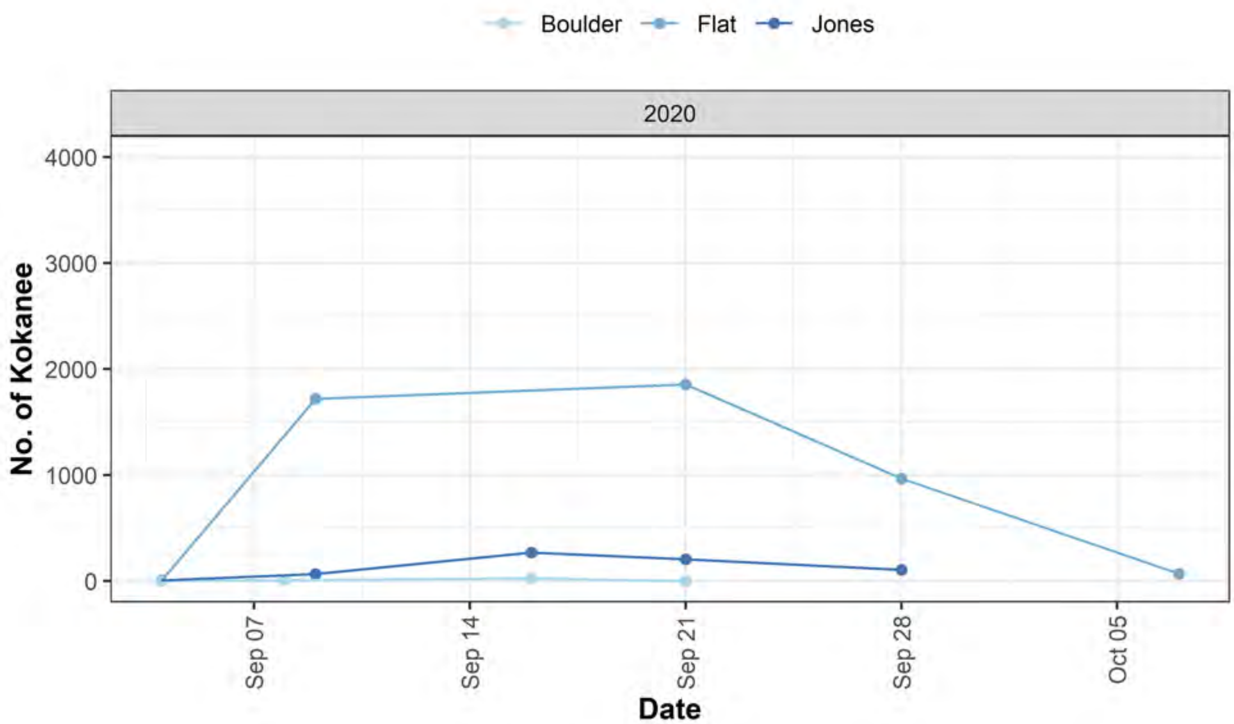


Figure 26. Kokanee spawner counts from each index stream (Boulder Creek, Flat Creek, and Jones Creek), 2020, Wahleach Reservoir, BC.

Table 11. Summary of biometric data from spawning Kokanee collected during spawner surveys, 2020, Wahleach Reservoir, BC. Data are 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 ($y = 1.3775x + 27.748$, $R^2 = 0.9578$) for years (2003-2020) when both POHL and FL were measured.

Year	Fork Length (mm)					Age				
	Mean	SD	Max	Min	N	Mean	SD	Max	Min	n
2020	250	18	280	200	43	2.3	0.6	3	1	43

Table 12. Summary of Kokanee fork length by age, 2020, Wahleach Reservoir, BC.

Age	Fork Length (mm)				
	Mean	SD	Max	Min	N
1+	202	3	204	200	2
2+	248	13	271	213	26
3+	260	14	280	227	15

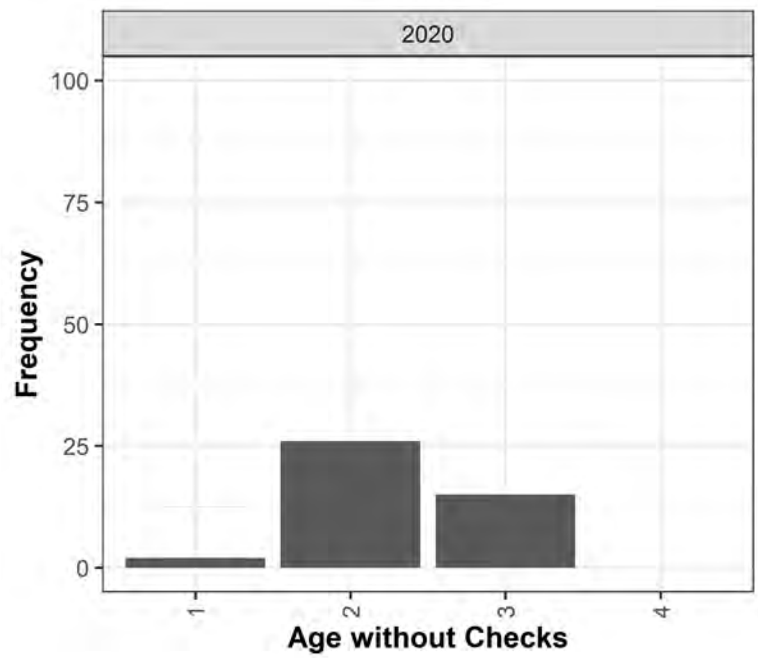


Figure 27. Age frequency of Kokanee spawners in index streams (Boulder Creek, Flat Creek and Jones Creek), 2020, Wahleach Reservoir, BC.

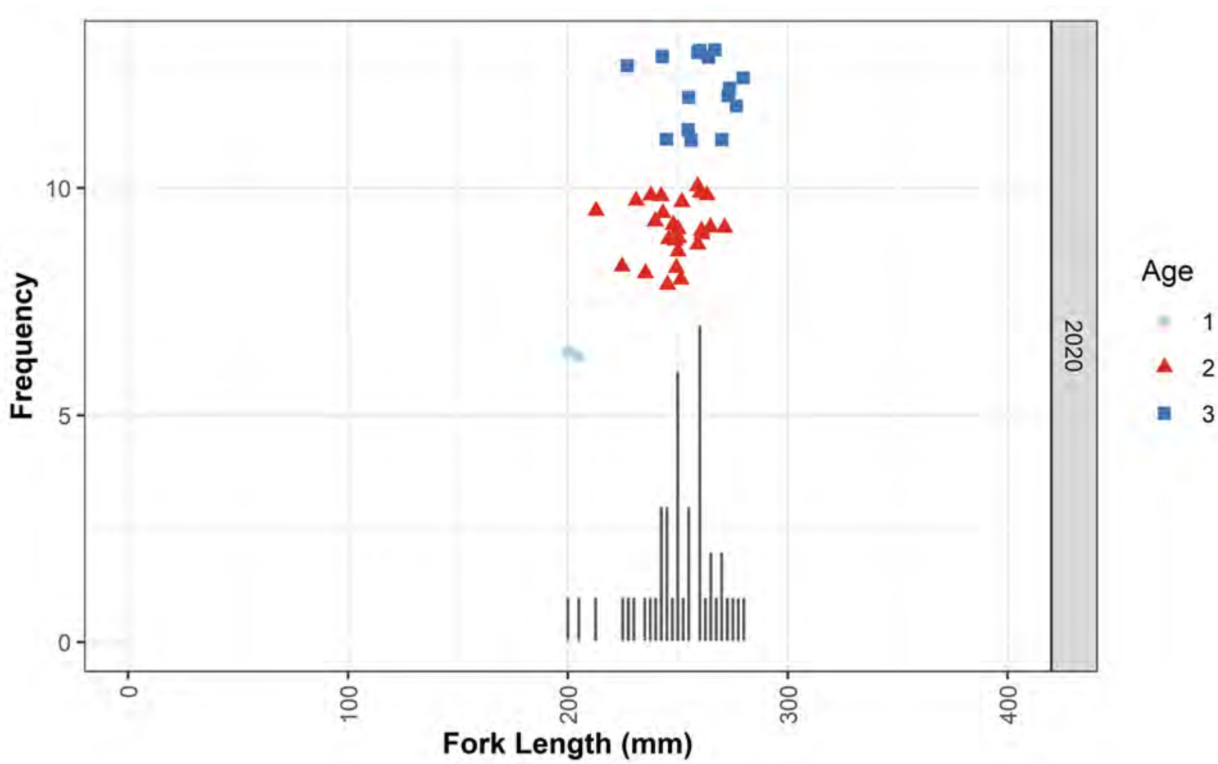


Figure 28. Length frequency distribution by age class of Kokanee spawners in index streams (Boulder Creek, Flat Creek and Jones Creek), 2020, Wahleach Reservoir, BC.

4.6.3 Rainbow Trout

In 2020, fall nearshore gillnet and minnow trap sampling captured a total of 59 Rainbow Trout, ranging in length from 110 to 280 mm and in weight from 13.5 to 211.0 g (Table 13). Length and weight of Rainbow Trout in 2020 was slightly 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). Age 1+ fish represented about half of the catch in 2020, while catch of older age classes (≥ 3+) was low (Table 14, Figure 29); this would account for the low mean length and weight in 2020 Rainbow Trout catches. Overall, Fulton's condition factor (K) for 2020 Rainbow Trout was 1.0 ± 0.08 indicating healthy somatic growth. Rainbow Trout length-weight regressions based on fall nearshore gillnetting and minnow trap data for 2020 are shown in Figure 30. The 2020 length-weight regression slope (b value) was 2.8 (Figure 30, Table 15); 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 13. Summary of Rainbow Trout biometric data from fall nearshore gillnetting and minnow trapping, including length, weight, and condition factor (K), 2020, Wahleach Reservoir, BC.

Year	n	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)	Mean K	SD K
2020	57	189	42	76.7	49.4	1.0	0.08

Table 14. Summary of Rainbow Trout biometrics by age, 2020, 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+	164	24	211	110	48.5	18.8	90.0	13.5	1.04	0.08	1.22	0.91	31
2+	195	27	255	152	78.8	33.8	168.0	36.5	1.00	0.05	1.12	0.9	17
3+	262	12	280	242	170.1	23.7	211.0	139.5	0.95	0.06	1.04	0.88	9

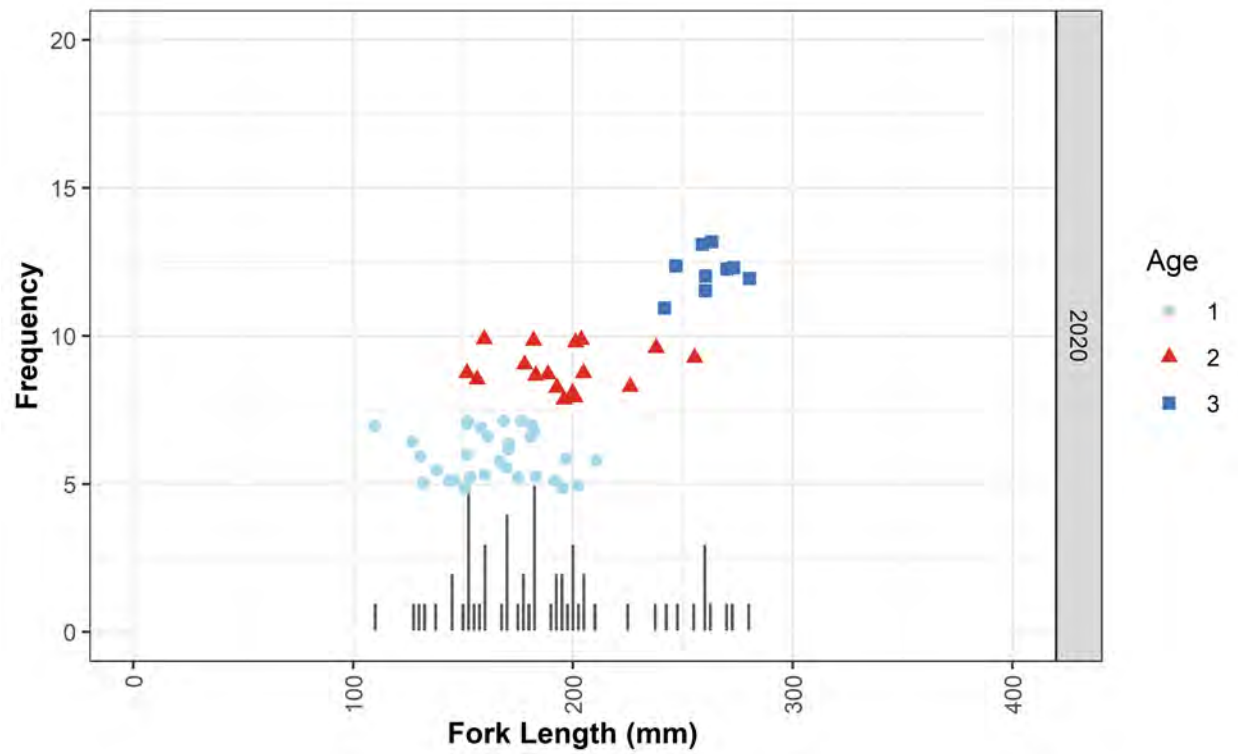


Figure 29. Length frequency by age class of Rainbow Trout in fall nearshore gillnets and minnow traps, 2020, Wahleach Reservoir, BC.

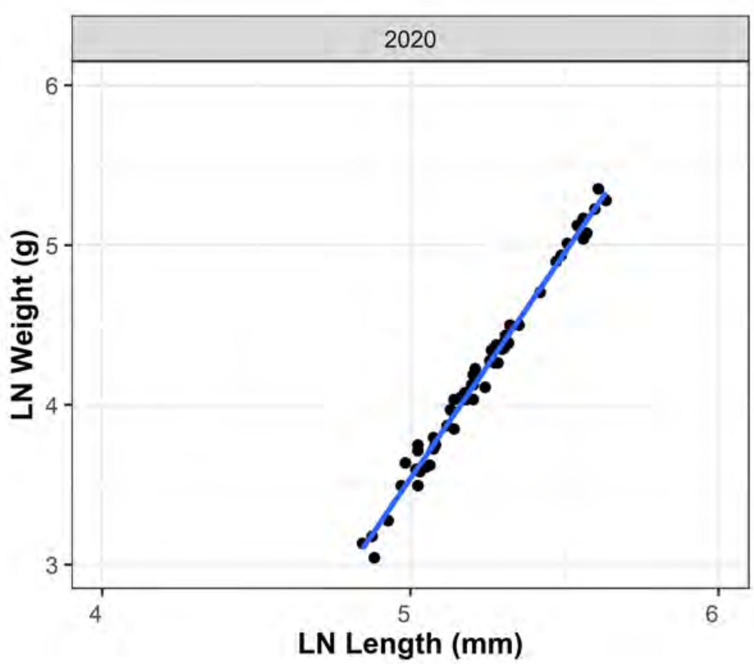


Figure 30. Length weight plot and relationship (Ln W=b · Ln L + Ln a) of Rainbow Trout, 2020, Wahleach Reservoir, BC.

Table 15. Summary of variables in R for Rainbow Trout length weight relationships (Ln W = b · Ln L + Ln a), 2020, Wahleach Reservoir, BC.

Year	Equation	R^2
2020	LN.weight.g = 2.82 *LN.length.mm -10.5	0.9875

4.6.4 Cutthroat Trout

Fall nearshore gillnet sampling in 2020 resulted in capture of 22 Cutthroat Trout ranging in length from 225 to 500 mm and in weight from 119.5 to 326.0 g (Table 16). Fulton's condition factor (K) had a mean of 0.95 indicating healthy somatic growth. Cutthroat Trout caught during 2020 were all age 1+ or 2+ with age 1+ representing a slight majority of the catch (Table 17, Figure 31). Two larger Cutthroat Trout with lengths of 370 and 500 mm were released alive, as such, weights and ages were not recorded; these likely represented older age categories. The length-weight regression slope (b value) for Cutthroat Trout in 2020 was close to 3 (Figure 32, Table 18); b values near 3 are common for fish (Anderson and Gutreuter, 1983; Cone, 1989).

Table 16. Summary of Cutthroat Trout biometric data, including length, weight, and condition factor (K), 2020, Wahleach Reservoir, BC.

Year	n	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)	Mean K	SD K
2020	19	282	61	184.0	59.8	0.95	0.07

Table 17. Summary of Cutthroat Trout biometrics by age, 2020, 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+	247	12	270	225	145.0	16.5	173.5	119.5	0.96	0.08	1.10	0.83	11
2+	292	23	325	250	237.8	55.8	326.0	159.5	0.94	0.05	1.02	0.87	8

**Dashes (-) indicate no data.*

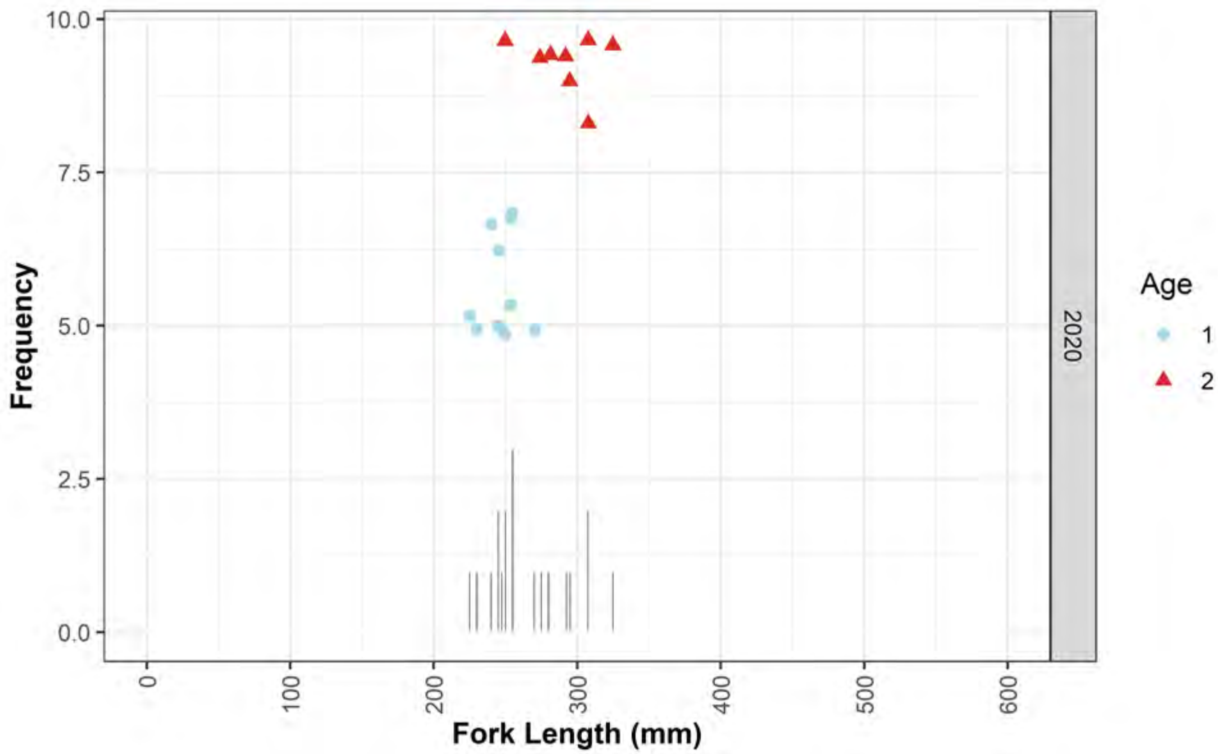


Figure 31. Length frequency of age classes of Cutthroat Trout in fall nearshore gillnets, 2020, Wahleach Reservoir, BC.

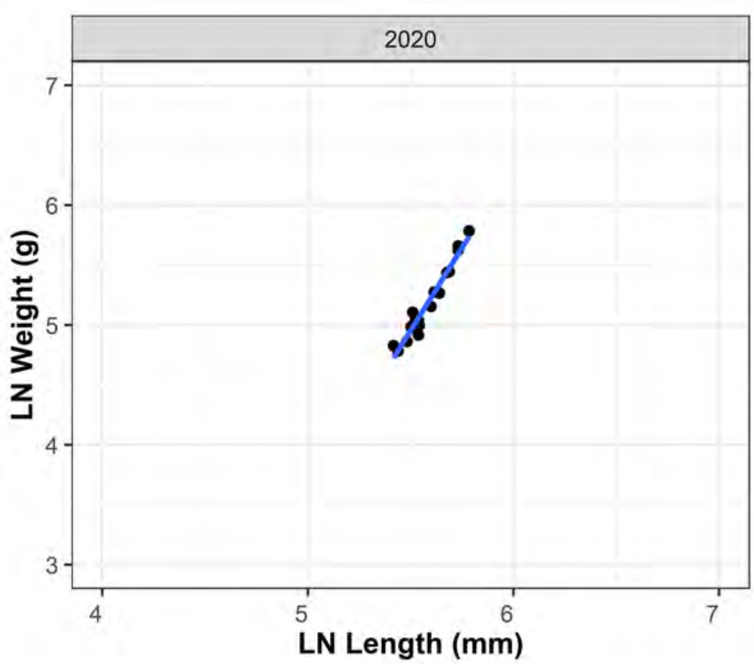


Figure 32. Length weight plot and relationship (Ln W = b · Ln L + Ln a) of Cutthroat Trout, 2020, Wahleach Reservoir, BC.

Table 18. Summary of variables in R for Cutthroat Trout length weight relationships (Ln W = b · Ln L + Ln a), 2020, Wahleach Reservoir, BC. Cutthroat Trout were not present in Wahleach Reservoir prior to nutrient restoration.

Year	Equation	R^2
2020	LN.weight.g = 2.75 *LN.length.mm -10.2	R^2=0.9512

4.6.5 Threespine Stickleback

Littoral minnow traps set in 2020 captured a total of 12 Threespine Stickleback with lengths ranging from 32 to 43 mm and all weighing approximately 0.5 g (Table 19, Figure 33). Threespine Stickleback catch remained lower than the 1994 baseline year (n=65).

Table 19. Summary of Threespine Stickleback length and weight data from minnow trapping, 2020, Wahleach Reservoir, BC.

Year	n	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)
2020	12	39	3	0.5	0

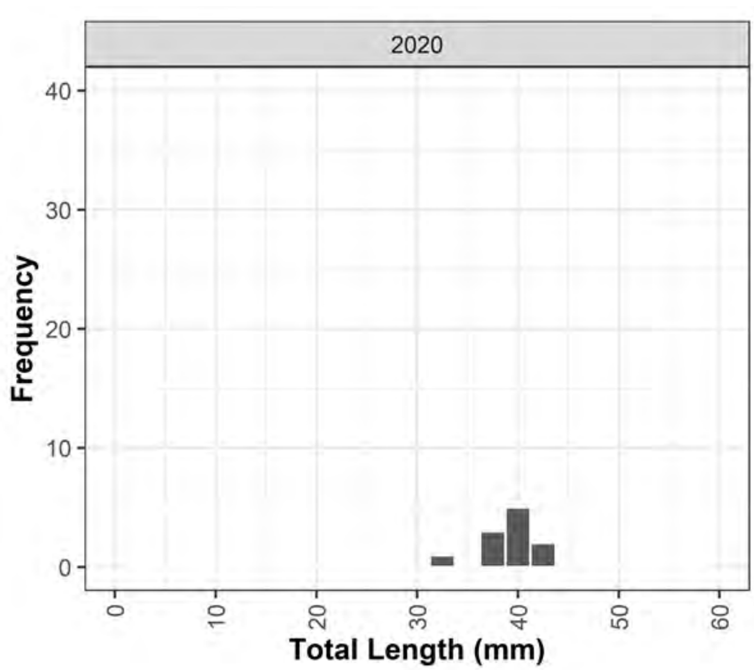


Figure 33. Length frequency of Threespine Stickleback caught in fall 2020, Wahleach Reservoir, BC.

4.6.6 Hydroacoustic Fish Distribution

Partitioning the acoustic targets for Threespine Stickleback and Kokanee fry is complicated as they have similar sizes, therefore target strengths encompassing the two species is retained for the small fish category and respective populations assumed based on depth. Previous trawl surveys have shown that Threespine Stickleback are slightly smaller in size than Kokanee fry. Threespine Stickleback are primarily found in the upper depth stratum of 2-6 m (Figure 34, panel b) and Kokanee are primarily found in 6-30 m depths (Figure 34, panel c).

Similarly, looking at distribution by depth and size; it shows smaller fish primarily in the shallower depth stratum while larger fish are concentrated deeper (Figure 35a). Focusing first on small fish, Threespine Stickleback represent the mode shallower than 6 m, while the deeper small fish mode is both Threespine Stickleback and Kokanee fry (Figure 35a), with Kokanee being the dominant species of the two. Large fish were evident in the 6-8 m layer, and mostly Kokanee Age 1-3+ peaked in the 10-12 m layer (Figure 35a). Figure 35b identifies the distribution of mostly Kokanee (some Threespine Stickleback may be present); age 0 peaks at 8-10 m, and Kokanee Age 1-3+ peak at 10-12 m.

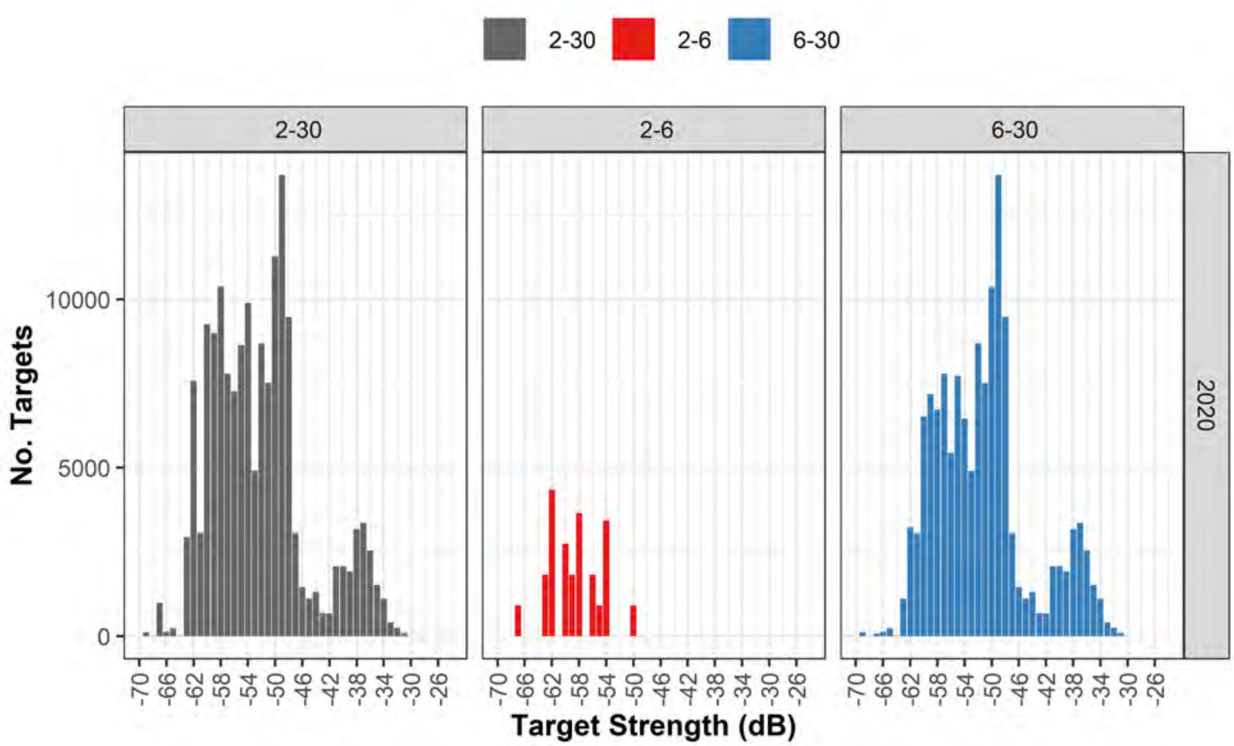
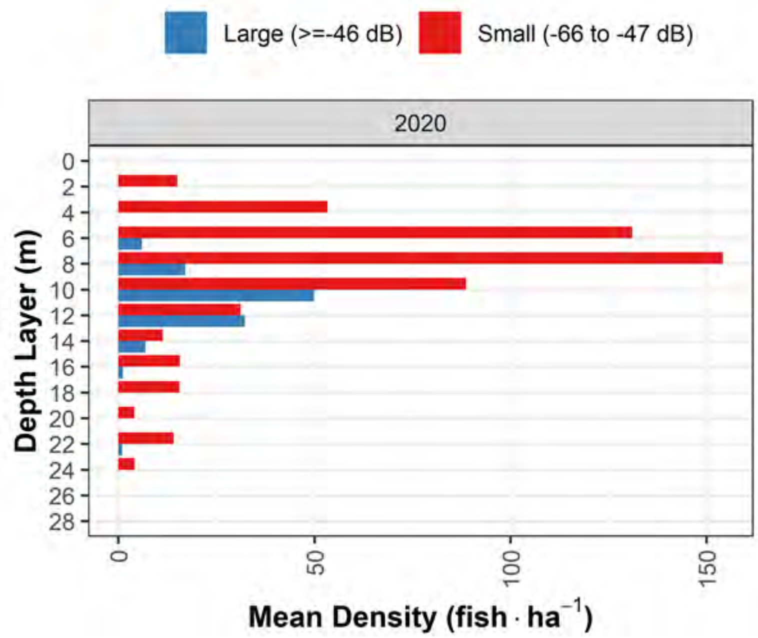


Figure 34. Target strength distributions by depth range (m) from hydroacoustic survey, 2020, Wahleach Reservoir, BC.

(a)



(b)

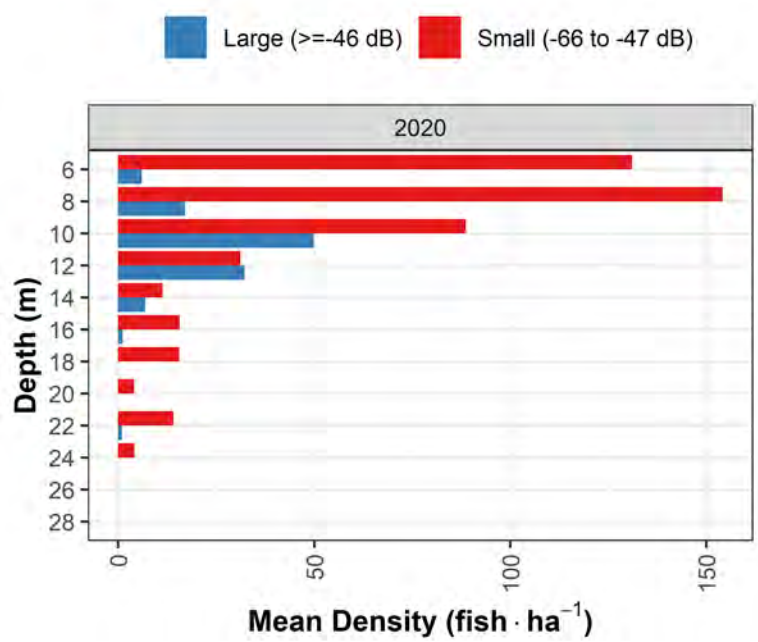


Figure 35. (a) Distribution of 'All fish' group densities by size group (small = -66 to -47 dB, large ≥ -46 dB) and depth layer (2-30 m) based on hydroacoustic survey, 2020, Wahleach Reservoir, BC. (b) Distribution of Kokanee densities by size group (small = -66 to -47 dB, large ≥ -46 dB) and Kokanee depth layer (6-30 m) based on hydroacoustic survey, 2020, Wahleach Reservoir, BC.

4.6.7 Population and Biomass Estimates

The total fish abundance for all depths (2-30 m), representing a mixed species assemblage, was ~152,000 individuals (ranging from ~122,000 to 182,000 individuals). The acoustic population for small fish was estimated at ~128,000 (ranging from ~101,000 to 155,000) individuals in 2020, with just under 33,000 Threespine Stickleback (Table 20). Age 0 Kokanee abundance was ~106,000 individuals (ranging from ~84,000 to 128,000) which was higher than the long-term average of ~83,000 (2009-2020; Table 20; data on file). Adult Kokanee (age ≥1) abundance in 2020 was ~24,000 individuals (ranging from ~16,000 to 32,000), which was slightly lower than the long-term average of ~25,000 (2009-2020; Table 20; data on file). In 2020, the total biomass of fish (all species) was estimated at 2,222 kg, which was above the long-term average of 1,817 kg from 2009-2020 (data on file). Generally, biomass was driven by the abundance of fish in the large size group, which was primarily made up of adult Kokanee.

Table 20. Population estimates with upper and lower confidence intervals for all fish and Kokanee based on hydroacoustic survey, 2020, Wahleach Reservoir, BC.

Year	Analysis Depths (m)	Group	Population Estimate	Lower CI	Upper CI
2020	2-30	All Fish	152,019	121,706	182,429
2020	2-30	Small Fish	128,179	101,292	154,518
2020	2-30	Large Fish	24,034	15,914	32,178
2020	6-30	All KO	129,963	103,963	156,359
2020	6-30	KO Fry	105,978	83,547	128,435
2020	6-30	Adult KO	24,049	15,915	31,952

5. Discussion

In 2020, the world was adjusting to COVID-19 along with new protocols and restrictions. Significant effort was put forth by the team to ensure the success of the nutrient restoration program at Wahleach Reservoir. Extra time and consideration were taken for approvals, logistics, workplans, and COVID-19 safety protocols, in order to keep this program running smoothly and on it’s scheduled timeline.

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., radiolabelled 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 2020, 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 Wahleach (Table 21).

Table 21. Trophic state classification using criteria defined by Wetzel (2001) and Wetzel (1983). Blue shading is indicative of Trophic Classifications during nutrient restoration, 2020, Wahleach Reservoir, BC.

Parameter (Units)	Mean ± SD (Range)	Trophic Classification, Mean (Range)			
	2019	Ultra-Oligotrophic	Oligotrophic	Mesotrophic	Eutrophic
TP ($\mu g \cdot L^{-1}$)	3.8 ± 1.1 (2.2 to 5.5)	(< 1-5)	8 (3-18)	27 (11-96)	84 (16-386)
TN ($\mu g \cdot L^{-1}$)	149 ± 18 (123 to 181)	(< 1-250)	661 (307-1,630)	753 (361-1,387)	1,875 (396-6,100)
Secchi (m)	5.5 ± 0.8 (4.7 to 7.0)	-	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 2020. Phosphorous was omitted in weeks 8 and 9 and reduced by half in week 13 to avoid unwanted phytoplankton blooms where *in situ* conditions suggested high particulate concentrations were present in the water. 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 incoming 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 approach focuses on keeping nitrogen limitation at bay, 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 2020 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 difficult due to the change in laboratory in 2019. 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 2020 season prior to the onset of *Daphnia* growth, which is common in Wahleach and was seen in previous years (data on file). Interestingly, while *Daphnia* density and biomass were both high in July and August, numbers peaked in September. This corresponds with Kokanee spawners leaving the reservoir indicating that *Daphnia* were likely being heavily grazed down by Kokanee during the summer. The species *Daphnia galeata mendotae* was present in 2020 samples for the first time on record. *Daphnia galeata mendotae* is one of the most common zooplankton species in BC Lakes and has likely been present in previous years but in low numbers (L. Vidmanic, personal communication, December 14, 2021). Overall, zooplankton densities and biomass in 2020 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 2020, the hydroacoustic data indicated that Kokanee (fry and adult) abundance was higher than the previous year (Vainionpaa et al., 2021). The 2020 hydroacoustic age ≥1+ Kokanee population was near the long-term average of 25,380 (2009-2020; data on file) at 24,049 individuals. Kokanee fry abundance in 2020 was above average at 105,978 compared to the long-term average of 82,635 (2009-2020; data on file). The 2020 total gillnet catch was below average for the last 10 years, but higher than the 2019 total gillnet catch. Overall catch totalled 106 fish, with just over half of those being Rainbow trout. Similar numbers of Cutthroat were caught compared to the previous several years, while only 19 Kokanee were caught, which is the lowest number since 2014 (data on file). While catch numbers are down, Kokanee size and condition in 2020 remained well above baseline years (Perrin and Stables, 2001).

Kokanee spawner escapement in 2020 was lower compared to the previous several years; however, this was an underrepresented escapement estimate due to high bear activity preventing survey completion during the peak time on Flat Creek. The mean fork length of Kokanee spawners captured was greater than the long-term mean (data on file) and spawning fish appeared in good condition. Boulder Creek spawner numbers have been steadily declining in recent years (Figure 36). As the name indicates, Boulder Creek substrate is mostly composed of larger boulders and cobbles and so historically, 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 flows were high and 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.

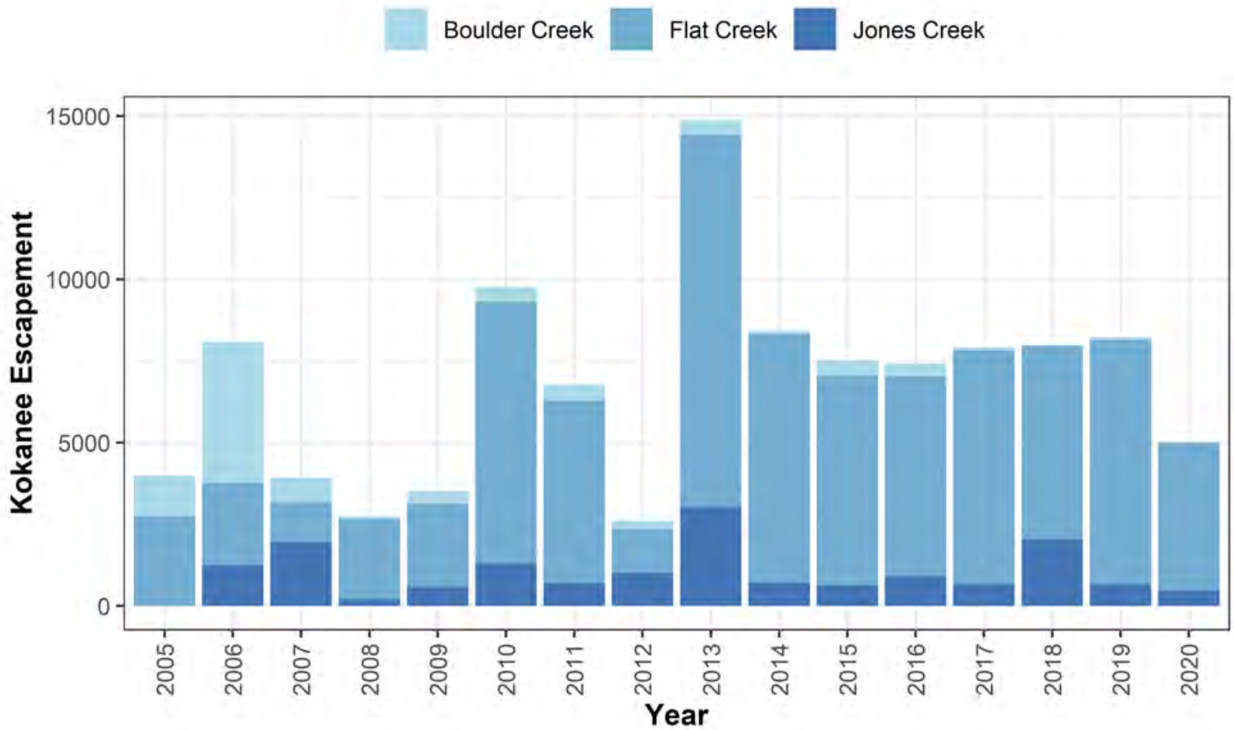


Figure 36. Kokanee spawner escapement from 2005-2020 in each index stream (Boulder Creek, Flat Creek, and Jones Creek), Wahleach Reservoir, BC.

The annual estimate of Threespine Stickleback abundance from the hydroacoustic surveys was 32,799 individuals, which was lower than the previous year, and lower than the long-term average of 77,143 (2009-2020; data on file). Overtime, the hydro acoustic data requires more refinement as we are understanding the reservoir dynamics further and use information gathered from other systems around the province. To standardize the methodology among other large lakes and increase precision in annual estimates of both age 0 Kokanee (fry) and Threespine Stickleback abundances, the acoustic timeseries will be re-analyzed applying the acoustic noise reduction, which was developed for Kinbasket and Revelstoke acoustic data (see Sebastian, and Weir, 2015). This revised approach should result in more precise and robust estimates for both species but is not expected to change estimates significantly. Minnow traps in 2020 caught only 12 Threespine Stickleback, which was lower than the 1994 baseline catch of 65 Threespine Stickleback.

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. 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 over twenty 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.

- 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.

- Collect water samples in June, July and August to be sent for microcystin toxin analysis. A recent phytoplankton taxonomy lab change has led to questions surrounding a visually similar blue-green algae. Results of this analysis will help to determine the presence of *Aphanothece minutissimus* (non-toxin-producing blue-green algae) versus *Microcystis* sp. (toxin-producing blue-green algae).

- Collect water samples in June, July and August for calcium. Though Wahleach reservoir is neutral in pH, alkalinity results have indicated it is highly sensitive to acidification. Calcium can also be used as an indicator of acid sensitivity within the reservoir. This will help to further understand the lake dynamics.

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 with a scaled-back approach focusing on capturing the peak and collecting a representative sample of spawning Kokanee.

- Continue with the hydroacoustic surveys in late July or early August in 2021 as field conditions are generally more favorable at that time (i.e., strong thermal stratification 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. As we learn more about the dynamics of the reservoir and apply knowledge from other systems across BC; it is also recommended that the timeseries be re-analyzed using a noise reduction method to refine age 0 Kokanee and Threespine Stickleback estimates. It is not expected to change values significantly but will make the estimates more precise. Estimate of completion of this re-analysis is to include it in the 2021 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. This task will take a few years to complete with an estimate of completion for the 2022 Report.

Recreational Fishery

- Creel surveys to assess the recreational fishery on Wahleach Reservoir should be incorporated into regular program monitoring. One creel survey over each five-year cycle should be sufficient to understand how anglers are responding to restoration actions; ideally, the survey would be scheduled for year three of the cycle with a contingency to allow for additional survey effort in years four or five in case of logistical or other issues (as has often been the case, due to road closures for example).

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9. Appendices

9.1 **Appendix A.** Phytoplankton species detected during 2020, Wahleach Reservoir, BC.

Species	**2020**	**Species**	**2020**
Amphidinium	+	*Komma* sp.	+
Ankistrodesmus sp.	+	*Mallomonas sp1*	+
Aphanothece minutissimus	+	*Mallomonas sp2*	+
Chlamydocapsa sp.	+	*Merismopedia* sp.	+
Chromulina sp1	+	*Monoraphidium* sp.	+
Chroococcus sp	+	*Nephrocytium sp.*	+
Chroomonas acuta	+	*Nephroselmis*	+
Chrysochromulina sp.	+	*Ochromonas* sp.	+
Chrysococcus sp.	+	*Oocystis* sp.	+
Cocconeis sp.	+	*Phacus* sp.	+
Cryptomonas sp3.	+	*Planktosphaeria* sp.	+
Cymbella sp.	+	*Rhizosolenia* sp.	+
Dichtyosphaerium sp.	+	*Scenedesmus* sp.	+
Dinobryon sp.	+	*Scourfieldia* sp.	+
Elakatothrix sp3	+	Small microflagellates	+
Fragilaria capucina	+	*Sphaerocystis* sp.	+
Gleotila sp.	+	*Synechococcus* sp. (coccoid)	+
Gymnodinium sp1	+	*Synechococcu*s sp. (rod)	+
Gymnodinium sp2	+	*Synechocystis* sp.	+
Gymnodinium sp3	+	*Tetraedron* sp.	+
Kephyrion sp.	+	*Trachelomonas sp.*	+

9.2 **Appendix B.** Zooplankton species detected during 2020, Wahleach Reservoir, BC

Order/Species	**2020**
CLADOCERA	
Bosmina longirostris	+
Chydorus sphaericus	r
Daphnia rosea	+
Daphnia galeata mendotae	r
Holopedium gibberum	+
Leptodora kindtii	+
Scapholeberis mucronata	r
COPEPODA	
Cyclops vernalis	+
Leptodiaptomus ashlandi	r

r = rare species, + = present