Wahleach Project Water Use Plan

Wahleach Reservoir Fertilization Program

Implementation Year 14

Reference: WAHWORKS-2

WAHLEACH RESERVOIR NUTRIENT RESTORATION PROJECT REPORT, 2018 - Fisheries Project Report No. RD 165

Study Period: 2018

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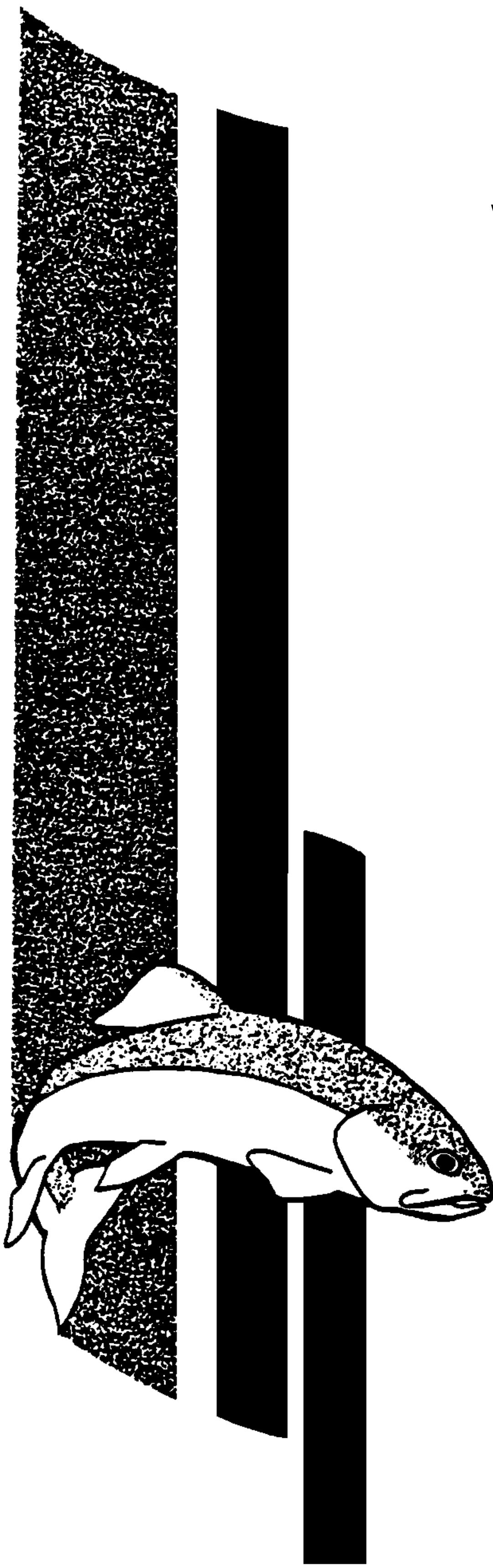

WAHLEACH RESERVOIR NUTRIENT RESTORATION PROJECT REPORT, 2018

by

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

Fisheries Project Report No. RD 165
2019

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

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Data and information contained within this report are subject to change.

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Executive Summary

The restoration of Wahleach Reservoir has continued to use a strategy of nutrient addition in combination with biomanipulation of the food web, via stocking of sterile Cutthroat Trout, to restore a self-sustaining population of Kokanee within the lake. A suite of physical, chemical and biological parameters were monitored to assess the ecosystem's response to treatments and adaptively manage the program. This document is intended as a summary data report for the 2018 monitoring year.

In 2018, 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 consisted primarily of edible species throughout the season, except in June and July when blooms of inedible *Microcystis* sp. occurred. The seasonal mean phytoplankton abundance was 4,906 cells·mL^{-1} (SD = 3,106). At the secondary trophic level, *Daphnia* densities averaged 2.5 individuals·L^{-1} and biomass averaged 71 μg·L^{-1}; *Daphnia* accounted for 52% of the total zooplankton density and 75% of the total biomass. Growth of other cladocerans was also strong early in the season. Overall, 2018 had the fourth greatest zooplankton biomass on record for the project period. Stimulation of lower trophic levels has translated into increased abundance and biomass of Kokanee, while the introduction of sterile Cutthroat Trout has supressed the growth of Threespine Stickleback. Kokanee were below detection limits and largely considered extirpated when the project began. In 2018, the adult (age >1 year) Kokanee population was estimated at approximately 20,000 individuals with an escapement of 7,907 spawners. The Threespine Stickleback catch in 2018 continued to remain below baseline numbers. As well, the hydroacoustic population estimate for small fish in the upper 6 m of the water column, the majority of which would be Threespine Stickleback, was approximately 20,000 individuals and well below the population estimate of 1.2 million individuals during the baseline years of the project. Results of the fall gillnetting program continued to demonstrate that Cutthroat Trout were remaining in the population long enough to reach the sizes required to exhibit piscivory. Cutthroat Trout catch for 2018 included a range of ages from age 2+ to age 6+, with a mean length of 310 ± 84 mm (range 241 to 412 mm). Condition factors were stable (mean 1.0 ± 0.08). Project monitoring data support the conclusion that nutrient addition has had a positive bottom-up effect on lower trophic levels, and subsequently, on the Kokanee population. Data also support that sterile Cutthroat Trout exhibit top-down pressure on the Threespine Stickleback population through predation and have reduced Threespine Stickleback abundance in the reservoir; thus, enabling Kokanee to take advantage of improved conditions. Combined restoration efforts have been able to improve and maintain Wahleach Reservoir's Kokanee population over the long-term. Overall, data from Wahleach Reservoir and other systems in BC have demonstrated that seasonal nutrient additions on large lakes and reservoirs are associated with positive ecological effects, particularly for the pelagic food web. Data also show that the desired effects would not be sustained without continued application of nutrients. Seasonal *in situ* data are required to adaptively manage nutrient additions and inform restoration actions so 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 production 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. Only 33 Kokanee were caught during the 1994 gillnetting program and they were considered extirpated by 1995 (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 or accidental introduction of Threespine Stickleback (*Gasterosteus aculeatus*) into the reservoir (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 was to restore and maintain recreational fish populations. The nutrient addition treatment was meant to increase nitrogen and phosphorus concentrations in a way that optimized food resources for higher trophic levels. It has been well established that nutrient additions can compensate for the loss in productivity resulting from dam construction and operation (Stockner and Shortreed 1985, Ashley et al. 1997) 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 (Thompson 1999, Perrin and Stables 2000, Perrin and Stables 2001). 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 nutrients additions (Hyatt and Stockner 1985). So top-down control of competitor fish species would ensure 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 subsequent monitoring completed in 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 a base 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). 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 that the project needed to continue until completion of the WUP Order Review when a long-term decision on the project could be made. As such, an addendum to the TOR was submitted to the Comptroller of Water Rights to continue the project until the WUP Order Review is completed, and was approved on April 27, 2015 (BC Hydro 2015). Due to delays in the WUP Order Review process, a three-year Memorandum of Understanding (valid until December 2020) was signed by BC Hydro and the Province to continue the project until the review is completed.

This summary report presents data from the 2018 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 Sto:lo First Nation (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 1953 with the construction of a dam at the original lake's outlet stream. Wahleach Reservoir has a surface area of 460 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 can also be 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.

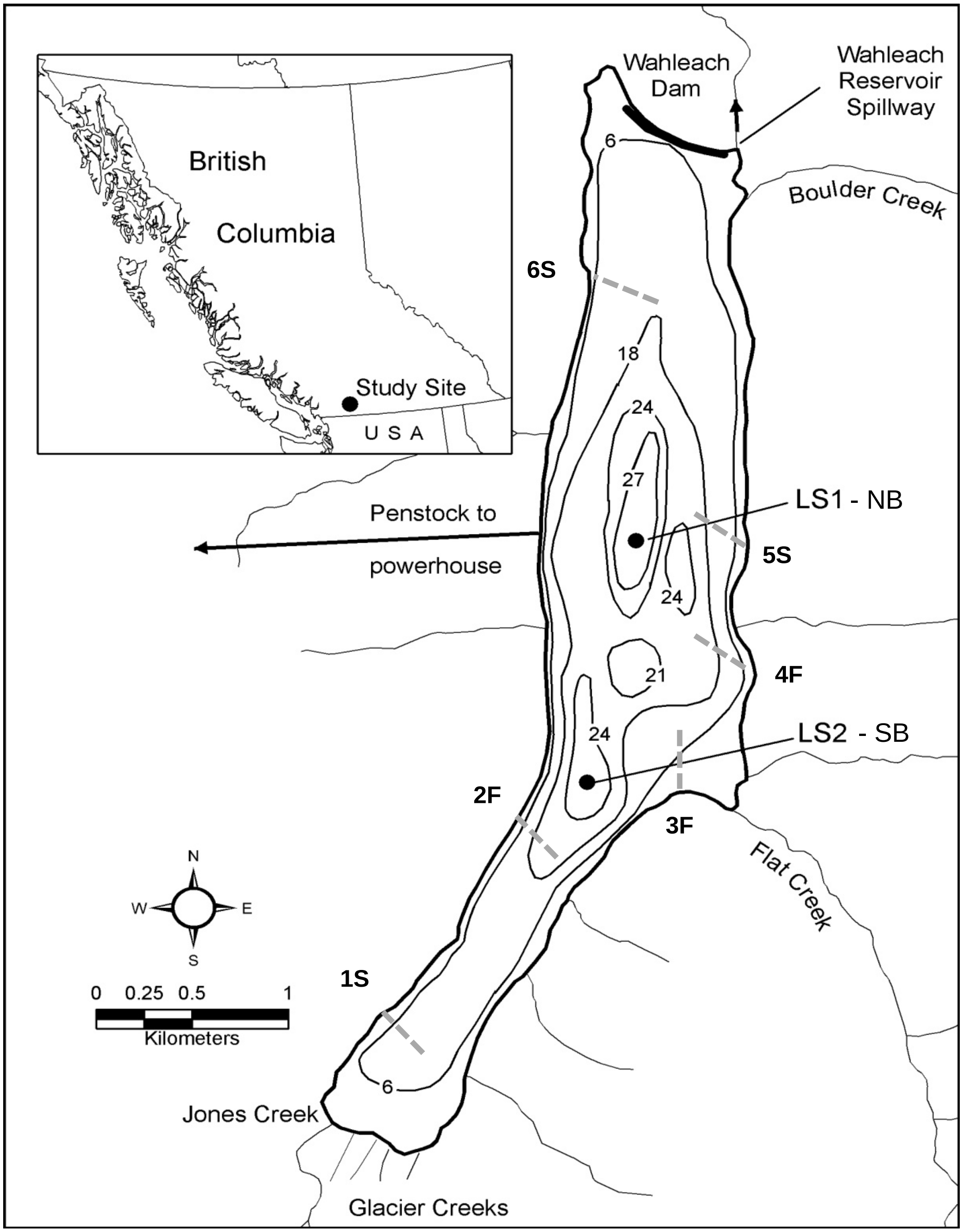

Figure 1. Map of Wahleach Reservoir, BC, including select sampling locations. LS2- SB and LS1-NB are limnological sample locations and 1S, 2F, 3F, 4F, 5S, and 6S are gillnetting locations, with S=Sinking net and F=Floating net. Bathymetric contour depths (m) represent the reservoir at full pool.

3. Methodology

All figures and analyses contained in this report were completed using R version 3.5.2 (R Core Team 2018) through RStudio version 1.1.463 integrated development environment for the R programming language. 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 1993-2018. Values used in a comparative context represent baseline conditions from 1993-1994, and nutrient restoration conditions from 1995-2018. Summary statistics were reported as means ± standard deviations. Methods were consistent with those reported in Sarchuk et al. (2016).

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. Seasonal 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 ratios for growth of edible phytoplankton. Planned annual phosphorus loading rates for Wahleach Reservoir were originally kept near 200 mg $P \cdot m^{-2}$ to improve the production of *Daphnia* based on recommendations by Perrin et al. (2006). In more recent years, actual phosphorus loading rates were approximately half this rate due to in-season modifications (see paragraph below for more details), yet negative effects on *Daphnia* growth were not observed (Sarchuk et al. 2016). As a result, beginning in 2016, planned phosphorus loading rates were adjusted lower than 200 mg $P \cdot m^{-2}$. 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 2018 included a few weeks of nitrogen-only applications beginning in week 4 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 results of the limnological monitoring program. While reservoir productivity is largely governed by nutrient loading, climate also strongly influences the ecosystem response. In 2018, actual nutrient loading rates were modified in weeks 9 and 10 when phosphorus loading was omitted (Figure 2, Table 1). Overall, weekly areal loading rates for phosphorus were greatest at the start of the season with a maximum of 12.3 mg $P \cdot m^{-2}$. Nitrogen loading increased rapidly during the first five weeks of the season with a maximum of 108 mg $N \cdot m^{-2}$ (Figure 2). The weekly molar nitrogen to phosphorus ratio peaked at 33.6 during the latter half of the season when both phosphorus and nitrogen loading rates were being ramped down (Figure 2).

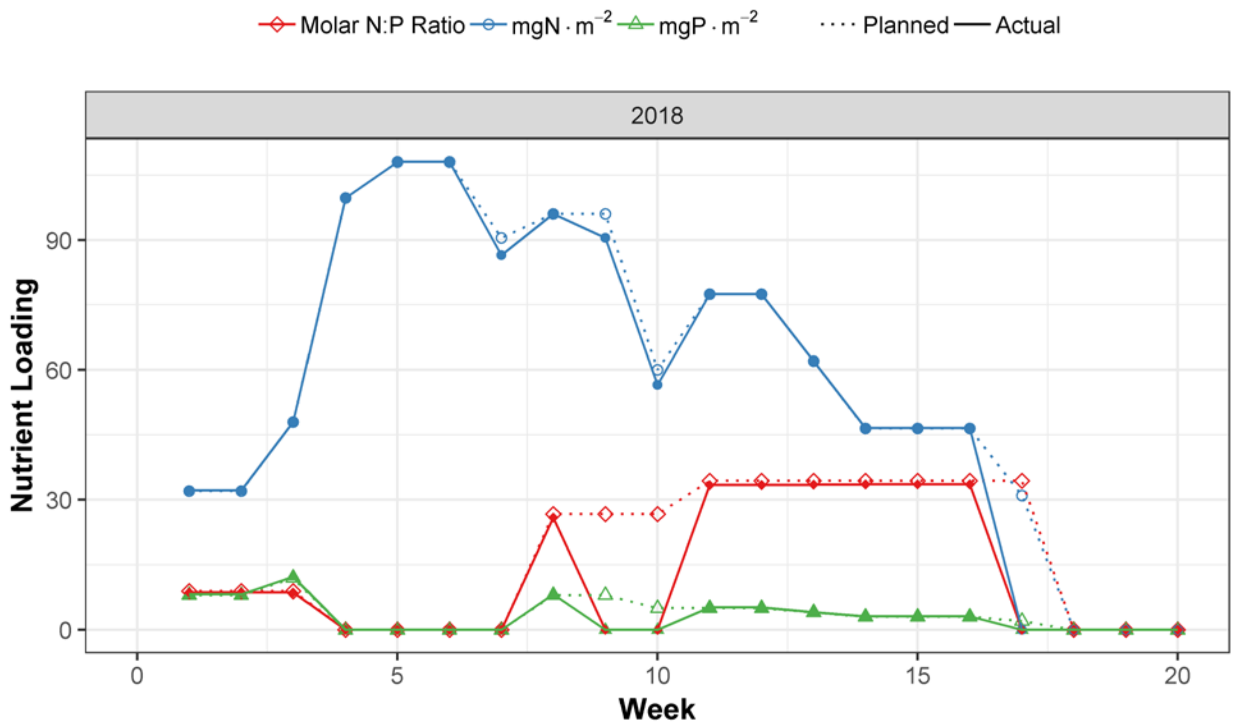

Figure 2. Seasonal planned and actual nutrient additions for Wahleach Reservoir, including areal nitrogen and phosphorus loading as well as molar N:P ratios, 2018; planned values are represented by hollow points, while actual values are represented by solid points.

Table 1. Annual nutrient additions by weight and areal loading, 2018, Wahleach Reservoir, BC

Year	Date Range	Fertilizer Blend		Total Phosphorus		Total Nitrogen	
		10-34-0	28-0-0				
		t	t	Kg	mg·m^{-2}	Kg	mg·m^{-2}
2018	6-Jun to 17-Sep	1.63	15.3	554	60.5	4,457	1,114

3.1.2 Fish Stocking

Stocking of sterile (triploid) Cutthroat Trout was continued to maintain top-down pressure on the Threespine Stickleback population. In 2018, a total of 2,000 sterile (triploid) Cutthroat Trout 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 Climate

Data were provided by BC Hydro. Analysis methods followed Sarchuk et al. (2016).

3.2.2 Hydrometrics and Reservoir Operations

Data were provided by BC Hydro. Analysis methods followed Sarchuk et al. (2016).

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, water chemistry (i.e. nutrient concentrations), and depth integrated 0.45 μm chlorophyll *a*. Discrete water chemistry samples were collected at 1 m (epilimnion) and 20 m (hypolimnion); a depth-integrated sample of the epilimnion was also collected. All reported values, unless explicitly defined, were from the 1 m epilimnetic samples. 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. Chlorophyll *a* data were not available at the time of writing. For additional field sampling and analysis methods refer to Sarchuk et al. (2016).

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). For additional field sampling and analysis methods, refer to Sarchuk et al. (2016).

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. (order *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. (2016).

3.2.6 Fish Populations

Fish populations were assessed through a combination of different survey types: gillnet, minnow trap, hydroacoustic, and spawner counts. Due to logistical challenges, a trawl survey was not conducted for 2018. For simplification, abbreviated fish species names are used in tables and graphs; these include Kokanee (KO), Rainbow Trout (RB), Cutthroat Trout (CT), and Threespine Stickleback (TSB).

3.2.6.1 Gillnet and Minnow Trap Surveys

Nearshore gillnet and minnow trap sampling sites are shown on Figure 1, with exact coordinates for 2018 in Table 2. Although exact coordinates may vary slightly, the general locations of sampling sites remain consistent from year to year.

Table 2. Locations of standard nearshore gillnet and minnow trap stations, 2018, Wahleach Reservoir, BC.

Station	Gear	Latitude	Longitude	Station	Gear	Latitude	Longitude
1S	GN	49°12.465 N	121°38.022 W	4F	GN	49°13.435 N	121°36.245 W
2F	GN	49°13.206 N	121°37.185 W	5S	GN	49°14.247 N	121°36.258 W
3F	GN	49°13.042 N	121°37.740 W	6S	GN	49°14.693 N	121°36.864 W
1M	MT	49°13.990 N	121°37.121 W	4M	MT	49°13.291 N	121°37.149 W
2M	MT	49°13.759 N	121°37.147 W	5M	MT	49°12.187 N	121°37.948 W
3M	MT	49°13.380 N	121°37.148 W	6M	MT	49°12.211 N	121°38.012 W

Standardized annual nearshore gillnet sampling was completed after Kokanee spawners had moved out of the reservoir on October 23 to 24, 2018. Each station was set with one standard 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 trap sampling targeting Threespine Stickleback was completed at the same time as gillnet sampling. In 2018, 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.

For additional field sampling and analysis methods, refer to Sarchuk et al. (2016).

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 5 to October 17, 2018. For additional field sampling and analysis methods, refer to Sarchuk et al. (2016).

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 2018 are shown in Table 3. Additional details on field and analysis methods can be found in Sarchuk et al. (2016).

Table 3. Summary of equipment and conditions for hydroacoustic surveys, 2018, Wahleach Reservoir, BC.

Year	Survey Date	Sounder	Reservoir Elevation[1] (m)	Avg Transect Start/End Depth (m)
2018	July 18	EK60	640.21	8.4

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

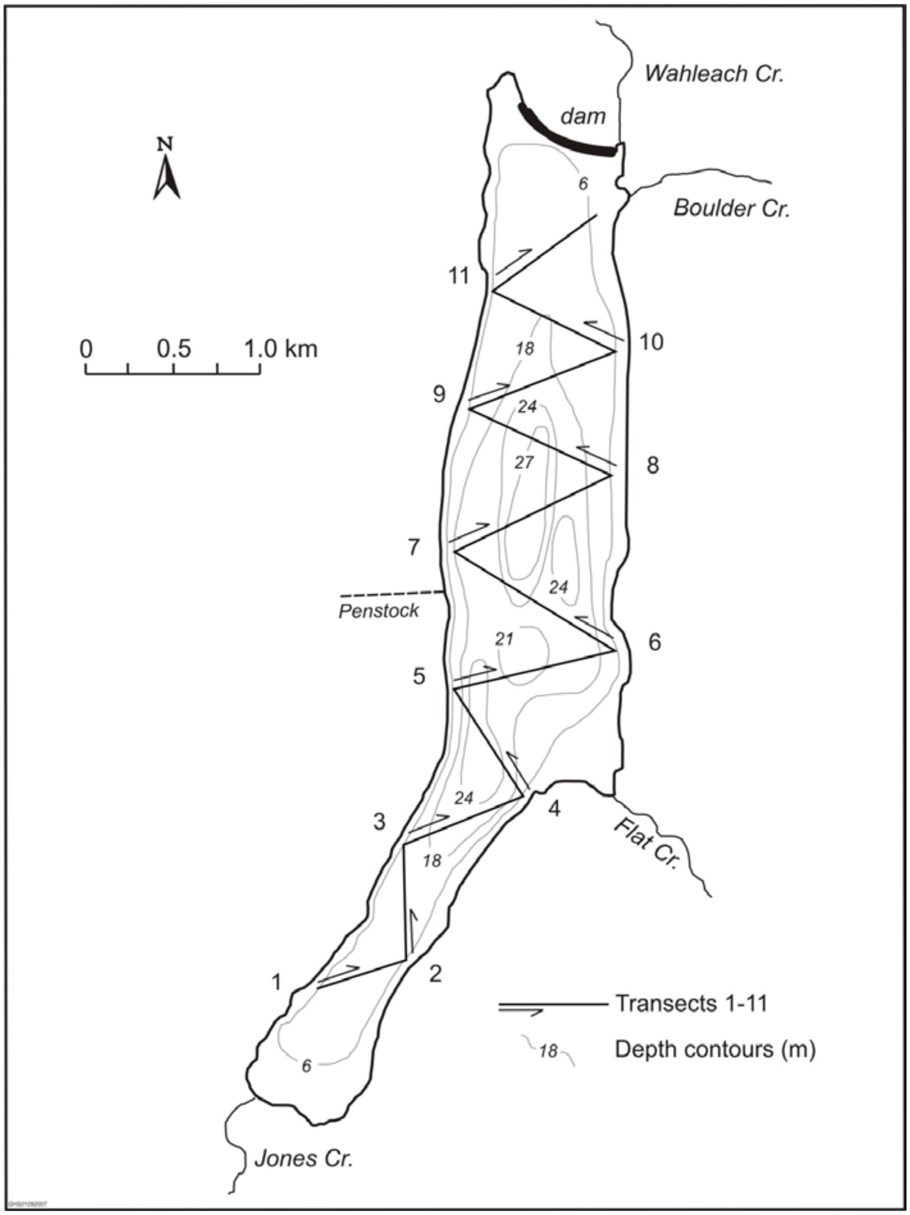

Figure 3. Locations of standardized hydroacoustic transects, Wahleach Reservoir, BC.

Population and Biomass

Data were analyzed using Sonar 5 post processing software version 6.0.1 described by Balk and Lindem (2011), down to a minimum of -70 dB and a maximum of -24 dB. Decibel thresholds were used to encompass the majority of fish targets while eliminating small non-fish targets, and to differentiate between small and large size fish (Table 4). Species differentiation within groups was challenging. In raw data form, the small size group represented primarily age-0 Kokanee (i.e. fry) and Threespine Stickleback; while the larger size group represented primarily age ≥1 Kokanee, as well as lesser numbers of Cutthroat Trout and Rainbow Trout. To eliminate the majority of non-target species, hydroacoustic data were partitioned by depth according to the vertical distribution of Kokanee in the reservoir (Table 4).

Population estimates assumed that targets distributed at depths with water temperatures <17˚C and dissolved oxygen concentrations >5 mg·L^{-1} were mainly Kokanee, as supported by results of pelagic gillnetting and directed trawling (Sarchuk et al. 2017). We refer to these depth-partitioned estimates simply 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, 2018, Wahleach Reservoir, BC.

Year	Analysis Depth Range (m)	KO Depth Range (m)	Small Fish dB Thresholds	Large Fish dB Thresholds	All Fish dB Threshold
2018	2-30	6-30	-66 to -49	≥ -48	≥ -66

We estimated fish populations with confidence intervals using a stochastic simulation approach (a Monte Carlo method). Simulations were done in R (R Core Team 2016), 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. (2016).

Initial biomass estimates for Wahleach Reservoir were presented in detail in Sarchuk et al. (2016); 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 were not reported for this reason. Methods for this report were consistent with the approach taken in Sarchuk et al. (2016).

4. Results

4.1 Hydrometrics and Reservoir Operations

4.1.1 Inflow

Mean daily inflow into Wahleach Reservoir during 2018 was 6.6 ± 5.4 m^3·s^{-1} (range 0 to 47.0 m^3 s^{-1}), which was similar to the long term mean of 6.3 ± 5.4 m^3·s^{-1} (range 0 to 96.1 m^3·s^{-1}). During the nutrient addition period (June to September, inclusive), mean daily inflow was lower at 4.9 m^3·s^{-1} (range 0.8 to 13.0 m^3·s^{-1}). Peak flows were observed during the fall and winter storm season; consistent high flows were also observed during spring freshet (Figure 4).

4.1.2 Discharge

Mean daily discharge from Wahleach Reservoir in 2018 was 6.8 ± 4.7 m^3·s^{-1} (range 0 to 13.0 m^3·s^{-1}), which was similar to the long term mean of 6.2 ± 4.7 m^3·s^{-1} (range 0 to 78.6 m^3·s^{-1}). During the nutrient addition period, mean daily discharge was 4.7 ± 3.8 m^3·s^{-1} (range 0.4 to 12.3 m^3·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.

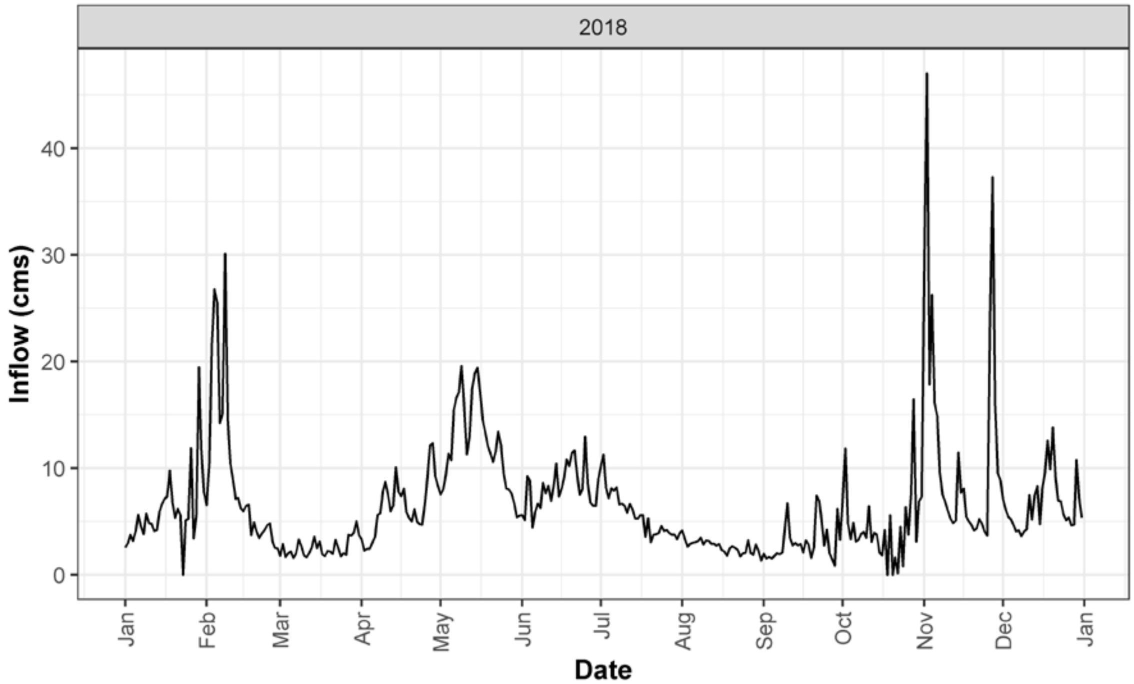

Figure 4. Daily inflow ($m^3 \cdot s^{-1}$), 2018, Wahleach Reservoir, BC.

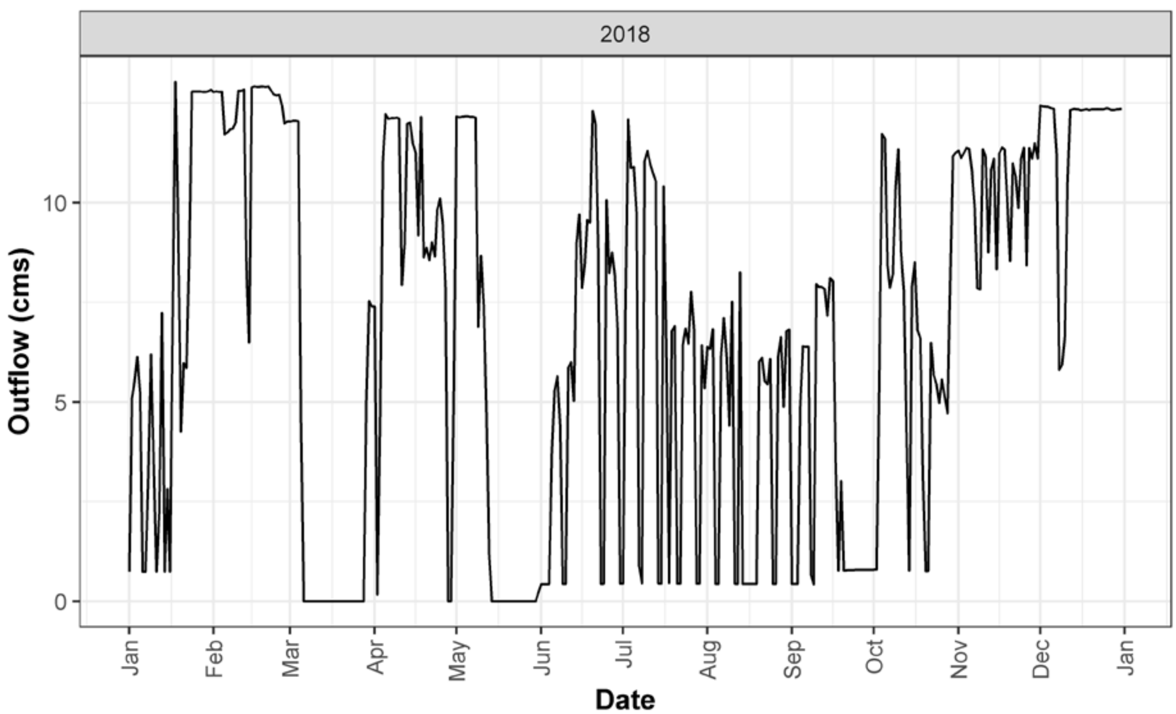

Figure 5. Daily discharge ($m^3 \cdot s^{-1}$), 2018, Wahleach Reservoir, BC.

4.1.3 Reservoir Elevation

Typically, Wahleach Reservoir reaches its minimum water elevation during the month of April or May; 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, as was observed during 2018. The annual drawdown was 7.5 m in 2018, which was lower than the long term (1993-2018) mean of 12.0 m, and reservoir elevations were maintained above the minimum standard operating level of 628 m (Figure 6).

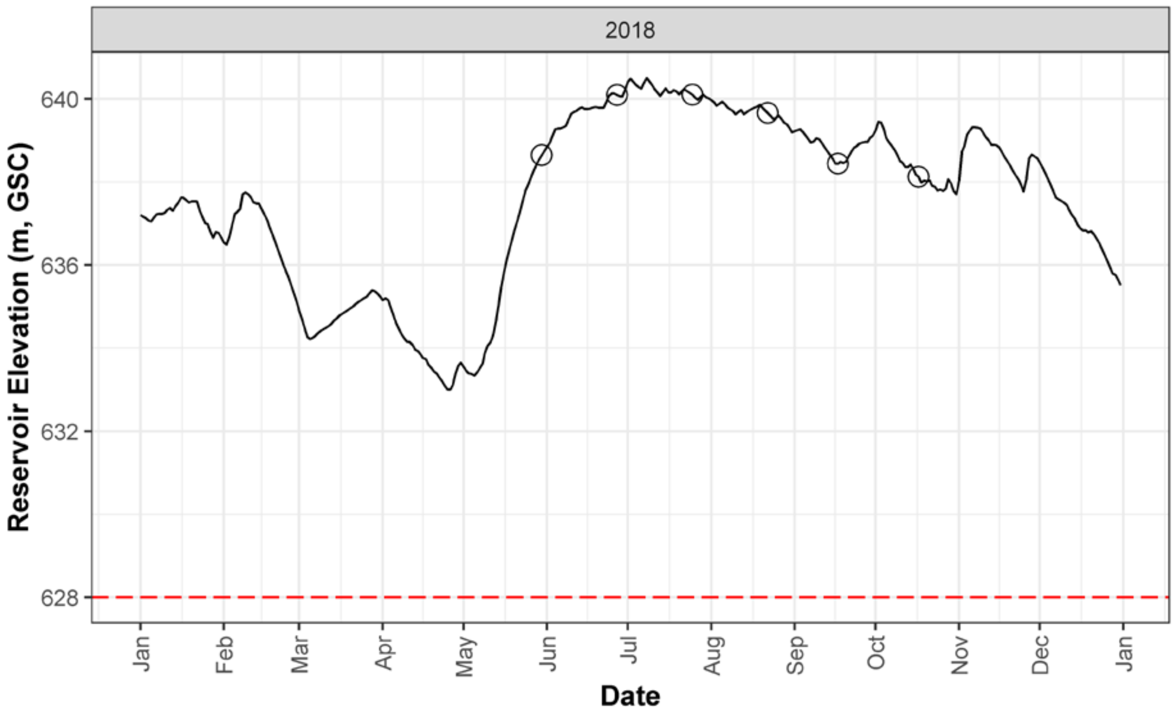

Figure 6. Daily reservoir surface elevation (m, Geodetic Survey of Canada), 2018, Wahleach Reservoir, BC. Open circles represent limnology sampling dates. The red dashed line represents minimum operating level of 628 m.

4.2 Climate

4.2.1 Air Temperature

Seasonal air temperatures in 2018 were the highest in July and lowest in February (Figure 7). Overall, the mean daily temperature in 2018 (7.5 ± 7.2°C, range -16.8 to 33.4°C) was similar to the long-term average (7.1 ± 6.8°C, range -22.3 to 33.9°C). During the nutrient addition period (June through September), mean daily temperatures were 14.7 ± 4.7°C (range 3.9 to 33.4°C), which was warmer than the long term mean but within the range (14.2 ± 3.9°C, range 0.8 to 33.9 °C).

4.2.2 Precipitation

Precipitation generally followed the inverse trend of air temperature; May, July and August had the least precipitation while January to April and September to December had the greatest precipitation (Figure 8). In 2018, mean daily (8 ± 14 mm, range 0 to 76 mm) precipitation was similar to the long term mean of 7 ± 13 mm (range 0 to 130 mm), but mean monthly precipitation was greater at 244 ± 161 mm (range 4 to 541 mm) compared to the long term mean of 219 ± 125 mm (range 4 to 733 mm). A total of 2,928 mm of precipitation fell in 2018, which was also greater than the long term mean (2,625 ± 268 mm, range 2,102 to 3,124 mm). During the nutrient addition period (June through September), the daily and monthly means for precipitation in 2018 were 4 ± 8 mm (0 to 33 mm) and 128 ± 92 mm (48 to 209 mm), respectively, which were similar to the long term means of 4 ± 9 mm (0 to 114 mm), and 124 ± 77 mm (8 to 335 mm), respectively. Total seasonal precipitation during the nutrient addition period in 2018 was 511 mm, which was also similar to the long term mean (494 ± 130 mm, range 202 to 746 mm).

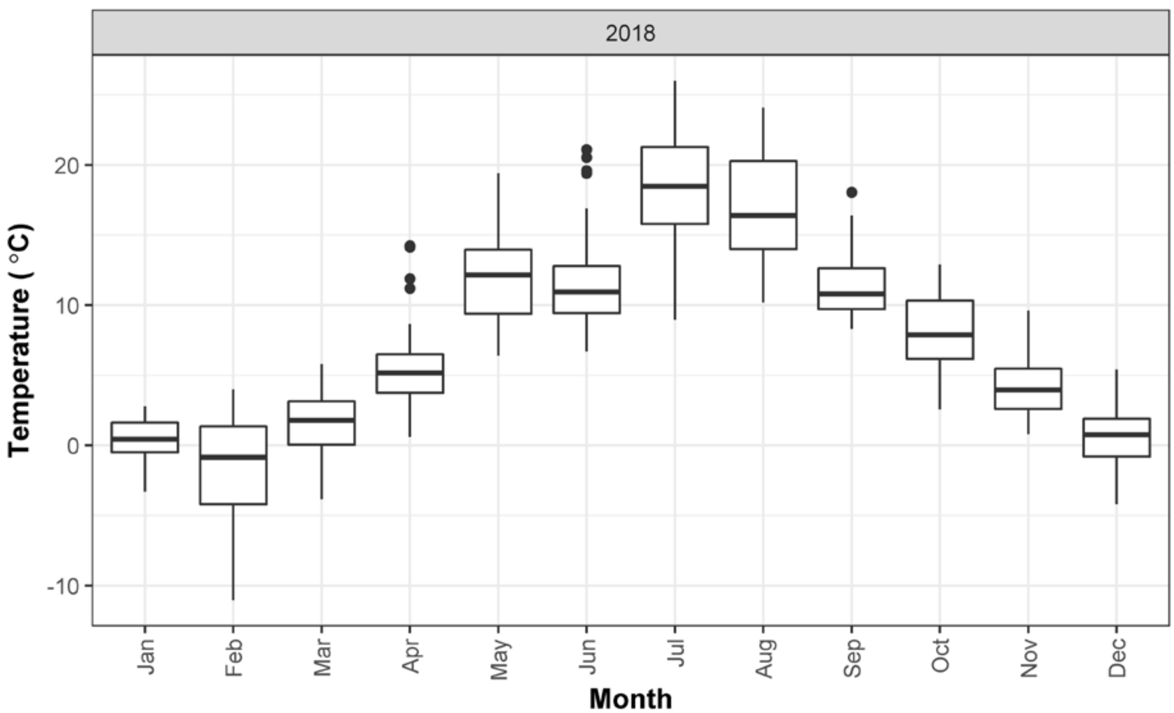

Figure 7. Boxplot of daily mean air temperatures (°C) during each month, 2018, Wahleach Reservoir, BC.

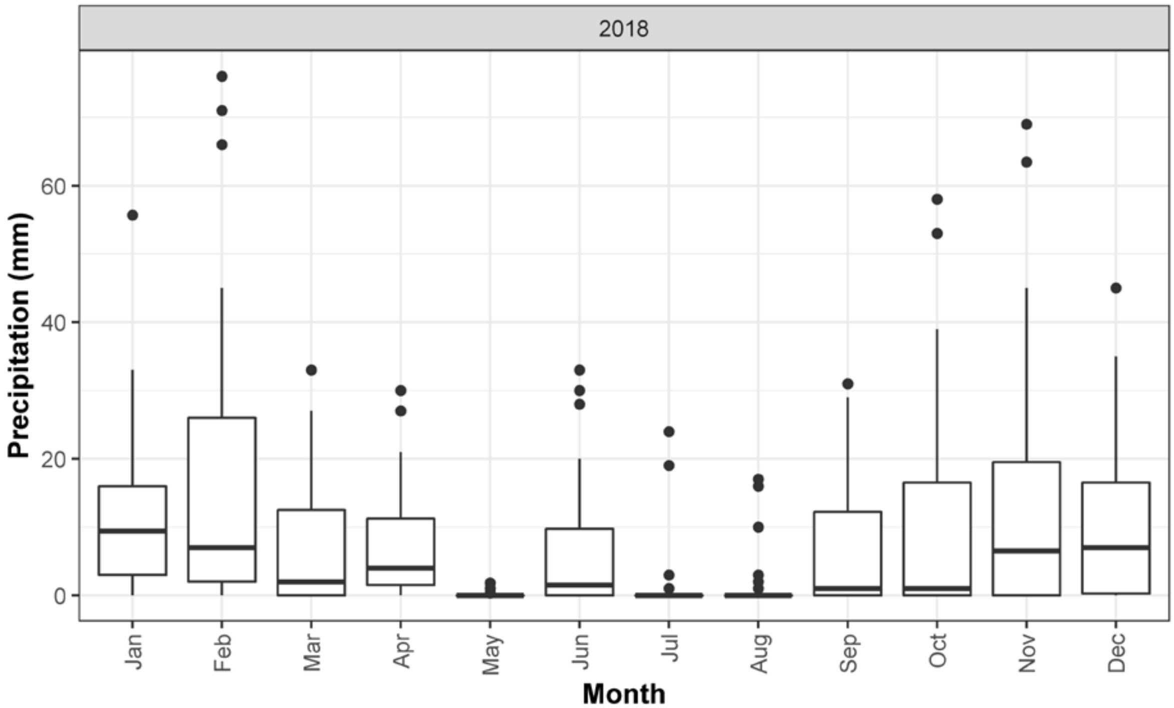

Figure 8. Boxplot of daily total precipitation (mm) during each month, 2018, Wahleach Reservoir, BC.

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 9. A thermocline begins to develop in June with strong thermal stratification in July and August, and then stratification begins to weaken by September. Generally, the water column is well-mixed (isothermal) in the spring (May) and fall (October). In 2018, thermocline depth ranged between 3-14 m (Figure 9). Water temperatures were similar between the north basin and the south basin with a combined mean temperature of 12.0 ± 3.3°C (range 6.9 to 20.5°C). 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 2018 for both basins combined was 8.8 ± 1.4 $mg \cdot L^{-1}$ (range 4.2 to 10.7 $mg \cdot L^{-1}$). During the latter half of the growing season, dissolved oxygen concentrations in the hypolimnion were below 6.5 $mg \cdot L^{-1}$ (Figure 9), which was below the federal guidelines for dissolved oxygen in cold water lakes for salmonid early life stages (9.5 $mg \cdot L^{-1}$) and other life stages (6.5 $mg \cdot L^{-1}$; CCME 1999). In July the water temperature and dissolved oxygen concentration values were omitted for the south basin (SB-LS2), due to errors in the data.

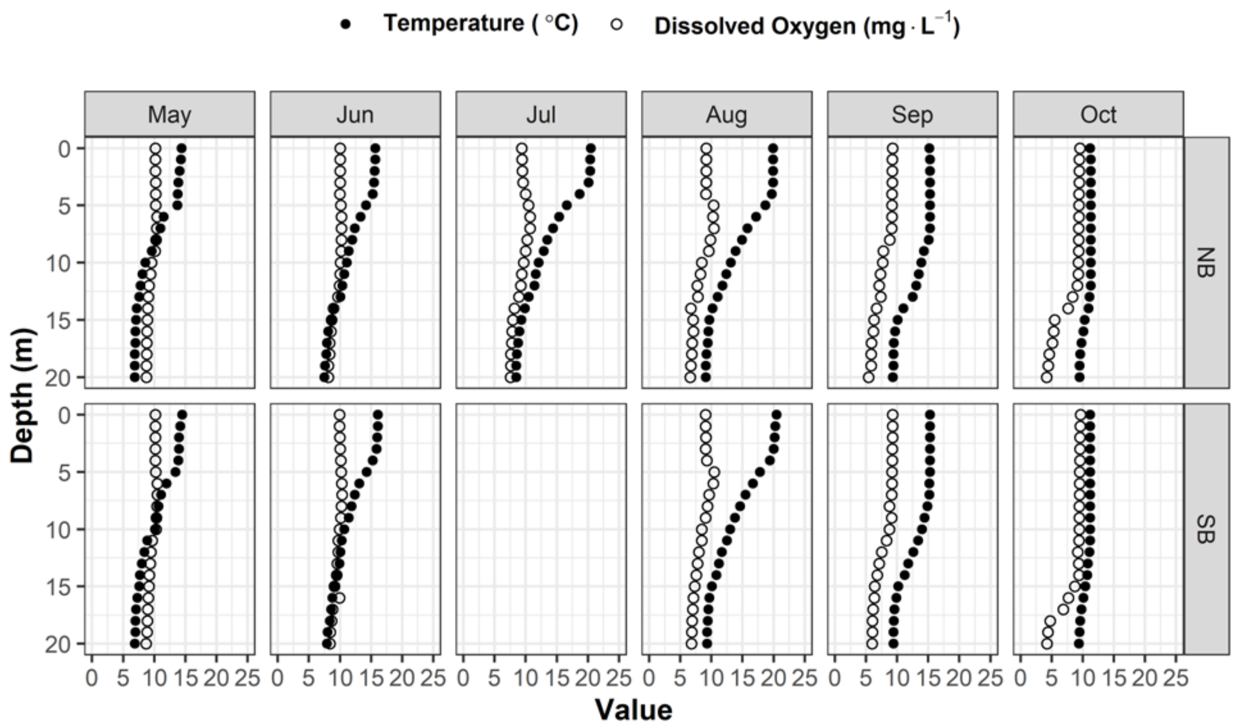

Figure 9. Water temperature (°C) and dissolved oxygen ($mg \cdot L^{-1}$) profiles at the north basin (NB-LS1) and south basin (SB-LS2) limnology sampling stations May to October, 2018, Wahleach Reservoir, BC.

The pH in Wahleach Reservoir, as taken from 1-m water samples, was neutral with a mean of 7.2 ± 0.1 (range 7.1 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 8.2 and 11.5 mg $CaCO_3 \cdot L^{-1}$ with a mean of 10.0 ± 1.1 mg $CaCO_3 \cdot L^{-1}$ in 2018 (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 $CaCO_3 \cdot L^{-1}$).

Secchi disk transparencies during 2018 averaged 6.2 ± 1.2 m (range 3.9 to 7.8 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).

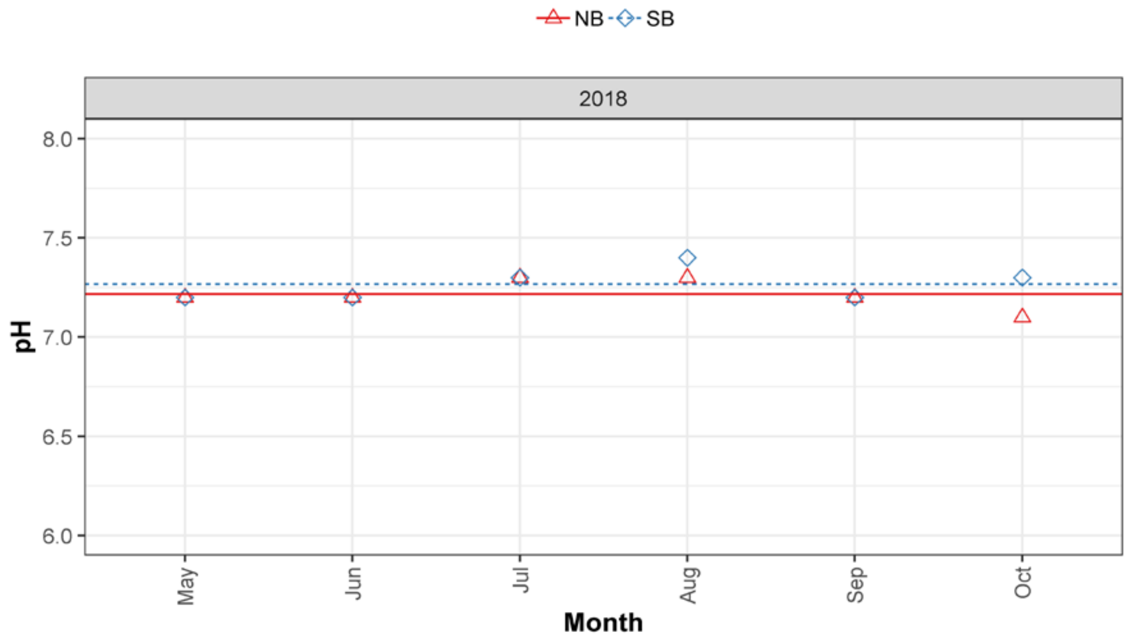

Figure 10. pH values from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to October, 2018, Wahleach Reservoir, BC. Horizontal bars represent seasonal mean for each station.

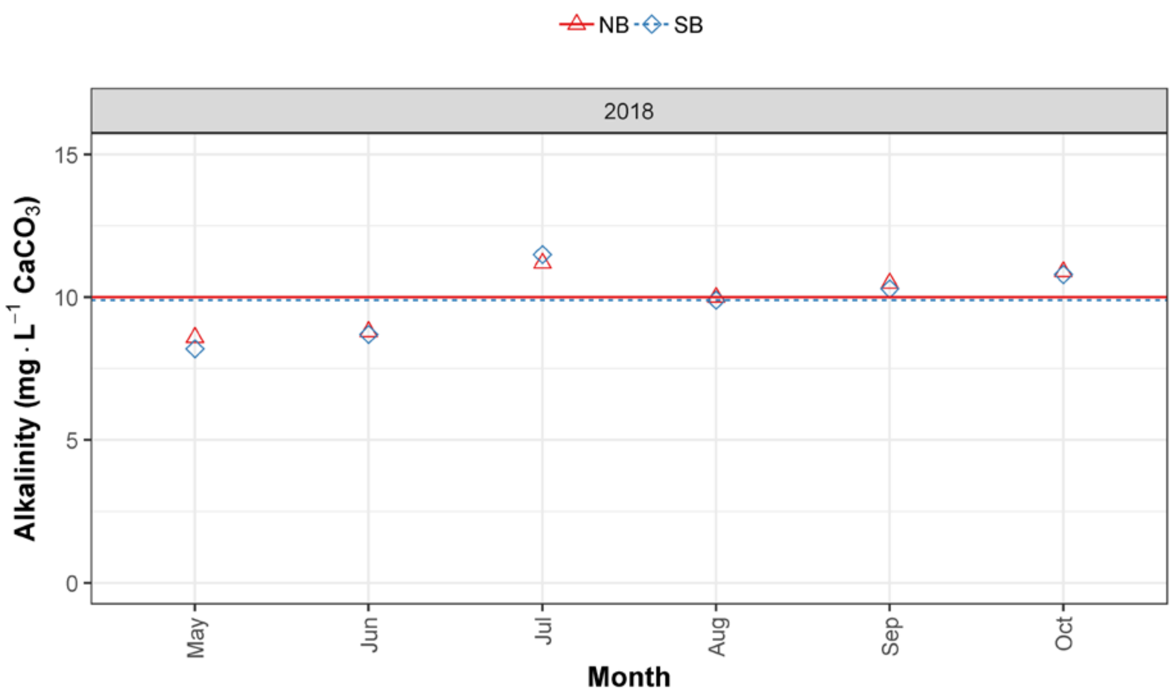

Figure 11. Alkalinity (mg $CaCO_3 \cdot L^{-1}$) values from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to October, 2018, Wahleach Reservoir, BC. Horizontal bars represent seasonal mean for each station.

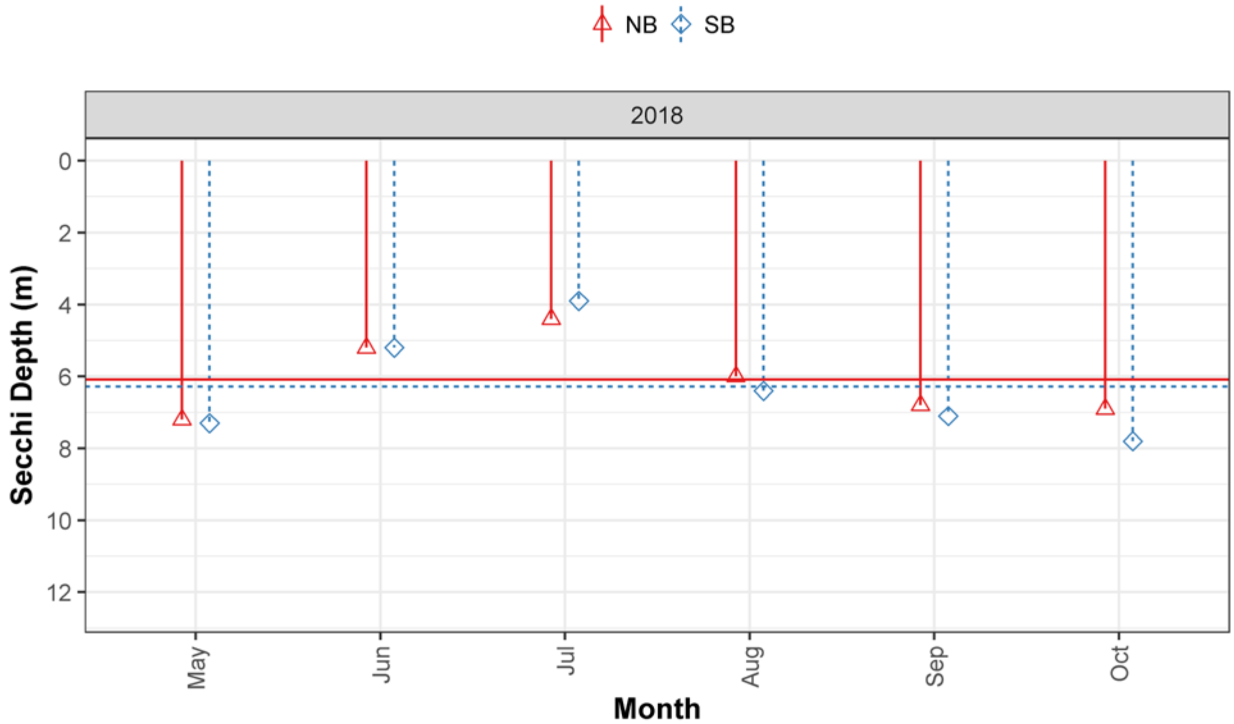

Figure 12. Secchi depths (m) at the north basin (NB) and south basin (SB) limnology sampling stations May to October, 2018, Wahleach Reservoir, BC. Horizontal bars represent seasonal means for each station.

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. 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. In 2018, TP values ranged from 2.9 to 5.1 µg·L^{-1} with a seasonal mean of 3.9 ± 0.7 µg·L^{-1} indicating phosphorus concentrations remained in the ultra-oligotrophic productivity range (Figure 13). The TP sample collected in October at the LS2 station was reported with a value of 57.3 µg·L^{-1}; being anomalously high, it was considered contaminated and discarded. Instead, the reported October value was estimated using an average of the integrated epilimnetic and hypolimnetic sample values, which was 4.6 µg·L^{-1}. If the anomalous sample was included, the seasonal mean would be reported at 8.3 ± 15.4 µg·L^{-1}

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 µg·L^{-1} with a range of 1 to 2 µg·L^{-1}. Despite phosphorus additions, all 2018 SRP samples were below the detection limit of 1 µg·L^{-1} (Figure 14) and suggests rapid uptake and assimilation of useable phosphorus by phytoplankton.

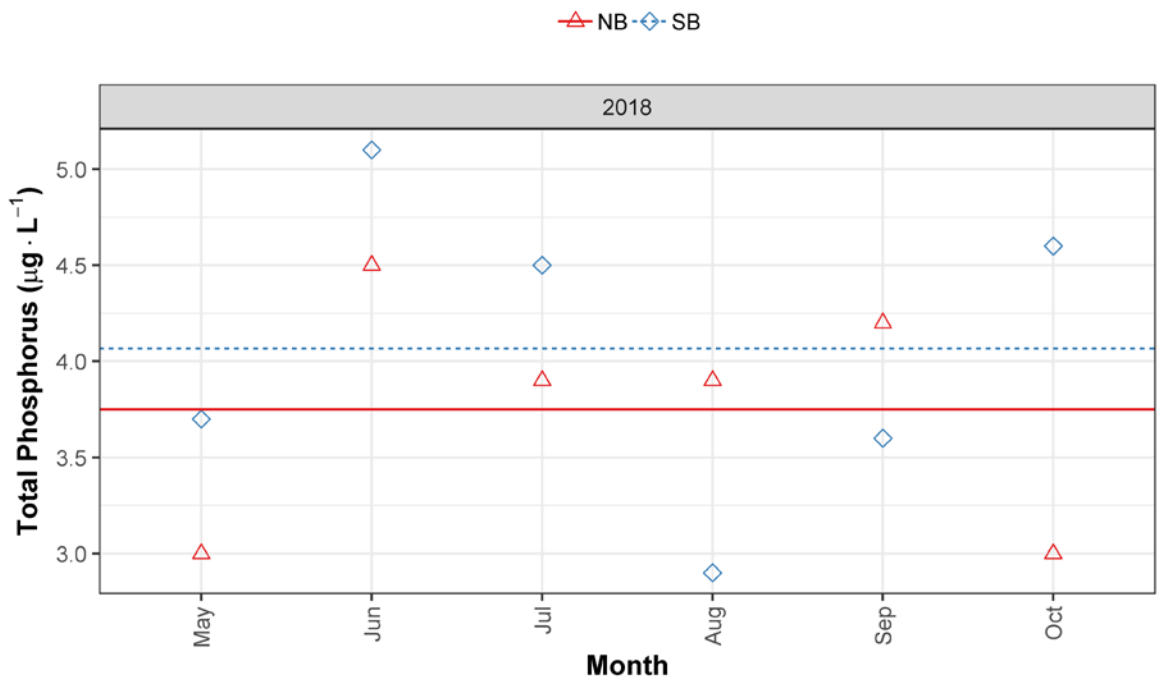

Figure 13. Total phosphorus concentration (µg·L^{-1}) from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to October, 2018, Wahleach Reservoir, BC.

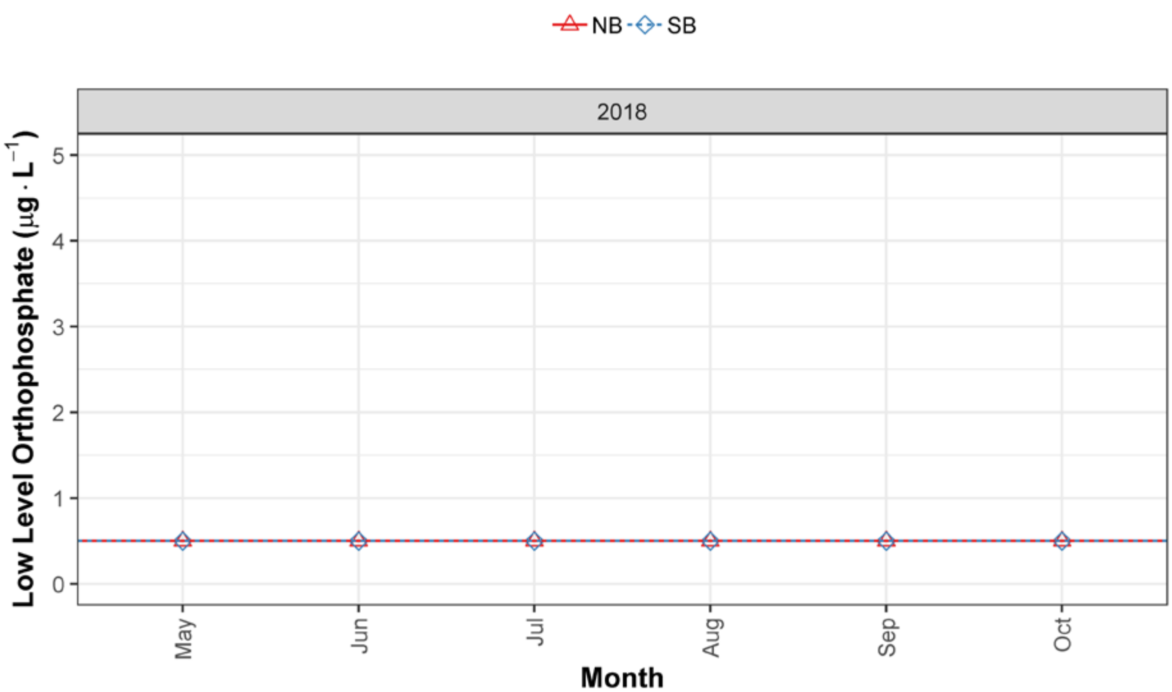

Figure 14. Low level orthophosphate concentrations (µg·L^{-1}) from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to October, 2018, Wahleach Reservoir, BC.

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 nitrogen by phytoplankton in the reservoir's epilimnion. In 2018, TN was higher in the spring before decreasing and remaining fairly consistent through the summer and fall (Figure 15). The mean TN concentration in 2018 was 141 ± 29 $\mu g \cdot L^{-1}$ (range 89 to 221 $\mu g \cdot L^{-1}$), 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 2018, the highest concentrations of NO_3+NO_2 were observed during spring when the reservoir was in a state of complete mixing; NO_3+NO_2 decreased throughout summer and began to rise again in September and October. Summer NO_3+NO_2 concentrations remained above, but were frequently near, the level considered limiting for phytoplankton growth (<20 $\mu g \cdot L^{-1}$); a pattern suggestive of strong biological utilization of NO_3+NO_2. The seasonal mean NO_3+NO_2 concentration in 2018 was 40 ± 20 $\mu g \cdot L^{-1}$ (range 21 to 84 $\mu g \cdot L^{-1}$; Figure 16), which was lower than baseline conditions of 66 ± 69 $\mu g \cdot L^{-1}$ (range 0.9 to 426 $\mu g \cdot L^{-1}$).

Ideal total nitrogen to total phosphorus ratios (TN:TP) to support the growth of phytoplankton are between 20-50; ratios above 50 suggest phosphorus limitation while ratios below 20 suggest nitrogen limitation (Guildford and Hecky 2000). In 2018, TN:TP ranged between 20 to 60 with a mean of 37 ± 10.9. Patterns in TN:TP indicate some phosphorus limitation in May prior to the onset of nutrient additions for the year, as well as conditions nearing nitrogen limitation in June (Figure 17). Overall, conditions in 2018 were more favourable for phytoplankton growth than during baseline years, during which TN:TP ranged between 3 to 67 with a mean of 27 ± 14.

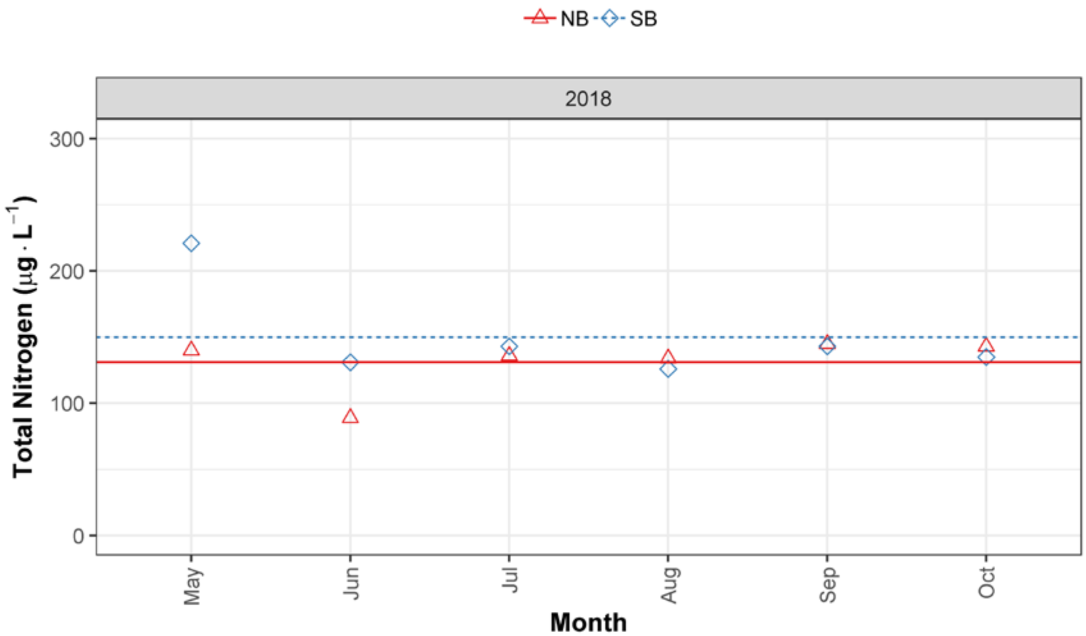

Figure 15. Total nitrogen concentrations (µg·L^{-1}) from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to October, 2018, Wahleach Reservoir, BC; horizontal lines represent seasonal means for each station.

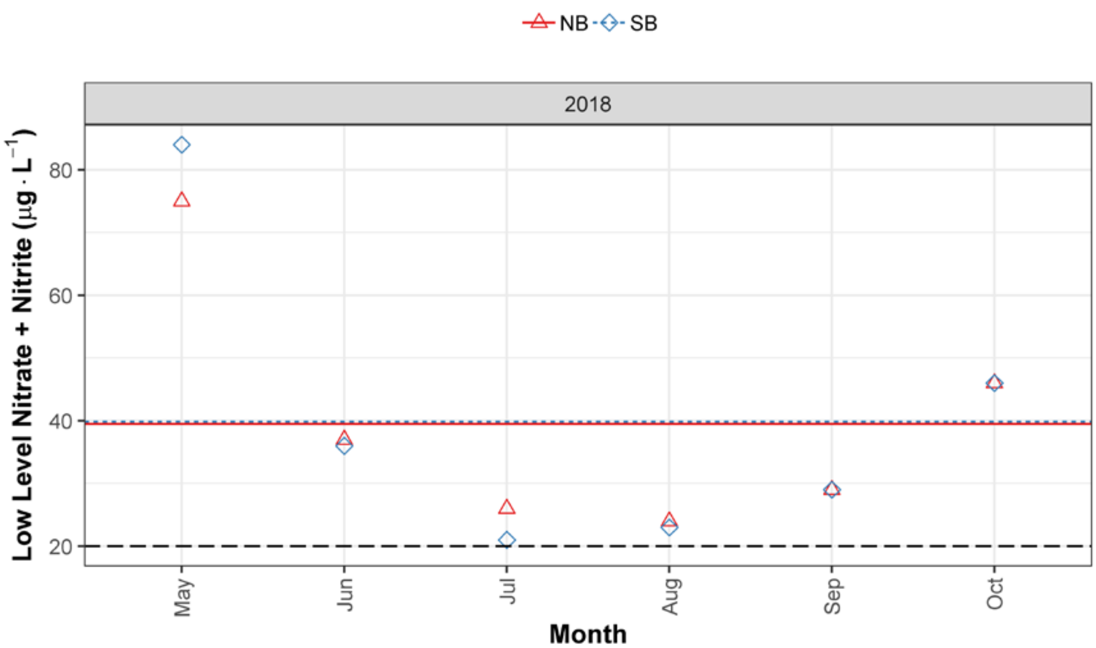

Figure 16. Low level nitrate + nitrite nitrogen concentrations (µg·L^{-1}) from 1 m discrete water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to October, 2018, Wahleach Reservoir, BC; black dashed line at 20 µg·L^{-1} represents the limiting concentration for phytoplankton growth.

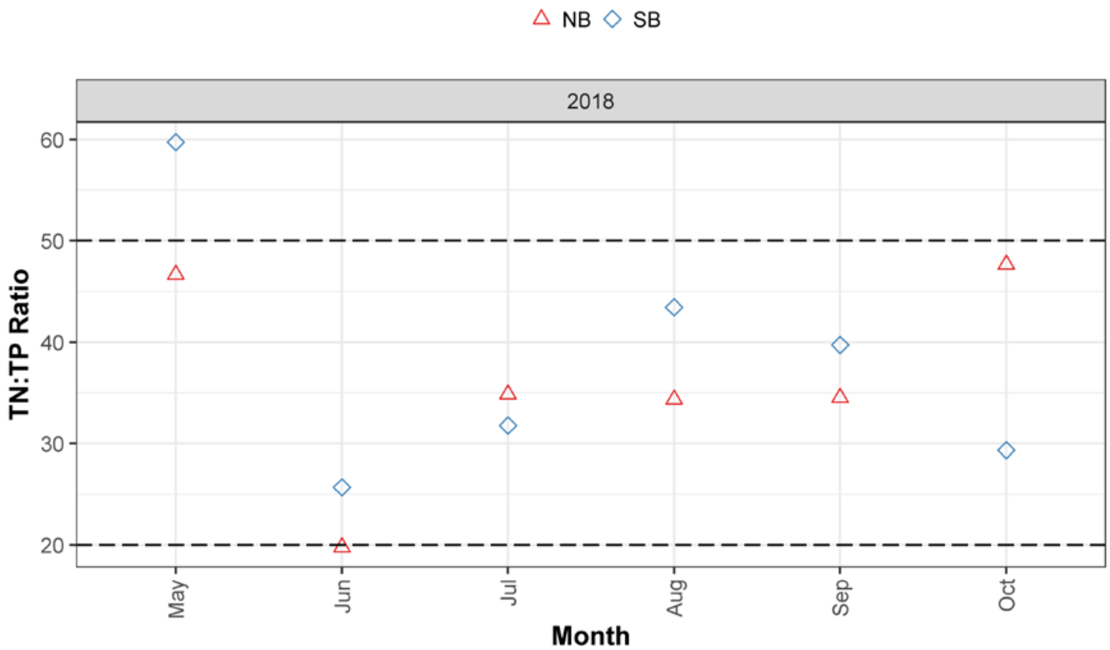

Figure 17. Total nitrogen (TN) to total phosphorus (TP) ratios based on 1 m water chemistry samples from the north basin (NB) and the south basin (SB) limnology stations May to October, 2018, Wahleach Reservoir, BC. Points above dashed line at 50 were likely in a state of P limitation, while points below dashed line at 20 were likely in a state of N limitation (Guildford and Hecky 2000).

4.4 Phytoplankton

A total of 56 phytoplankton species were detected in Wahleach Reservoir during 2018 (Appendix A), which was higher than the 1994 baseline year, when only 38 phytoplankton species were detected. Mean phytoplankton abundance in 2018 was 4,906 ± 3,106 cells·mL^{-1} (range 1,287 to 11,090 cells·mL^{-1}), which was lower than the 1994 baseline year abundance of 8,793 ± 4,929 cells·mL^{-1} (4,632 to 20,093 cells·mL^{-1}). Abundance in 2018 was driven largely by growth of *Merismopedia* sp. and to a lesser extent *Microcystis* sp; both of which are small blue-green algae belonging to the class *Cyanophyceae* (Figure 18). Flagellates (*Chryso-* & *Cryptophyceae*) were the second most numerically dominant class and were consistently high throughout the 2018 growing season (Figure 18). The phytoplankton community consisted primarily of edible species and forms throughout the season (3,643 ± 2,030 cells·mL^{-1}; range 1,227 to 7,805 cells·mL^{-1}; Figure 19). Inedible fractions (1,240 ± 1,371 cells·mL^{-1}; range 20 to 3,649 cells·mL^{-1}) were generally low with the exception of June and July when increased abundance of inedible *Microcystis* sp. occurred.

Phytoplankton biovolume in 2018 was 0.95 ± 0.82 mm^{3}·L^{-1} (range 0.23 to 2.24 mm^{3}·L^{-1}) which was higher than observed during baseline years (0.88 ± 0.51 mm^{3}·L^{-1}; range 0.20 to 1.90 mm^{3}·L^{-1}). Early in the season, biovolume was largely driven by *Microcystis* sp. and flagellates, *Dinobryon* sp. and *Ochromonas* sp. During the latter half of the growing season, diatoms (class *Bacillariophyceae*; e.g., *Tabellaria fenestrata*) were the primary contributors to biovolume results (Figure 20). Diatoms, as well as colonies of *Microcystis* sp. generally made up the inedible biovolume fraction (0.59 ± 0.65 mm^{3}·L^{-1}; range 0.01 to 1.8 mm^{3}·L^{-1}); flagellates, chlorophytes and to a lesser extent, *Merismopedia* sp. generally made up the edible fraction (0.33 ± 0.21 $mm^3 \cdot L^{-1}$; range 0.11 to 0.78 $mm^3 \cdot L^{-1}$). Observed phytoplankton biovolume was mainly due to larger inedible species and forms (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.

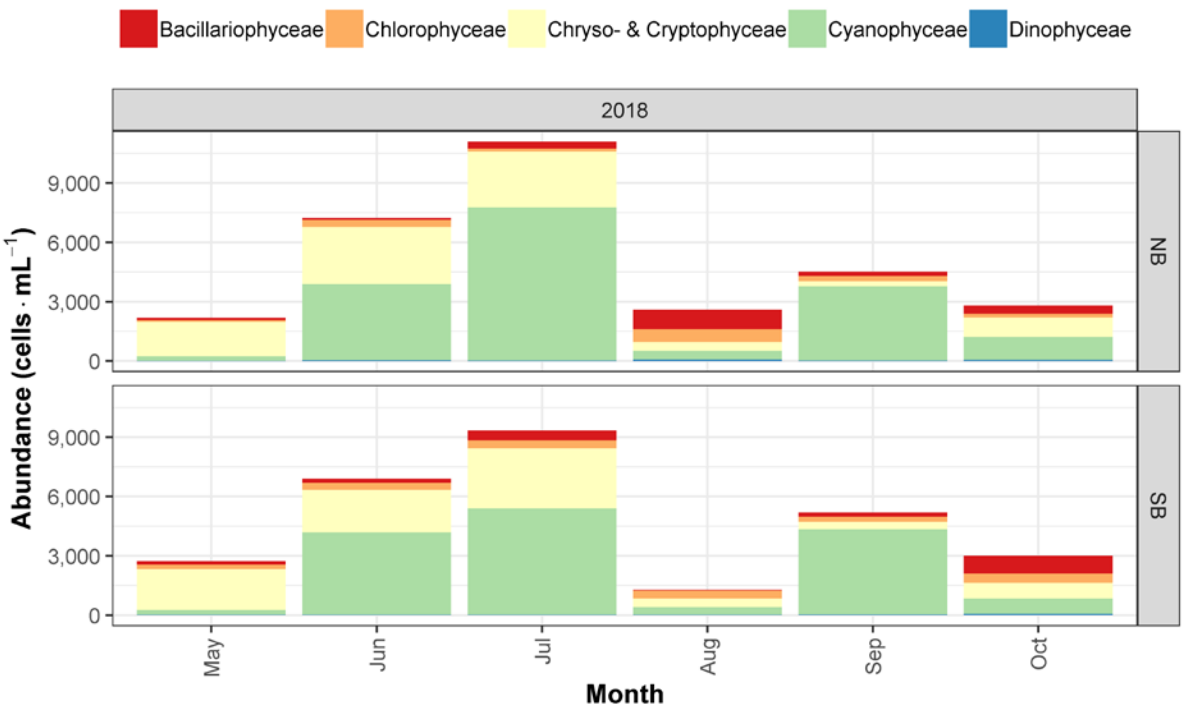

Figure 18. Seasonal phytoplankton abundance (cells·mL^{-1}) by class at the north basin (NB) and south basin (SB) limnology stations May to October, 2018, Wahleach Reservoir BC.

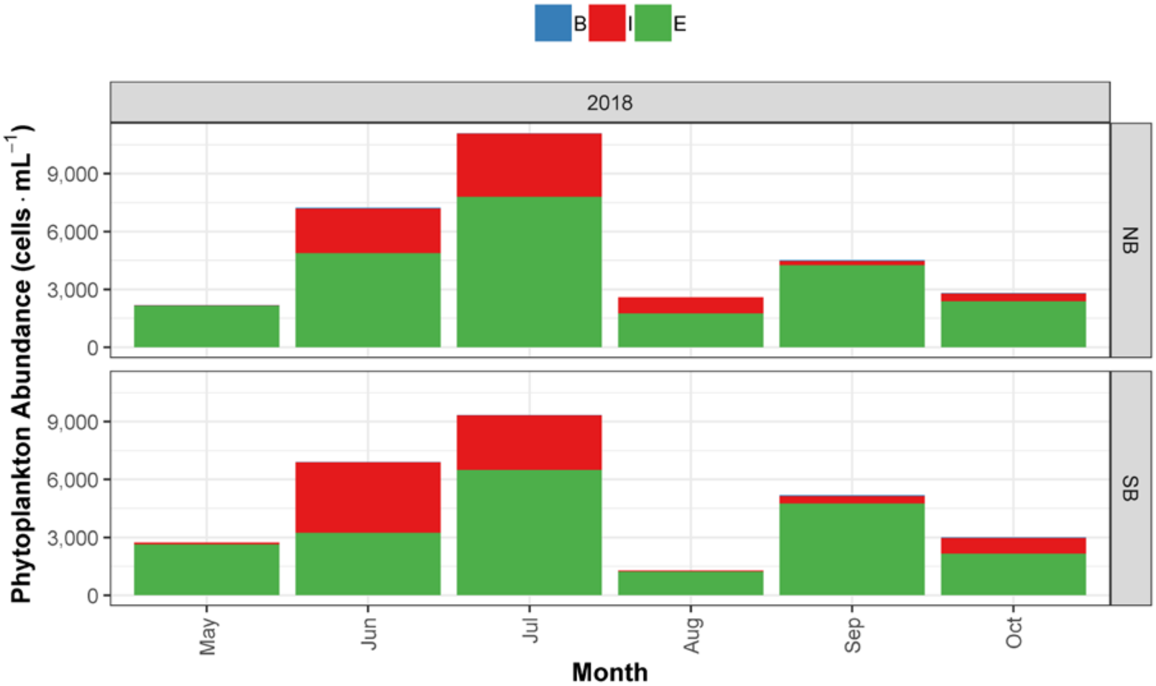

Figure 19. Seasonal phytoplankton abundance (cells·mL^{-1}) by edibility (E=edible, I=inedible, B= both edible and inedible forms) at the north basin (NB) and south basin (SB) limnology station May to October, 2018, Wahleach Reservoir, BC.

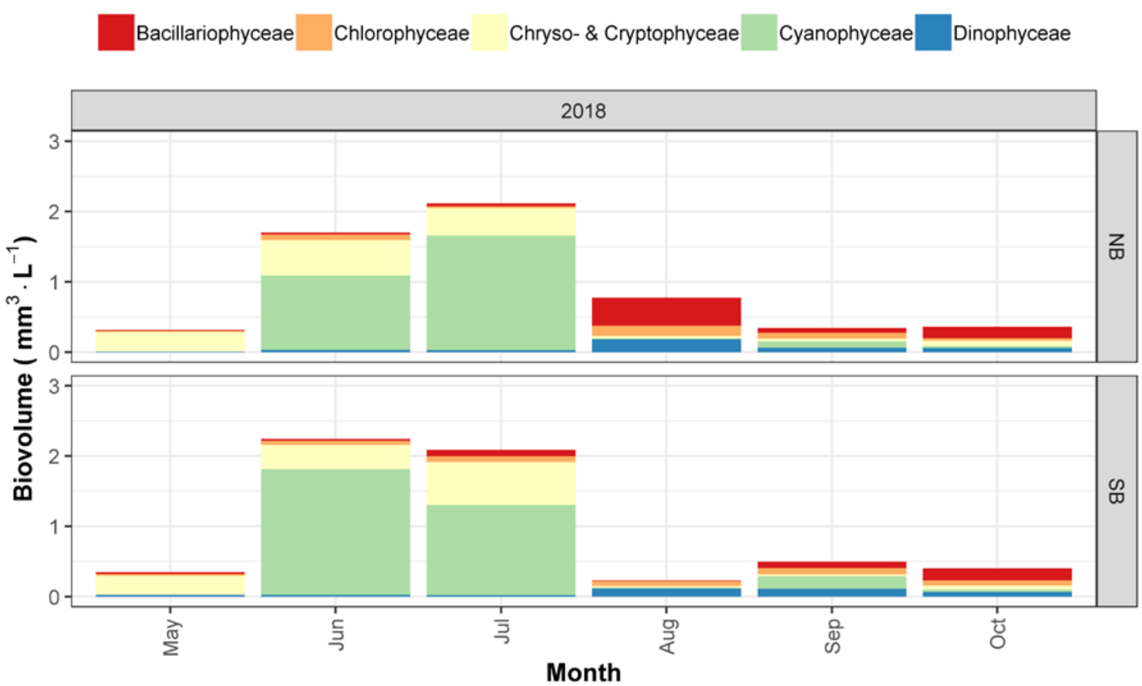

Figure 20. Seasonal phytoplankton biovolume (mm^{3}·L^{-1}) by class at the north basin (NB) and south basin (SB) limnology stations May to October, 2018, Wahleach Reservoir, BC.

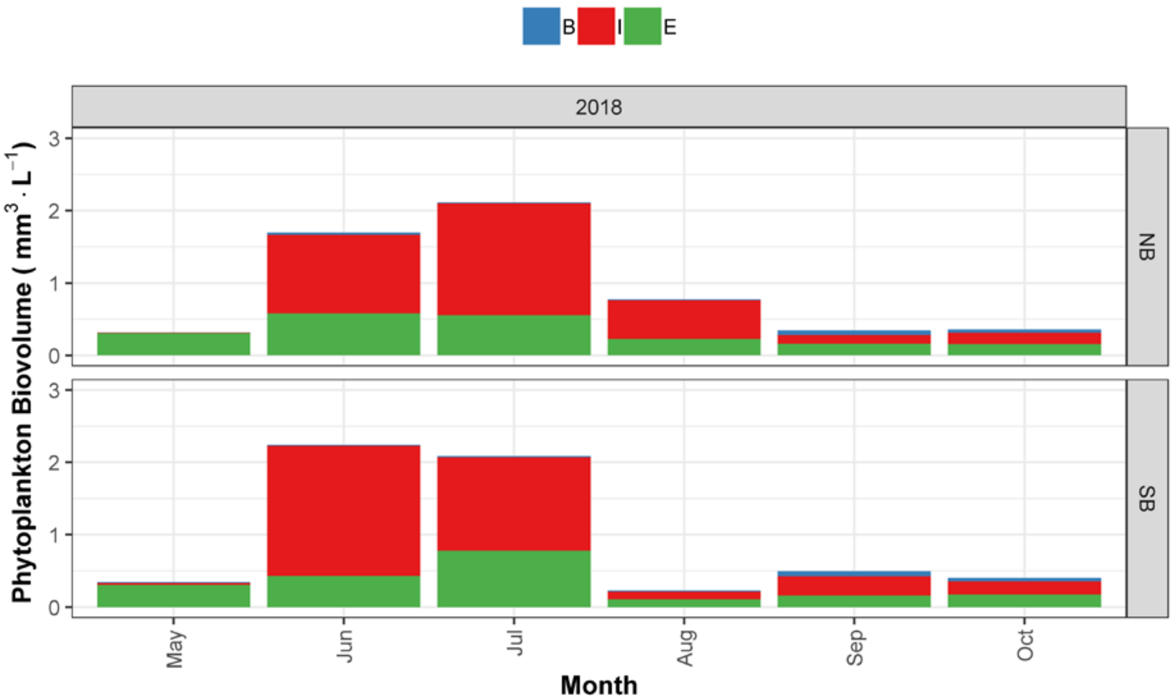

Figure 21. Seasonal phytoplankton biovolume ($mm^3 \cdot L^{-1}$) by edibility (E= edible, I=inedible, B= both edible and inedible forms) at the north basin (NB) and south basin (SB) limnology station May to October, 2018, Wahleach Reservoir, BC.

4.5 Zooplankton

Seven *Cladocera* species and one *Copepoda* species were identified in Wahleach Reservoir in 2018 (Appendix B). Species such as *Cyclops vernalis* (Fischer), *Daphnia rosea* (Sars), *Bosmina longirostris* (O.F.M.), and *Holopedium gibberum* (Zaddach) were common, while others such as *Alona* sp. (Baird), *Leptodora kindtii* (Focke), *Scapholeberis mucronata* (O.F.M.) and *Chydorus sphaericus* (O.F.M.) were rare and/or 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.

Seasonal zooplankton density in 2018 (4.8 ± 1.8 individuals·L^{-1}; range 1.8 to 7.5 individuals·L^{-1}) was greater than observed during baseline years (1.0 ± 1.0 individuals·L^{-1}; range 0.1 to 4.5 individuals·L^{-1}). As well, seasonal zooplankton biomass was the fourth greatest on record at 95.2 ± 40.0 µg·L^{-1} (range 30.7 to 183.8 µg·L^{-1}). Early in the season, zooplankton density was driven by cladocerans other than *Daphnia*. Beginning in June and then continuing for the rest of the season, *Daphnia* were the dominant driver of density and biomass (Figure 22, Figure 23). Copepods experienced peak densities in July (Figure 22). Seasonal densities and biomass of each major zooplankton group are detailed in Table 5. Overall in 2018, *Daphnia* made up 52% of the seasonal zooplankton density and 75% of biomass, while other cladocerans made up 30% of density and 24% 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), 2018, Wahleach Reservoir, BC.

Taxonomic Group	Density (individuals·L^{-1})				Biomass (µg·L^{-1})			
	Mean	**SD**	**Max**	**Min**	**Mean**	**SD**	**Max**	**Min**
Copepoda	0.8	1.0	3.3	0.07	1.4	1.7	5.4	0.1
Daphnia	2.5	1.4	4.8	0.3	71.3	44.0	159.7	5.4
Other Cladocera	1.5	1.7	5.3	0.1	22.6	20.2	74.7	1.0

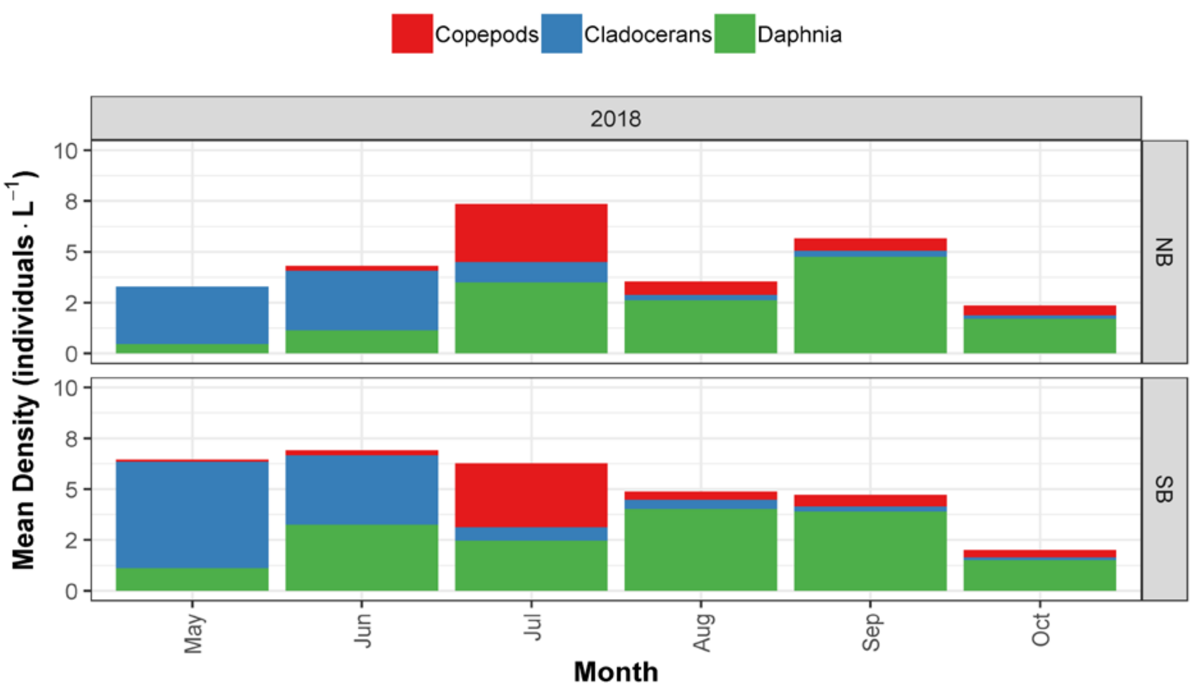

Figure 22. Monthly zooplankton density (individuals·L-1) by major group (Copepoda, *Daphnia* and other Cladocera) at the north basin (NB) and south basin (SB) limnology stations, 2018, Wahleach Reservoir, BC.

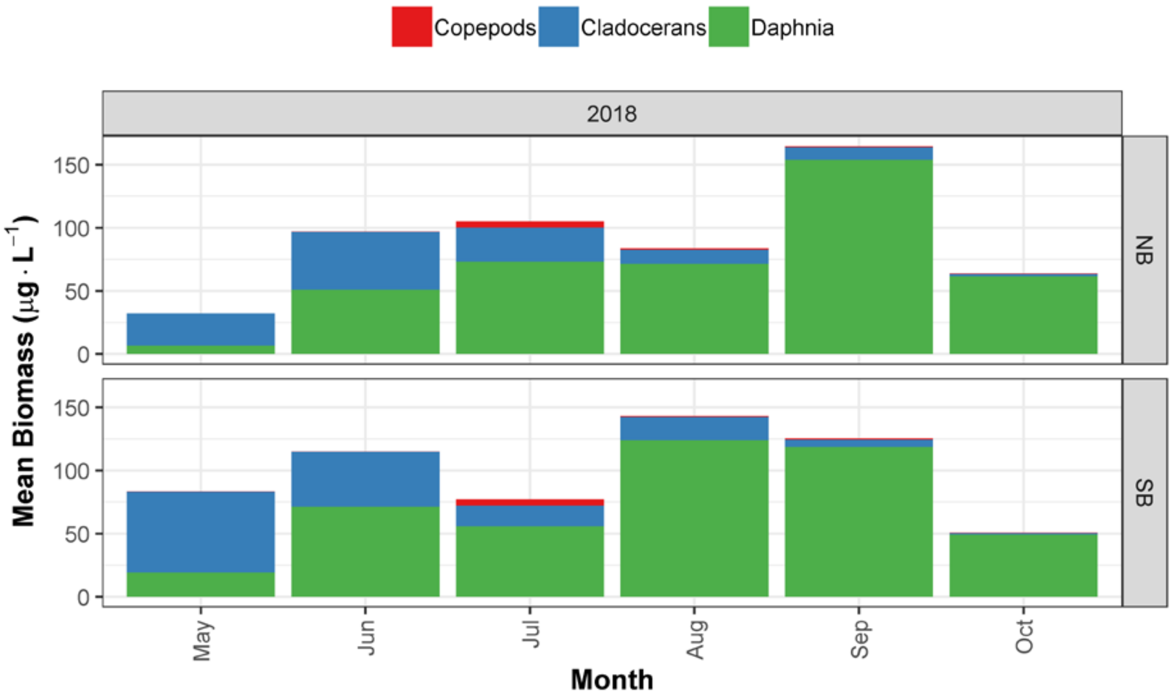

Figure 23. Monthly zooplankton biomass (µg·L^{-1}) by major group (Copepoda, *Daphnia* and other Cladocera) at the north basin (NB) and south basin (SB) limnology stations, 2018, Wahleach Reservoir, BC.

4.6 Fish

4.6.1 Catch & CPUE

Total catch during the nearshore gillnet sampling in 2018 was 213 fish, which was the highest recorded catch in recent years (Table 6). The majority of the catch was Rainbow Trout at 77%, while 12% were Kokanee (Table 6). Of the total catch, 29% was 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 $fish \cdot 100m^{-2} \cdot hr^{-1}$. Catch during the minnow trap sampling was 60 Threespine Stickleback and two juvenile Rainbow Trout. Total soak time in 2018 was 116 trap hours with CPUE at 0.5 fish per trap hour.

Table 6. Summary of fall nearshore gillnetting catch and percentage (%), 2018, Wahleach Reservoir, BC. Species include Kokanee (KO), Cutthroat Trout (CT), and Rainbow Trout (RB).

Species	2018[1]	%
CT	23	11
RB	164	77
KO	26	12
Total	213	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, 2018, Wahleach Reservoir, BC. The 1.25" panel was added in 2014 and will now be used regularly.

Species	2018 - Standard	2018 - 1.25"
CT	20	3
RB	109	55
KO	23	3
Total	152	61

4.6.2 Kokanee

Kokanee captured during the fall nearshore gillnetting program in 2018 were all age 1+ and 2+ with summary statistics on biometrics presented in Table 8 and Table 9. Due to the timing of sampling after the spawning period, no age 3+ or 4+ Kokanee were captured during the fall nearshore gillnetting program (Figure 24) and all were classified as immature (except for one mature age 2+ male). When comparing summary statistics of Kokanee size by age class, individuals caught in 2018 were larger and in better condition than during the baseline years, at which time 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 2018 were also larger than the age 2+ Kokanee from baseline years. Kokanee length-weight regressions based on the 2018 fall nearshore gillnetting data (Figure 25, Table 10), had a slope (b value) of 3.1; b values near 3 are common for fish (Anderson et al. 1983, Cone 1989).

Table 8. Summary of Kokanee biometric data, including length, weight, and condition factor (K), 2018, Wahleach Reservoir, BC.

Year	Species	n	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)	Mean K	SD K
2018	KO	26	204	19	107.7	29.5	1.2	0.06

Table 9. Summary of Kokanee biometrics by age, 2018, 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	14	202	165	73.3	19.6	105	53	1.2	0.06	1.27	1.12	6
2+	213	13	239	193	120.8	21.5	164	91	1.2	0.06	1.34	1.13	18

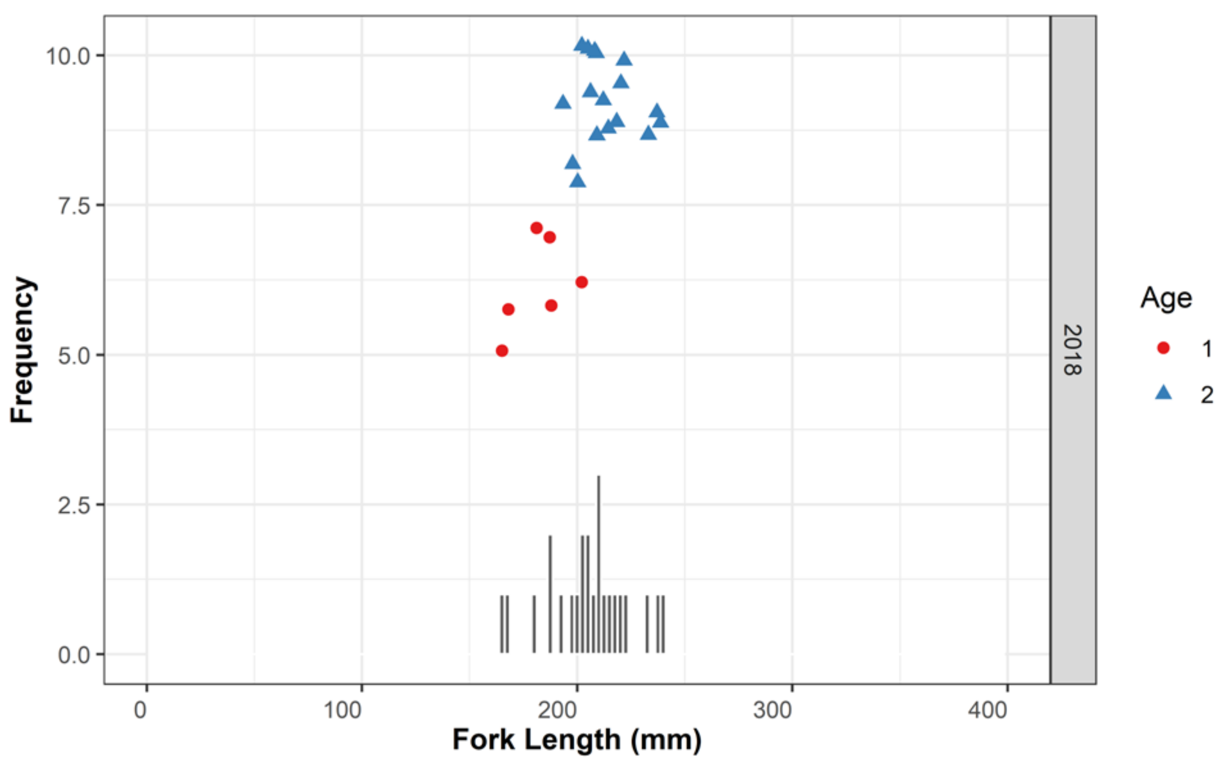

Figure 24. Length frequency distribution by age class of Kokanee, 2018, Wahleach Reservoir, BC.

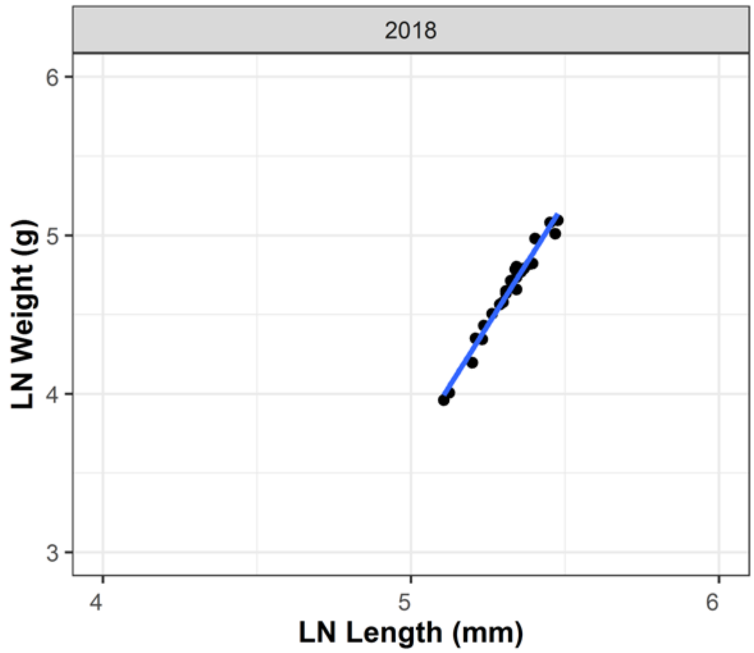

Figure 25. Natural logarithm of length weight linear regression (LN W = LN a * LN Lb) of Kokanee, 2018, Wahleach Reservoir, BC.

Table 10. Summary of variables in R for Kokanee length weight relationships (Ln W = b · Ln L + Ln a), 2018, Wahleach Reservoir, BC.

Year	**Equation**	**R^2**
2018	LN.weight.g = 3.1 * LN.length.mm -11.8	0.9733

4.6.2.1 Spawners

Timing of Kokanee spawning in 2018 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 2018 was 7,975. Flat Creek had the most spawners (5,924), followed by Jones Creek (2,034), and then Boulder Creek (17); this pattern has been observed since 2009 (data on file; Sarchuk et al. 2016). 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 235 ± 13 mm (range 207 to 260 mm) and were age 2+ or 3+, with the majority of spawners aged at 2+ years (Table 11, Figure 27). Length frequency and associated age-at-length data show age 3+ fish were smaller on average than those age 2+; however, there was substantial overlap in the lengths between each of the age classes and a much smaller sample size for age 3+ (Table 12, Figure 28).

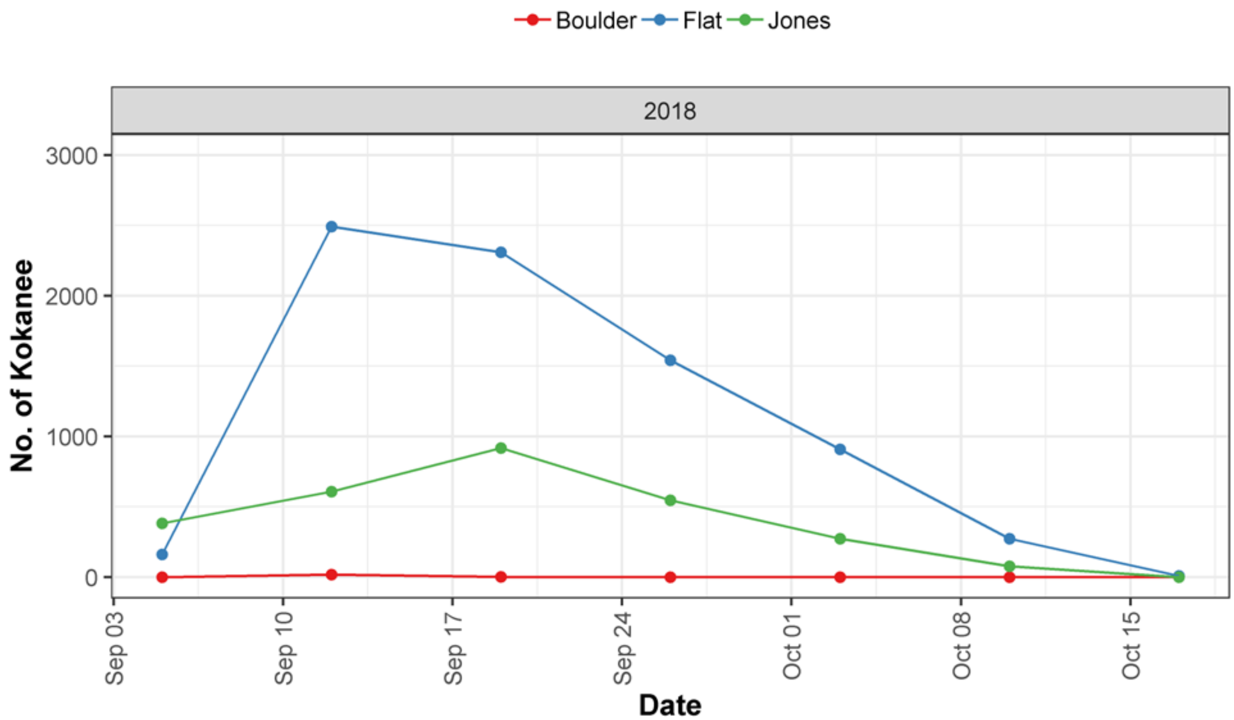

Figure 26. Kokanee spawner counts from each index stream (Boulder Creek, Flat Creek, and Jones Creek), 2018, Wahleach Reservoir, BC.

Table 11. Summary of biometric data from spawning Kokanee collected during spawner surveys, 2018, 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 = 1.1231x + 21.005, R^2 = 0.8111) for years (2003-2018) when both POHL and FL were measured.

Year	**Fork Length (mm)**					**Age**				
	Mean	SD	Max	Min	N	Mean	SD	Max	Min	n
2018	235	13	260	207	55	2	0.3	3	2	54

Table 12. Summary of Kokanee fork length by age, 2018, Wahleach Reservoir, BC.

Age	**Fork Length (mm)**				
	Mean	SD	Max	Min	N
2+	236	13	260	210	48
3+	223	12	236	207	6

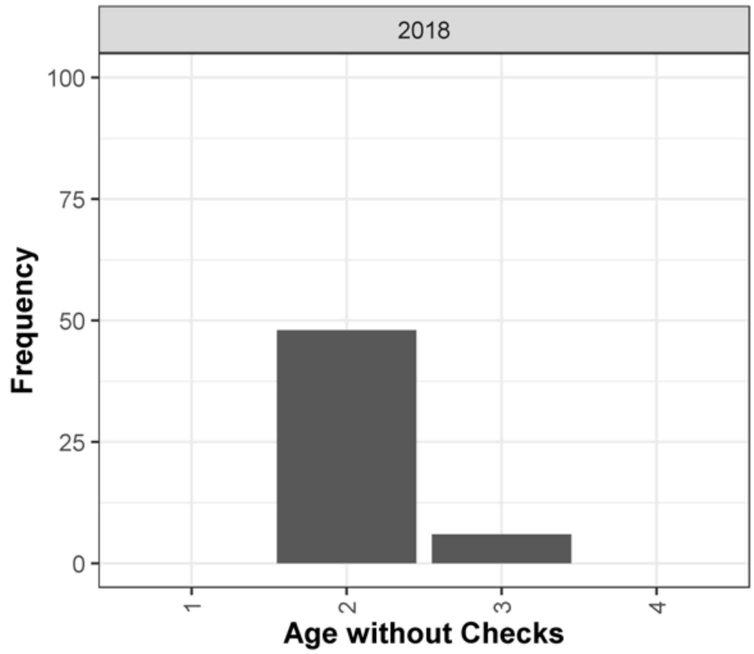

Figure 27. Age frequency of Kokanee spawners in index streams (Boulder Creek, Flat Creek and Jones Creek), 2018, Wahleach Reservoir, BC.

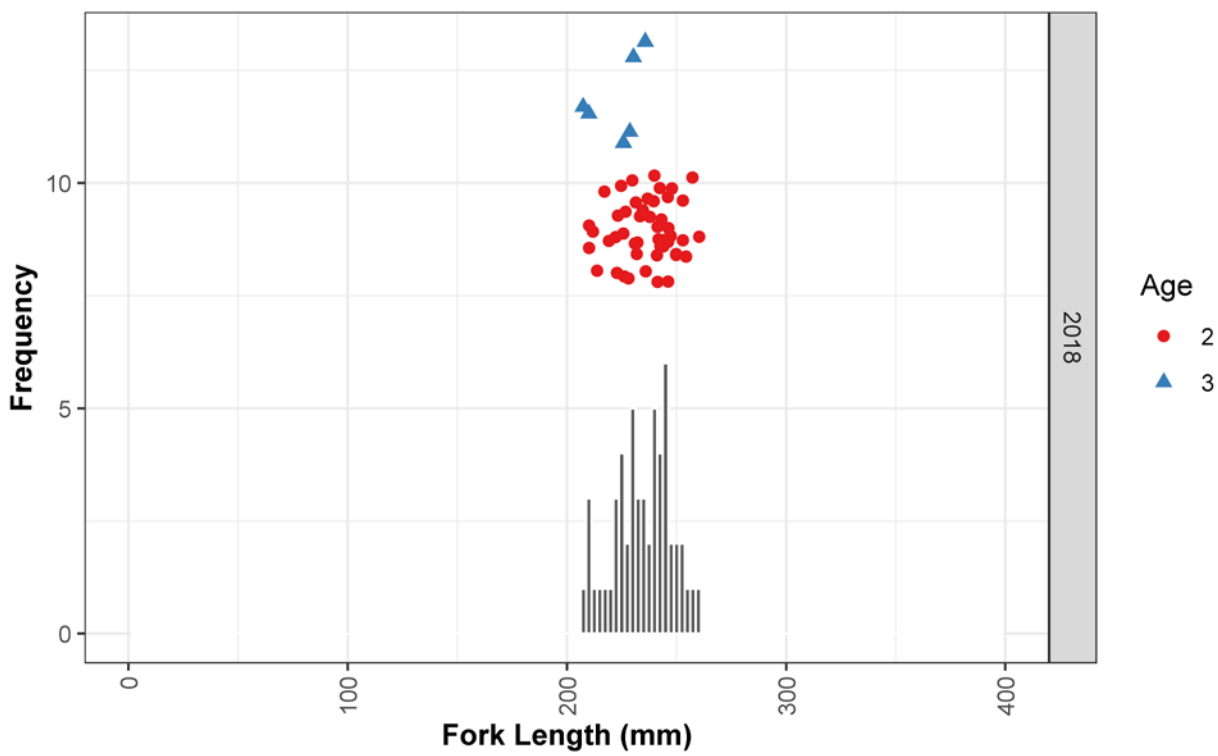

Figure 28. Length frequency distribution by age class of Kokanee spawners in index streams (Boulder Creek, Flat Creek and Jones Creek), 2018, Wahleach Reservoir, BC.

4.6.3 Rainbow Trout

In 2018, fall nearshore gillnet and minnow trap sampling captured a total of 166 Rainbow Trout ranging in length from 74 to 380 mm and in weight from 4 to 705 g (Table 13). Lengths of Rainbow Trout in 2018 were slightly higher than baseline years and the maximum size of individuals caught was also greater. Rainbow Trout ranged in length from 109 to 329 mm (186 ± 45 mm) during baseline years and weights of Rainbow Trout ranged from 14 to 316 g (72 ± 52 g). Age 2+ fish represented the majority of the catch in 2018, and catch of older age classes (age 4+) was low (Table 14, Figure 29); this would account for the low mean length and weight in 2018 Rainbow Trout catches. Overall, Fulton's condition factor (K) for 2018 Rainbow Trout was 1.1 ± 0.12 indicating healthy somatic growth. Rainbow Trout length-weight regressions based on fall nearshore gillnetting data for 2018 are shown in Figure 30. Length-weight regression slopes (b value) were close to but less than 3 indicating a slimmer body shape (Figure 30, Table 15); a regression slope of 3 is common for fish (Anderson et al. 1983, Cone 1989).

Table 13. Summary of Rainbow Trout biometric data from fall nearshore gillnetting and minnow traps, including length, weight, and condition factor (K), 2018, Wahleach Reservoir, BC.

Year	Species	n	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)	Mean K	SD K
2018	RB	166	197	49	99.9	79.9	1.1	0.12

Table 14. Summary of Rainbow Trout biometrics by age, 2018, 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	
0	74	-	74	74	4	-	4	4	0.99	-	0.99	0.99	1
1	153	22	251	111	43.1	19.5	140.5	16.0	1.14	0.10	1.42	0.89	55
2	201	29	258	156	95.7	40.1	226.5	39.5	1.11	0.13	1.84	0.94	66
3	255	27	309	132	178.6	43.3	320.5	86.5	1.02	0.10	1.22	0.70	35
4	305	-	305	305	309.5	-	309.5	309.5	1.09	-	1.09	1.09	1

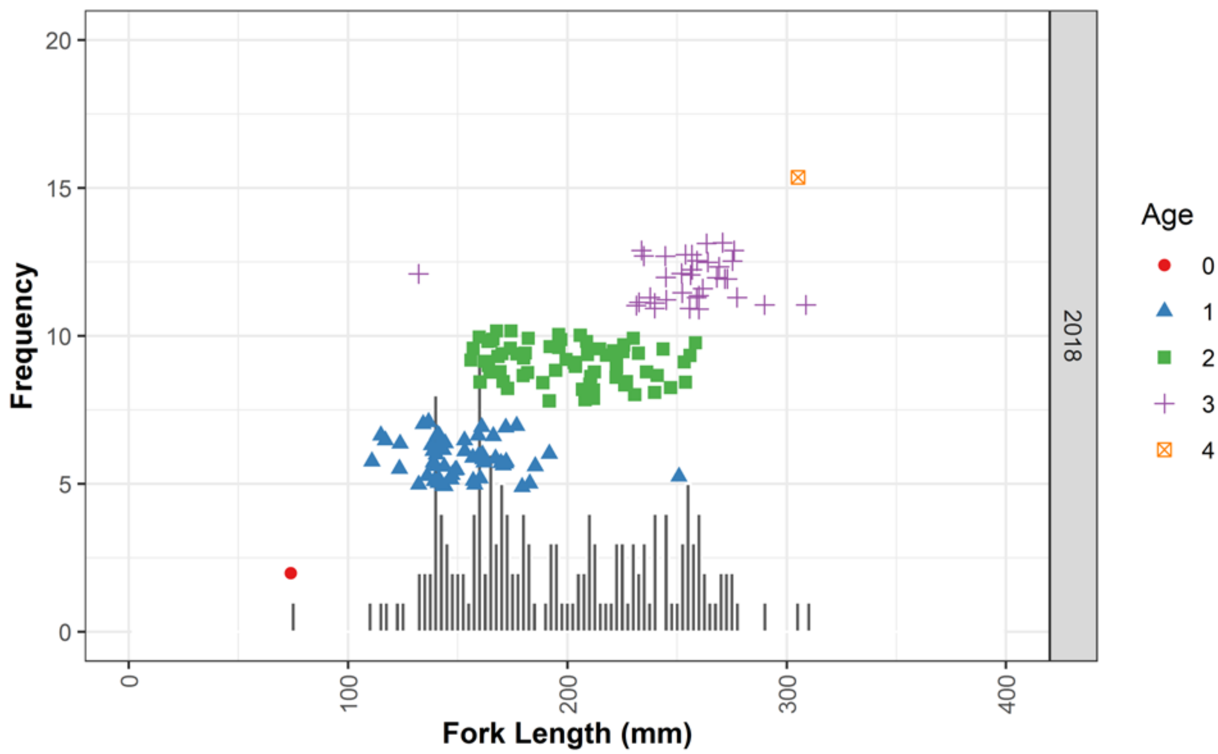

Figure 29. Length frequency by age class of Rainbow Trout in fall nearshore gillnets and minnow traps, 2018, Wahleach Reservoir, BC.

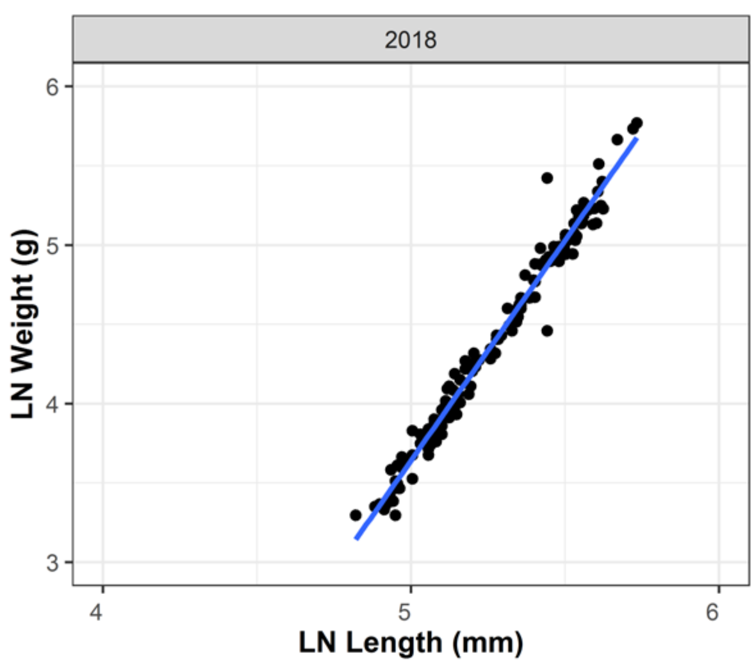

Figure 30. Length weight plot and relationship (Ln W=b · Ln L + Ln a) of Rainbow Trout, 2018, Wahleach Reservoir, BC.

Table 15. Summary of variables in R for Rainbow Trout length weight relationships (Ln W = b · Ln L + Ln a), 2018, Wahleach Reservoir, BC.

Year	Equation	R^2
2018	LN.weight.g = 2.83 *LN.length.mm -10.5	0.9797

4.6.4 Cutthroat Trout

Fall nearshore gillnet sampling in 2018 resulted in capture of 23 Cutthroat Trout ranging in length from 232 to 514 mm and in weight from 115.5 to 1620 g (Table 16). Fulton's condition factor (K) had a mean of 1.0 indicating healthy somatic growth. Cutthroat Trout caught during 2018 ranged from age 2+ to 5+ with age 3+ representing most of the catch (Table 17, Figure 31). The length-weight regression slope (b value) for Cutthroat Trout in 2018 was slightly greater than 3 indicating a thicker body shape (Figure 32, Table 18); b values near 3 are common for fish (Anderson et al. 1983, Cone 1989).

Table 16. Summary of Cutthroat Trout biometric data, including length, weight, and condition factor (K), 2018, Wahleach Reservoir, BC.

Year	Species	n	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)	Mean K	SD K
2018	CT	23	310	84	361.6	410.8	1.0	0.08

Table 17. Summary of Cutthroat Trout biometrics by age, 2018, 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	262	27	301	241	145.2	2.2	147.5	143.0	0.95	0.06	1.02	0.91	4
3	265	19	288	232	187.2	42.1	254.5	128.0	1.00	0.05	1.07	0.91	7
4	362	71	412	312	277.5	-	277.5	277.5	0.91	-	0.91	0.91	2
5	385	-	385	385	524.5	-	524.5	524.5	0.92	-	0.92	0.92	1

**Dashes (-) indicate no data.*

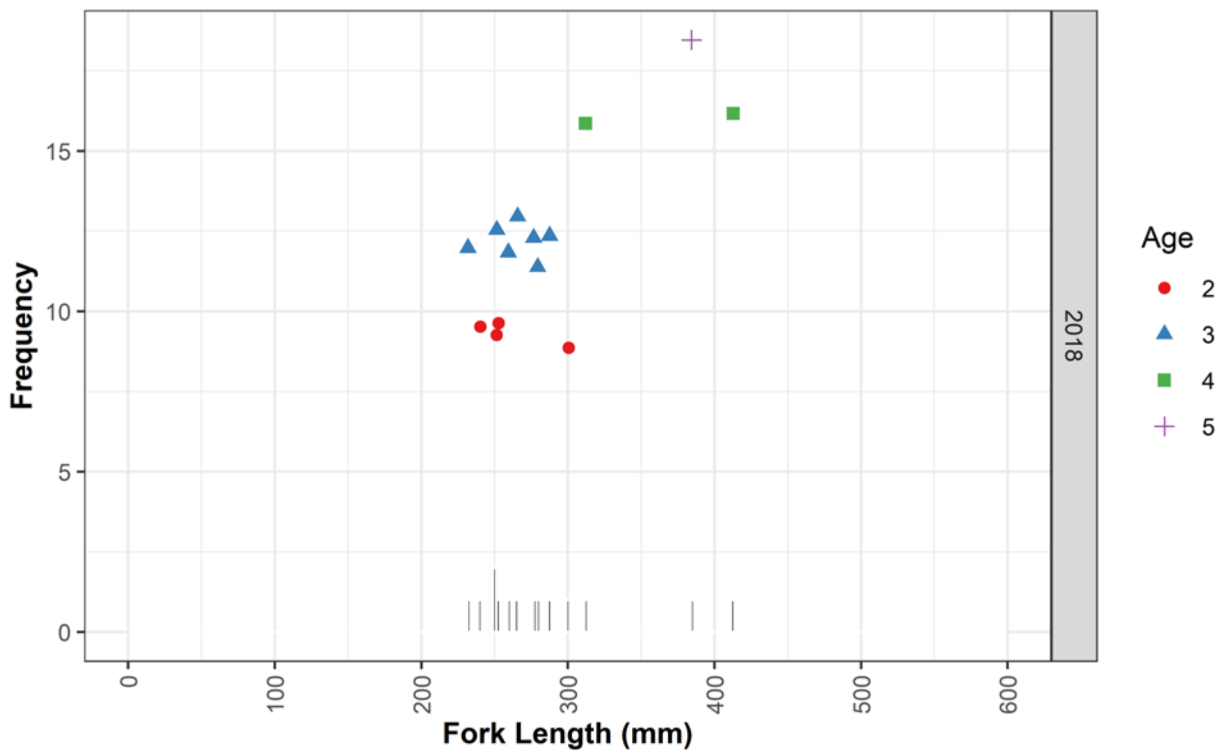

Figure 31. Length frequency of age classes of Cutthroat Trout in fall nearshore gillnets, 2018, Wahleach Reservoir, BC.

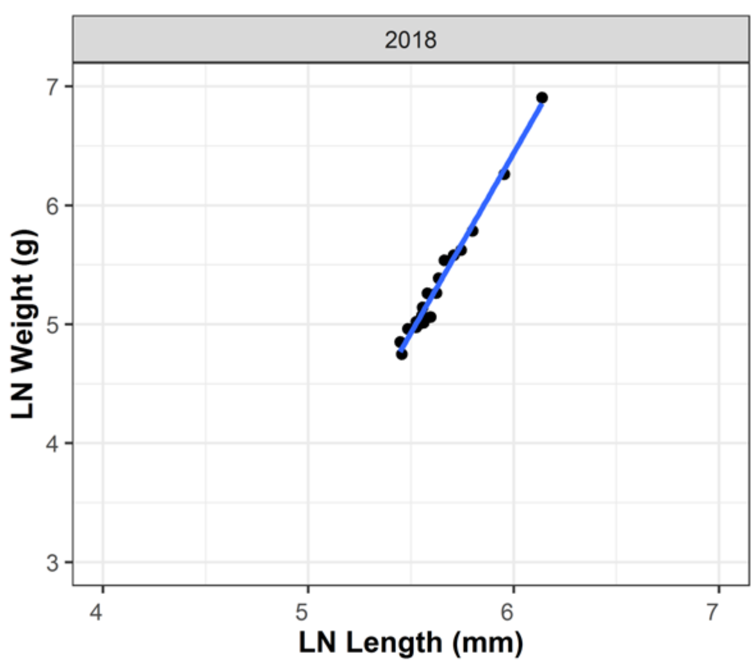

Figure 32. Length weight plot and relationship (Ln W = b · Ln L + Ln a) of Cutthroat Trout, 2018, Wahleach Reservoir, BC.

Table 18. Summary of variables in R for Cutthroat Trout length weight relationships (Ln W = b · Ln L + Ln a), 2018, Wahleach Reservoir, BC. Cutthroat Trout were not present in Wahleach Reservoir prior to nutrient restoration.

Year	Equation	R^2
2017	LN.weight.g = 3.16 *LN.length.mm -12.5	R^2=0.9903

4.6.5 Threespine Stickleback

Littoral minnow traps set in 2018 captured a total of 60 Threespine Stickleback with a range of 35-47 mm in length and 0.3-1.0 g in weight (Table 19, Figure 33). Threespine Stickleback catch remained lower than the 1994 baseline year (n=65); however, the 2018 catch was the highest recorded in recent years (Sarchuk et al. 2016).

Table 19. Summary of Threespine Stickleback length and weight data from minnow trapping, 2018, Wahleach Reservoir, BC.

Year	n	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)
2018	60	41	2	0.5	0.1

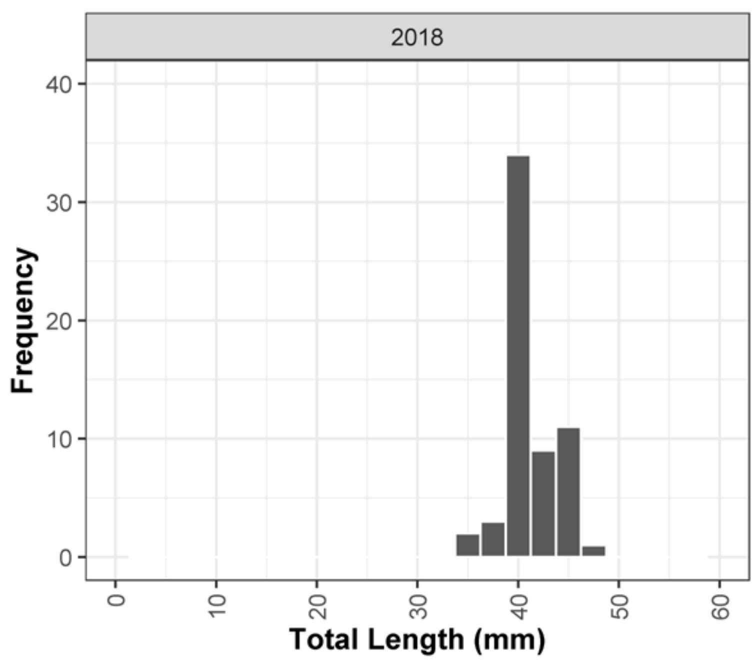

Figure 33. Length frequency of Threespine Stickleback caught in fall 2018, Wahleach Reservoir, BC.

4.6.6 Hydroacoustic Fish Distribution

Figure 34 illustrates the acoustic target size distribution; once partitioned to the depths preferred by Kokanee (6-30 m), the distribution of acoustic targets more closely resembles Kokanee-only distributions found in other lakes in BC (FLNRORD data on file). Trawl data from previous years has demonstrated size differences between Threespine Stickleback and Kokanee fry; Threespine Stickleback were smaller in length than Kokanee fry and would be represented within the smallest range of acoustic targets within the small target size group (-66 to -49 dB). The majority of targets within the upper depth stratum of 2-6 m were very small (less than -60 dB) (Figure 34), consistent with the expected decibel size range of Threespine Stickleback. The greatest density of small fish was found at 2 m, presumed to be Threespine Stickleback (Figure 35). Large fish were primarily located at or below 6 m with peak densities occurring in the 12-14 m stratum (Figure 35). Acoustic density distributions by transect are detailed in Appendix C.

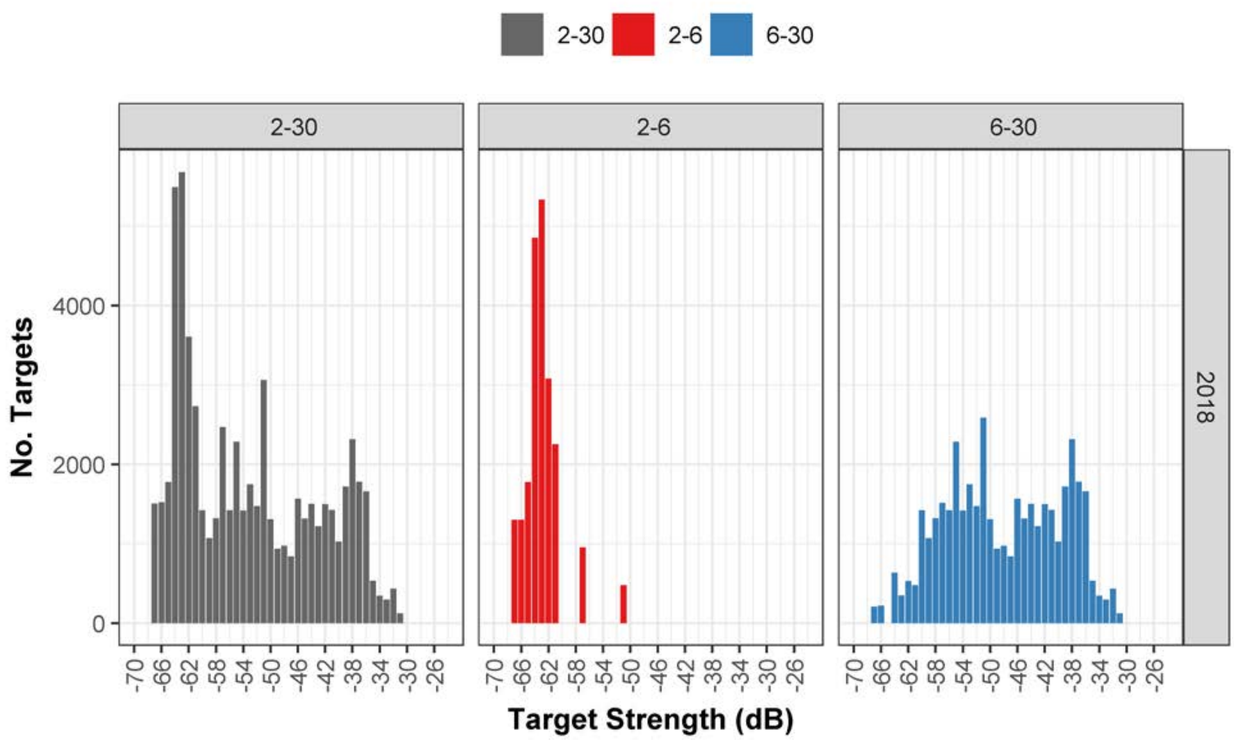

Figure 34. Target strength distributions by depth range (m) from hydroacoustic survey, 2018, Wahleach Reservoir, BC.

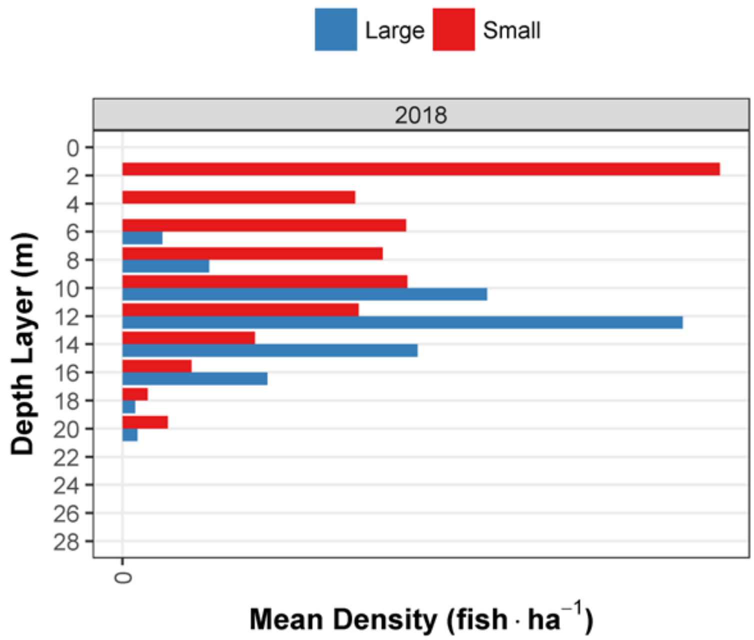

Figure 35. Distribution of fish densities by size group (small = -66 to -49 dB, large ≥ -48 dB) and depth layer based on hydroacoustic survey, 2018, Wahleach Reservoir, BC.

4.6.7 Population and Biomass Estimates

The total fish abundance for all depths (2-30 m), representing a mixed species assemblage, was 46,000 to 75,000 individuals. The acoustic population for small fish (which is mostly limnetic Threespine Stickleback) in the 2-6 m depth strata was estimated at just under 20,000 individuals in 2018. Looking specifically at Kokanee population estimates in 2018, fry abundance was between 13,000 and 27,000 individuals, which was the lowest estimate in the time series for recent years (Table 20, Sarchuk et al. 2016, Hebert et al. 2017). Adult Kokanee (age > 1 year) abundance was between 16,000 to 25,000 individuals (Table 20). In 2018, the total biomass of fish (all species) was estimated at 1,401 kg, which was below the average from 2009-2018 (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, 2018, Wahleach Reservoir, BC.

Year	Analysis Depths (m)	Group	Population Estimate	Lower CI	Upper CI
2018	2-30	All Fish	59,998	45,652	74,594
2018	2-30	Small Fish	39,948	26,296	53,492
2018	2-30	Large Fish	20,269	15,979	24,569
2018	6-30	All KO	40,435	32,142	48,853
2018	6-30	KO Fry	20,211	13,162	27,229
2018	6-30	Adult KO	20,248	15,927	24,575

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. 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 can be directly measured through a variety of methods (e.g. radio-labelled carbon, oxygen production or dissolved inorganic carbon uptake measurement) requiring a high degree of technical expertise and effort; it is a metric commonly used to assess the trophic status of lakes and reservoirs including those with nutrient addition programs (e.g. Harris 2015, Schindler et al. 2014, Stephens and MacKenzie-Grieve 1973). The benefit of primary productivity measurements is that they are a direct assessment of a system's productivity, and unlike abundance and biomass measurements, are not confounded by losses such as grazing, sinking and transport or alternatively by accumulation of inedible algae. 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 2018, Wahleach Reservoir was characterized by ultra-oligotrophic conditions in terms of nutrient concentrations, and exhibited Secchi transparency depths indicative of oligotrophic to mesotrophic conditions (Table 21).

Table 21. Trophic state classification using criteria defined by Wetzel (2001) and Wetzel (1983) during nutrient restoration, 2018, Wahleach Reservoir, BC. Blue shading is indicative of Trophic Classifications for 2018.

Parameter (Units)	**Mean ± SD (Range)**	**Trophic Classification, Mean (Range)**			
	2017	Ultra-Oligotrophic	Oligotrophic	Mesotrophic	Eutrophic
TP ($\mu g \cdot L^{-1}$)	3.9 ± 0.7 (2.9 to 5.1)	(< 1-5)	8 (3-18)	27 (11-96)	84 (16-386)
TN ($\mu g \cdot L^{-1}$)	141 ± 29 (89 to 221)	(< 1-250)	661 (307-1,630)	753 (361-1,387)	1,875 (396-6,100)
Secchi (m)	6.1 ± 1.2 (3.9 to 7.8)	-	9.9 (5.4-29.3)	4.2 (1.5-8.1)	2.5 (0.8-7.0)

Patterns in 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 deviated from planned loading minimally this year. The slight deviation from the planned load was in response to reservoir conditions. 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.

Phytoplankton Edibility & Zooplankton Community

Keeping the dynamic nature of phytoplankton and zooplankton communities in mind when interpreting monitoring 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 2018 primarily consisted of edible species throughout the season that would support the growth of the zooplankton community. Zooplankton production across all major taxonomic groups has increased since the nutrient restoration project began. The most significant result has been the appearance of *Daphnia*. *Daphnia* metrics in 2018 were at average levels when compared to the most recent review period (Sarchuk et al. 2016). As well, the abundance and biomass of other cladocerans was strong early in the 2018 season prior to the onset of *Daphnia* growth. Overall, zooplankton densities and biomass in 2018 represent the fourth greatest zooplankton biomass on record and demonstrate an increase in food availability for Kokanee. Baseline zooplankton (1993-94) consisted of *Bosmina longirostris*, *Cyclops* sp., and *Holopedium gibberum* and no *Daphnia* (data on file), which are favoured by Kokanee.

Fish Population Response

Stimulation of lower trophic levels has evidently translated into increased fish abundance and biomass since the program's inception, and these increases were not due to increases in undesirable fish species (i.e. Threespine Stickleback). In 2018, the number of Threespine Stickleback captured in minnow traps set in littoral areas and the limnetic population estimate from hydroacoustic surveys continued to be lower than baseline years (Perrin et al. 2006). The Wahleach Reservoir Nutrient Restoration Project has successfully re-established the Kokanee population. Monitoring results indicated a significant increase in Kokanee abundance and biomass, which were below detection limits and considered extirpated in 1995 (Perrin 1996). The adult Kokanee population in 2018 was similar to average population levels since 2009 (Sarchuk et al. 2016). Data showed that Kokanee were also longer, heavier and in better condition than in baseline years (Perrin 2001). Kokanee caught in 2018 had a higher frequency of age 2+ than of age 1+, which differs from previous years where age 1+ typically was the dominant class; with the exception of 2012 where 2+ dominated, and 2017 when the two ages were equally represented (Table 9, Sarchuk et al. 2016, 2017).Kokanee spawner escapement in 2018 was estimated at 7,975 individuals. Kokanee spawner escapements have been stable for the past five years (data on file).

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 sterile Cutthroat Trout stocked in Wahleach Reservoir exhibit top-down pressure on the Threespine Stickleback population and allowed Kokanee to take advantage of improved forage conditions. These combined restoration efforts have been able to maintain 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 showed 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.

- Stocking of Kokanee and Rainbow Trout is not recommended.

Monitoring Programs

Limnology

- Continue monthly limnology sampling to adaptively manage the nutrient restoration program approach.
- 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 a total metals sample earlier in the growing season (e.g. June) to look at calcium concentrations in relation to *Holopedium* densities.

- Complete analysis of chlorophyll *a* samples.

Fish Populations

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

- Continue annual Kokanee spawner surveys on index streams. Since the earlier years of the program, the distribution of Kokanee spawners within index stream has changed. Surveying additional areas of Flat Creek and side tributaries of Jones Creek (while recording new survey areas separately) is recommended to explore how this affects escapement estimates.

- Continue with hydroacoustic and trawl program in late July or early August as field conditions are generally the most favorable at that time (i.e. thermal stratification is strongest to best determine fish species distribution and if Kokanee spawners are still present in the reservoir) and will ensure consistency of more recent time-series data.

- Complete a thorough review of the hydroacoustic and trawl program prior to the WUP Order Review report to evaluate its efficacy in smaller mixed-species systems.

Recreational Fishery

- Creel surveys to assess the recreational fishery on Wahleach Reservoir should be incorporated into regular program monitoring. Over the long-term, 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).

- It is recommended that outreach materials be developed to inform anglers of the opportunity to fish for Kokanee, including an explanation of Kokanee feeding behaviour, where they reside within the reservoir, and how to catch them. This information could be included on a BC Hydro website and in public information signage at the two public boat launches along with general information on the Wahleach Reservoir Nutrient Restoration Project. It could be beneficial to work with the Freshwater Fish Society on this initiative.

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9. Appendices

Appendix A. Phytoplankton species detected during 2018, Wahleach Reservoir, BC.

Species	2018	Species	2018
Achnanthidium sp.	+	*Kephyrion* sp.	+
Ankistrodesmus sp.	+	*Komma* sp.	+
Asterionella formosa var1	+	*Lyngbya* sp.	+
Cateria sp.	+	*Merismopedia* sp.	+
Ceratium sp.	+	*Microcystis* sp.	+
Chlorella sp.	+	*Monoraphidium* sp.	+
Chromulina sp1	+	*Navicula* sp.	+
Chroomonas acuta	+	*Ochromonas* sp.	+
Chrysochromulina sp.	+	*Oocystis* sp.	+
Chrysococcus sp.	+	*Peridinium* spp.	+
Clamydocapsa sp.	+	*Phacus* sp.	+
Coelastrum sp.	+	*Planctosphaeria* sp.	+
Cosmarium sp.	+	*Planktothrix* sp.	+
Crucigenia sp.	+	*Pseudokephrion* sp.	+
Cryptomonas sp.	+	*Rhizosolenia* sp.	+
Cyclotella comta	+	*Scenedesmus* sp.	+
Cyclotella glomerata	+	*Scourfieldia* sp.	+
Cyclotella stelligera	+	Small microflagellates	+
Diatoma elongatum	+	*Sphaerocystis* sp.	+
Dichtyosphaerium sp.	+	*Staurodesmus* sp.	+
Dinobryon sp.	+	*Synechococcus* sp. (coccoid)	+
Elakatothrix sp3	+	*Synechococcu*s sp. (rod)	+
Fragilaria capucina	+	*Synechocystis* sp.	+
Fragilaria construens	+	*Synedra acus*	+
Fragilaria crotonensis	+	*Synedra nana*	+
Gymnodinium sp1	+	*Tabellaria fenestrata*	+
Gymnodinium sp2	+	*Tabellaria flocculosa*	+
Gyromitus sp.	+	*Tetraedron* sp.	+

Appendix B. Zooplankton species detected during 2018, Wahleach Reservoir, BC.

Order/Species	2018
CLADOCERA	
Alona sp.	r
Bosmina longirostris	+
Chydorus sphaericus	+
Daphnia rosea	+
Holopedium gibberum	+
Leptodora kindtii	+
Scapholeberis mucronata	r
COPEPODA	
Cyclops vernalis	+

r = rare species, + = present

Appendix C. Acoustic density distribution by size group (small = -66 to -49 dB, large ≥ -48 dB) and transect, 2018, Wahleach Reservoir, BC.