Wahleach Project Water Use Plan

Wahleach Reservoir Fertilization Program

Implementation Year 13

Reference: WAHWORKS-2

WAHLEACH RESERVOIR NUTRIENT RESTORATION PROJECT REPORT, 2017 - Fisheries Project Report No. RD 161

Study Period: 2017

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

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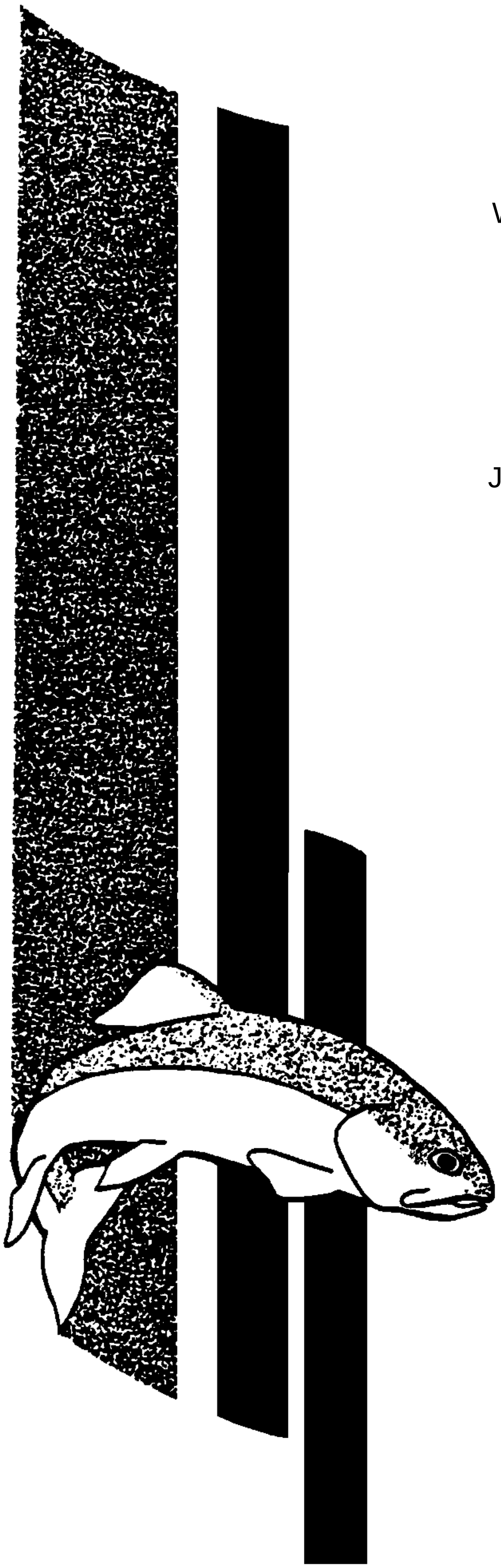

WAHLEACH RESERVOIR NUTRIENT RESTORATION PROJECT REPORT, 2017

by

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

Fisheries Project Report No. RD 161
2018

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

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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. Annual monitoring of a suite of physical, chemical and biological parameters was completed to adaptively manage the program and assess the ecosystem's response to treatments. This document is intended as a simple data report for 2017.

In 2017, Wahleach Reservoir was characterized by nutrient concentrations as ultra-oligotrophic and by secchi depths as oligotrophic to mesotrophic. 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. The phytoplankton community consisted primarily of edible species throughout the season, with the exception of a bloom of inedible *Microcystis* sp. in August. Phytoplankton seasonal mean abundance was 6,263 ± 5,474 cells·mL^{-1}. At the secondary trophic level, *Daphnia* densities averaged 3 individuals·L^{-1} and biomass averaged nearly 67 µg·L^{-1}; *Daphnia* accounted for 47% of total zooplankton density and 69% of the total biomass. As well, growth of other cladocerans was strong early in the season. Overall, 2017 had the fourth greatest zooplankton biomass on record for the project period. Stimulation of lower trophic levels has translated into increased fish abundance and biomass of Kokanee, while the growth of the undesirable, Threespine Stickleback was suppressed by the introduction of sterile Cutthroat Trout. Fisheries assessments indicated a significant increase in Kokanee abundance and biomass, which were below detection limits and considered extirpated when the project began. The 2017 adult (age >1) Kokanee population was estimated at approximately 29,000 individuals with an escapement of 7,907 spawners. The acoustic population estimate for small fish in the upper 6 m of the water column, the majority of which would be Threespine Stickleback, was 13,000 individuals which were lower than the original population estimate of 1.2 million individuals during baseline years of the project (Perrin et al. 2006). 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 piscivorous feeding and that the condition factor of individuals in the population was stable.

As demonstrated from program monitoring data, nutrient addition has had a positive bottom-up effect on lower trophic levels and subsequently on the Kokanee population. Data confirmed sterile Cutthroat Trout stocked in Wahleach Reservoir exhibit top-down pressure on the Threespine Stickleback population through predation and have reduced Threespine Stickleback abundance in the reservoir thus, enabling the Kokanee population to take advantage of improved conditions. Combined restoration efforts have clearly been able to restore and maintain Wahleach Reservoir's Kokanee population over the long-term.

Overall, data from Wahleach and other systems in BC have clearly demonstrated that seasonal nutrient additions on large lakes and reservoirs are associated with positive ecological effects, particularly for the pelagic food web. *In-situ* data are required to seasonally adjust nutrient additions and inform restoration actions so that desired outcomes are achieved. Data also show that desired effects would not be sustained without continued application of nutrients.

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1. Introduction

The Wahleach Reservoir Nutrient Restoration Project is a unique project originally developed as part of a complex fisheries management strategy focused primarily on Kokanee (*Oncorhynchus nerka*) production. The first phase of restoration was initiated in 1993, at a time when the recreational fishery on Wahleach Reservoir had collapsed. Rainbow Trout (*Oncorhynchus mykiss*) in the reservoir were stunted (<20 cm) and in poor condition, and Kokanee were recorded in very low numbers (eventually to be considered extirpated by 1995). The collapse of Wahleach 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 fish stocks in Wahleach Reservoir, 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 food web manipulation achieved through fish stocking. This was the first nutrient addition project in BC coupled with a biomanipulation experiment.

Generally, the goal of the Wahleach Reservoir Nutrient Restoration Project was to restore and maintain 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, the intent of nutrient additions was to promote growth of edible phytoplankton, so that carbon is efficiently transferred through the food web to zooplankton species such as *Daphnia* spp. which are a key forage item for planktivorous fish such as Kokanee (Thompson 1999, Perrin and Stables 2000, Perrin and Stables 2001). Thus, the bottom-up effect of nutrient additions plays a key role in increasing 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 in a top-down manner through the addition of a sterile predator fish species. The latter was meant to ensure nutrient additions had the intended effects on Kokanee restoration, as in some systems competition between Kokanee and other fish species counteracted the positive effects of nutrients additions (Hyatt and Stockner 1985). In Wahleach Reservoir, sterile Cutthroat Trout (*Oncorhynchus clarkii*), a known piscivore, were introduced to decrease Threespine Stickleback populations and associated forage pressure on *Daphnia* sp., thus freeing up resources for Kokanee.

The Wahleach Reservoir Nutrient Restoration Project consisted of three phases: baseline data collection completed in 1993 and 1994, nutrient addition treatment from 1995 onward, and fish stocking treatment from 1997 onward. Project funding was provided by BC Hydro from 1993-2002 for delivery of the program by Limnotek Research and Development. While the Water Use Plan (WUP) was in development, limited funding for the 2003 and 2004 field season 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 Wahleach watershed. Amongst other things, the WUP included reservoir operating constraints and a commitment to the Nutrient Restoration Project (WAHWORKS-2) to 2014 (BC Hydro 2004). The objective of the restoration project as stated in the WUP terms of reference (TOR) is 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 the restoration project has been effective at restoring and maintaining the Kokanee population; these programs were generally outlined in the original TOR and 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 nutrient restoration project (WAHWORKS-2) needed to continue until completion of the WUP Order Review when a long-term decision can be made on the project. As such, a TOR addendum was submitted to the Comptroller of Water Rights to continue the project until the WUP Order Review is completed; this addendum was approved on April 27, 2015 (BC Hydro 2015). Due to delays in the WUP Order Review process, another TOR addendum will be required in 2018.

This summary report presents data from the 2017 monitoring season.

2. Study Area

Wahleach Reservoir is located at 49°13'N, 121°36'W, approximately 25 km southwest of Hope and 100 km east of Vancouver, British Columbia within the traditional territory claimed by the Sto:lo Nation (Figure 1). It is situated in the Cascade Mountains at 642 m above sea level with a drainage area of 88 km^2. Wahleach Reservoir was created in 1953 with the construction of a dam at the original lake's outlet stream to allow for hydroelectric generation. Wahleach Reservoir has a surface area of approximately 460 ha, and can hold 66 million m^3 of water at a maximum depth of 29 m; the minimum operating level is 628 m (BC Hydro 2004). The reservoir is dimictic – having two seasons (spring and fall) of complete mixing within the water column, and two seasons of thermal stratification (summer and winter). Ice cover on Wahleach Reservoir generally occurs from December through March. Fish species in Wahleach Reservoir include: Kokanee, Rainbow Trout, sterile Cutthroat Trout, and Threespine Stickleback.

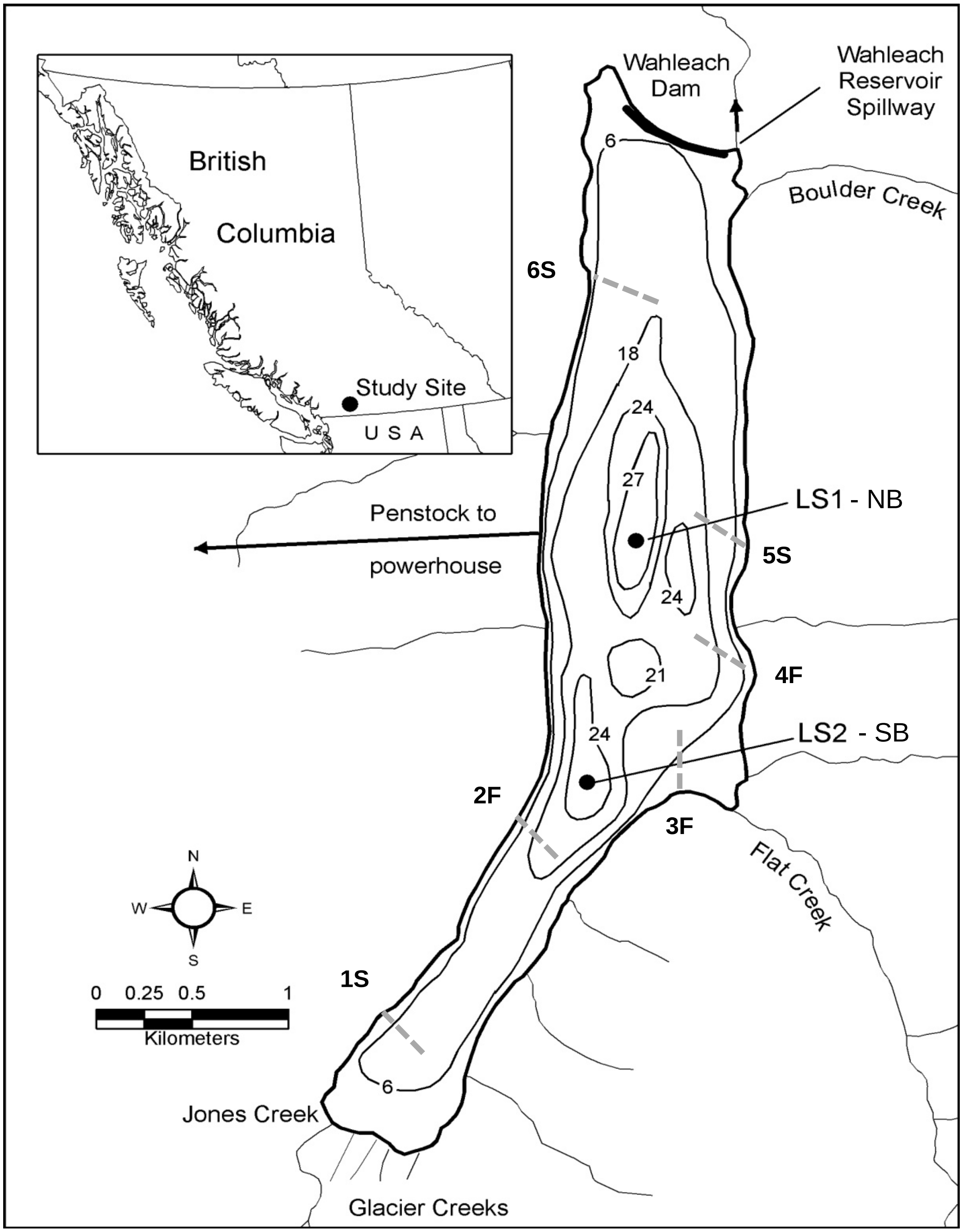


Figure 1. Map of Wahleach Reservoir, BC, including select sampling locations. LS2- SB and LS1-NB are limnological sample locations and 1S, 2F, 3F, 4F, 5S, and 6S are gillnetting locations, with S=Sinking net and F=Floating net. Bathymetric contour depths (m) represent the reservoir at full pool.

3. Methodology

All figures and analyses contained in this report were completed using R version 3.3.1 (R Core Team 2016) through RStudio version 0.99.903 integrated development environment for the R programming language. Supporting packages used included doBy, dplyr, ggplot2, and reshape2. Long term mean values reported were calculated for the duration of the Wahleach Reservoir Nutrient Restoration Project, representing years 1993-2017. Values used for comparison to baseline conditions represented study years 1993-1994, while the nutrient restoration era represented study years 1995-2017. 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. Typically, planned annual phosphorus loading rates for Wahleach Reservoir were kept near 200 mg $P \cdot m^{-2}$ to improve the production of *Daphnia* sp. based on recommendations by Perrin et al. (2006); however, in recent years, actual phosphorus loading rates were approximately half this rate due to in-season modifications (see paragraph below for more details), however negative effects on *Daphnia* growth have not been observed (Sarchuk et al. 2016). Subsequently, beginning in 2016, planned loading rates were adjusted from those of previous years. 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 maintain a suitable N:P ratio. As in 2016, N:P ratios for the 2017 season increased earlier in the season and included a few weeks of nitrogen-only loading in an effort to prevent nitrogen limitation (Figure 2).

All nutrient addition programs in British Columbia (Arrow, Kootenay, Alouette and Wahleach) are adaptively managed based on results obtained from the comprehensive monitoring programs delivered in concert with nutrient applications. In-season modifications are made based on *in situ* conditions of the reservoir (e.g. secchi depth, visual inspection of 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 response to monitoring program results, actual nutrient loading rates were modified throughout the season (Figure 2). In 2017, actual and planned loading rates were generally consistent, with the exception of a week missed early in the season (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 was also high early in the season with a maximum of 108 mg $N \cdot m^{-2}$ (Figure 2). The weekly molar N:P ratio peaked at 40.4 during the latter part of the season when phosphorus and nitrogen loading were being ramped down (Figure 2). Elimination of the nutrient load during week 5 was a result of logistical issues rather than a response to reservoir conditions (Figure 2).

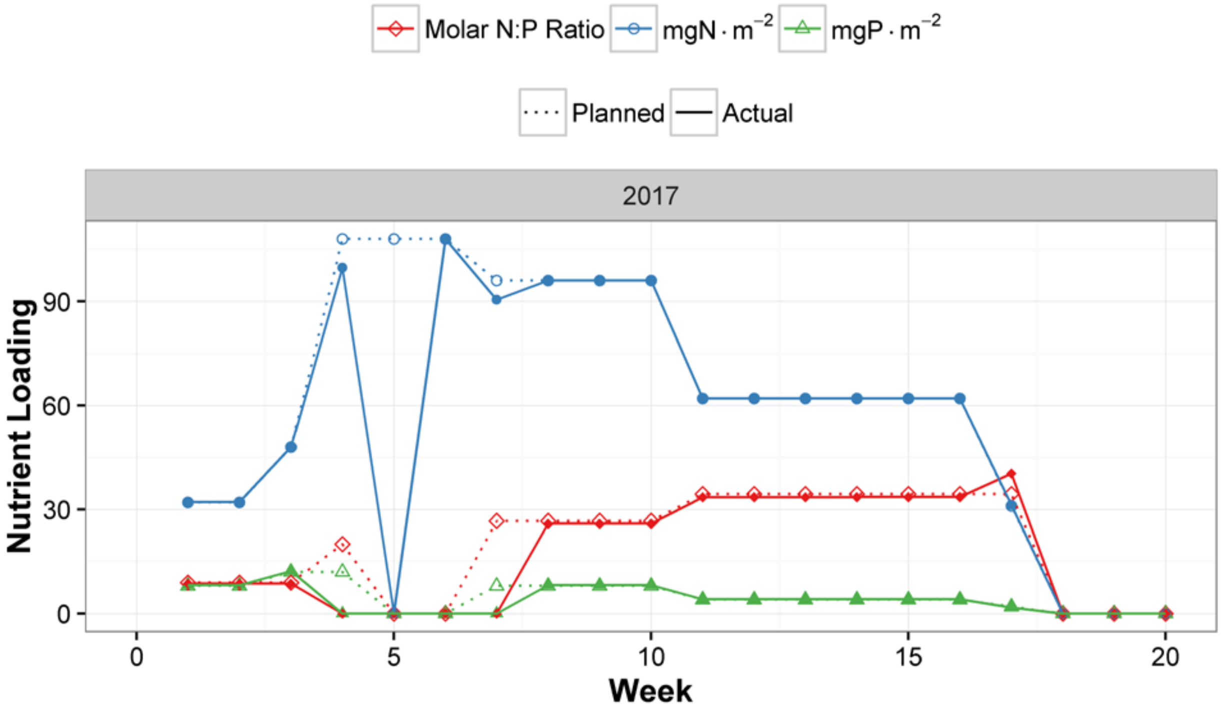


Figure 2. Seasonal planned and actual nutrient additions for Wahleach Reservoir, including areal nitrogen and phosphorus loading as well as molar N:P ratios, 2017; planned values are represented by hollow points, while actual values are represented by solid points.

Table 1. Annual nutrient additions by weight and areal loading, 2017, Wahleach Reservoir, BC

Year	Date Range	Fertilizer Blend		Total Phosphorus		Total Nitrogen	
		10-34-0	28-0-0				
		t	t	Kg	$mg{\cdot}m^{-2}$	Kg	$mg{\cdot}m^{-2}$
2017	7-Jun to 26-Sep	2.14	15.0	729	79.6	4,408	1,102

3.1.2 Fish Stocking

Stocking of sterile (3N) Cutthroat Trout continued as the biomanipulation portion of the program to ensure top down pressure on the Threespine Stickleback population was maintained. In 2017, a total of 2,000 sterile (3N) Cutthroat Trout were stocked into the reservoir. The decision to stock is evaluated annually based on the results of the gillnetting program, specifically condition and growth of Cutthroat Trout, 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 limnology sampling 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 depth, water chemistry, and depth integrated 0.45 μm chlorophyll *a*. Water chemistry samples were analyzed by ALS Laboratory in Burnaby, BC. Where samples were reported below detection limits, a value of one half the detection limits was assigned 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

Phytoplankton sampling (depth integrated samples of the epilimnion) was conducted monthly from May to October. Samples were analyzed by taxa for abundance, biovolume and edibility. Edibility refers to whether a phytoplankton species is considered edible to zooplankton and is categorized either 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 150 μm mesh Wisconsin plankton net. Samples were analyzed by taxa for density, biomass and fecundity. 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 gillnet, minnow trap, hydroacoustic, trawl and spawner surveys. For simplification, abbreviated 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 sites are shown on Figure 1 with exact coordinates for 2017 in Table 2. Although exact coordinates may vary slightly, the general locations of sampling sites remain the same from year to year.

Table 2. Locations of standard nearshore gillnet and minnow trap stations, 2017, 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°13.214 N	121°37.177 W	5S	GN	49°14.139 N	121°36.232 W
3F	GN	49°13.044 N	121°37.706 W	6S	GN	49°14.666 N	121°36.839 W
1M	MT	49°13.978 N	121°37.123 W	4M	MT	49°12.212 N	121°37.150 W
2M	MT	49°13.759 N	121°37.148 W	5M	MT	49°12.212 N	121°38.044 W
3M	MT	49°13.378 N	121°37.148 W	6M	MT	49°12.201 N	121°38.003 W

Standardized annual nearshore gillnetting was completed October 24 to 25, 2017 after Kokanee spawners had left the reservoir. Each net station was set with one standard seven panel RISC net (measuring a total of 106.4 m long by 2.4 m deep) with mesh sizes: 25 mm, 89 mm, 51 mm, 76 mm, 38 mm, 64 mm, 32 mm (i.e. 1", 3.5", 2", 3", 1.5", 2.5”, 1.25“). Starting 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 32 mm mesh were recorded separately to allow for consistency in comparisons of time series data, where required.

Minnow traps targeting Threespine Stickleback were set and retrieved at the same time as gillnets. In 2017, six minnow traps baited with salmon roe were set on the bottom 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 survey methods. Spawner surveys were conducted weekly on index streams from September 6 to October 18, 2017 depending on observed trends in spawner numbers. 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 2017 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, 2017, Wahleach Reservoir, BC.

Year	Survey Date	Sounder	Reservoir Elevation[1] (m)	Avg Transect Start/End Depth (m)
2017	July 26	EK60	640.14	6.3

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

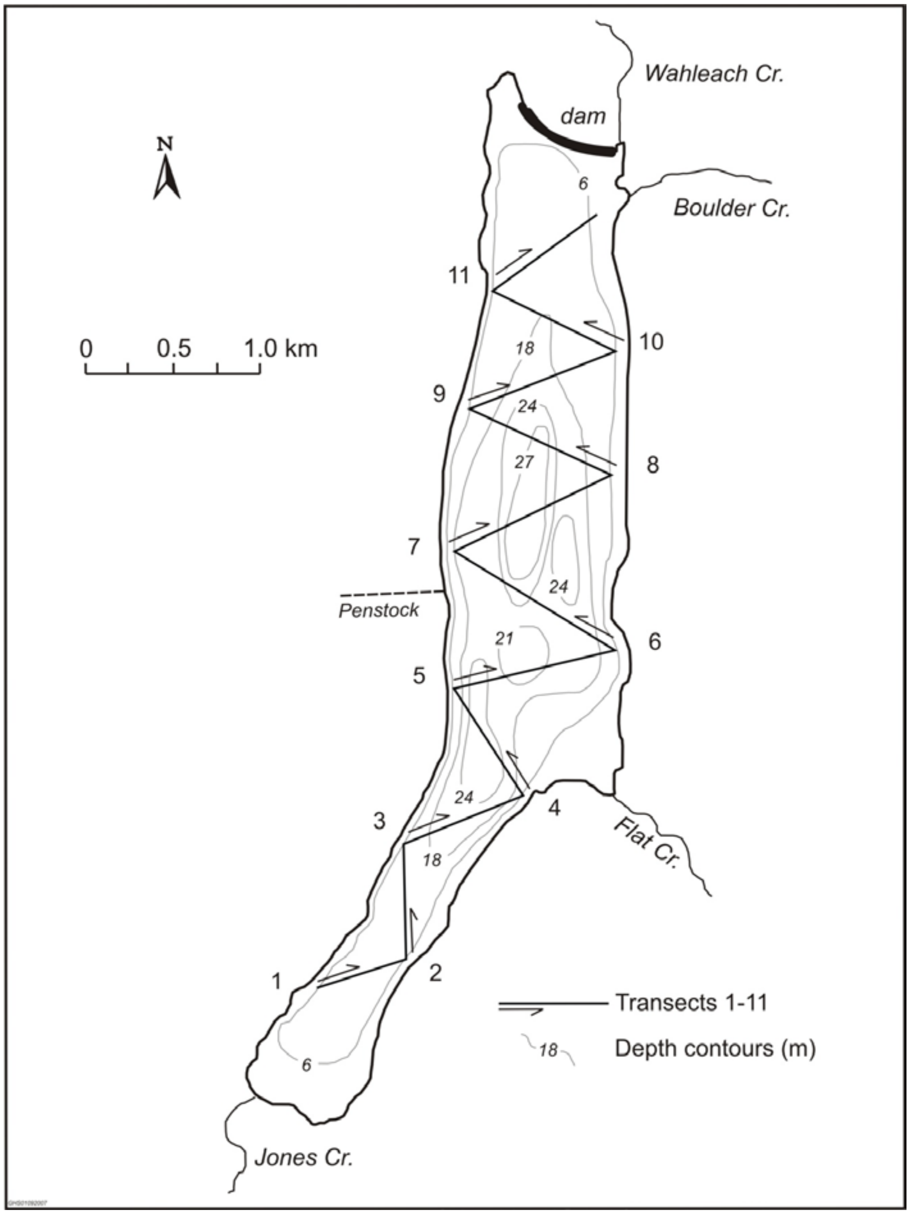


Figure 3. Locations of standardized hydroacoustic transects, Wahleach Reservoir, BC.

Population and Biomass

Split beam 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 expected to encompass the majority of fish targets while eliminating smaller non-fish targets, as well as to differentiate between small and large size fish are in 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, acoustic data were partitioned by depth according to the vertical distribution of Kokanee in the reservoir (Table 4); population estimates assumed targets distributed at depths with water temperatures <17˚C and dissolved oxygen concentrations >5 $mg \cdot L^{-1}$ were mainly Kokanee, as supported by results of pelagic gillnetting and directed trawling (Sarchuk et al. 2017). For simplicity, we refer to these depth partitioned estimates as Kokanee populations, specifically Kokanee fry (age-0), adult Kokanee (age >1), and all Kokanee (age-0 plus age >1).

Table 4. Summary of analysis parameters for hydroacoustic data, 2017, Wahleach Reservoir, BC.

Year	Analysis Depth Range (m)	KO Depth Range (m)	Fry-sized Fish dB	Adult-sized Fish dB	All Fish dB
2017	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 preferred 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 and vary from typical biomass estimation reported 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).

3.2.6.4 Trawl Surveys

A trawl survey was completed following the acoustic survey on July 26, 2017 to evaluate fish species distribution, specifically between Kokanee fry and Threespine Stickleback. Trawls were directed at the highest fish target densities and depths within the preferred Kokanee temperature range, as determined by an initial analysis of the acoustic data. Due to reservoir bathymetry and criteria for safe trawling conditions, all trawls were conducted running parallel to shore just west of the reservoir’s center, between acoustic transects 3 to 9. Additional trawl information is located in Table 5. We assumed Kokanee fry and all age classes of Threespine Stickleback were equally vulnerable to the trawl gear.

Table 5. Summary of equipment and effort for trawl surveys, 2017, Wahleach Reservoir, BC.

Year	Survey Date	Net Size (l×w×h in m)	No. Hauls	Haul Depth Range (m)	Haul Time Range (min)	Method Reference(s)
2017	July 26	12 × 2.5 × 2.5	2	6-11	38 &39	Gjernes 1979; Hebert et al. 2015; 2016

To illustrate the vertical distribution of fish based on trawl surveys, catch data was pooled by species; the center of each haul depth range was calculated (e.g. centre of a 13-15 m haul would be 14 m) and then each haul was assigned a depth category based on 5 m depth increments (i.e. 0-5 m, 5-10 m etc.).

3.2.6.5 Creel Survey

A random stratified survey design (Pollock et al. 1994) was used to conduct seasonal angler surveys on Wahleach Reservoir during 2017. Five days per month were surveyed with a creel technician stationed at the primary public access point generally from 10:00-20:00 h. There are only three boat launches on Wahleach Reservoir with one being private and used less frequently by anglers. The survey time period essentially permitted interviews at the end of the fishing day for nearly all who fished on a particular day. No doubt some anglers were missed during some survey days especially if anglers departed at the same time from different access points hence estimated effort and catch would be considered conservative. Survey dates were chosen using the Microsoft Excel function “Randbetween” to randomly select dates. The survey days were drawn from weekdays (Monday-Thursday) and weekend days (Friday-Sunday). Results from individual survey days were then expanded for the full month.

4. Results

4.1 Hydrometrics and Reservoir Operations

4.1.1 Inflow

Boulder (via the Boulder Diversion), Flat, and Jones Creek provide the majority of the inflow to the reservoir. Mean daily inflow to Wahleach Reservoir in 2017 was 6.3 ± 6.4 $m^3 s^{-1}$ (0 to 75.6 $m^3 s^{-1}$), which was similar to the long term mean of 6.2 ± 5.4 $m^3 s^{-1}$ (0 to 96.1 $m^3 s^{-1}$). During the 2017 nutrient addition period (June to September, inclusive), mean daily inflow was lower at 5.0 ± 3.7 $m^3 s^{-1}$ (0.1 to 19.8 $m^3 s^{-1}$). Peak flows were generally observed during the winter storm season (Figure 4).

4.1.2 Discharge

Mean daily discharge from Wahleach Reservoir in 2017 was 6.0 ± 4.3 $m^3 s^{-1}$ (0 to 12.7 $m^3 s^{-1}$), which was similar to the long term mean of 6.2 ± 4.7 $m^3 s^{-1}$ (0 to 78.6 $m^3 s^{-1}$). During the 2017 nutrient addition period, mean daily discharge was 3.6 ± 3.8 $m^3 s^{-1}$ (0 to 12.6 $m^3 s^{-1}$). Figure 5 shows the annual pattern in discharge, which was highly variable, but was generally greatest during the fall/winter seasons when inflows were also greatest, when power generation needs are generally also higher, and was again high during spring freshet.

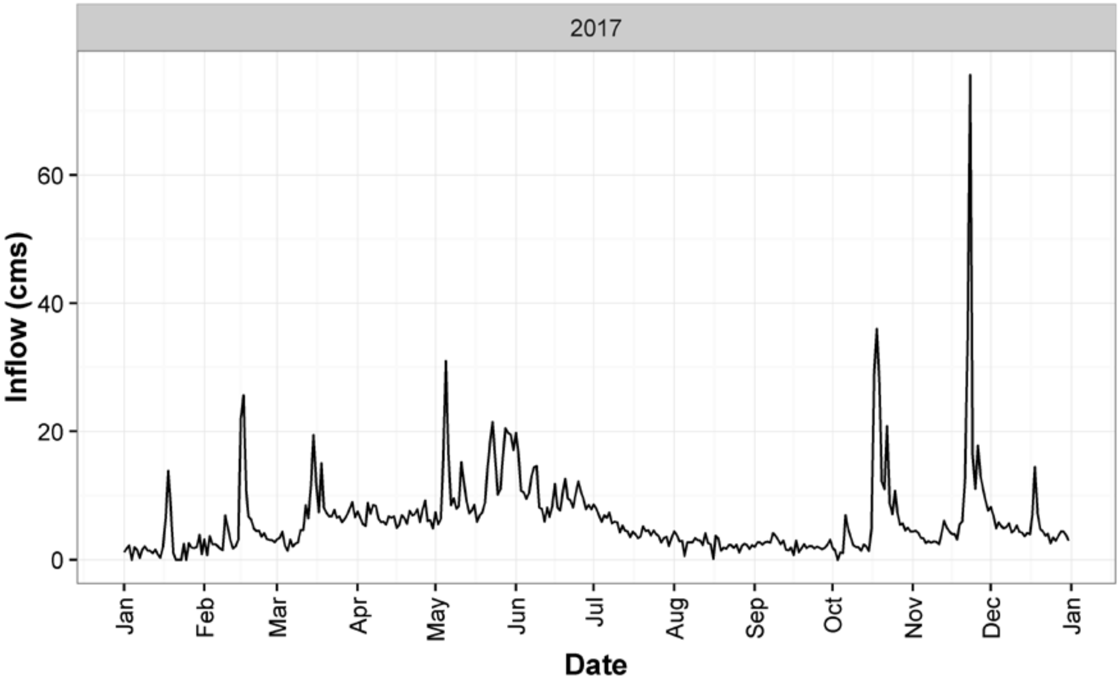


Figure 4. Daily inflow ($m^{3\cdot}s^{-1}$), 2017, Wahleach Reservoir, BC.

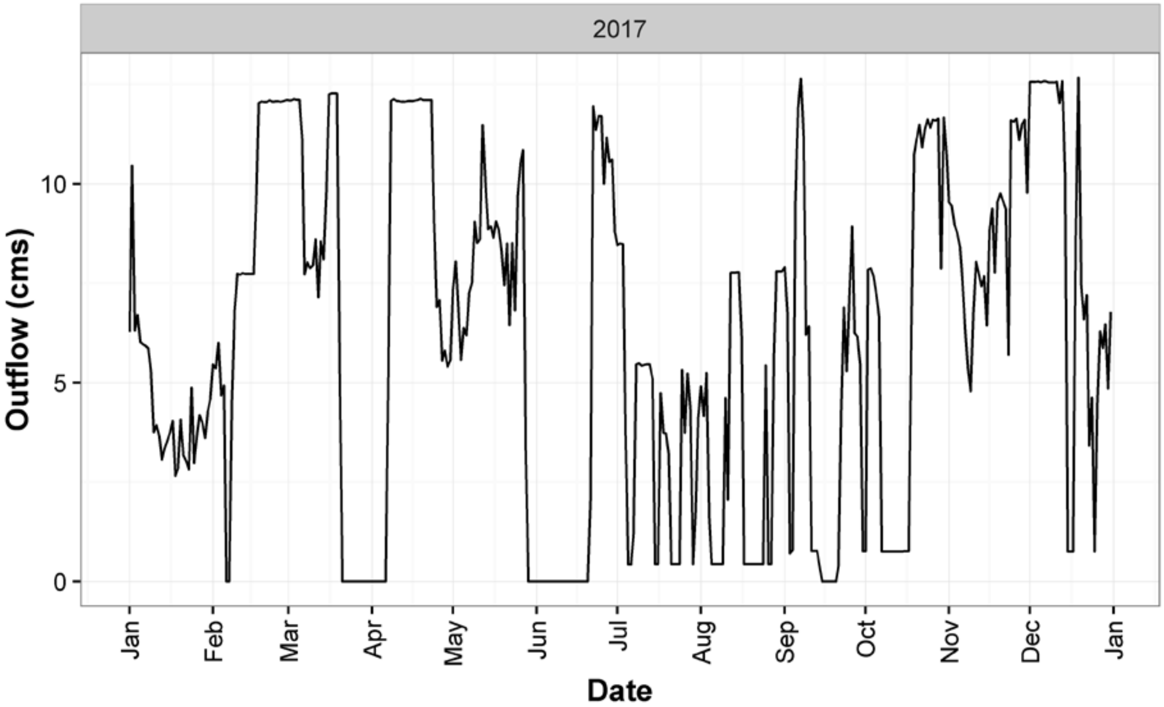


Figure 5. Daily outflow ($m^3{\cdot}s^{-1}$), 2017, Wahleach Reservoir, BC.

4.1.3 Reservoir Elevation

Typically on Wahleach Reservoir, drawdown begins in late summer with the reservoir reaching its minimum water elevation around April; the reservoir is recharged during annual freshet with the maximum water elevation occurring around June which corresponds with the start of nutrient additions. Surface water elevations are generally stable throughout the nutrient addition season, as was observed during 2017. Overall, annual drawdown was 9.9 m in 2017, which was lower than the long term mean of 12.2 m, and reservoir elevations stayed above the minimum standard operating level of 628 m (Figure 6).

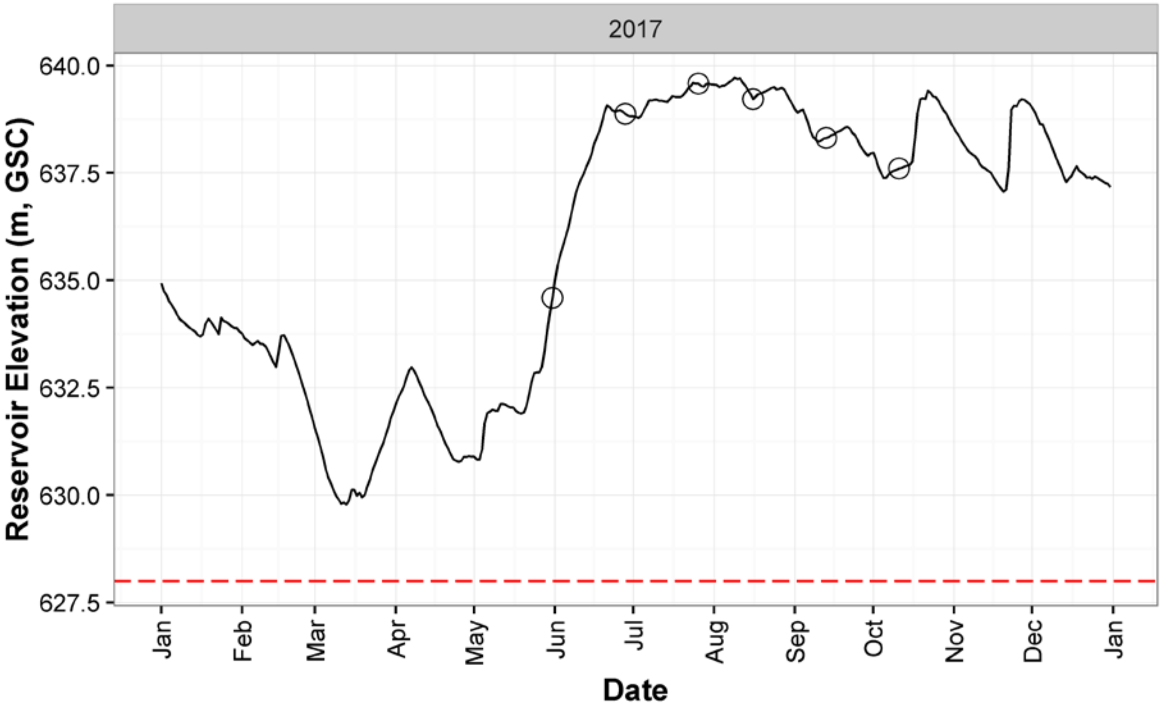


Figure 6. Daily reservoir surface elevation (m, Geodetic Survey of Canada), 2017, Wahleach Reservoir, BC. Open circles represent limnology sampling dates. The red dashed line represents minimum operating level of 628 m.

4.2 Climate

4.2.1 Air Temperature

Seasonal air temperatures in 2017 were the highest in August and lowest in January (Figure 7). Overall, the mean daily temperature in 2017 (6.9 ± 8.0°C, range -18.3 to 30.1°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 15.6 ± 4.1°C (4.3 to 30.1°C), which was warmer than the long term mean but within the range (14.2 ± 3.8°C, range 0.8 to 33.9 °C).

4.2.2 Precipitation

Precipitation generally followed the inverse trend of air temperature; July and August had the least precipitation while January to April and October to December had the greatest precipitation (Figure 8). In 2017, mean daily (7 ± 13 mm, range 0 to 98 mm) and mean monthly (212 ± 165 mm, range 8 to 481 mm) precipitation were similar to the long term means of 7 ± 13 mm (0 to 130 mm) and 218 ± 87 mm (66 to 426 mm), respectively. A total of 2,550 mm of precipitation fell in 2017, which was comparable to the long term mean (2,613 ± 266 mm, range 2,102 to 3,124 mm).

During the nutrient addition period (June through September), precipitation was generally low. The daily and monthly means for precipitation in 2017 was 2 ± 5 mm (0 to 34 mm) and 51 ± 45 mm (8 to 99 mm), respectively, which were lower than the long term means of 4 ± 9 mm (0 to 114 mm), and was 124 ± 77 mm (8 to 335 mm) respectively. Total seasonal precipitation during the nutrient addition period in 2017 was 202 mm, which was lower than the long term mean (494 ± 130 mm, range 202 to 746 mm).

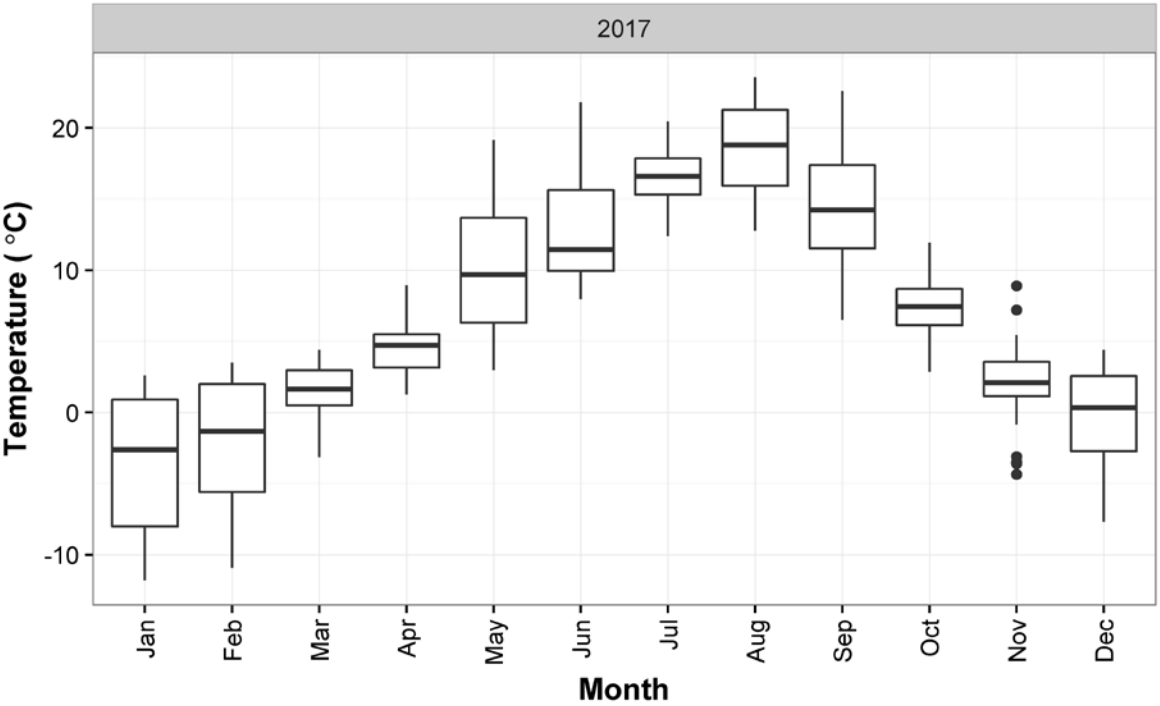


Figure 7. Boxplot of daily mean air temperatures (°C) during each month, 2017, Wahleach Reservoir, BC.

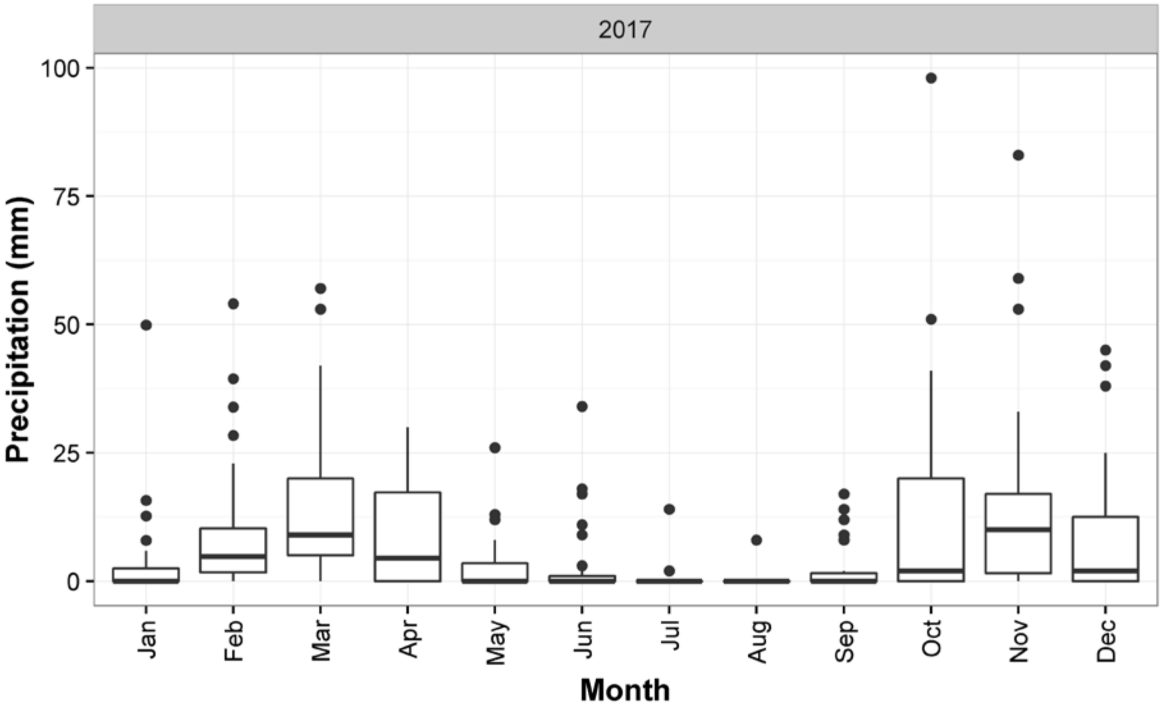


Figure 8. Boxplot of daily total precipitation (mm) during each month, 2017, Wahleach Reservoir, BC.

4.3 Physical and Chemical Limnology

Wahleach Reservoir exhibits a seasonal pattern of thermal stratification typical of 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 2017, thermocline depth ranged between 4-8 m (Figure 9). Water temperatures were similar between the north basin and the south basin with a mean temperature of 12.7 ± 3.5°C (7.9 to 21.0°C). No instances of water temperatures at or above 25°C were observed, the lethal temperature for most resident salmonids (Ford et al. 1995).

Mean dissolved oxygen concentration in 2017 for both basins combined was 9.1 ± 1.3 mg·L^{-1} (2.5 to 10.9 mg·L^{-1}). The lowest dissolved oxygen value in 2017 was 2.5 mg·L^{-1}; it occurred in the south basin during the May sampling trip at 20 m depth; however, this may have been due to probe being at the bottom. During the latter half of the growing season, dissolved oxygen concentrations in the hypolimnion decreased below 6.5 mg·L^{-1} (Figure 9). The federal guideline for dissolved oxygen in cold water lakes for early life stages is 9.5 mg·L^{-1} and 6.5 mg·L^{-1} for other life stages (CCME 1999).

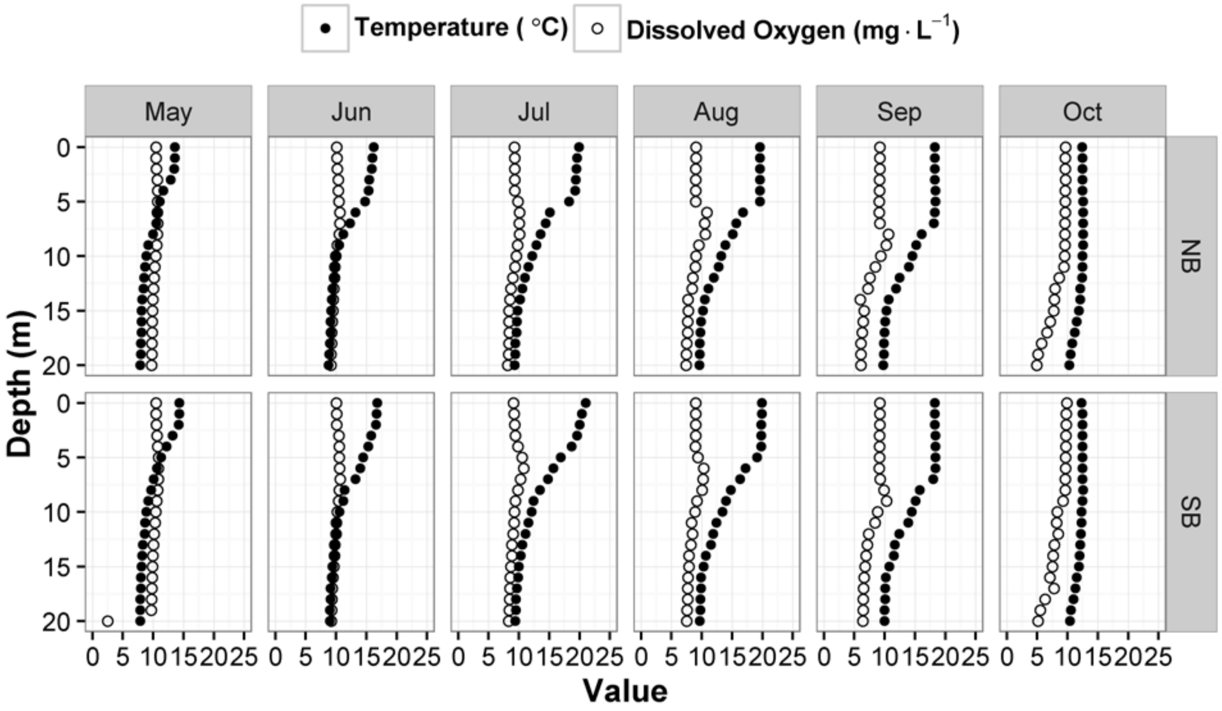


Figure 9. Water temperature (°C) and dissolved oxygen (mg·L^{-1}) profiles at the north basin (NB-LS1) and south basin (SB-LS2) limnology sampling stations May to October, 2017, Wahleach Reservoir, BC.

The pH from 1 m depth in Wahleach Reservoir was neutral with a mean of 7.2 ± 0.1 (7.1 to 7.3) in 2017 (Figure 10), which was similar to baseline pH levels (7.2 ± 0.3 in 1993 and 7.0 ± 0.2 in 1994). 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 11.2 mg $CaCO_3 \cdot L^{-1}$, with a mean of 9.7 ± 1.0 mg $CaCO_3 \cdot L^{-1}$ in 2017 (Figure 11), which was lower than alkalinity measured in 1993, 13.8 ± 2.4 mg $CaCO_3 \cdot L^{-1}$ and a range of 11.7 to 16.5 mg $CaCO_3 \cdot L^{-1}$.

Secchi disk depth averaged 4.8 ± 1.3 m (2.6 to 7.2 m) in Wahleach Reservoir during 2017 (Figure 12). Secchi depths were similar in both the north basin (NB) and south basin (SB). This year’s average was shallower when compared to the 1994 baseline average secchi depth of 7 ± 0.4 m (6.2 to 7.6 m).

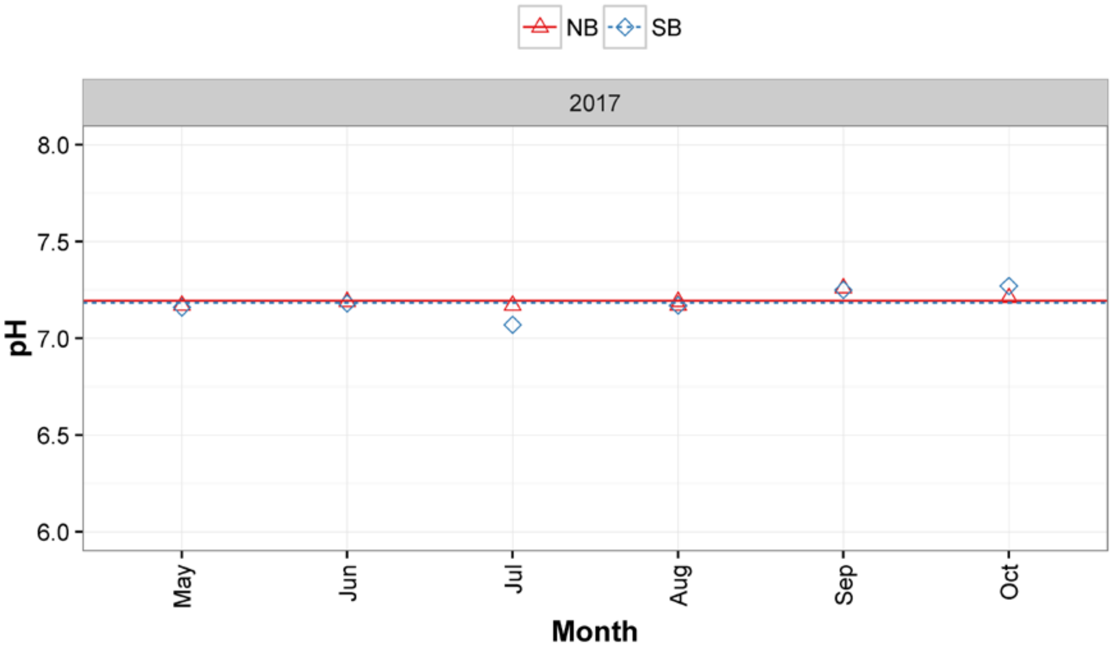


Figure 10. pH values from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May-October, 2017, Wahleach Reservoir, BC. Horizontal bars represent seasonal mean for each station.

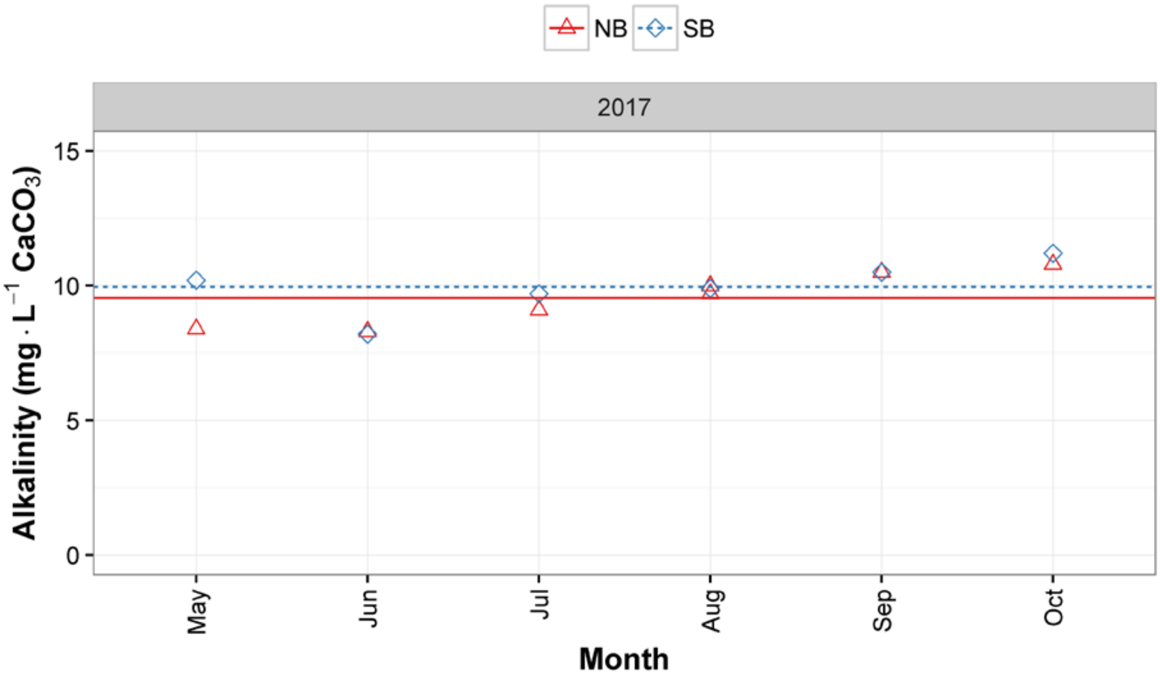


Figure 11. Alkalinity (mg $CaCO_3 \cdot L^{-1}$) values from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May-October, 2017, Wahleach Reservoir, BC. Horizontal bars represent seasonal mean for each station.

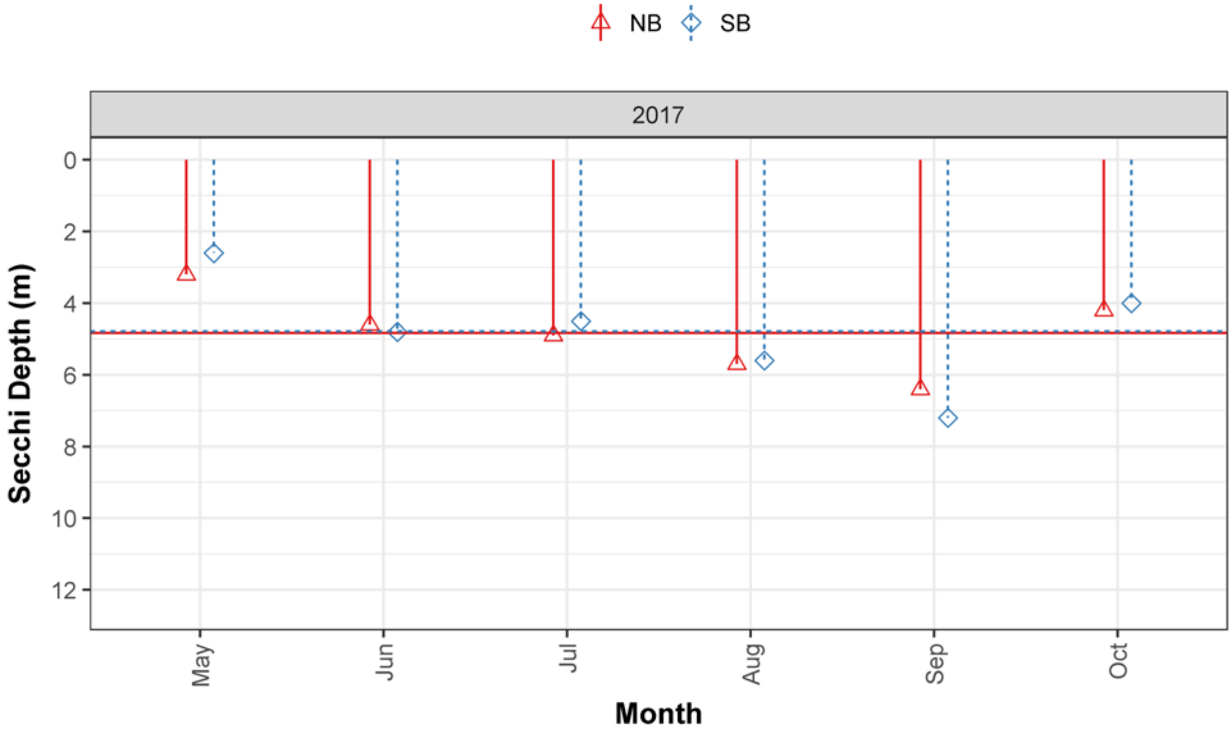


Figure 12. Secchi depths (m) at the north basin (NB) and south basin (SB) limnology sampling stations, 2017, Wahleach Reservoir, BC. Horizontal bars represent seasonal means for each station.

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}, values representative of ultra-oligotrophic productivity nearing oligotrophic productivity. In 2017, TP values ranged from 1.0 to 15.9 µg·L^{-1} (this value is uncharacteristically high and should be used cautiously; sample may be contaminated) with a seasonal mean of 4.1 ± 3.6 µg·L^{-1} (without the 15.9 µg·L^{-1} the seasonal mean is 3.2 ± 0.9 µg·L^{-1}) indicating phosphorus concentrations remained 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. SRP 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 2017 SRP samples were below the detection limit of 1 µg·L^{-1} (Figure 14) suggesting rapid uptake and assimilation of useable phosphorus by phytoplankton.

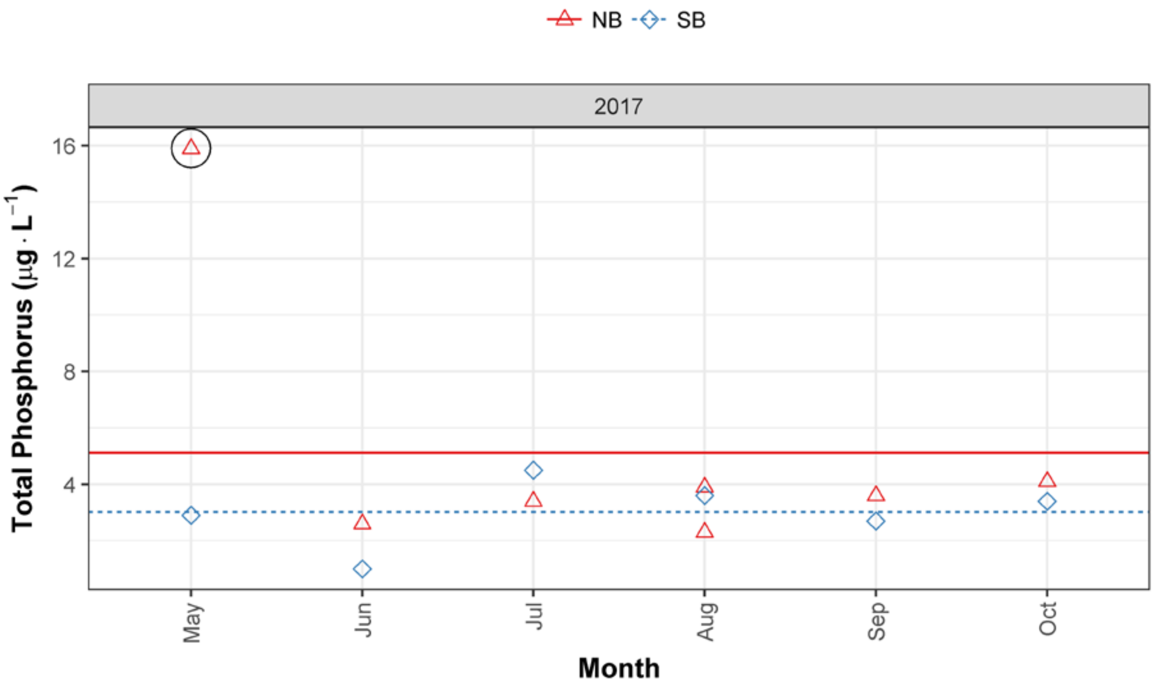


Figure 13. Total phosphorus concentration (µg·L^{-1}) from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to October, 2017, Wahleach Reservoir, BC. Black circle around value indicates uncharacteristically high value, suspected sample was contaminated.

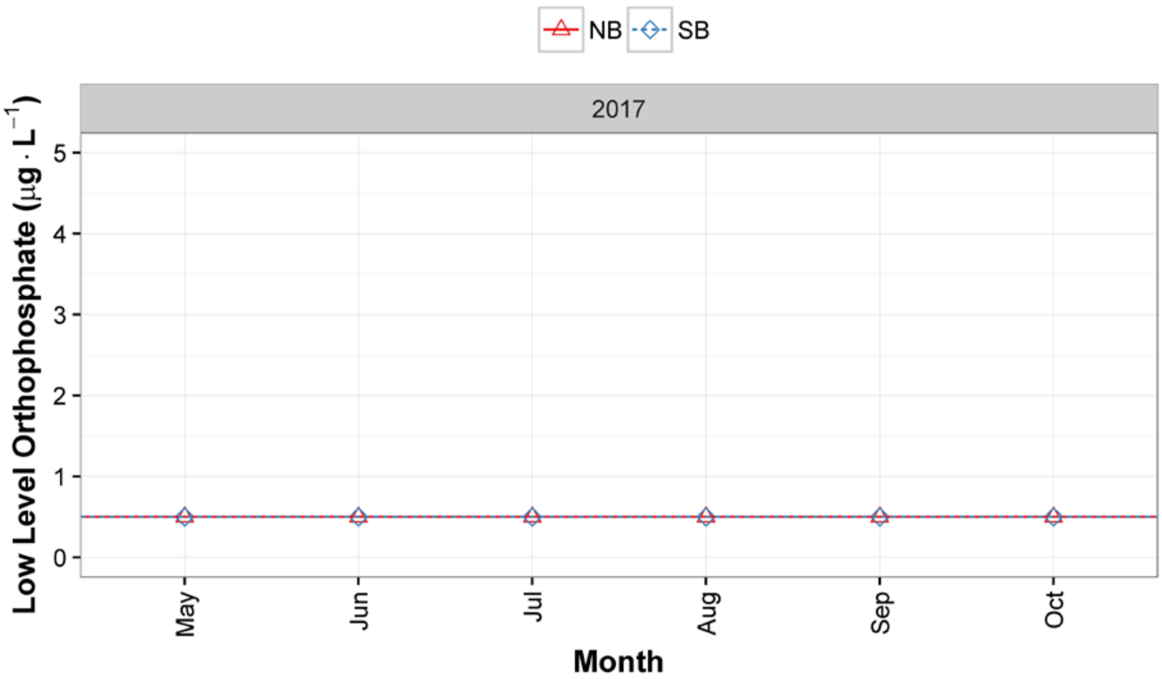


Figure 14. Low level orthophosphate concentrations (µg·L^{-1}) from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May-October, 2017, Wahleach Reservoir, BC.

Total nitrogen (TN) represents dissolved inorganic forms of nitrogen (i.e. nitrate, nitrite and ammonia) and particulate forms of nitrogen (mainly organic). Typically the epilimnetic TN concentrations are slightly higher in spring, and gradually decreased through the summer and fall. This pattern coincides with the seasonal growth and utilization of nitrogen by phytoplankton in the reservoir's epilimnion. In 2017, TN was higher in the spring and then fluctuated around the mean with the exception of one replicate value in August in the north basin which was unusually high (Figure 15). TN concentrations in 2017 were 155 ± 37 µg·L^{-1} (119 to 259 µg·L^{-1}), which was higher than baseline values of 112 ± 48 µg·L^{-1} (9 to 220 µg·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 2017, the highest concentrations of NO_3+NO_2 were observed during spring mixing; NO_3+NO_2 decreased through summer and remained low until October. Summer NO_3+NO_2 concentrations were frequently near or below the level considered limiting for phytoplankton (<20 µg·L^{-1}) suggesting strong biological utilization of NO_3+NO_2. The seasonal mean NO_3+NO_2 concentration in 2017 was 45 ± 46 µg·L^{-1} (9.2 to 155 µg·L^{-1}) (Figure 16), which was similar to baseline levels of 46 ± 14 µg·L^{-1} (27 to 72 µg·L^{-1}) in 1993 and lower compared to 1994 levels of 86 ± 92 µg·L^{-1} (0.9 to 426 µg·L^{-1}).

Ideal TN:TP ratios for phytoplankton growth are between 20-50; ratios above 50 suggest phosphorus limitation while ratios below 20 suggest nitrogen limitation (Guildford and Hecky 2000). TN:TP ratios for 2017 ranged between 12 to 119 with a mean of 52 ± 31 (Figure 17); seasonally, suggesting Wahleach Reservoir was likely in a state of phosphorus limitation at the beginning of the season. Baseline TN:TP ratios were lower than levels observed in 2017 and ranged between 3 to 57 with a mean of 27 ± 16 in 1993 and 3 to 67 with a mean of 26 ± 13 in 1994.

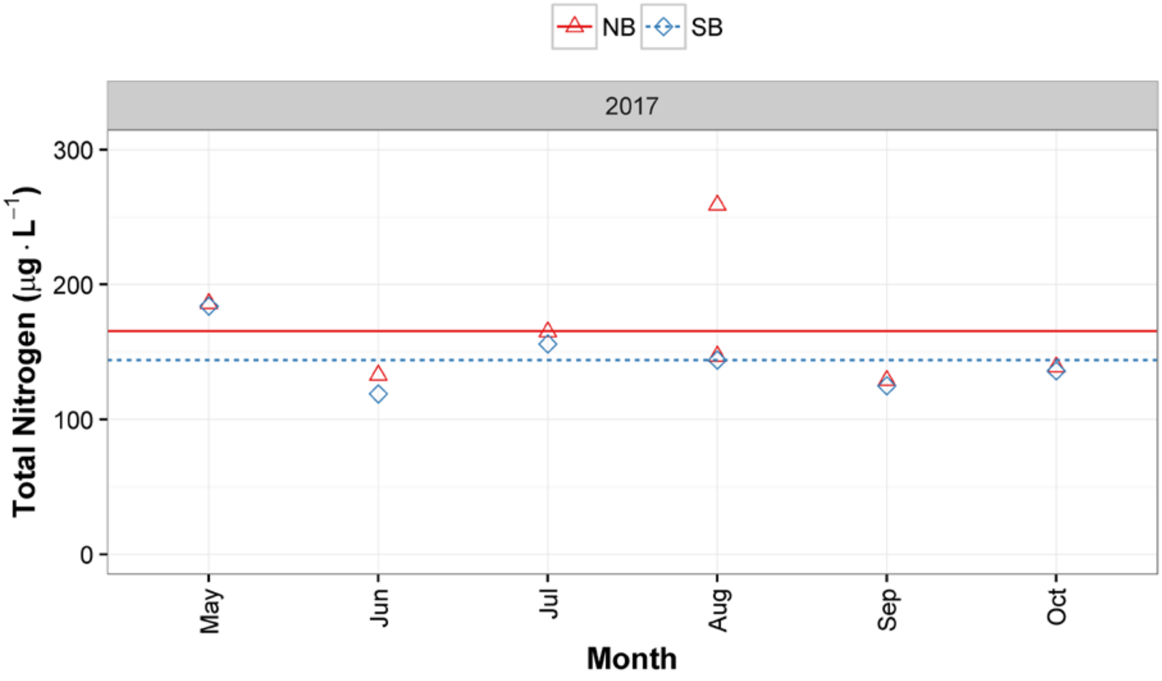


Figure 15. Total nitrogen concentrations (µg·L^{-1}) from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May-October, 2017, Wahleach Reservoir, BC; horizontal lines represent seasonal means for each station. Extra NB during Aug is a replicate sample.

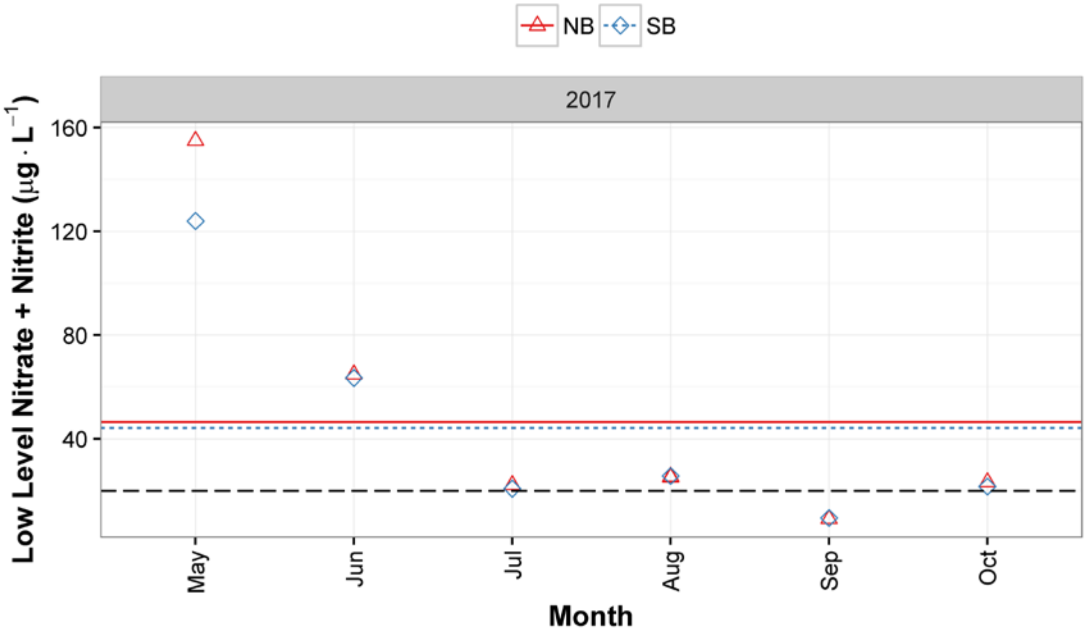


Figure 16. Low level nitrate + nitrite nitrogen concentrations (μg·L^{-1}) from 1 m discrete water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May-October, 2017, Wahleach Reservoir, BC; black dashed line at 20 μg·L^{-1} represents the limiting concentration for phytoplankton growth.

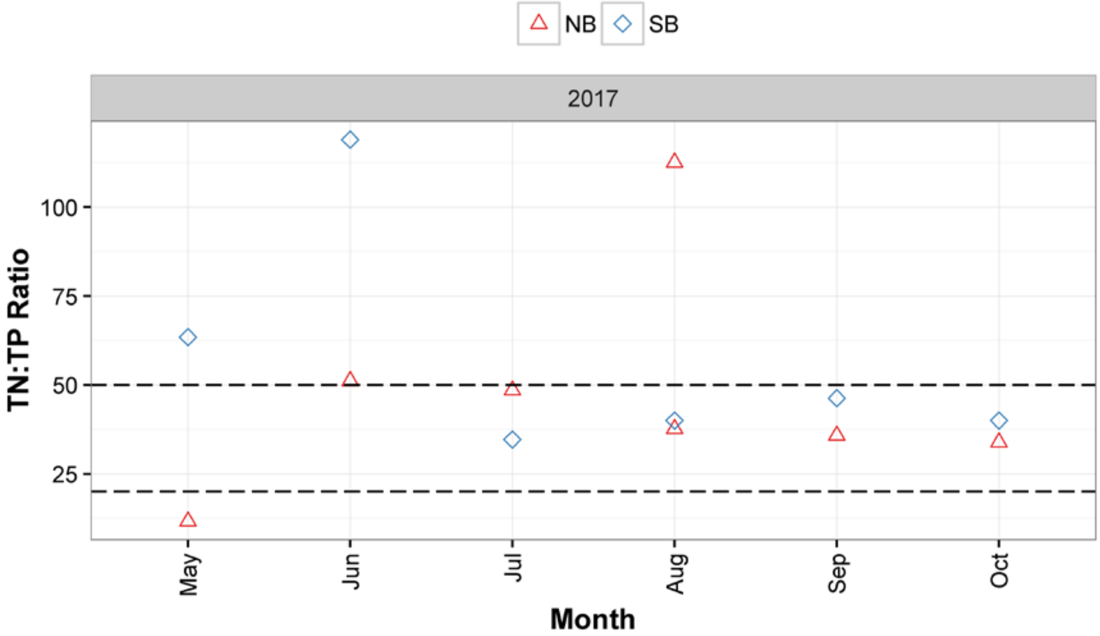


Figure 17. Total nitrogen (TN) to total phosphorus (TP) ratios based on 1 m water chemistry samples from the north basin (NB) and the south basin (SB) limnology stations May-October, 2017, Wahleach Reservoir, BC. Points above dashed line at 50 were likely in a state of P limitation, while points below dashed line at 20 were likely in a state of N limitation (Guildford and Hecky 2000).

4.4 Phytoplankton

A total of 55 phytoplankton species were detected in Wahleach Reservoir during 2017 (Appendix A), which was higher than the 1994 baseline year, when only 38 phytoplankton species were detected. Mean phytoplankton abundance in 2017 was 6,263 ± 5,474 cells·mL^{-1} (2,625 to 23,188 cells·mL^{-1}), which was similar to the 1994 baseline year abundance of 8,793 ± 4,929 cells·mL^{-1} (4,632 to 20,093 cells·mL^{-1}). Abundance was driven largely by growth of *Microcystis* sp. and to a lesser extent *Merismopedia* sp. in August; both species are small blue-green algae belonging to the class *Cyanophyceae* (Figure 18). Flagellates (*Chryso-* & *Cryptophyceae*) were the second most numerically dominant class of phytoplankton in 2017 (Figure 18). Overall, the phytoplankton community was primarily edible species and forms throughout the season (3,352 ± 1,518 cells·mL^{-1}; 1,075 to 6,031 cells·mL^{-1}) (Figure 19). Inedible fractions (2,736 ± 5,049 cells·mL^{-1}; 324 to 18,216 cells·mL^{-1}) were low with the exception of August when a bloom of inedible *Microcystis* sp. occurred.

Phytoplankton biovolume in 2017 of 1.55 ± 2.42 mm^3·L^{-1}; (0.37 to 9.02 mm^3·L^{-1}) was above average for the nutrient addition era (1.0 ± 1.1 mm^3·L^{-1}) and was higher than previously observed during baseline years (0.88 ± 0.51 mm^3·L^{-1}). As with abundance, biovolume was largely driven by large sized *Microcystis* sp. Flagellates (*Dinobryon* sp. and *Ochromonas* sp.), as well as *Tabellaria fenestrata* (class *Bacillariophyceae*) and *Planctosphaeria* (class *Chlorophyceae*) were also significant contributors to biovolume results in 2017 (Figure 20). Colonies of *Microcystis* sp. (class *Cyanophyceae*) generally made up the inedible fraction (1.1 ± 2.5 mm^3·L^{-1}; 0.03 to 8.7 mm^3·L^{-1}) of the biovolume, while flagellates, chlorophytes and to a lesser extent, dinoflagellates (class *Dinophyceae*) generally made up the edible fraction (0.42 ± 0.25 mm^3·L^{-1}; 0.12 to 1.02 mm^3·L^{-1}). Throughout the growing season, phytoplankton biovolume generally consisted of more edible than inedible species and forms; excluding August when inedible species dominated (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.

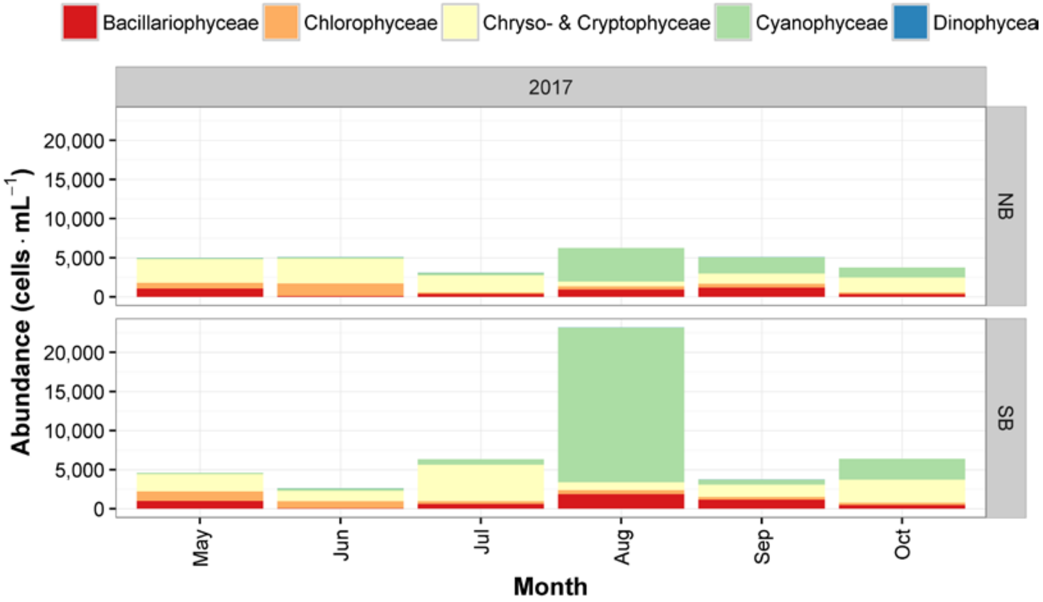


Figure 18. Seasonal phytoplankton abundance (cells·mL^{-1}) by class at the north basin (NB) and south basin (SB) limnology stations May to October, 2017, Wahleach Reservoir BC.

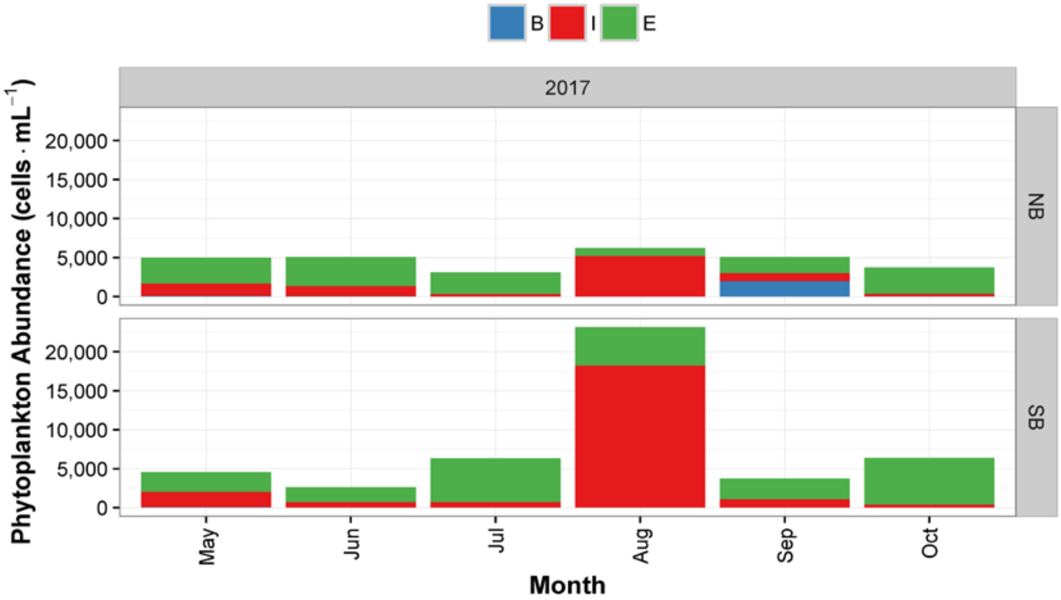


Figure 19. Seasonal phytoplankton abundance (cells·mL^{-1}) by edibility (E=edible, I=inedible, B= both edible and inedible forms) at the north basin (NB) and south basin (SB) limnology station May to October, 2017, Wahleach Reservoir, BC.

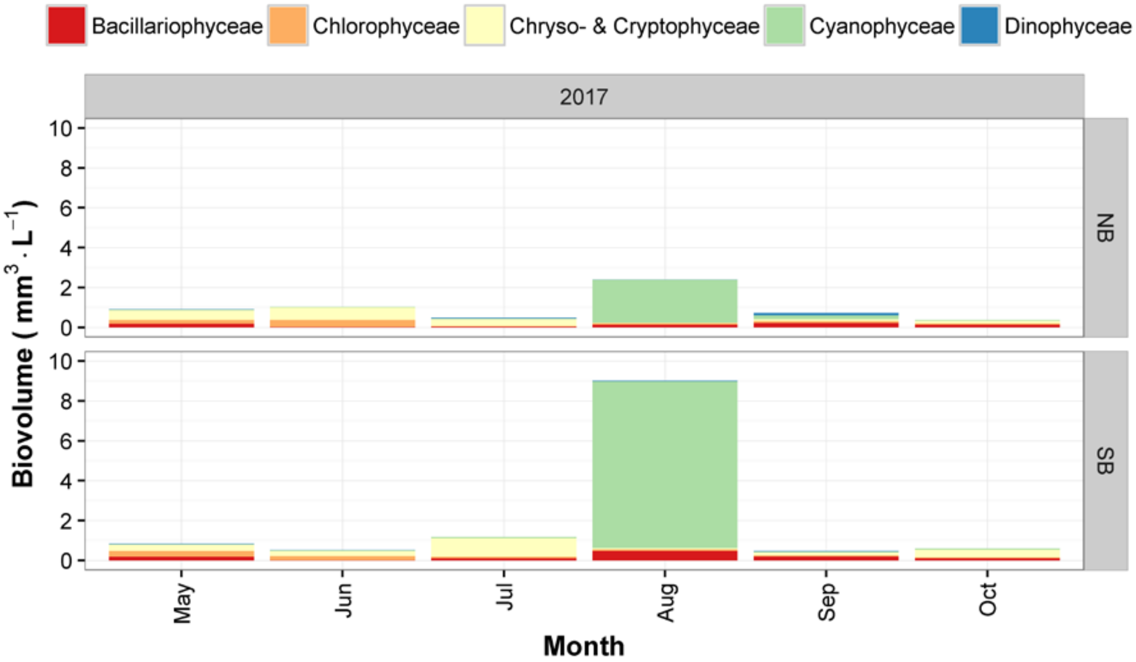


Figure 20. Seasonal phytoplankton biovolume (mm^3·L^{-1}) by class at the north basin (NB) and south basin (SB) limnology stations May-October, 2017, Wahleach Reservoir, BC.

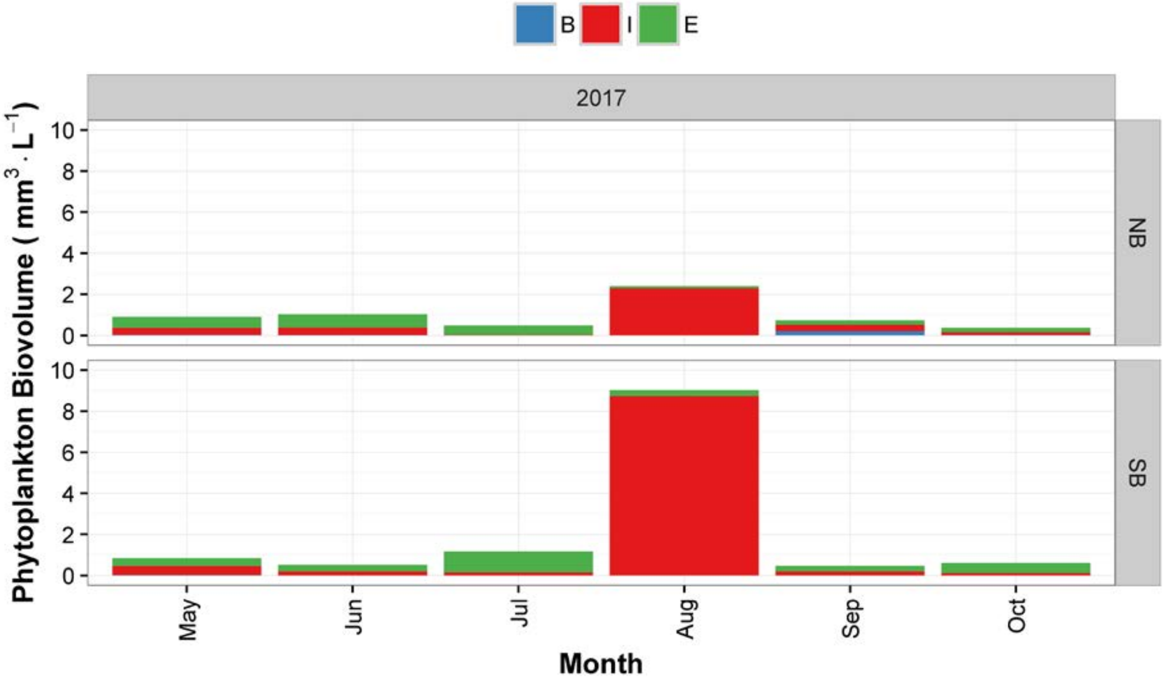


Figure 21. Seasonal phytoplankton biovolume (mm^3·L^{-1}) by edibility (E= edible, I=inedible, B= both edible and inedible forms) at the north basin (NB) and south basin (SB) limnology station May to October, 2017, Wahleach Reservoir, BC.

4.5 Zooplankton

Seven *Cladocera* species and one *Copepoda* species were identified in Wahleach Reservoir in 2017 (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 2017 of 6.2 ± 3.6 individuals·L^{-1} (2.0 to 15.4 individuals·L^{-1}) was below average but within the standard deviation for the nutrient addition era (8.5 ± 8.5 individuals·L^{-1}) and was higher than previously observed during baseline years (1.0 ± 1.0 individuals·L^{-1}). Both sampling stations had similar values for density, with the north basin typically having slightly greater values than the south basin (Figure 22). Early in the season, cladocerans other than *Daphnia* sp. contributed most to density of the zooplankton community; beginning in July and then continuing for the rest of the season, *Daphnia* were dominant species present (Figure 22). Overall in 2017, *Daphnia* contributed 47% of seasonal density, while cladocerans other than *Daphnia* made up 42% of density. Seasonal densities of each major zooplankton group are detailed in Table 6.

Seasonal zooplankton biomass was the fourth greatest on record at 93.2 ± 75.9 µg·L^{-1} (11.0 to 271.8 µg·L^{-1}). Similar to zooplankton density, both sampling stations had similar values for biomass, with the north basin typically having slightly higher values than the south basin (Figure 23). Also similar to zooplankton density, early in the season cladocerans other than *Daphnia sp.* contributed most to the biomass of the zooplankton community; beginning in July and then continuing for the rest of the season, *Daphnia* were the dominant species present (Figure 23). Overall in 2017, *Daphnia* made up 69% of biomass, while other cladocerans, the majority of which were *Holopedium*, contributed 29% of biomass. Seasonal biomass for each major zooplankton group is detailed in Table 6.

Table 6. Summary statistics for seasonal zooplankton density and biomass of each major group (Copepoda, *Daphnia* and other Cladocera), 2017, Wahleach Reservoir, BC.

Taxonomic Group	Density (individuals·L^{-1})				Biomass (µg·L^{-1})			
	Mean	SD	Max	Min	Mean	SD	Max	Min
Copepoda	0.6	0.6	2.0	0.02	1.3	1.3	4.1	0.02
Daphnia	3.0	3.1	11.2	0.01	66.7	69.0	203.6	0.03
Other Cladocera	2.6	2.8	12.2	0.2	28.0	30.0	123.7	3.4

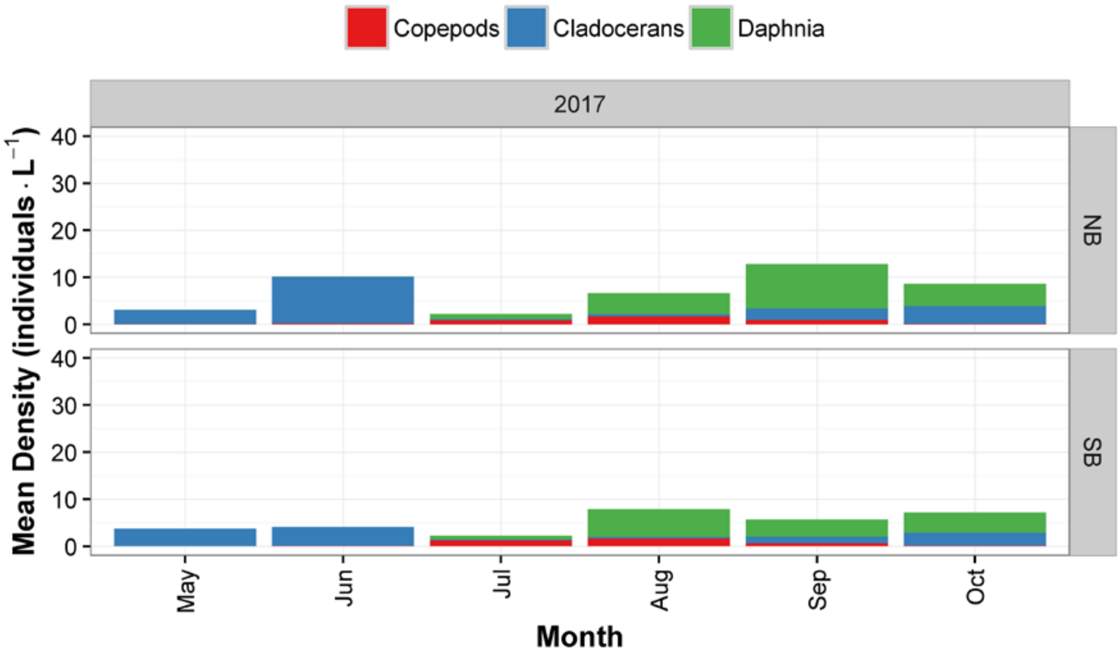


Figure 22. Monthly zooplankton density (individuals·L-1) by major group (Copepoda, *Daphnia* and other Cladocera) at the north basin (NB) and south basin (SB) limnology stations, 2017, Wahleach Reservoir, BC.

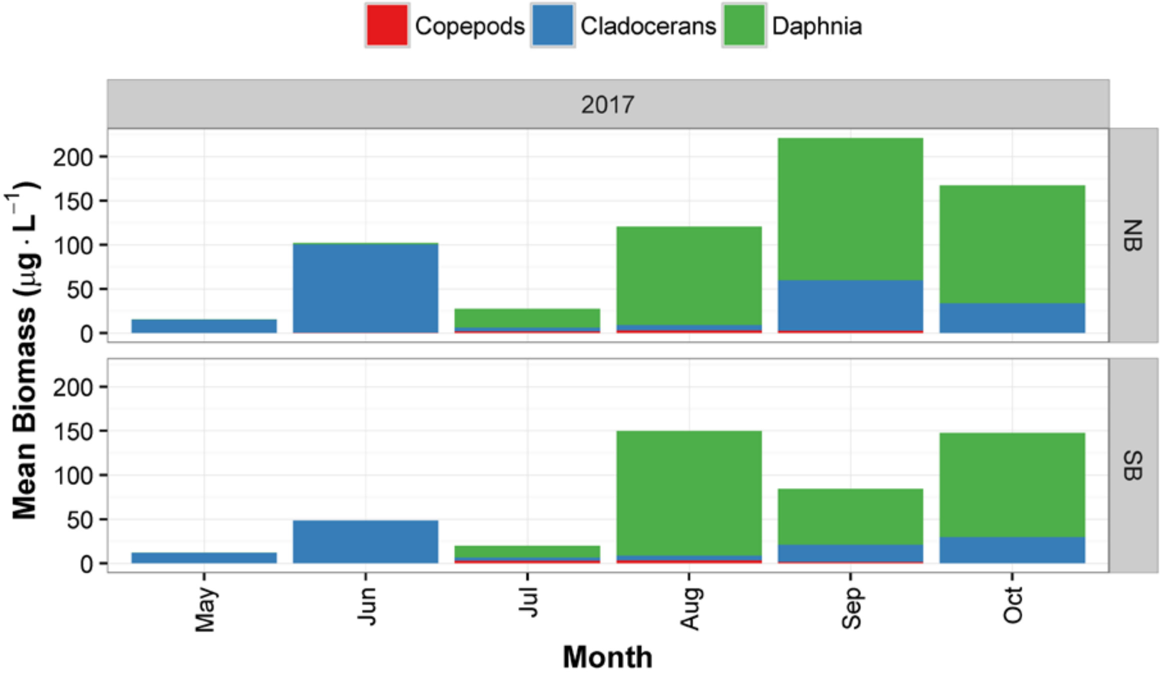


Figure 23. Monthly zooplankton biomass (µg·L^{-1}) by major group (Copepoda, *Daphnia* and other Cladocera) at the north basin (NB) and south basin (SB) limnology stations, 2017, Wahleach Reservoir, BC.

4.6 Fish

4.6.1 Catch & CPUE

Nearshore gillnetting total catch in 2017 was 141, which was lower than the previous two years (Table 7; Sarchuk et al. 2016). The majority of the catch was Rainbow Trout at 53%, while about 21% were Kokanee (Table 7). In 2017, about 28% of the total catch was caught in the 1.25" panels (Table 8). Overall, catch-per-unit-effort (CPUE) for all species combined in the nearshore gillnetting was 0.08 fish$\cdot$100m$^{-2}\cdot$hr^{-1}). CPUE was about 40% lower in 2017 compared to 2016 and 2015 (Sarchuk et al. 2016).

Table 7. Summary of fall nearshore gillnetting catch and percentage (%), 2017, Wahleach Reservoir, BC. Species include Kokanee (KO), Cutthroat Trout (CT), and Rainbow Trout (RB).

Species	2017[1]	%
CT	37	26.2
RB	75	53.2
KO	29	20.6
Total	141	100

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

Table 8. Summary of fall nearshore gillnetting catch for standard RISC panels vs. 1.25" panel, 2017, Wahleach Reservoir, BC. The 1.25" panel was added in 2014 and will now be used regularly.

Species	2017 - Standard	2017 - 1.25"
CT	30	7
RB	49	26
KO	22	7
Total	101	40

In 2017, minnow trap catch was very low with only one Threespine Stickleback caught. No juvenile salmonids were captured. Total soak time was 117 trap hours. CPUE for 2017 was very low compared to previous years at 0.008 fish per trap hour versus 0.392 fish per trap hour in 2016; however, 2016 was the highest catch on record after baseline years (Sarchuk et al. 2016).

4.6.2 Kokanee

Kokanee captured during the fall nearshore gillnetting in 2017 were generally longer than in recent years (e.g. 2015 and 2016) (Table 9, Sarchuk et al. 2016). As expected due to the timing of sampling after the spawning period, no 3+ or 4+ Kokanee were captured during the fall nearshore gillnetting program (Figure 24; Figure 25). Kokanee caught in 2017 had equal representation of the two age classes, age 1+ and age 2+, which differs from previous years where age 1+ typically was the dominant class; with the exception of 2010 and 2012 where 2+ dominated (Table 10, Sarchuk et al. 2016). This age shift accounts for the higher mean length of the overall catch compared to recent years (Figure 24, Figure 25). When comparing summary statistics of Kokanee size by age class, individuals caught in 2017 were larger and in better condition than during the baseline years; in 1993 and 1994 combined catch statistics for age 2+ individuals had a mean length of 178 mm, mean weight of 55.5 g, and condition factor of 1.0 (data on file). The 2017 1+ Kokanee were essentially the same size as the 2+ Kokanee from baseline years (1993-94).

However, the gillnetting in 1993 and 1994 was conducted in September when Kokanee are still spawning with 39% of the 2+ being mature. Furthermore, Kokanee length-weight regressions based on 2017 fall nearshore gillnetting data, as presented in Figure 26 and Table 13, had a slope (b value) of 3 which is common for fish (Anderson et al. 1983, Cone 1989).

Table 9. Summary of Kokanee biometric data, including length, weight, condition factor (K) and age, 2017, Wahleach Reservoir, BC.

Year	Species	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)	Mean K	SD K
2017	KO	178	19	66.3	19.2	1.1	0.10

**Even frequency of 1+ and 2+ Kokanee caught*

Table 10. Summary of Kokanee biometrics by age, 2017, 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	170	21	193	116	57.7	18.1	80	16	1.1	0.06	1.23	1.03	13
2	184	15	211	162	72.1	18.6	113	48	1.1	0.06	1.16	1.06	13

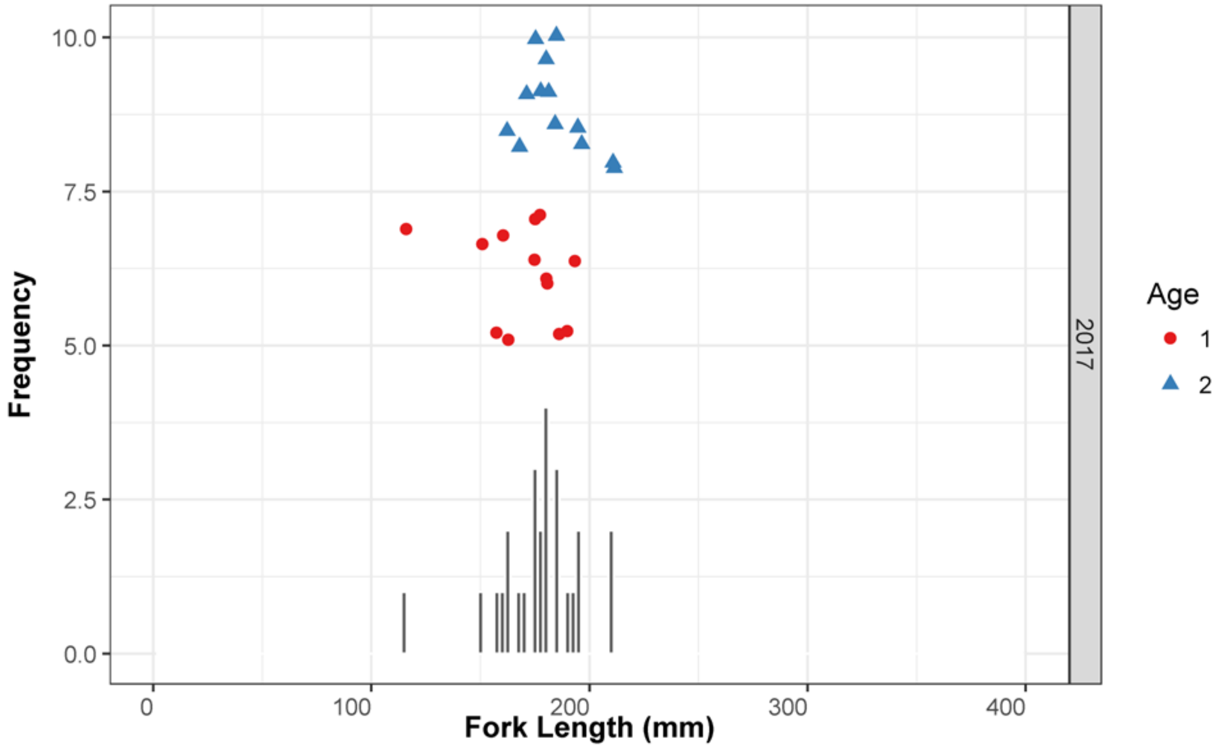


Figure 24. Length frequency distribution by age class of Kokanee, 2017, Wahleach Reservoir, BC.

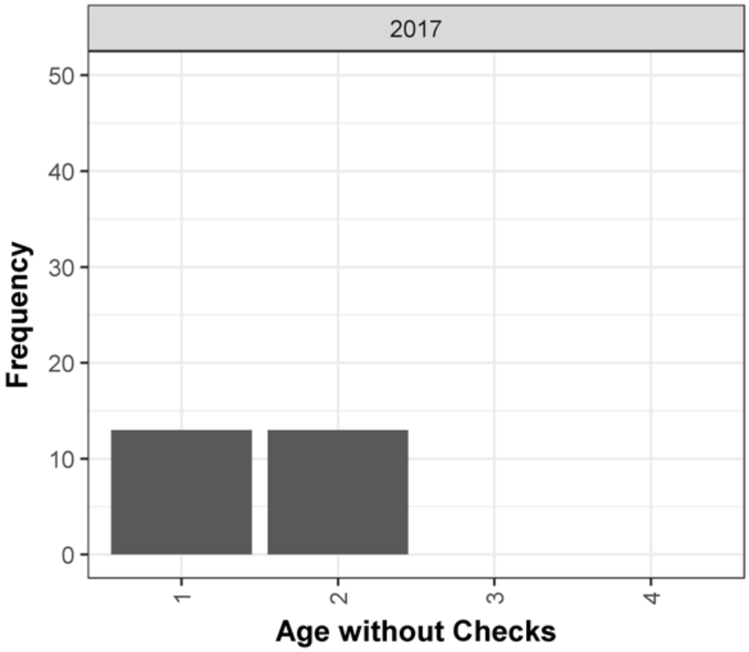


Figure 25. Age frequency for Kokanee, 2017, Wahleach Reservoir, BC.

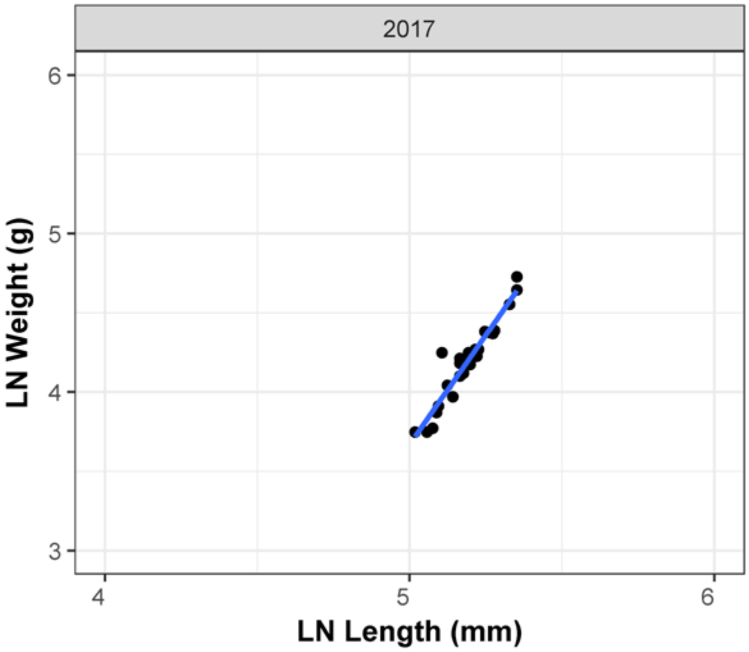


Figure 26. Natural logarithm of length weight linear regression (LN W = LN a * LN Lb) of Kokanee, 2017, Wahleach Reservoir, BC.

Table 11. Summary of variables in R for Kokanee length weight relationships (Ln W = b · Ln L + Ln a), 2017, Wahleach Reservoir, BC.

Year	Equation	R^2
2017	LN.weight.g = 3.00 * LN.length.mm -11.4	0.9523

4.6.2.1 Spawners

Timing of Kokanee spawning in 2017 was similar to previous years where Kokanee were observed in index streams by the second week of September with peak numbers occurring in late September and most of the spawning completed by early October (Figure 27). Kokanee escapement in 2017 was 7,907. Flat Creek had the most spawners (7,149), followed by Jones Creek (672), and then Boulder Creek (86); 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 193 ± 17 mm (162 to 237 mm) and ranged from age 2+ to 3+ with the majority of spawners aged at 2+ years (Table 14, Figure 28). Length frequency and associated age-at-length data show substantial overlap in the lengths between each of the age classes.

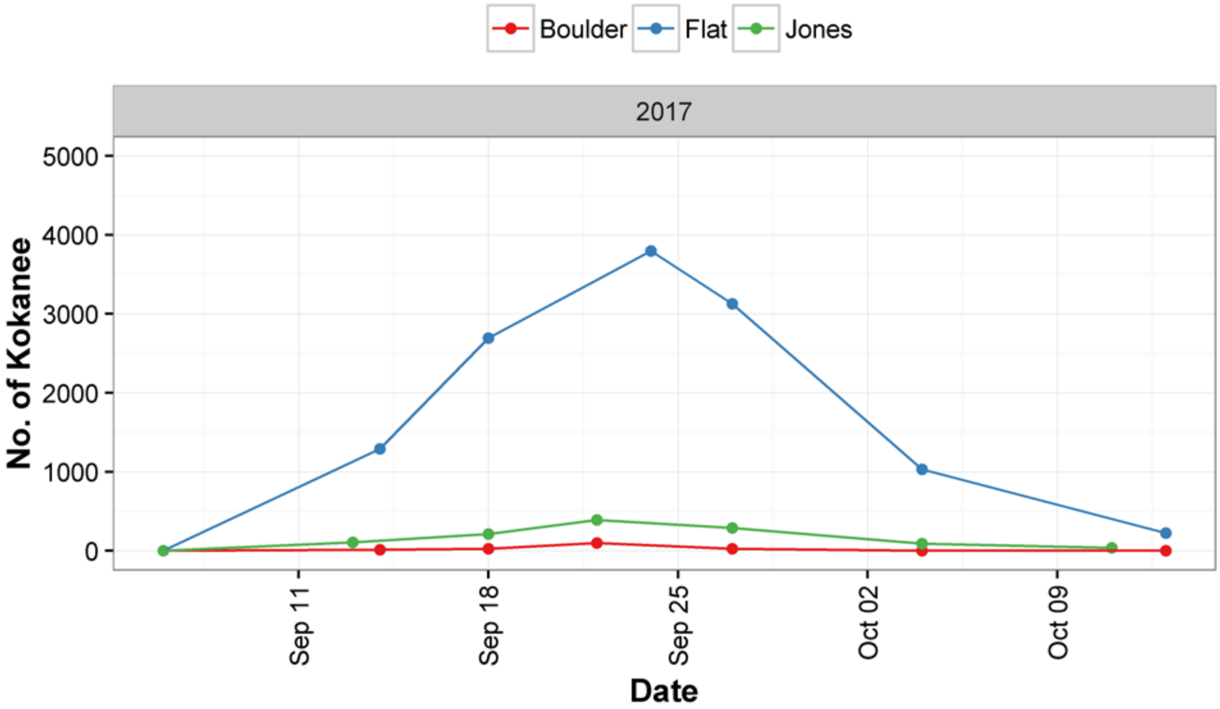


Figure 27. Kokanee spawner counts from each index stream (Boulder Creek, Flat Creek, and Jones Creek), 2017, Wahleach Reservoir, BC.

Table 12. Summary of Kokanee biometric data during spawning season, 2017, Wahleach Reservoir, BC. Data are for all three index streams combined: Boulder Creek, Flat Creek, and Jones Creek. If fork length (FL) was not measured for an individual, it was calculated based on a regression equation (y = 1.1231x + 21.005, R² = 0.8111) for years (2003-2017) when both POHL and FL were measured.

Year	**Fork Length (mm)**					**Age**				
	Mean	SD	Max	Min	n	Mean	SD	Max	Min	n
2017	192	17	237	162	41	2	0.4	3	2	33

Table 13. Summary of Kokanee fork length by age, 2017, Wahleach Reservoir, BC.

Age	**Fork Length (mm)**				
	Mean	SD	Max	Min	n
2	192	19	237	162	25
3	196	17	220	173	8

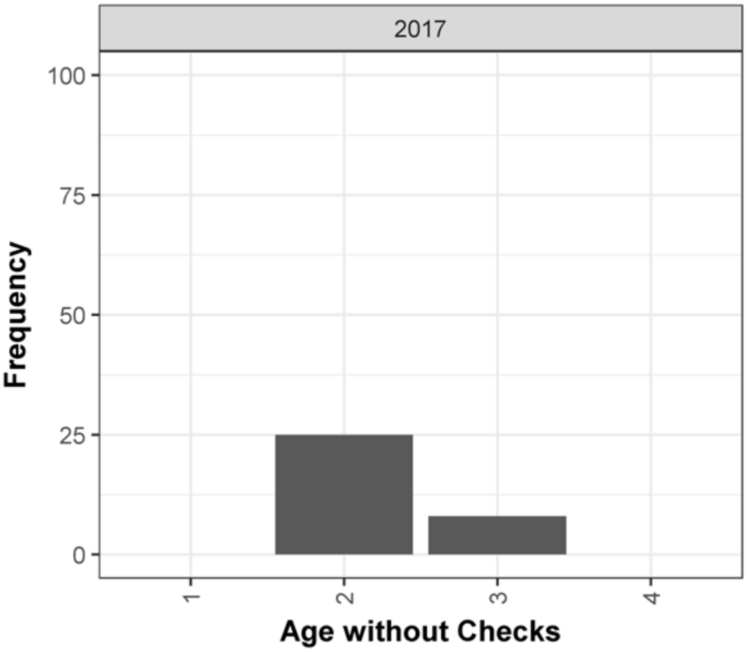


Figure 28. Age frequency of Kokanee spawners in index streams (Boulder Creek, Flat Creek and Jones Creek), 2017, Wahleach Reservoir, BC.

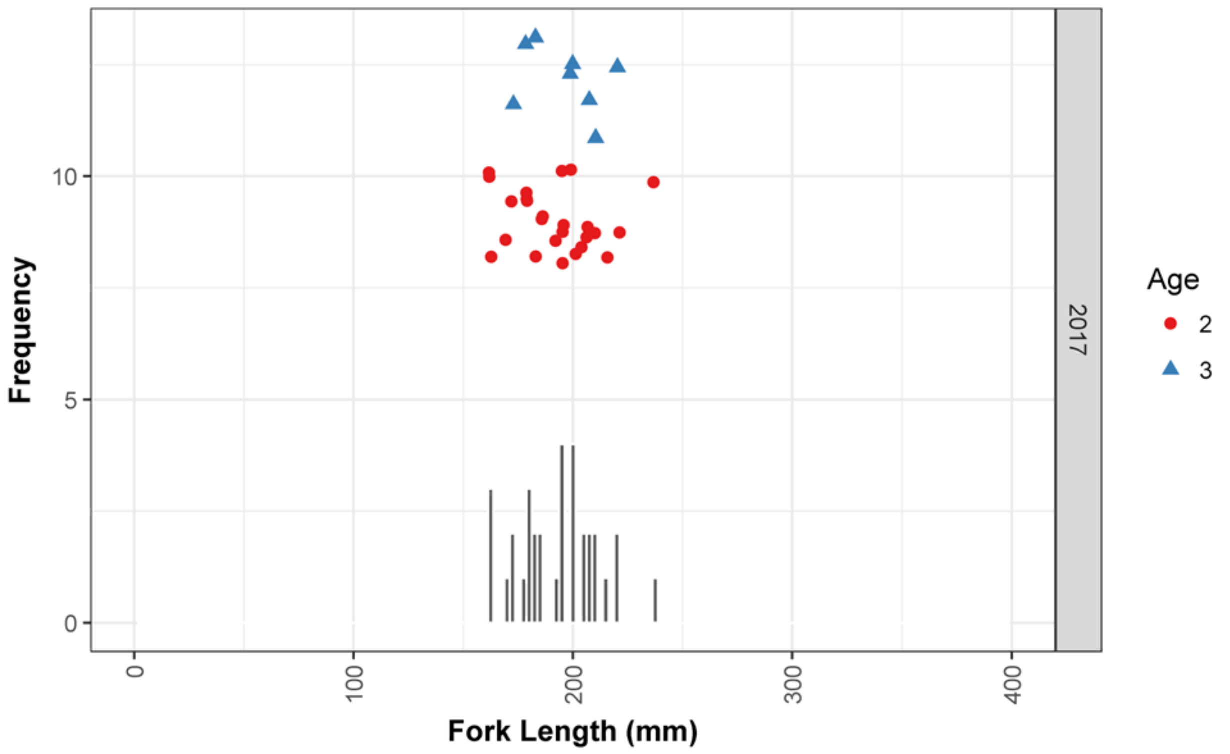


Figure 29. Length frequency distribution by age class of Kokanee spawners in index streams (Boulder Creek, Flat Creek and Jones Creek), 2017, Wahleach Reservoir, BC.

4.6.3 Rainbow Trout

In 2017, fall nearshore gillnet sampling captured a total of 75 Rainbow Trout ranging in length from 124 to 345 mm and in weight from 21.5 to 469.5 g (Table 14). Lengths of Rainbow Trout in 2017 were similar to baseline years; however, the maximum sizes of fish caught in 2017 was greater. Rainbow Trout ranged from 111 to 312 mm (200 ± 53 mm) in 1993 and 118 to 324 mm (182 ± 38 mm) in 1994 and weights of Rainbow Trout during baseline years ranged from 14 to 307 g (87 ± 61 g) in 1993 and 18 to 276 g (70 ± 46 g) in 1994. The, Age 2+ and 1+ represented the majority of the catch in 2017, and catch of older age classes (age 4+) was low (Table 15, Figure 31, Figure 30); this would account for the low mean length and weight in 2017 Rainbow Trout catches. Overall, Fulton's condition factor (K) for 2017 Rainbow Trout was 1.1 ± 0.09 indicating healthy somatic growth. Rainbow Trout length-weight regressions based on fall nearshore gillnetting data for 2017 are shown in Figure 32. Length-weight regression slopes (b value) were close to but less than 3 indicating a slimmer body shape (Figure 32, Table 16); a regression slope of 3 is common for fish (Anderson et al. 1983, Cone 1989).

Table 14. Summary of Rainbow Trout biometric data from fall nearshore gillnetting, including length, weight, condition factor (CF) and age, 2017, Wahleach Reservoir, BC.

Year	Species	n	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)	Mean K	SD K
2017	RB	75	195	43	87.7	62.6	1.1	0.09

Table 15. Summary of Rainbow Trout biometrics by age, 2017, 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	151	14	176	124	38.3	10.4	59.0	21.5	1.09	0.10	1.30	0.93	23
2	190	21	243	162	76.3	24.5	141.0	44.0	1.09	0.08	1.24	0.98	24
3	244	33	345	212	154.2	90.2	469.5	103.5	1.00	0.07	1.14	0.88	15
4	242	14	262	223	138.7	19.4	160.5	110.0	0.98	0.05	1.03	0.89	8

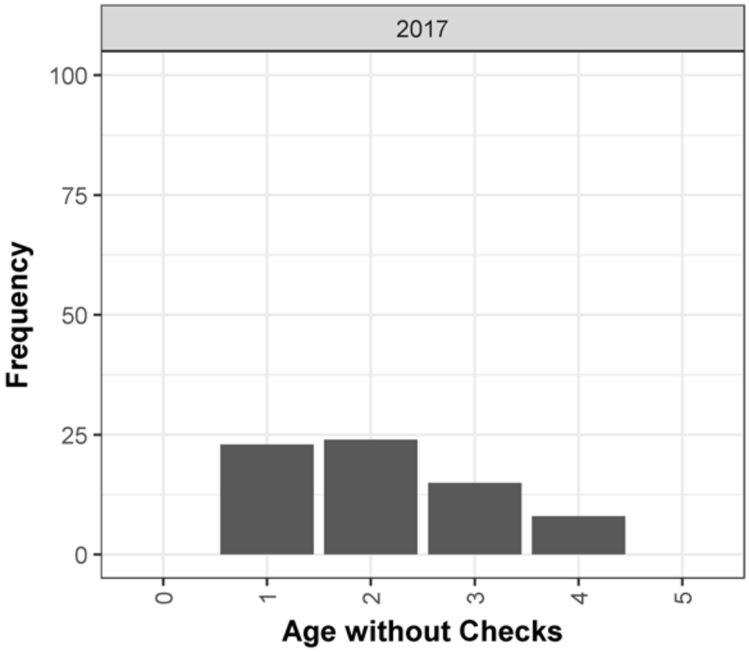


Figure 30. Age frequency of Rainbow Trout in fall nearshore gillnets, 2017, Wahleach Reservoir, BC.

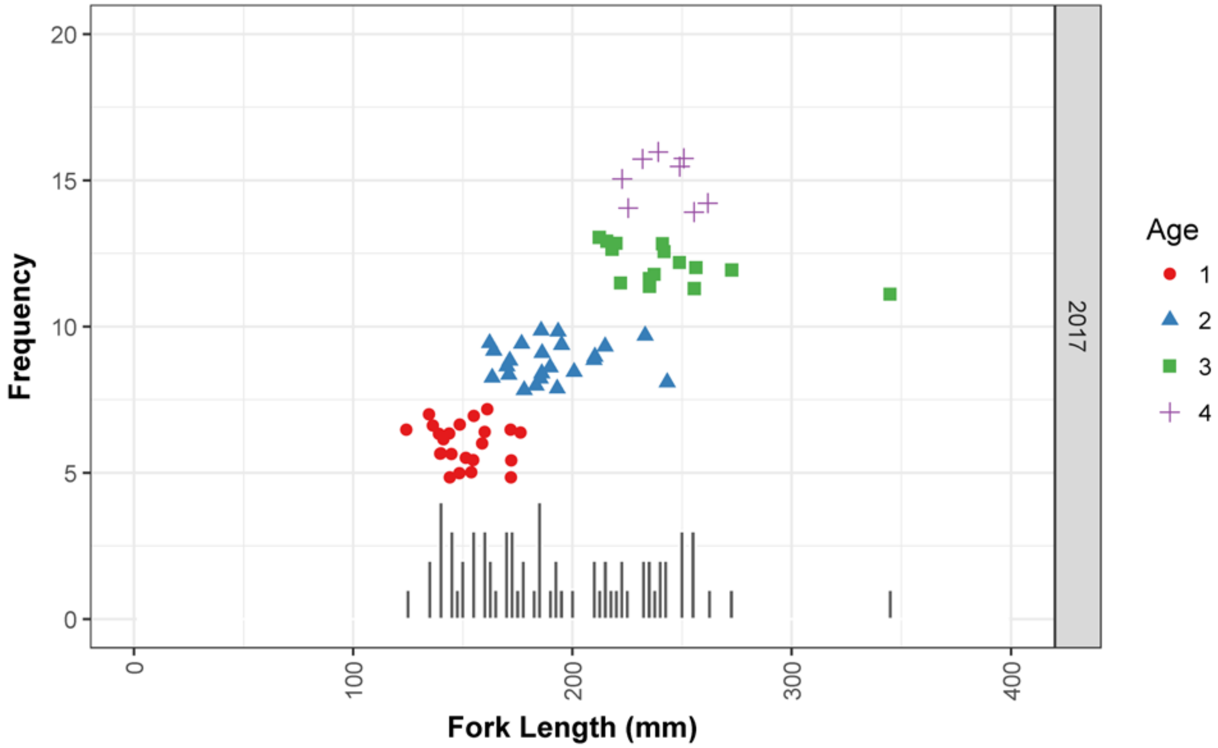


Figure 31. Length frequency by age class of Rainbow Trout in fall nearshore gillnets, 2017, Wahleach Reservoir, BC.

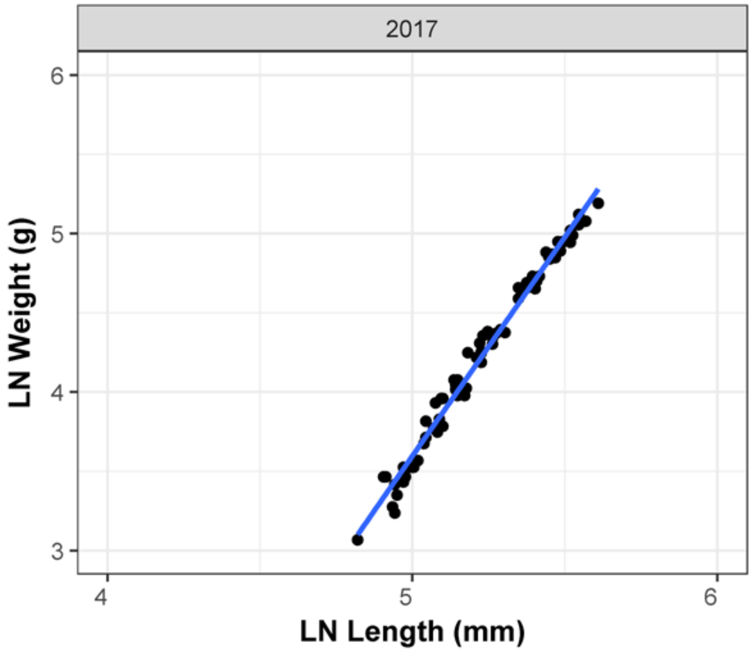


Figure 32. Length weight plot and relationship (Ln W=b . Ln L + Ln a) of Rainbow Trout, 2017, Wahleach Reservoir, BC.

Table 16. Summary of variables in R for Rainbow Trout length weight relationships (Ln W = b · Ln L + Ln a), 2017, Wahleach Reservoir, BC.

Year	Equation	R^2
2017	LN.weight.g = 2.8 *LN.length.mm -10.4	0.9851

4.6.4 Cutthroat Trout

Fall nearshore gillnet sampling in 2017 resulted in capture of 37 Cutthroat Trout ranging in length from 196 to 507 mm and in weight from 67.0 to 1400.0 g (Table 17). Fulton's condition factor (K) had a mean of 0.9 indicating healthy somatic growth. Cutthroat Trout caught during 2017 were relatively evenly distributed amongst size and age, ranging from age 1+ to 7+ with age 2+ and 3+ representing most of the catch (Table 18, Figure 33, and Figure 34). The length-weight regression slope (b value) for Cutthroat Trout in 2017 was slightly greater than 3 indicating a thicker body shape (Table 19, Figure 35, Table 18); b values near 3 are common for fish (Anderson et al. 1983, Cone 1989). Sterile Cutthroat Trout were introduced to Wahleach Reservoir as the biomanipulation part of the nutrient restoration project, thus no comparisons were made to baseline years.

Table 17. Summary of Cutthroat Trout biometric data, including length, weight, condition factor (CF) and age, 2017, Wahleach Reservoir, BC.

Year	Species	n	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)	Mean K	SD K
2017	CT	37	334	90	418.3	323.3	0.9	0.15

Table 18. Summary of Cutthroat Trout biometrics by age, 2017, 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	206	11	219	196	75.3	9.1	86.0	67.0	0.85	0.03	0.89	0.82	4
2	301	23	328	259	247.4	55.9	314.0	146.5	0.89	0.03	0.92	0.84	6
3	343	49	389	260	396.3	170.1	618.0	148.0	0.92	0.08	1.05	0.84	5
4	376	-	376	376	437.5	-	437.5	437.5	082	-	0.82	0.82	1
5	403	25	436	375	656.3	115.2	742.0	487.5	1.00	0.11	1.12	0.90	4
6	474	36	507	436	1093.5	309.8	1400.0	780.5	1.00	0.07	1.07	0.94	3
7	450	-	450	450	718	-	718.0	718.0	0.79	-	0.79	0.79	1

**Dashes (-) indicate no data.*

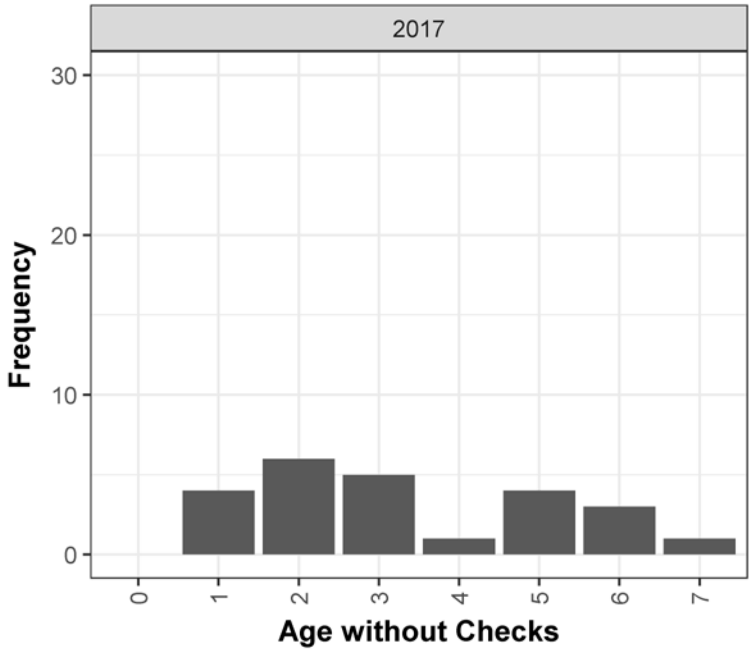


Figure 33. Age frequency of Cutthroat Trout, 2017, Wahleach Reservoir, BC.

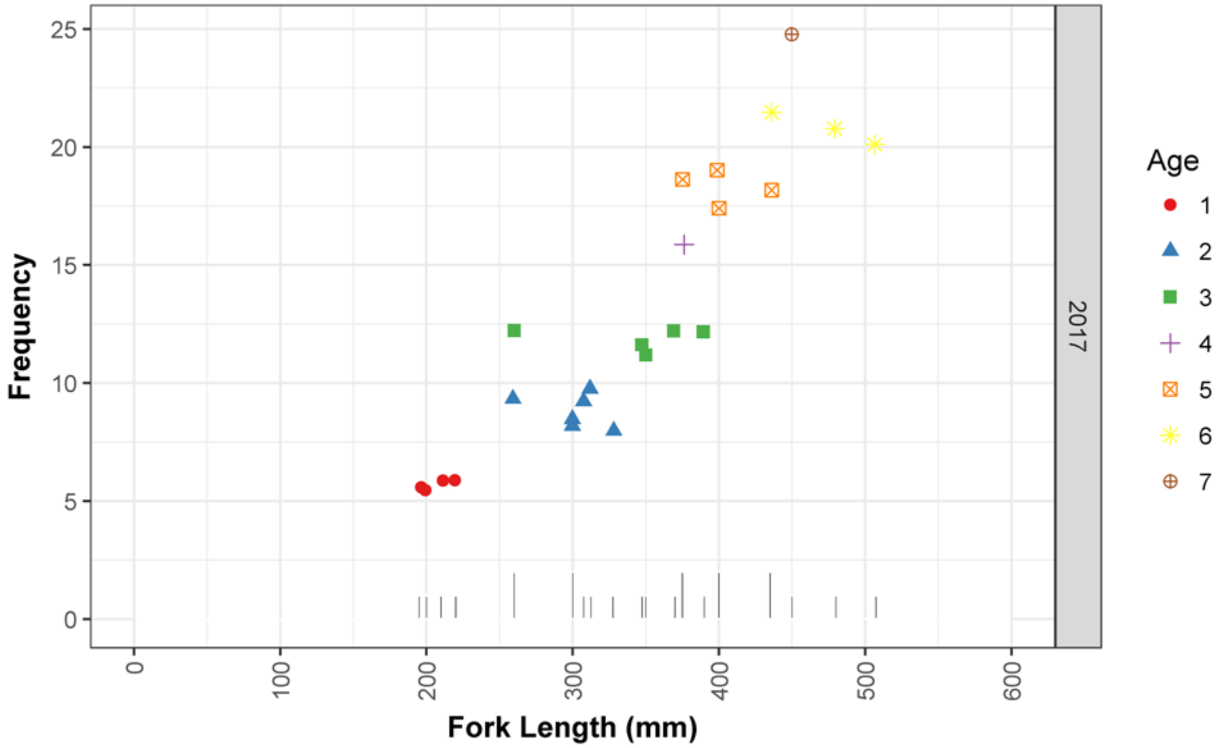


Figure 34. Length frequency of age classes of Cutthroat Trout in fall nearshore gillnets, 2017, Wahleach Reservoir, BC.

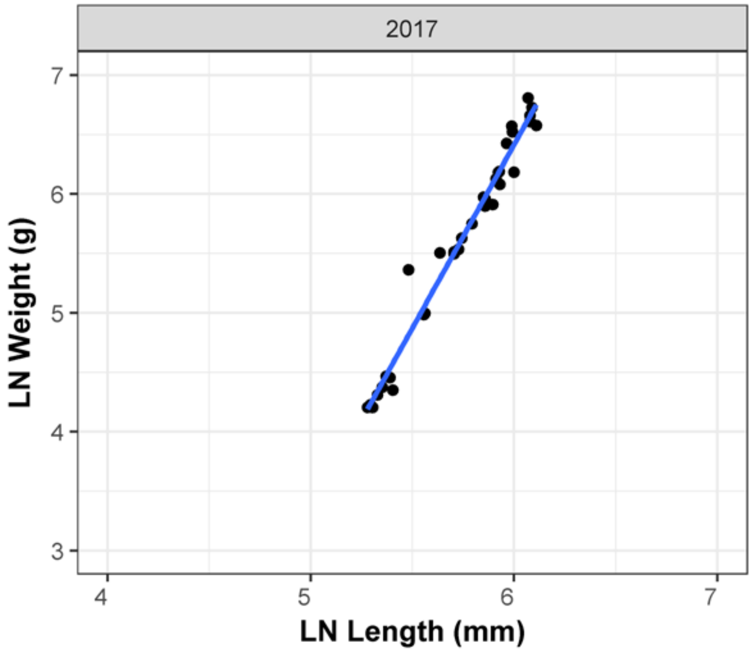


Figure 35. Length weight plot and relationship (Ln W = b · Ln L + Ln a) of Cutthroat Trout, 2017, Wahleach Reservoir, BC.

Table 19. Summary of variables in R for Cutthroat Trout length weight relationships (Ln W = b · Ln L + Ln a), 2017, Wahleach Reservoir, BC. Cutthroat Trout were not present in Wahleach Reservoir prior to nutrient restoration.

Year	**Equation**	**R^2**
2017	LN.weight.g = 3.11 *LN.length.mm -12.2	R^2=0.9762

4.6.5 Threespine Stickleback

Littoral minnow traps set in 2017 captured only a single Threespine Stickleback, 40 mm in length and weighing 0.5 g. Threespine Stickleback catch was significantly lower than in baseline years (n=65 in 1994).

4.6.6 Hydroacoustics & Trawl: Fish Distribution

Figure 37 illustrates the acoustic target size distribution by depth (2-30 m); 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). Previous years trawl data has demonstrated size differences between Threespine Stickleback and Kokanee fry where Threespine Stickleback were smaller in length than Kokanee fry and are represented within the smaller scale of acoustic targets (fry sized fish target -66 to -49 dB, Appendix D). A shallow trawl (6-8.5 m) was completed which exclusively contained *Holopedium*. When target density by size and depth layer was plotted, it showed large fish were primarily located at or below 6 m with the greatest densities occurring between 8 m and 18 m, with the peak at 12 m (Figure 38). Small fish had greatest densities at 8 m and a secondary smaller peak density down deep at 26 m (Figure 38); these two peaks were considered to represent differences in the distribution of Kokanee fry at depth and Threespine Stickleback near the surface. Acoustic density distributions by transect are detailed in Appendix C.

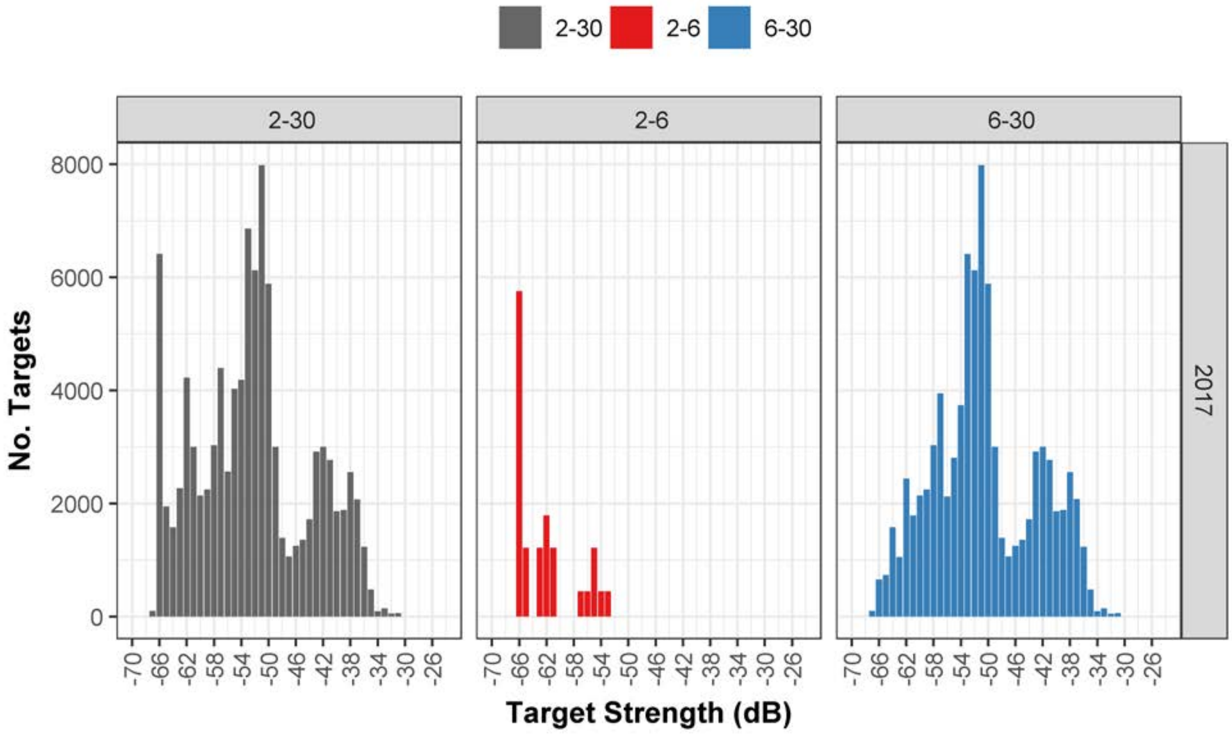


Figure 36. Target strength distributions by depth range (m) from hydroacoustic survey, 2017, Wahleach Reservoir, BC.

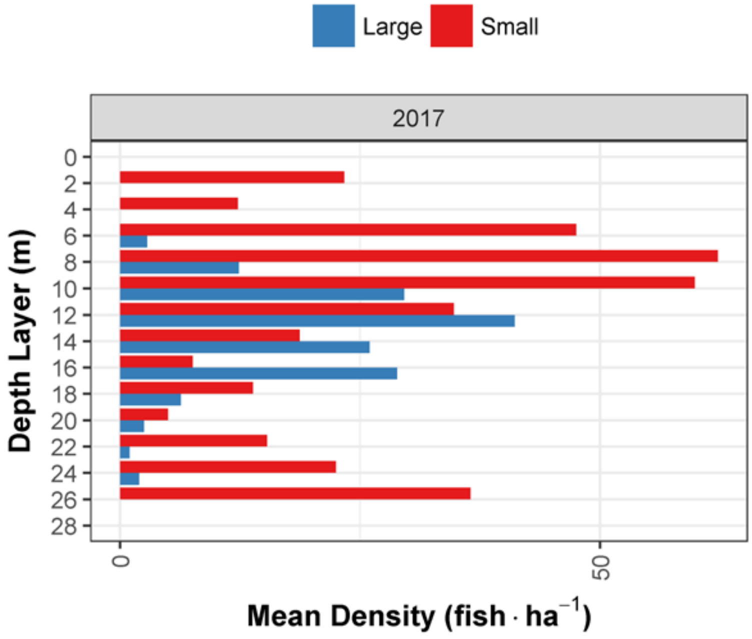


Figure 37. Distribution of fish densities by size group (small = -66 to -49 dB, large ≥ -48 dB) and depth layer based on hydroacoustic survey, 2017, Wahleach Reservoir, BC.

4.6.7 Population and Biomass Estimates

Total fish abundance by size group for all depths (2-30 m) represented a mixed species assemblage. Looking at population estimates within the Kokanee depth layer (6-30 m), Kokanee fry abundance was estimated between 48,000 and 69,000 individuals, which was lower than the previous few years and comparable to 2013 (Table 20, Sarchuk et al*.* 2016, Hebert et al. 2017). Threespine Stickleback were distributed within shallower depths, and were estimated at approximately 13,000 individuals in 2017. In 2017, the adult Kokanee (aged > 1 year) was between approximately 23,000 to 35,000 individuals, which was less than the record high of approximately 65,000 individuals in 2015 but within the average range observed since 2009 (Table 20, Sarchuk et al. 2016, Hebert et al. 2017). The total biomass of fish (all species) was estimated at 1,404 kg in 2017, which was below the long-term average (2009-2017) (Sarchuk et al. 2016, Hebert et al. 2017, 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, 2017, Wahleach Reservoir, BC.

Year	Analysis Depths (m)	Group	Population Estimate	Lower CI	Upper CI
2017	2-30	All Fish	100,282	85,899	114,625
2017	2-30	Small Fish	71,374	59,023	83,698
2017	2-30	Large Fish	28,972	23,001	34,877
2017	6-30	All KO	87,709	74,671	100,700
2017	6-30	KO Fry	58,586	47,994	69,242
2017	6-30	Adult KO	28,957	23,031	34,995

4.6.8 Recreational Fishery

The recreational fishery on Wahleach Reservoir is seasonal with highest effort during the spring months, May to June in 2017 and gradually declining by September (Figure 38). Most anglers were casual fishers seeking trout and many had no preference. The 2017 Kokanee population was lower than in previous years (see section 3.6.2 Kokanee) and most anglers caught trout – either Rainbow or Cutthroat with the majority of anglers not able to distinguish the difference. Trolling was the method of choice for anglers who fished the surface waters using a variety of lures.

The 2017 creel survey was conducted from May-September and the effort pattern was more typical of most small lake fishing in the lower mainland area. That is, effort was highest during the spring months declining as the summer advanced with a slight increase in September (Figure 53). Total estimated effort for the 5 months surveyed was 3775 rod hours based on 1237 angler days and 3.1 rod hours per day. An estimated total of 3611 fish were caught, with about 124 being Kokanee and 3356 Trout (Rainbow and Cutthroat Trout). The division between the trout species catch is somewhat arbitrary as most anglers could not distinguish between the two. In 2017, trout (Rainbow and Cutthroat) dominated the catch with Kokanee as only a small contributor (Figure 39). Catch-per-unit-effort (CPUE) was highest in the spring and has increased since the 2009 survey (Figure 40, data on file). The issue for the fishery is that trout are typically too small for anglers to want keep; however, in 2017 more and more people prefer to catch and release fish. The release rate for 2017 was exceedingly high at 91%.

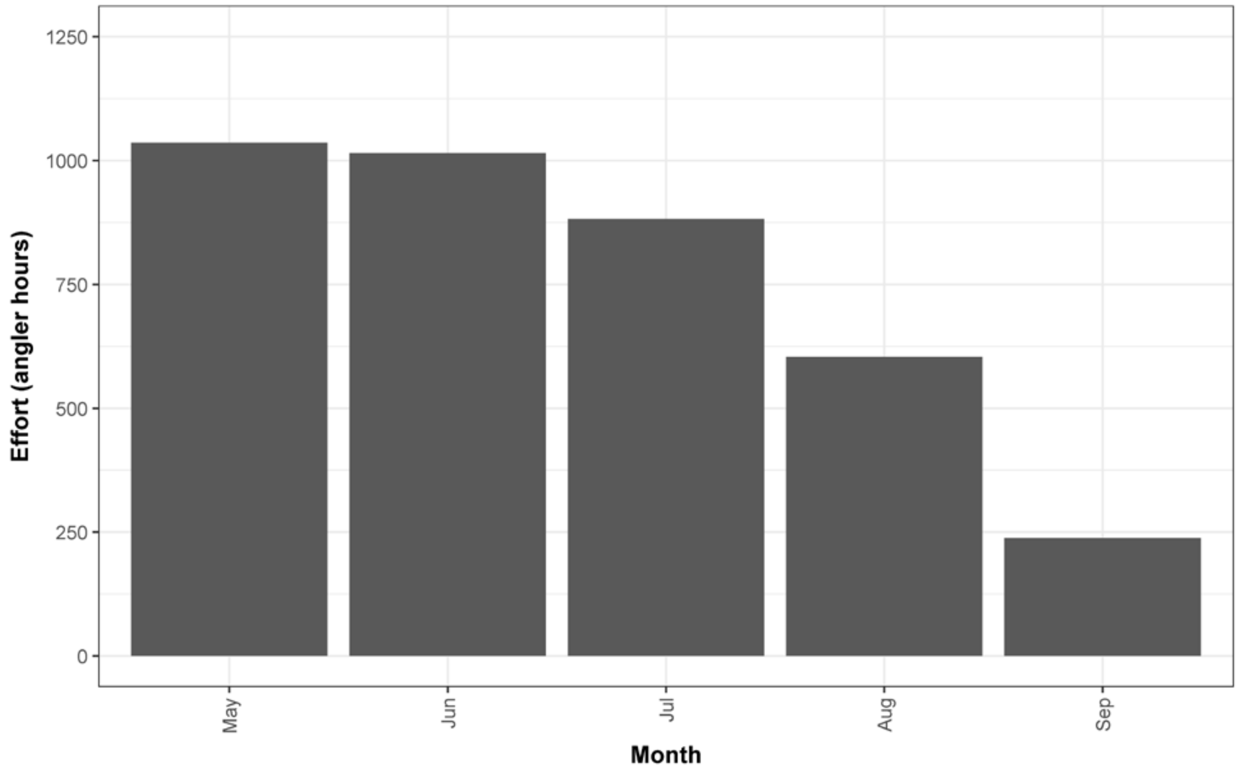


Figure 38. Total monthly angler effort, 2017, Wahleach Reservoir, BC.

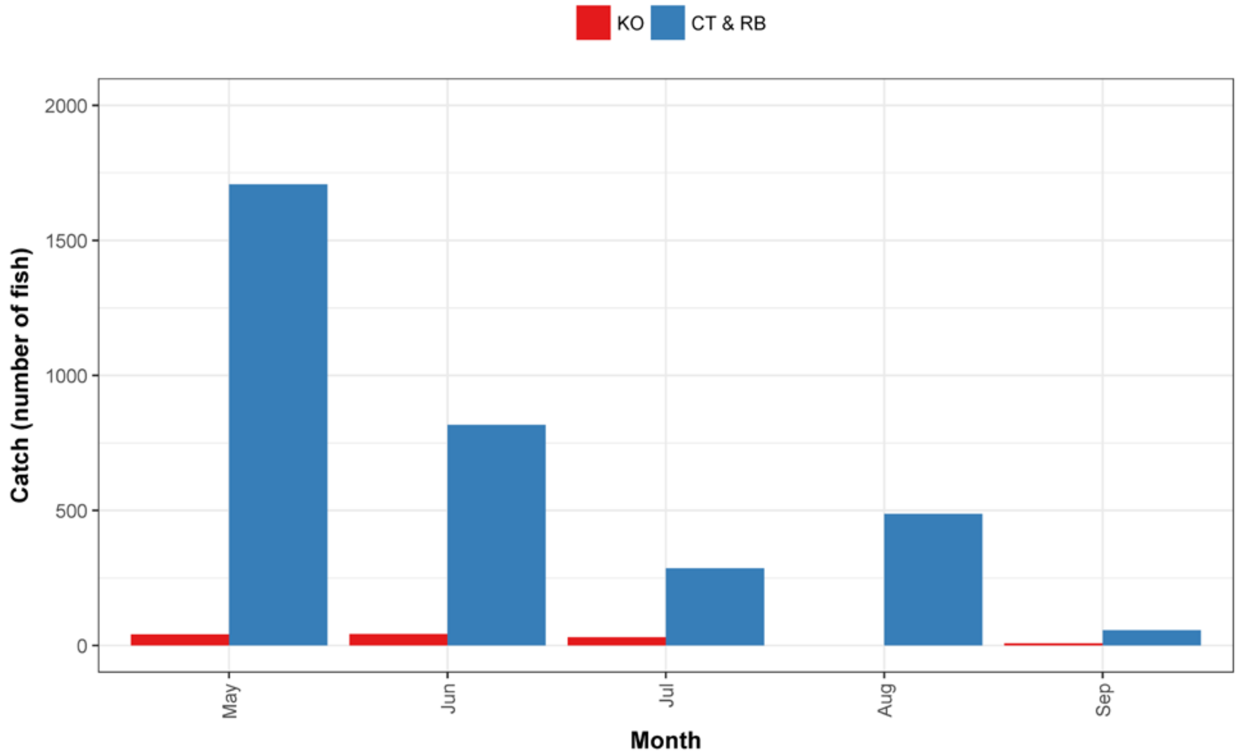


Figure 39. Monthly catch estimates of Kokanee and trout (Rainbow and Cutthroat), 2017, Wahleach Reservoir, BC.

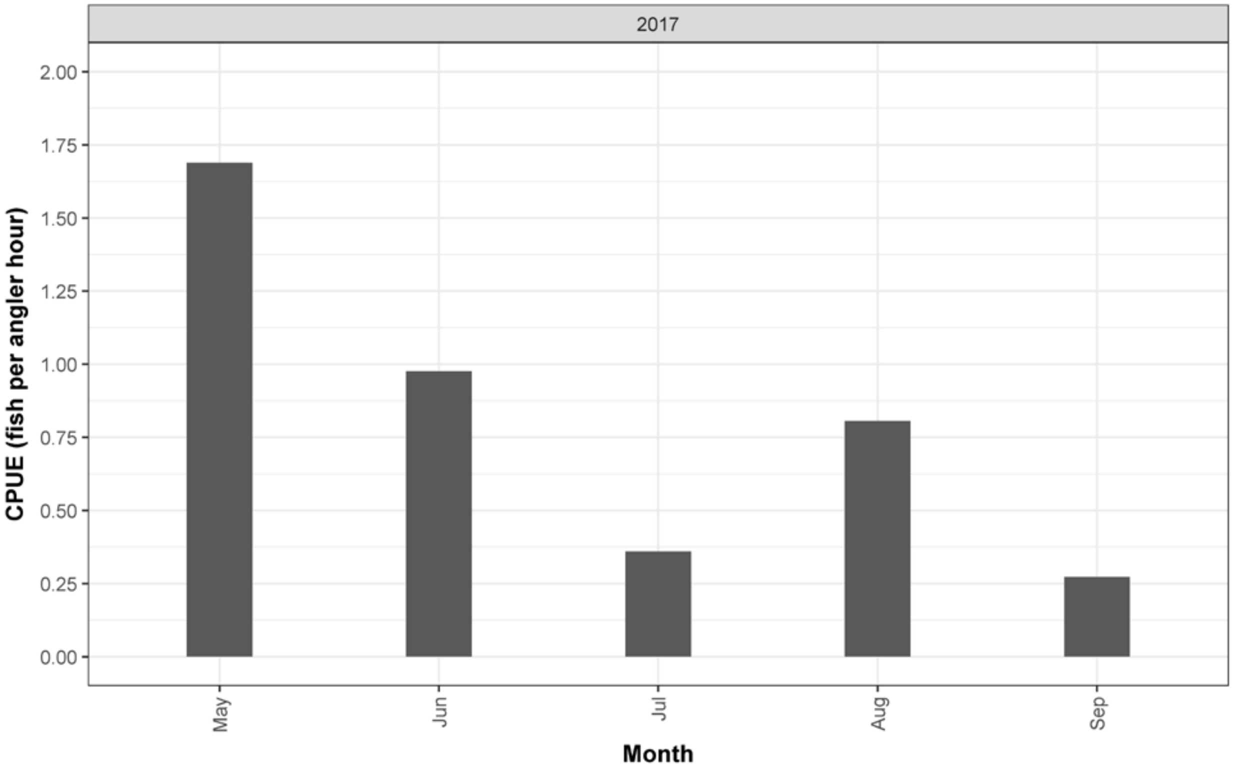


Figure 40. Monthly catch-per-unit-effort (CPUE) for all three sport fish species (Kokanee, Rainbow Trout, Cutthroat Trout), 2017, Wahleach Reservoir, BC.

5. Discussion

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

Trophic State & Nutrient Dynamics

There is compelling evidence in the scientific literature supporting 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. 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; and 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). The benefit is that primary productivity measurements allow for a direct assessment of a system, 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 for Wahleach Reservoir, other parameters were used to assess its trophic state and response to nutrient restoration, including total phosphorus, total nitrogen and secchi depth. In Wahleach Reservoir, 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). In 2017, Wahleach Reservoir was characterized by ultra-oligotrophic conditions in terms of nutrient concentrations and exhibited secchi 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, 2017, Wahleach Reservoir, BC. Blue shading is indicative of Trophic Classifications for 2017.

Parameter (Units)	**Mean ± SD (Range)**	**Trophic Classification, Mean (Range)**			
	2017	Ultra-Oligotrophic	Oligotrophic	Mesotrophic	Eutrophic
TP (µg·L^{-1})	4.1 ± 3.6 (1.0 to 15.9)	(< 1-5)	8 (3-18)	27 (11-96)	84 (16-386)
TN (µg·L^{-1})	156 ± 37 (119 to 259)	(< 1-250)	661 (307-1,630)	753 (361-1,387)	1,875 (396-6,100)
Secchi (m)	4.8 ± 1.3 (2.6 to 7.2)	-	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 deviation from the planned load was due to logistics rather than 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. Comparing 2017 with baseline conditions, TP and TN have increased and secchi depth has decreased (data on file); however, not pushing the reservoir too hard from the baseline conditions.

Phytoplankton Edibility & Zooplankton Community

Monitoring the response of phytoplankton and zooplankton communities 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. Nutrient additions are 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 as such would leave minimal evidence of enhancement at the phytoplankton trophic level. Most importantly, one must keep the dynamic nature of these two trophic levels in mind when interpreting monitoring results.

The phytoplankton community in 2017 primarily consisted of edible species throughout the season, excluding August when a larger bloom of inedible *Microcystis* sp. was observed. Edible species of flagellates (Chryso- & Cryptophyceae) were consistently high throughout the growing season. Abundance was lower in 2017 compared to previous years (data on file) and was largely driven by the growth of *Merismopedia* sp. and *Microcystis* sp., small blue-green algae belonging to the class *Cyanophyceae*. *Dinobryon* sp., *Ochromonas* sp. and small microflagellates (class *Chryso-* &

Cryptophyceae) also contributed to abundance. As with abundance, biovolume was driven predominantly by *Microcystis* sp. growth. A few key species of flagellates, chlorophytes and to a lesser extent, dinoflagellates contributed to the edible fraction of the phytoplankton 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*. In 2017, *Daphnia* densities averaged 3 individuals·L^{-1} and biomass averaged over 65 µg·L^{-1}. This accounted for 47% of overall zooplankton density and 69% of total zooplankton biomass. Overall, *Daphnia* metrics in 2017 were at average levels when compared to the most recent review period (Sarchuk et al. 2016). Moreover, abundance and biomass of other cladocerans was strong early in the 2017 season prior to the onset of *Daphnia* growth. Zooplankton densities and biomass in 2017 represent the fourth greatest zooplankton biomass on record. These results clearly indicate that the nutrient restoration program has increased 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.

Holopedium gibberum was exclusively caught in a shallow water trawl and were also present in very low densities and biomass in the zooplankton hauls in July and August. Historically in Wahleach Reservoir, *H. gibberum* was found in low densities and started to become more prominent in 2000 (data on file). Jeziorski et al. (2014) suggests that low calcium (Ca) concentrations below 1.5-2 mg·L^{-1} impacts *Daphnia* survival, growth, development, and reproduction. Low calcium concentrations may afford a competitive advantage to *Holopedium* who have low calcium requirements. (Ashforth and Yan 2008; Riessen et al. 2012; Jeziorski et al. 2015). Water quality samples collected in September show calcium concentrations in Wahleach average about 4 mg·L^{-1} of Ca for the past three years (data on file). Since metals are not currently taken in July, calcium concentrations are unknown during that time. However, calcium appears to be sufficient for Daphnia growth and our monitoring results clearly show *Daphnia* are present; calcium is not likely controlling *Daphnia* growth in Wahleach Reservoir.

Fish Population Response

Due to its smaller size, mixed species composition and large littoral habitat area, reliably determining fish abundance and biomass using acoustic-trawl methods on Wahleach Reservoir has been challenging. Methods in 2017 were consistent with years covered in the recent review report (Sarchuk et al. 2016). Unfortunately, due to the small area of available habitat to trawl, the trawl surveys in 2017 were not successful at obtaining a sample size greater than 30 individuals to assist with refinement of acoustic data. Assessment of the value of trawl sampling on this system over the long term will be reviewed upon completion of the WUP. Acoustic-trawl surveys were important for fish biomass estimation; the methods used in this report were a novel approach (see Sarchuk et al. 2016 for detailed methods) and will continue to be refined to produce biomass density estimates, the metric most useful for comparisons of Kokanee populations across systems. Despite some of the difficulties with the acoustic-trawl surveys and the population and biomass analyses, the information gained from these metrics has resulted in important insights into Wahleach Reservoir's fish populations.

It is clear that stimulation of lower trophic levels has translated into increased fish abundance and biomass since the program's inception, and that these increases were not due to increases in undesirable fish species (i.e. Threespine Stickleback). In 2017, a single Threespine Stickleback was captured in minnow traps, which was significantly lower than baseline years. The acoustic population for small fish (which is mostly Threespine Stickleback) in the 2-6 m depth strata was just under 13,000 individuals, which was below the average since 2009 (mean 59,765, data on file) and overall was lower than original population estimates of 1.2 million individuals during baseline years of the project (Perrin et al. 2006).

Assessments of Wahleach Reservoir's fish populations indicate a significant increase in Kokanee abundance and biomass, which were below detection limits and considered extirpated in 1995 when no Kokanee were caught during gillnetting and spawner surveys observed zero Kokanee in the tributaries (Boulder Creek, Flat Creek, and Jones Creek). The adult Kokanee population in 2017 was estimated at approximately 29,000 individuals; and although this was less than the record high estimates observed in 2015 (Sarchuk et al. 2016), it was on par with average population levels since 2009 and was evidence of the successful re-establishment of the Kokanee population following onset of the Wahleach Reservoir Nutrient Restoration Program. Furthermore, fluctuations in the reservoir's Kokanee abundance over time are not surprising, as Kokanee populations are most often regulated by density-dependent processes that result in compensatory changes in growth, survival and reproduction (Rieman and Myers 1992, Askey and Johnston 2013). It is likely that the Kokanee population in Wahleach Reservoir is also regulated by density-dependent processes, similar to those observed in many large lake/reservoirs throughout BC (Andrusak 2016, Schindler et al. 2013, 2014).

In addition, fall nearshore gillnetting and the spawner assessment in 2017 provide evidence of a healthy, self-sustaining Kokanee population in Wahleach Reservoir. Data from 2017 continued to show Kokanee were in better condition than in baseline years. Kokanee caught in 2017 were longer and heavier compared to recent years due to a higher frequency of age 2+ individuals. Kokanee spawner escapement in 2017 was estimated at 7,907 individuals, demonstrating the presence of a restored Kokanee population on Wahleach Reservoir. Kokanee spawners escapement have been stable for the past several years, 2014-2017 (data on file).

Recreational Fishery

Wahleach Reservoir currently supports only a modest recreational sport fishery as evidenced by the relatively low angler effort; however, this increased slightly during the 2017 survey (data on file). On the other hand, total catches have been quite high with an increasing CPUE in 2017 (data on file); however, some of the fishers interviewed were experienced fishers which may bias the CPUE slightly.

Anglers reported their catches were either too small to keep or they were practicing catch and release. Regulations introduced earlier in the project (i.e. retention of 2 trout, none over 40 cm) were meant to protect stocked Cutthroat Trout and allow them to reach a size where they would exhibit piscivory on Threespine Stickleback. Today, the fishing regulations allow the retention of 4 trout of any size with only 1 allowed over 40 cm. This change allows anglers to keep Rainbow Trout while protecting larger piscivorous Cutthroat Trout that prey on Threespine Stickleback. From the fish sampled during the creel survey the average length of Cutthroat Trout was 36.5 cm (n=31) whereas Rainbow Trout average length was 24.3 mm (n=117); thus showing that the Cutthroat Trout were larger as expected for a piscivorous species.

Increased size and catch rates for Kokanee are important factors in attracting anglers to recreational fisheries (Askey and Johnston 2013). Wahleach Kokanee have varied in size from year to year, displaying an osculating increase and decrease in length since the Nutrient Restoration Program commenced. From the 2017 creel survey very few Kokanee were caught and/or retained which is a decrease from previous creel survey years (data on file). Kokanee escapements in recent years have been between 7,000 - 8,000 yet sport catch from the 2017 survey is low.

In some years there has been high potential for greater catches of Kokanee that exceed 22 cm, the known minimal threshold size for satisfying angler interest (Askey and Johnston 2013). Anglers need to be informed of appropriate angling techniques to take advantage of these fish. As the reservoir stratifies, Kokanee move from surface waters deeper in the water column; therefore, during the day they are usually found below the thermocline. Instead of surface trolling, anglers need to change their techniques by switching their gear to fish in deeper water and troll near the thermocline, which in most years develops by mid-June at about 5 m in depth. Kokanee are also very susceptible to certain trolling gear such as small pink or red lures called "wedding rings", small apex lures or glow hooks.

6. Conclusion

It is evident that nutrient addition on Wahleach Reservoir has had a positive effect on the lower trophic levels and has ultimately supported the reservoir's self-sustaining Kokanee population, as demonstrated from program monitoring data. 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 clearly 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 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 if the monitoring program indicates top down pressure on the Threespine Stickleback population is needed.

- Kokanee and Rainbow Trout stocking is not necessary

Monitoring Programs

Limnology

- Continue monthly limnology sampling to adaptively manage the nutrient restoration program approach. Recommend to sample for total metals in May or June to look at calcium concentrations if *Holopedium* is present in high densities in the hydroacoustic trawl in July.

- Depending on in-season sampling results, an additional limnology sampling trip may be warranted 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.

- 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.
- 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 in the next 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 completed at least once over each five year cycle to understand how anglers are responding to restoration actions.
- It is recommended that outreach materials be developed to inform anglers of the opportunity to fish for Kokanee, including an explanation of Kokanee biology, where they reside within the reservoir, and how to catch them. This information could be included 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 to include how to catch Kokanee on their website.

8. References

Anderson, R.O., and S.J. Gutreuter, 1983. Length weight and associated structural indices. In: Nielsen, L.A., Johnson, D.L. (Eds.), Fisheries Techniques, American Fisheries Society, Bethesda, Maryland, pp. 283-300.

Andrusak, G.F. 2016. Alouette Kokanee Age Structure Analysis (ALUMON #6)-2016. Ministry of Environment and BC Hydro, Vancouver, B.C.

Ashforth, D., and ND Yan. 2008. The interactive effects of calcium concentration and temperature on the survival and reproduction of *Daphnia pulex* at high and low food concentrations. Limnol. Oceanogr. 53, 420–432.

Ashley, K., L.C. Thompson, D.C. Lasenby, L. McEachern, K.E. Smokorowski, and D. Sebastian. 1997. Restoration of an interior lake ecosystem: the Kootenay Lake fertilization experiment. Water Qual. Res. J. Canada. 32: 295-323.

Askey, P.J., and N.T. Johnston. 2013. Self-regulation of the Okanagan Lake kokanee recreational fishery: dynamic angler effort response to varying fish abundance and productivity. North Am. J. Fish. Manag. 33(5): 926–93.

Balk, and Lindem. 2011. Sonar4 and Sonar5-Pro post processing systems, Operator manual version 6.0.1, 464p. Lindem Data Acquisition Humleveien 4b. 0870 Oslo Norway.

BC Hydro. 2004. Wahleach Project Water Use Plan. Prepared for the Comptroller of Water Rights. 10 p + appendices.

BC Hydro. 2005. Wahleach Water Use Plan, Physical Works Terms of Reference, WAHWORKS #2-Wahleach Reservoir Fertilization Program. 9 p.

BC Hydro. 2006. Wahleach Water Use Plan, Physical Works Terms of Reference, WAHWORKS #2-Wahleach Reservoir Fertilization Program Rev 1. 7 p.

BC Hydro. 2008. Wahleach Water Use Plan, Physical Works Terms of Reference, Addendum 1 to WAHWORKS#2 Wahleach Reservoir Fertilization Program. 4 p.

BC Hydro. 2010. Wahleach Water Use Plan, Physical Works Terms of Reference, Addendum 2 to WAHWORKS#2 Wahleach Reservoir Fertilization Program. 2 p.

BC Hydro. 2015. Wahleach Water Use Plan, Physical Works Terms of Reference, Addendum 3 to WAHWORKS#2 Wahleach Reservoir Fertilization Program. 3 p.

CCME. 1999. Canadian Environmental Quality Guidelines. Guidelines are for the protection of freshwater aquatic life, 1999 plus updates. Canadian Council of Environment Ministers, Winnipeg.

Cone, R.S. 1989. The need to reconsider the use of condition indices in fishery science. Trans. Am. Fish. Soc. 118 (5). 510-514.

Ford, B.S., P.S. Higgins, A.F. Lewis, K.L. Cooper, T.A. Watson, C.M. Gee, G.L. Ennis, and R.L. Sweeting. 1995. Literature reviews of the life history, habitat requirements and mitigation/compensation strategies for selected fish species in the Peace, Liard and Columbia River drainages of British Columbia. Report prepared for the Dep. of Fish. and Oceans and B.C. Ministry of Environment, Lands and Parks, Victoria, B.C. 23 pp.

Guildford, S.J., and R.E. Hecky. 2000. Total nitrogen, total phosphorus, and nutrient limitation in lakes and oceans: Is there a common relationship? Limnol. Oceanogr. 45(6): 1213-1223.

Gjernes, T. 1979. A portable midwater trawling system for use in remote lakes. Fish. Mar. Serv. Tech. Rep. 888: 13 p.

Harris, S.L. 2015. Primary productivity in Kinbasket and Revelstoke Reservoirs. 2013. Biodiversity Branch, Ministry of Environment, Province of British Columbia. In Bray, K.E. 2016. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 6 (2013). BC Hydro, Environment. Study No. CLBMON-3 and CLBMON-56.

Hebert A.S., S.L. Harris, T. Weir, M.B. Davies, and A. Schellenberg. 2015. Wahleach Reservoir Nutrient Restoration Project. 2013-2014. RD 153. Ecosystems Protection & Sustainability Branch, Ministry of Environment, Province of British Columbia.

Hebert, A.S., G.F. Andrusak, S.L. Harris, H. Andrusak, and T. Weir. 2016. Alouette Reservoir Nutrient Restoration Project, 2014-2015. RD 154. Ecosystems Protection & Sustainability Branch, Ministry of Environment, Province of British Columbia.

Hebert, A.S., J.A. Sarchuk, S.L. Harris, and T. Weir. 2017. Wahleach Reservoir Nutrient Restoration Project, 2016. RD 157. Ecosystems Protection & Sustainability Branch, Ministry of Environment, Province of British Columbia.

Hyatt, K.D., and J.G. Stockner. 1985. Responses of sockeye salmon (*Oncorhynchus nerka)* to fertilization of British Columbia coastal lakes. Canadian Journal of Fisheries and Aquatic Sciences 42: 320-331.

Ney, J.J. 1996. Oligotrophication and its discontents: effects of reduced nutrient loading on reservoir fishes. P. 285-295 in L.E. Mirandah and D.R. DeVries Eds. American Fisheries Symposium 16. Bethesda, Maryland.

Jeziorski, A., A.J. Tanentzap, N.D. Yan, A.M. Paterson, M.E. Palmer, J. B. Korosi, J.A. Rusak, M.T. Arts, W. Keller, R. Ingram, A. Cairns, and J.P. Smol. 2015. The jellification of north temperate lakes. Proc. R. Soc.B 282: 20142449.

Perrin, C.J., and T.B. Stables. 2000. Restoration of fish populations in Wahleach Reservoir, 1997 – 1999. Report prepared by Limnotek Research and Development Inc. for B.C. Hydro. 175p.

Perrin, C.J., and T.B. Stables. 2001. Restoration of fish populations in Wahleach Reservoir: Fish and zooplankton in 2000. Report prepared by Limnotek Research and Development Inc. for B.C. Ministry of Water Land and Air Protection. 67p.

Perrin, C.J., M.L. Rosenau, T.B. Stables, and K.I. Ashley. 2006. Restoration of a montane reservoir fishery via biomanipulation and nutrient addition. N. Amer. J. of Fish. Management. 26: 391-407

R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Riessen, H.P., R.D. Linley, I. Altshuler, M. Rabus, T. Sollradl, H. Clausen-Schaumann, C. Laforsch, N.D. Yan. 2012 Changes in water chemistry can disable plankton prey defenses. Proc. Natl Acad. Sci. USA 109, 15 377–15 382.

Sarchuk, J.A., A.S. Hebert, H. Andrusak, S.L. Harris, T. Weir, and D. Sebastian. 2016. Wahleach Reservoir Nutrient Restoration Project, Review Report, 2009-2015. RD 155. Ecosystems Protection & Sustainability Branch, Ministry of Environment, Province of British Columbia.

Schallenberg, M. 1993. Effects of impoundment on the oxygen and nutrient dynamics of sub-arctic reservoirs. James Bay Publication Series. North Wind Information Services Inc.

Schindler, D.W., F.A.J. Armstrong, S.K. Holmgren, and G.J. Brunskill. 1971. Eutrophication of Lake 227, Experimental Lakes Area, northwestern Ontario, by the addition of phosphate and nitrate. J.Fish. Res. Bd. Can. 28: 1763-1782.

Schindler, E.U., D. Sebastian, T. Weir, H. Andrusak, G.F. Andrusak, M. Bassett, L. Vidmanic, and K.I. Ashley. 2013. Kootenay Lake Nutrient Restoration Program, Years 18 and 19 (North Arm) and Years 6 and 7 (South Arm) (2009 and 2010). Fisheries Project Report No. RD 136, Ministry of Forests, Lands and Natural Resource Operations, Nelson, BC.

Schindler, E.U., T. Weir, M. Bassett, L. Vidmanic, K.I. Ashley, and D. Johner. 2014. Kootenay Lake Nutrient Restoration Program, Years 18 and 19 (north Arm) and Years 6 and 7 (south Arm) (2009 and 2010). Fisheries Project Report, Ministry of Forests, Lands and Natural Resource Operations.

Scott, W.B., and E.J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Bd. Can. Bulletin 184.

Sebastian, D., and T. Weir. 2016. Kinbasket and Revelstoke Reservoirs kokanee population monitoring – year 8 (2015). Prepared for BC Hydro under the Columbia River Water Use Plan, Water License Requirements Study No. CLBMON-2. 61p.

Stockner, J.G. 1981. Whole-lake fertilization for the enhancement of sockeye salmon (*Oncorhynchus nerka*) in British Columbia, Canada. Verh. Int. Verein. Limnol. 21:293-299.

Stockner, J.G., and K.S. Shortreed. 1985. Whole-lake fertilization experiments in coastal British Columbia lakes: empirical relationships between nutrient inputs and phytoplankton biomass and production. Canadian Journal of Fisheries and Aquatic Sciences Vol. 42, No. 4, p 649-658, April, 1985.

Thompson, L.C. 1999. Abundance and production of zooplankton and kokanee salmon (*Oncorhynchus nerka*) in Kootenay Lake, British Columbia during artificial fertilization. Ph. D Thesis. Vancouver: University of British Columbia, Department of Zoology. 252p.

Vollenweider, R.A. 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Organ. Econ. Coop. Dev. Tech. Rep. DAS/CS1/68.27

Vollenweider, R.A. 1976. Advances in defining critical loading levels for phosphorus in lake eutrophication. Mem. Ist. Ital. Idrobiol. 33: 53-83.

Wetzel, R.G. 1983. Limnology: lake and river ecosystems, 2nd edition. Saunders College Publishing. Philadelphia, PA.

Wetzel, R.G. 2001. Limnology: lake and river ecosystems, 3rd edition. Academic Press. San Diego, California.

9. Appendices

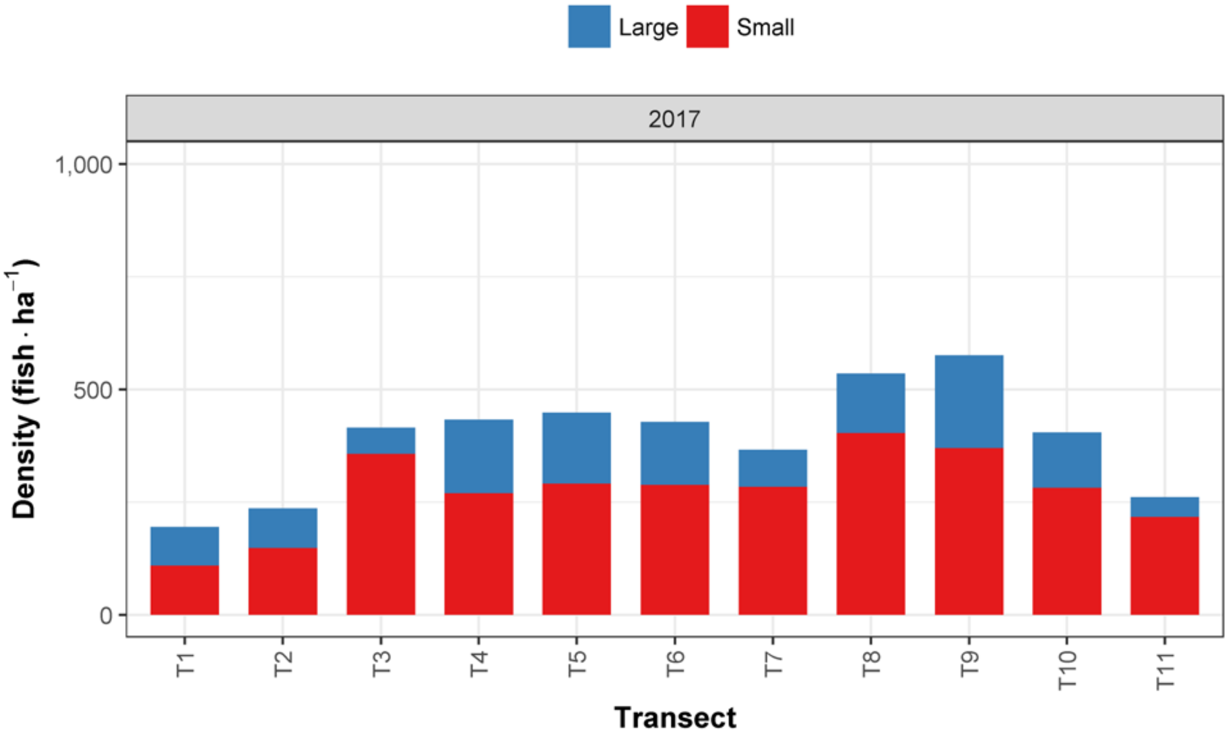
Appendix A. Phytoplankton species detected during 2017, Wahleach Reservoir, BC.

Species	**2017**	**Species**	**2017**
Achnanthidium sp.	+	*Kephyrion* sp.	+
Ankistrodesmus sp.	+	*Komma* sp.	+
Aphanothecae sp.	+	*Lyngbya* sp.	+
Asterionella formosa var1	+	*Mallomonas* sp2	+
Cateria sp.	+	*Merismopedia* sp.	+
Ceratium sp.	+	*Microcystis* sp.	+
Chlorella sp.	+	*Monoraphidium* sp.	+
Chromulina sp1	+	*Navicula* sp.	+
Chroococcus sp.	+	*Ochromonas* sp.	+
Chroomonas acuta	+	*Oocystis* sp.	+
Chrysochromulina sp.	+	*Phacus* sp.	+
Coelastrum sp.	+	*Planctosphaeria* sp.	+
Cosmarium sp.	+	*Pseudokephrion* sp.	+
Crucigenia sp.	+	*Pyramimonas* sp.	+
Cryptomonas sp.	+	*Rhizosolenia* sp.	+
Cyclotella comta	+	*Scenedesmus* sp.	+
Cyclotella glomerata	+	*Scourfieldia* sp.	+
Cyclotella stelligera	+	Small microflagellates	+
Diatoma elongatum	+	*Sphaerocystis* sp.	+
Dinobryon sp.	+	*Staurodesmus* sp.	+
Elakatothrix sp3	+	*Synechococcus* sp. (coccoid)	+
Eunotia sp.	+	*Synechococcu*s sp. (rod)	+
Fragilaria capucina	+	*Synechocystis* sp.	+
Fragilaria construens	+	*Synedra acus*	+
Fragilaria crotonensis	+	*Synedra nana*	+
Gymnodinium sp1	+	*Tabellaria fenestrata*	+
Gymnodinium sp2	+	*Tetraedron* sp.	+
Gyromitus sp.	+		

Appendix B. Zooplankton species detected during 2017, Wahleach Reservoir, BC.

Order/Species	2017
CLADOCERA	
Alona sp.	+
Bosmina longirostris	+
Chydorus sphaericus	+
Daphnia rosea	+
Holopedium gibberum	+
Leptodora kindtii	+
Scapholeberis mucronata	+
COPEPODA	
Cyclops vernalis	+

Appendix C. Acoustic density distribution by size group (small = -66 to -49 dB, large ≥ -48 dB) and transect, 2017, Wahleach Reservoir, BC.



Appendix D. Detailed haul and catch information from trawl surveys, 2017, Wahleach Reservoir, BC.

Trawl No	Start Coordinates (UTM)			End Coordinates (UTM)			Comment
	Zone	Easting	Northing	Zone	Easting	Northing	
1	10 U	600470	545389	10 U	601138	5454707	TR 9 to 4
2	10 U	-	-	10 U	600470	545389	TR 5 to 9

Dashes (-) indicate no data

Trawl No	Start Time	Duration (min)	End Time	Cable Length (m)	Net Depth (m)	Target Depth (m)
1	0.23	39	1:02	58	6	6-8.5
2	1:26	38	2:04	69	9	8.5-11

Trawl No	Sample No	Species	Length (mm)	Weight (g)	Condition Factor	Comment
1	-	-	-	-	-	No fish caught in trawl 1 (cod end filled with *Holopedium*)
2	1	KO	50.0	1.30	1.04	Some *Holopedium* but less than first trawl
2	2	KO	49.0	0.90	0.76	
2	3	KO	51.0	1.30	0.98	
2	4	TSB	25.0	0.10	0.64	

**Dashes (-) indicate no data*