Wahleach Project Water Use Plan

Wahleach Reservoir Fertilization Program

Implementation Year 12

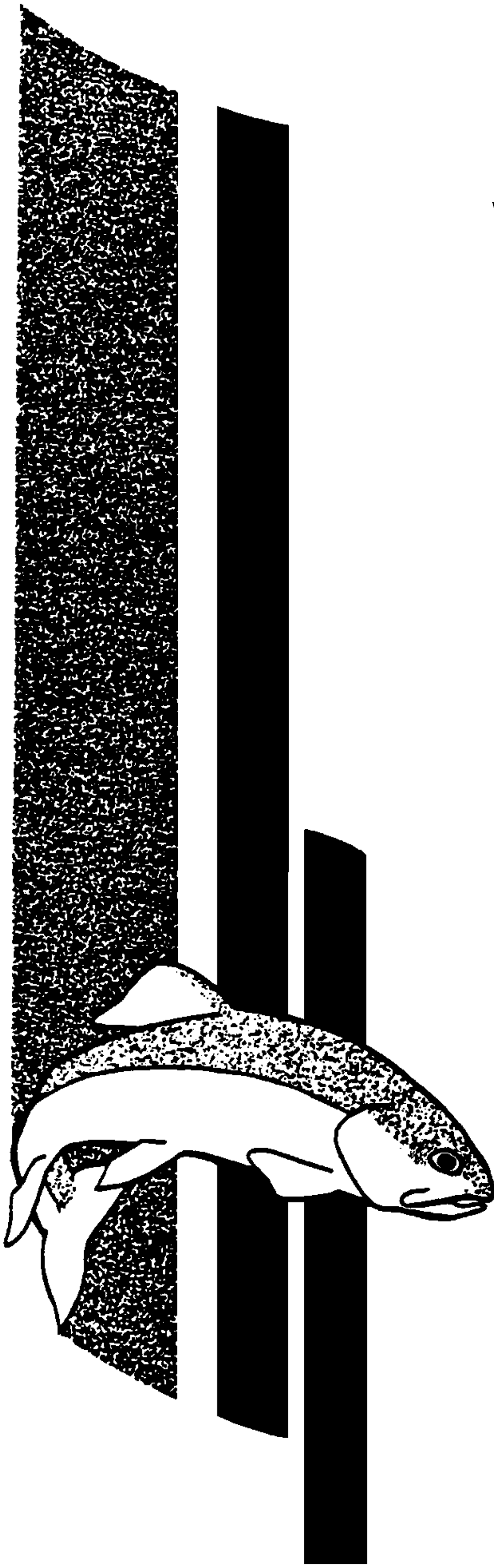
Reference: WAHWORKS-2

WAHLEACH RESERVOIR NUTRIENT RESTORATION PROJECT REPORT, 2016 - Fisheries Project Report No. RD 163

Study Period: 2016

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

October 10, 2019



WAHLEACH RESERVOIR NUTRIENT RESTORATION PROJECT REPORT, 2016

by

A.S. Hebert, J.A. Sarchuk, S.L. Harris, and T. Weir

Fisheries Project Report No. RD 163
2019

Province of British Columbia
Ministry of Environment and Climate Change Strategy
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Data and information contained within this report are subject to change.

Acknowledgements

This project was completed by the Ministry of Environment, Conservation Science Section under a Memorandum of Understanding with BC Hydro.

Field assistance was provided by Robert W. Land, Andrew Schellenberg, and Kevin Gould. Climate and hydrometric data were provided by BC Hydro Power Records staff. Taxonomic identification and enumeration of phytoplankton samples were conducted by Dr. John Stockner, Eco-Logic Ltd. Identification and enumeration of zooplankton samples were conducted by Lidija Vidmanic, Ecolab Ltd. David Johner and Sam Albers with the Ministry of Forests, Lands and Natural Resource Operations (Victoria) conducted hydroacoustic and trawl surveys. Kokanee spawner enumerations were completed by students of the British Columbia Institute of Technology, Fish and Wildlife Program: Heather Vainionpaa, Mae Whyte, and Chelsey Wierks. Neil Burton, a British Columbia Conservation Foundation contractor, provided tank farm security, assistance with fertilizer applications, as well as considerable logistical support during the field season; including help with repairs of the tank farm shed when a wind storm blew down a large tree onto the building. The Freshwater Fisheries Society of British Columbia was responsible for fish stocking, including triploiding, rearing and marking of Cutthroat Trout. Thanks to Greg Andrusak with the Ministry of Forests, Lands and Natural Resource Operations (Victoria) for his advice and snippets of R code for the fish analyses.

Teri Neighbor of BC Hydro provided considerable logistical support. A warm thank you to Kerry Baird with the British Columbia Conservation Foundation for contract management. Our gratitude is also extended to Anita Rebner, financial analyst with the Ministry of Environment. We thanks the Jones Lake Cabin Association for their continued support of our program and for allowing continued use of a lot for fertilizer and boat storage. We also appreciate the support from Manjit Kerr-Upal and Dr. Brett van Poorten – Director of the Conservation Science Section and unit head of the Applied Fisheries Research group at UBC.

Financial support for this project was provided by BC Hydro and the Ministry of Environment.

Executive Summary

The restoration of Wahleach Reservoir has continued using a strategy of nutrient addition in combination with biomanipulation of the food web via stocking of sterile Cutthroat Trout to restore the Kokanee population. Tracking the ecosystem's response to treatments included monitoring a suite of physical, chemical and biological parameters from May to October in 2016. This document presents the analysis of that data for 2016.

Nutrient concentrations were indicative of ultra-oligotrophic conditions and Secchi depths show oligotrophic to mesotrophic conditions in Wahleach Reservoir. Seasonal 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 and had the greatest seasonal mean abundance on record (25,789 ± 40,616 cells·mL^{-1}) owing to growth of unicellular forms of *Merismopedia* sp. and *Microcystis* sp. *Daphnia sp.* densities averaged near 3 individuals·L^{-1} and biomass averaged near 60 µg·L^{-1}; *Daphnia* accounted for 35% of total zooplankton density and 50% of the total biomass. As well, growth of other cladocerans was strong early in the season. Overall 2016 had the third greatest zooplankton biomass on record for the project period. The data shows that stimulation of lower trophic levels has translated into increased fish abundance and biomass of the target species since the program's inception. Assessments of Wahleach Reservoirs' fish populations indicated a significant increase in Kokanee abundance and biomass, which considered extirpated when the project began. The 2016 adult (age >1) Kokanee population was estimated at approximately 30,000 individuals with an escapement of 7,411 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 57,000 individuals; significantly lower than 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 have clearly demonstrated that seasonal nutrient additions to the reservoir 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.

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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 and eventually 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). Sterile Cutthroat Trout (*Oncorhynchus clarkii*), a known piscivore, were introduced into Wahleach Reservoir to decrease Threespine Stickleback populations and releasing 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 likely be required in 2018.

This summary report presents the analysis of data from the 2016 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 and 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.

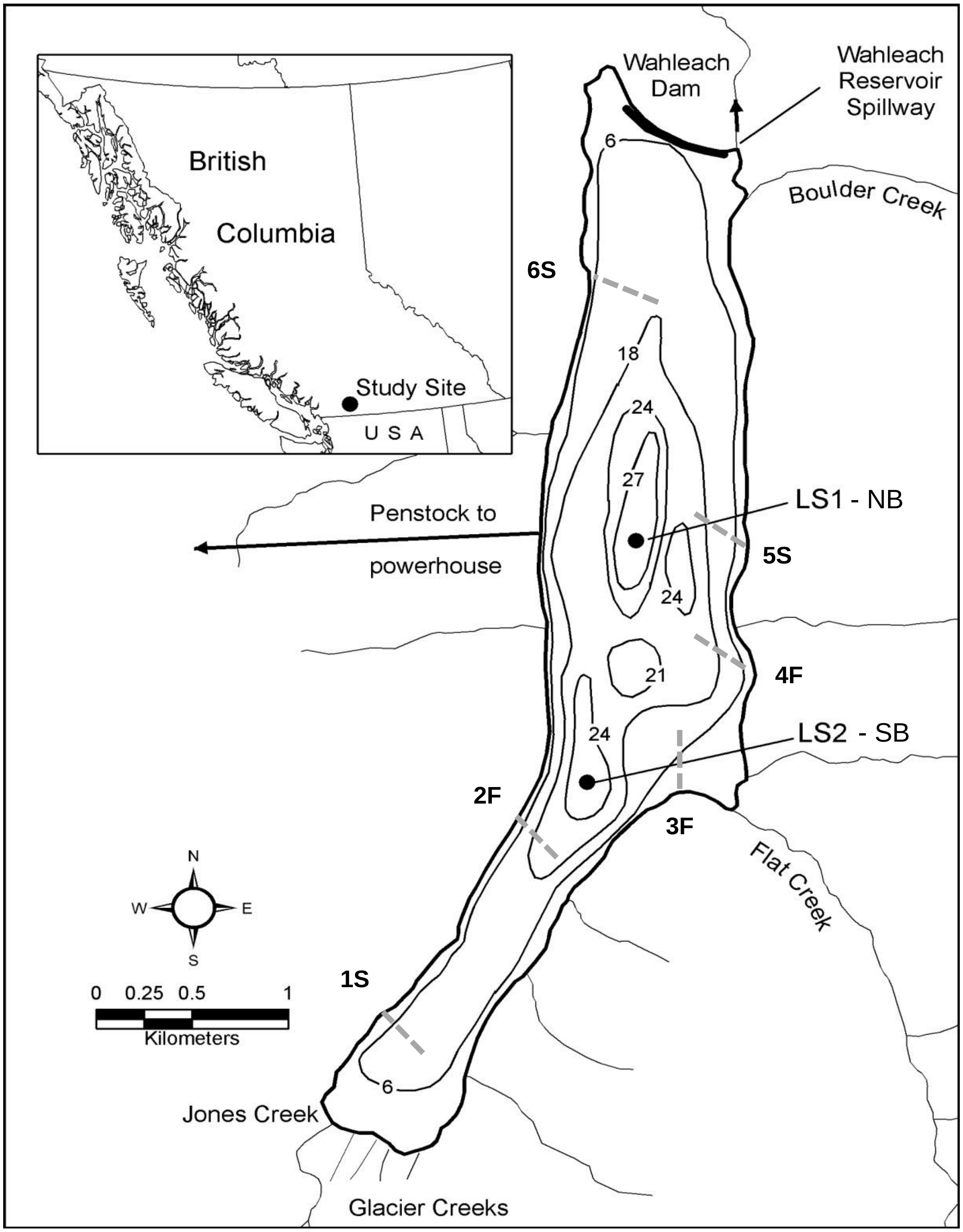

Figure 1. Map of Wahleach Reservoir, BC, including select sampling locations. Bathymetric contour depths (m) represent the reservoir at full pool.

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 1993-2016. Values used for comparison to baseline conditions represented study years 1993-1994, while the nutrient restoration period represented study years 1995-2016. Methods were consistent with those reported in Sarchuk et al. (2016).

3.1 Restoration Treatments

3.1.1 Nutrient Additions

Nutrient applications in the form of 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 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 have only ever reached about half that level due to in-season modifications (see paragraph below for more details), and negative effects on *Daphnia* growth have not been observed (Sarchuk et al. 2016). Subsequently, planned loading rates for 2016 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 to maintain a suitable N:P ratio. For the 2016 season, planned N:P ratios were 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 to 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 results obtained by our monitoring program, actual nutrient loading rates were modified throughout the season (Figure 2). In most years on Wahleach Reservoir, nutrient loading rates were consistent with planned rates early in the season, after which nutrient loads were generally reduced or eliminated in an effort to prevent algal blooms. In order to fully benefit from nutrient additions, the water column should be thermally stratified. Therefore, the last two planned loads were eliminated as thermal stratification in the reservoir had broken down. Hence, total annual loading rates (Figure 2, Table 1) were less than planned loading.

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 33.4 during the latter part of the season when phosphorus and nitrogen loading were being ramped down (Figure 2). Elimination/reduction of nutrient loads during weeks 7-9 was a result of logistical issues rather than a response to reservoir conditions; as a result, nitrogen loads were increased in weeks 11 and 12 (Figure 2).

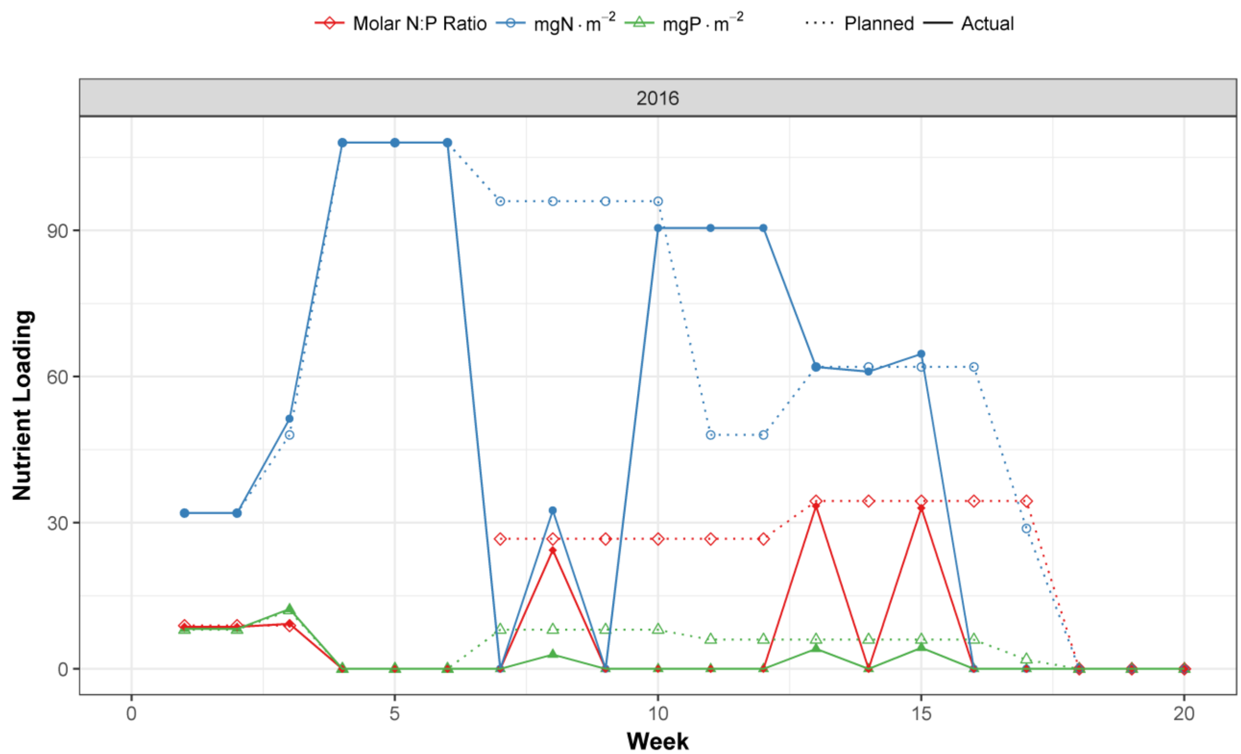

Figure 2. Seasonal planned and actual nutrient additions for Wahleach Reservoir, including areal nitrogen and phosphorus loading as well as molar N:P ratios, 2016; planned values are represented by hollow points, while actual values are represented by solid points.

Table 1. Annual nutrient additions by weight and areal loading, 2016, 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	$mg{\cdot}m^{-2}$
2016	1-Jun to 7-Sep	1.08	12.9	367	40.1	3,724	931

3.1.2 Fish Stocking

Stocking of sterile (3N) Cutthroat Trout continued to ensure top down pressure on the Threespine Stickleback population was maintained. In 2016, a total of 2,050 yearling 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 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, chemical and plankton data were collected from these locations. Parameters measured included water temperature and dissolved oxygen profiles, Secchi depth, water chemistry, and mixed layer 0.45 μm chlorophyll *a*. Water chemistry samples were analyzed by ALS Laboratory in Burnaby, BC. Appendix A outlines parameters and other sampling details. Where samples were reported below detection limits, a value of one half the detection limit 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 (mixed layer) was conducted monthly from May to October. Samples were analyzed by taxa for abundance, biovolume and edibility by Ecologic Ltd. 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 157 μm mesh Wisconsin plankton net. Samples were analyzed by taxa for density, biomass and fecundity by Ecolab Ltd. 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 are shown on Figure 1 with exact coordinates for 2016 in Table 2. Although exact coordinates may vary slightly, the general locations of sampling sites are consistent from year to year.

Table 2. Locations of standard nearshore gillnet and minnow trap stations, as well as non-standard limnetic minnow trap stations, 2016, 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
AM*	MT	49°14.385 N	121°36.819 W	DM*	MT	49°12.705 N	121°37.424 W
BM*	MT	49°14.333 N	121°36.862 W	EM*	MT	49°13.596 N	121°36.429 W
CM*	MT	49°12.628 N	121°37.523 W	FM*	MT	49°13.676 N	121°36.430 W

* denotes non-standard sampling sites; set limnetic habitat suspended from buoys at depths of 3 m and 6 m

Standardized annual nearshore gillnetting was completed October 18 to 19, 2016 after Kokanee had left the reservoir to spawn. 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"). Beginning in 2014, the provincial standard net composition included an additional panel of 32 mm (1.25") mesh to better sample fish in the age-1 size range; the new 32 mm panel was attached to the 64 mm (2.5") mesh size at the end of each net. 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 2016, six minnow traps baited with salmon roe were set on the bottom in 1 to 3 m of water at standard littoral habitat stations; an additional six traps were also set in limnetic habitat suspended from buoys at depths of 3 m and 6 m.

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 August 31 to October 19, 2016 depending on observed trends in spawner numbers. For additional field sampling and analysis methods refer to Sarchuk et al. (2016). Kokanee spawner samples were taken by dip net, and if fork length (FL) could not be measured for an individual, it was calculated based on a regression equation ($y = 1.4181x – 36.631$, $R^2 = 0.9648$) for sample years (2003-2016) when both post-orbital hypural length (POHL) and FL were measured.

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**Error! Reference source not found.**) using a Simrad EK60 120 kHz split beam system. Survey conditions for 2016 are shown in Table 3 and Appendix B. Additional details on field and analysis methods can be found in Appendix C and Sarchuk et al. (2016).

Table 3. Summary of equipment and conditions for hydroacoustic surveys, 2016, Wahleach Reservoir, BC.

Year	Survey Date	Sounder	Reservoir Elevation[1] (m)	Avg Transect Start/End Depth (m)
2016	July 26	EK60	640.1	6.1

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

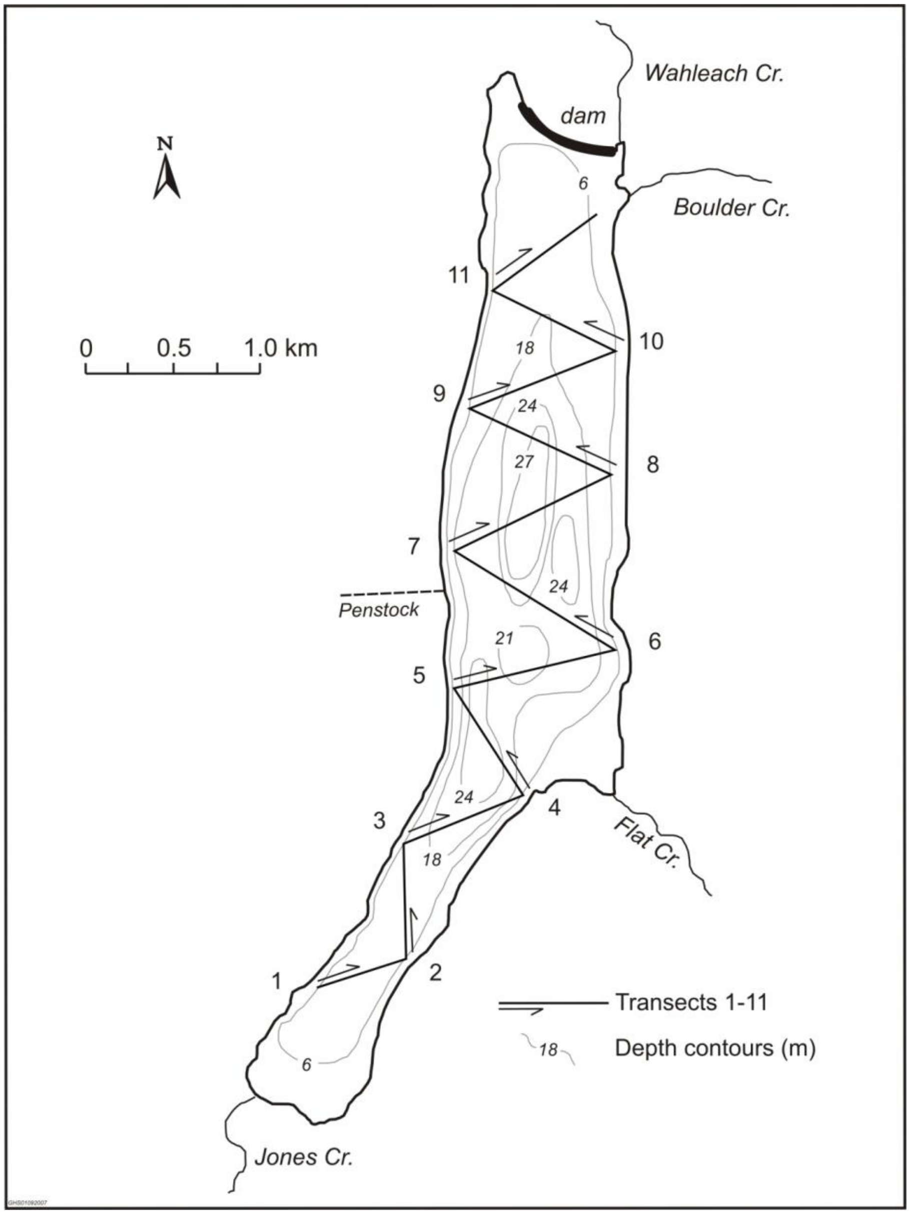

Figure 3. Locations of standardized hydroacoustic transects, Wahleach Reservoir, BC.

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 described 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. 2016). 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, 2016, Wahleach Reservoir, BC.

Year	Analysis Depth Range (m)	KO Depth Range (m)	Fry-sized Fish dB	Adult-sized Fish dB	All Fish dB
2016	2-30	6-30	-66 to -47	≥ -46	≥ -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 Survey

A trawl survey was completed to evaluate fish species distribution, specifically Kokanee fry and Threespine Stickleback, the night after the acoustic survey on July 27, 2016. 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, 2016, Wahleach Reservoir, BC.

Year	Survey Date	Net Size (l×w×h in m)	No. Hauls	Haul Depth Range (m)	Haul Time (min)	Method Reference(s)
2016	July 27	12 × 2.5 × 2.5	3	8.0-19.5	40-60	Gjernes 1979; Hebert et al. 2015

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.). Catch by species from each depth category was then plotted.

4. Results

4.1 Hydrometrics and Reservoir Operations

4.1.1 Inflow

Mean daily inflow to Wahleach Reservoir in 2016 was 5.8 ± 4.2 m^3 s^{-1} (range 0 to 50.3 m^3 s^{-1}), which was lower and less variable than the long term mean of 6.2 ± 5.4 m^3 s^{-1} (range 0 to 96.1 m^3 s^{-1}). Peak flows were observed during the winter storm season in January (Figure 4).

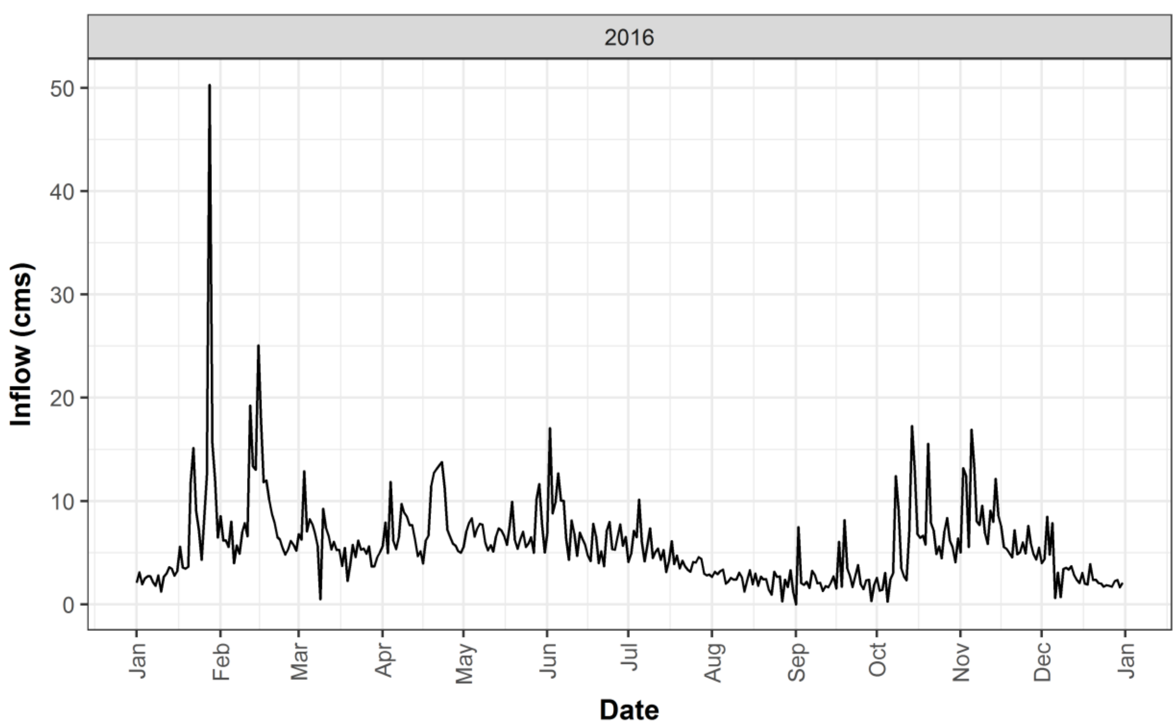

Figure 4. Daily inflow ($m^{3\cdot}s^{-1}$) in 2016 to Wahleach Reservoir, BC.

4.1.2 Discharge

Mean daily discharge from Wahleach Reservoir in 2016 was 5.9 ± 4.2 m^3 s^{-1} (range 0 to 12.6 m^3 s^{-1}), which was similar to the long term mean of 6.2 ± 4.7 m^3 s^{-1} (range 0 to 78.6 m^3 s^{-1}). 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.

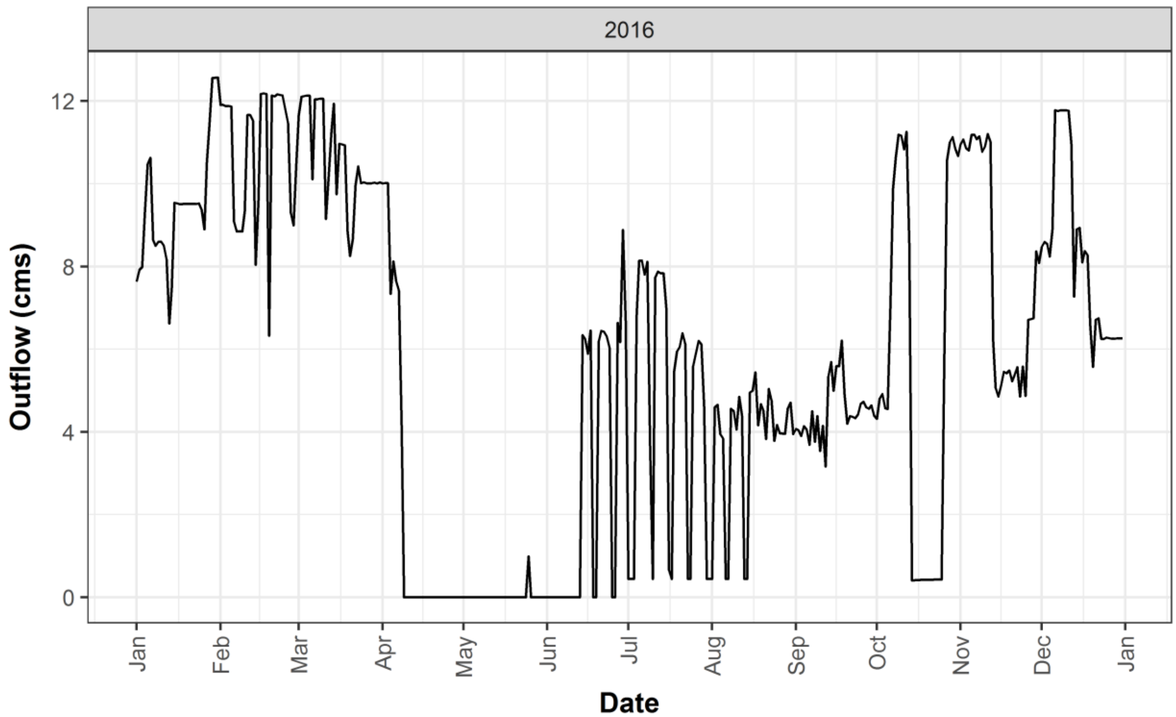

Figure 5. Daily outflow ($m^3 \cdot s^{-1}$) in 2016 from Wahleach Reservoir, BC.

4.1.3 Reservoir Elevation

Typically on Wahleach Reservoir, drawdown begins in late summer through the winter 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 were stable throughout the nutrient addition season. The annual drawdown was 11.8 m in 2016 and reservoir elevations stayed above the minimum standard operating level of 628 m (Figure 6).

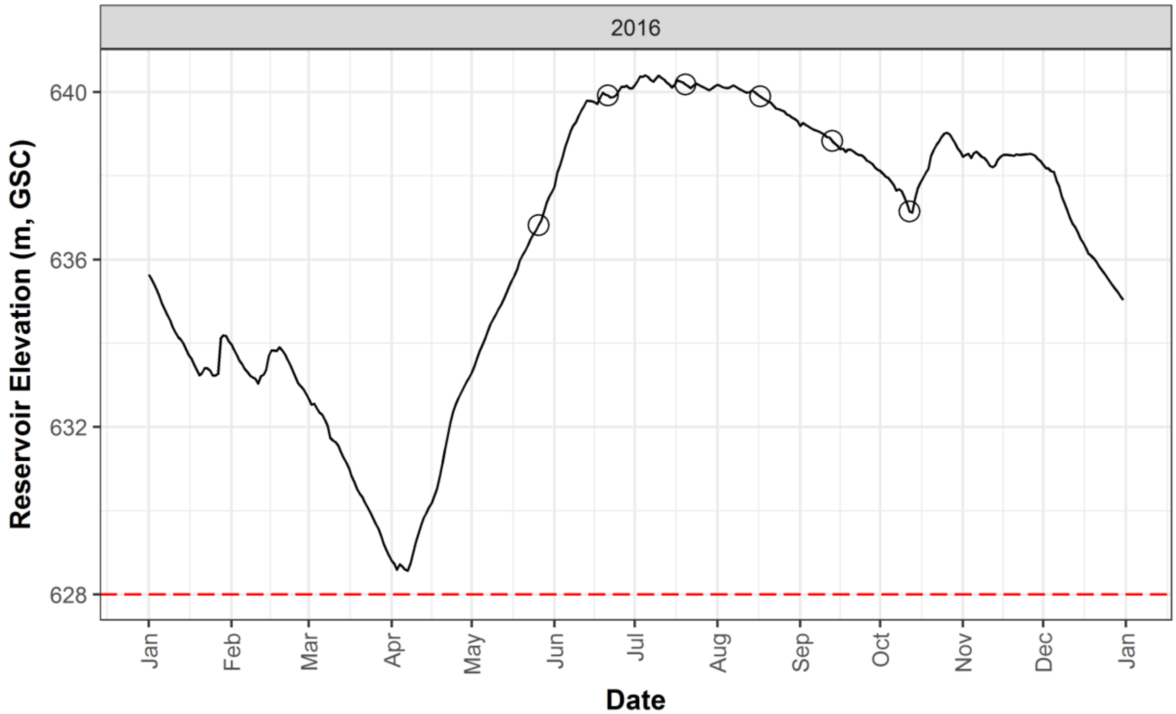

Figure 6. Daily reservoir surface elevation (m, Geodetic Survey of Canada) in 2016 of Wahleach Reservoir, BC. Open circles represent limnology sampling dates. The red dashed line represents minimum operating level of 628 m.

4.2 Climate

4.2.1 Air Temperature

Seasonal air temperatures in 2016 were peaked in August while minimum temperatures were observed in December (Figure 7). The mean daily temperature in 2016 was warmer, 8.0 ± 6.7°C (-15.1 to 31.9°C) than the long term average of 7.1 ± 6.7°C, (-22.3. to 33.9°C). During the nutrient addition period (June through September), mean daily temperatures were 14.4 ± 3.7°C (4.1 to 31.9°C), which was similar to the long term mean (14.1 ± 3.8°C, range 0.8 to 33.9 °C).

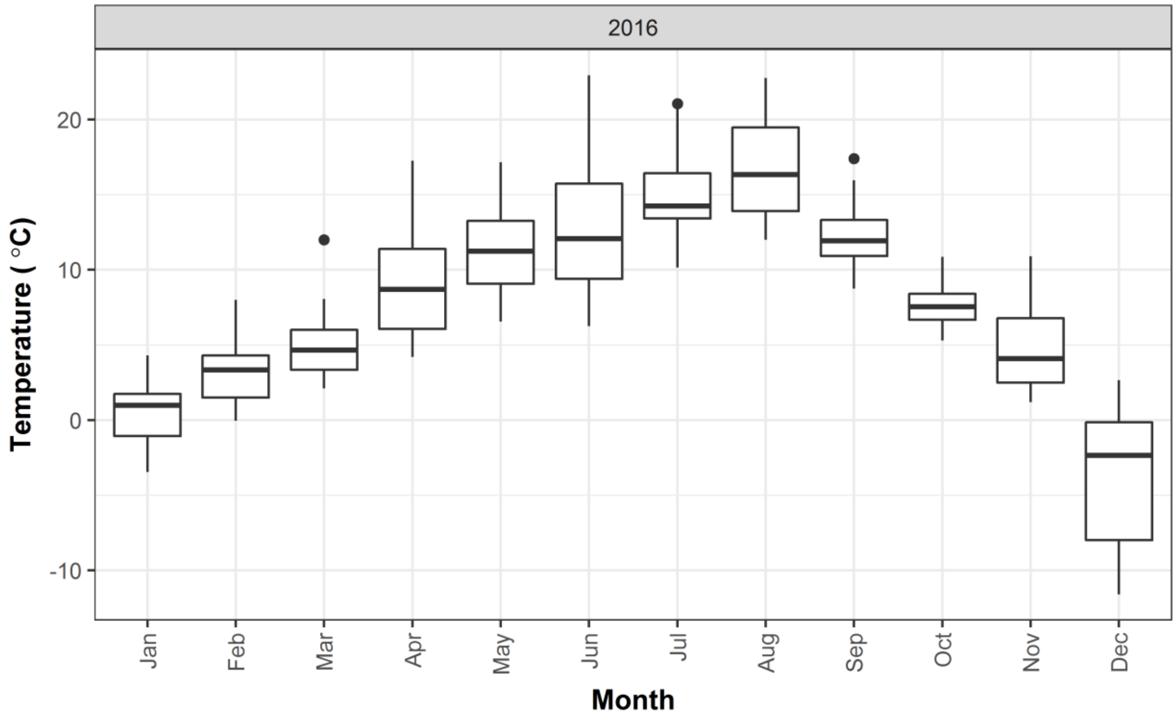

Figure 7. Boxplot of daily mean air temperatures (°C) during each month in 2016 at Wahleach Reservoir, BC.

4.2.2 Precipitation

Precipitation generally followed the inverse trend of air temperature; July and August had the lowest precipitation while October through December, and January to March had the greatest precipitation (Figure 8). In 2016, mean daily (7 ± 12 mm, range 0 to 64 mm) and mean monthly (222 ± 117 mm, range 22 to 399 mm) precipitation were similar to the long term means of 7 ± 13 mm (range 0 to 130 mm) and 218 ± 88 mm (range 89 to 363 mm), respectively. A total of 2,663 mm of precipitation fell in 2016, which was comparable to the long term mean (2,616 ± 271 mm, range 2,102 to 3,124 mm).

During the nutrient addition season (June through September), the long term mean daily precipitation was 4 ± 9 mm (0 to 114 mm), while the long term monthly mean was 127 ± 77 mm (range 8 to 335 mm). Daily and monthly means for precipitation in 2016 were similar to the long term means with (4 ± 9 mm (range 0 to 45 mm) and 119 ± 79 mm (range 22 to 189 mm). Total seasonal precipitation in 2016 was 476 mm, which was also in the range of the long term mean (506 ± 118 mm, range 280 to 687 mm).

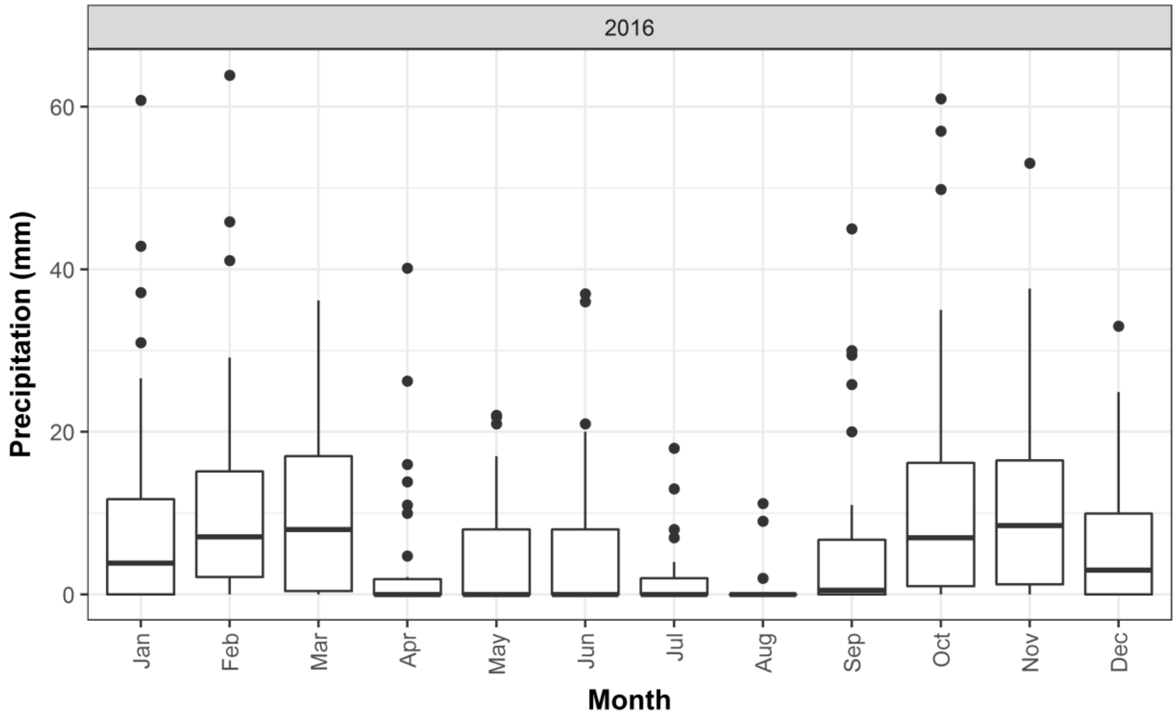

Figure 8. Boxplot of daily total precipitation (mm) during each month in 2016 at Wahleach Reservoir, BC.

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 began to develop in June with strong thermal stratification in July and August, and then stratification weakened by September. Generally, the water column is well-mixed showing an isothermal profile in the spring (May) and fall (October). In 2016, thermocline depth was generally between 4-8 m (Figure 9). Water temperatures were similar between the north basin and the south basin with a combined mean of 12.5 ± 2.8°C (range 8.6 to 21.4°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 2016 for both basins combined was 8.5 ± 1.6 mg·L^{-1} (2.8 to 10.8 mg·L^{-1}). 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).

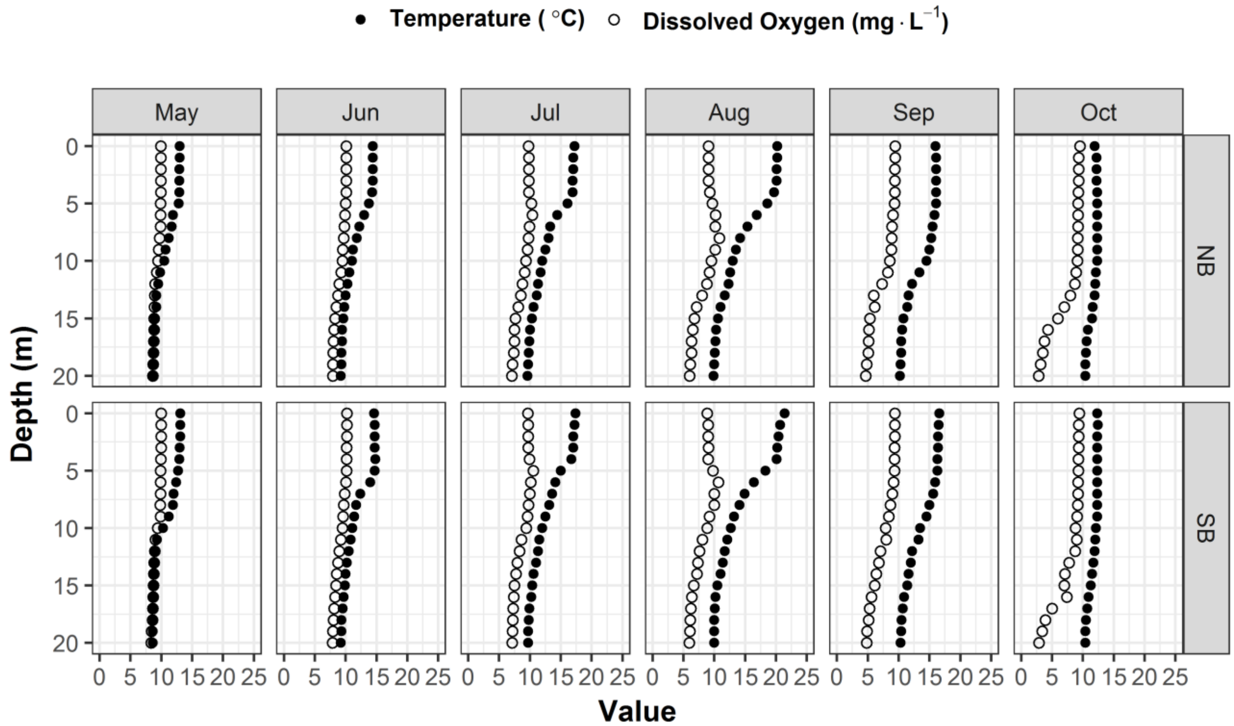

Figure 9. Water temperature (°C) and dissolved oxygen (mg·L^{-1}) profiles taken at the north basin (NB) and south basin (SB) limnology sampling stations May to October, 2016 in Wahleach Reservoir, BC.

The pH in Wahleach Reservoir was neutral with a mean of 7.3 ± 0.1 (7.2 to 7.4) in 2016 (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 9.3 and 11.9 mg $CaCO_3 \cdot L^{-1}$, with a mean of 10.4 ± 0.9 mg $CaCO_3 \cdot L^{-1}$ in 2016 (Figure 11) which is 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 $CaCO_3 \cdot L^{-1}$.

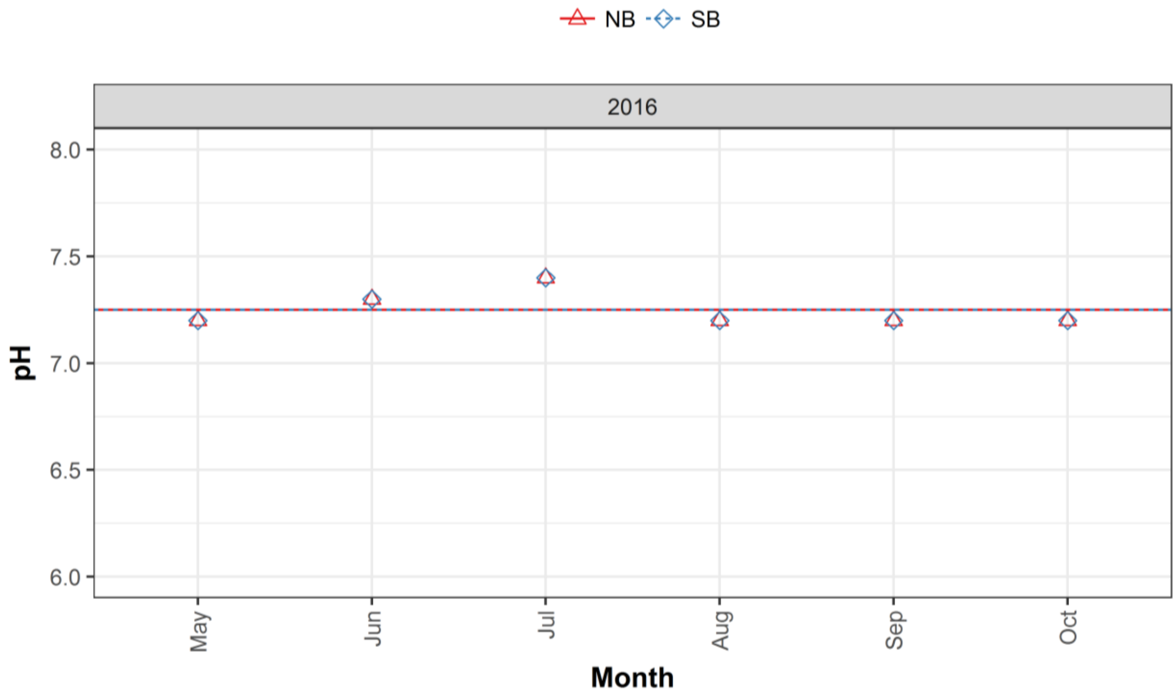

Figure 10. pH values from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May-October in Wahleach Reservoir, BC. Horizontal bars represent seasonal mean for each station.

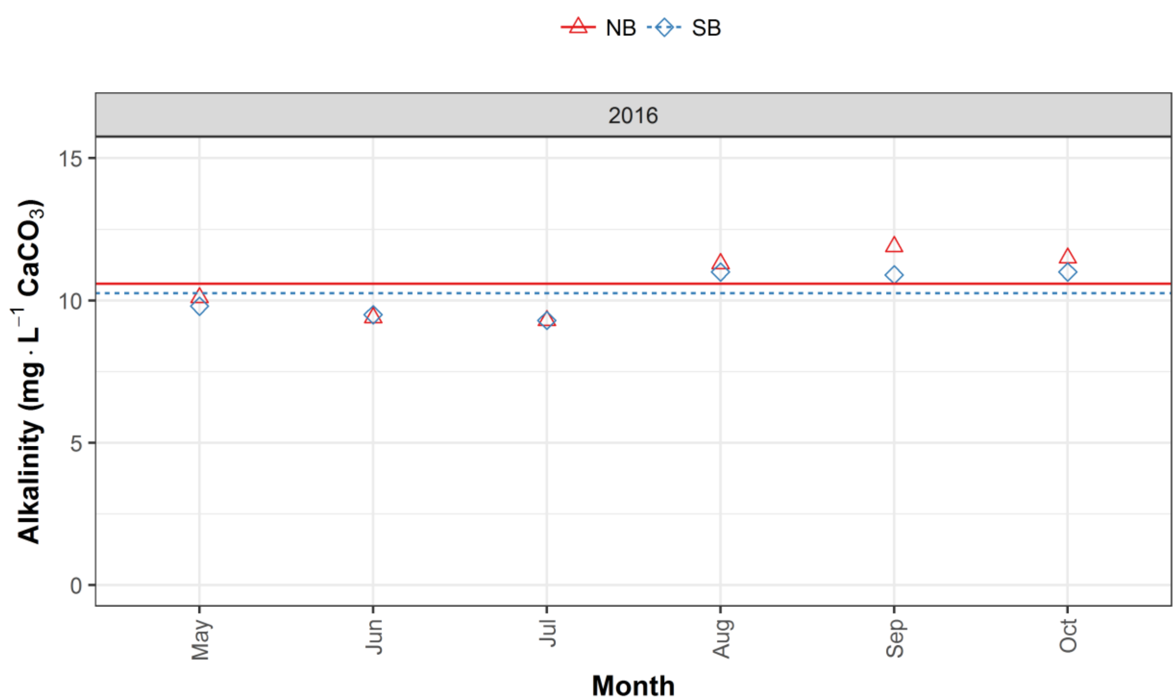

Figure 11. Alkalinity (mg $CaCO_3 \cdot L^{-1}$) values from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May-October in Wahleach Reservoir, BC. Horizontal bars represents seasonal mean for each station.

Secchi disk depth averaged 5.3 ± 1.2 m (range 3.7 to 7.2 m) in Wahleach Reservoir during 2016 (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 1993 baseline average of 7.0 ± 0.4 m (6.2 to 7.6 m).

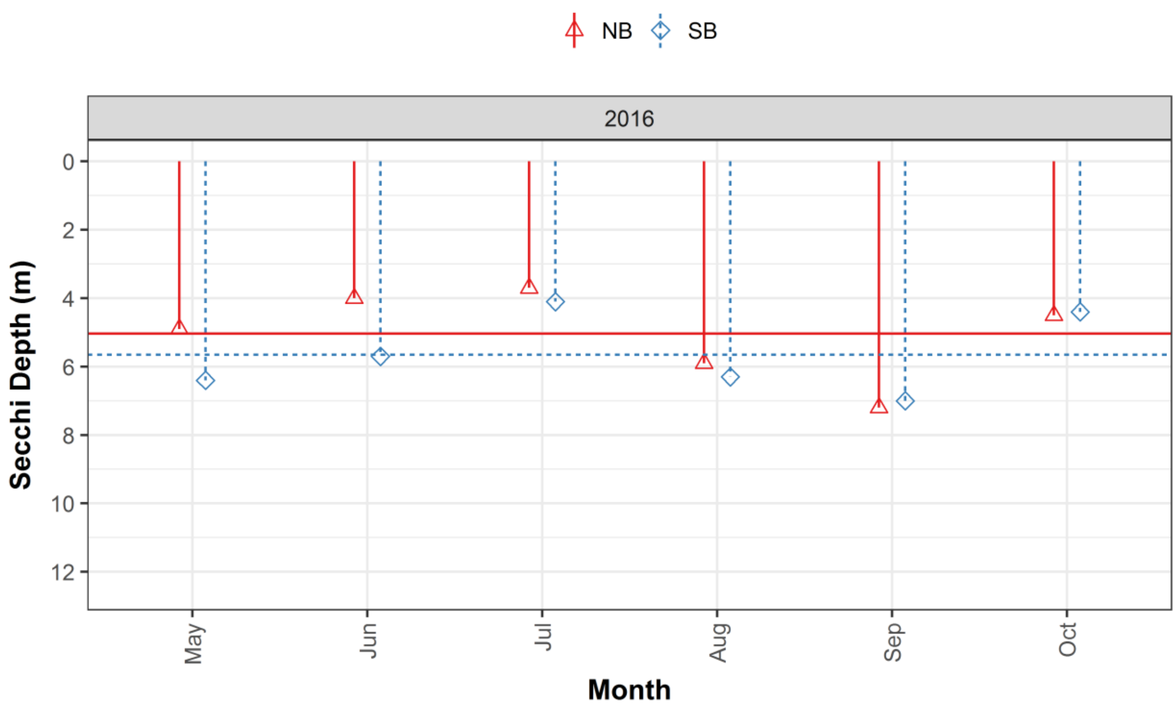

Figure 12. Secchi depths (m) taken at the north basin (NB) and south basin (SB) limnology sampling stations, 2016 in Wahleach Reservoir, BC. Horizontal bars represent seasonal means for each station.

Vollenweider (1968) found TP concentrations below 5 $\mu g \cdot L^{-1}$ were indicative of ultra-oligotrophic productivity, while TP concentrations between 5-10 $\mu g \cdot L^{-1}$ were indicative of oligotrophic productivity. Prior to nutrient restoration, seasonal mean epilimnetic TP was 4.3 ± 2.0 $\mu g \cdot L^{-1}$, and ranged from 2.9 to 12.0 $\mu g \cdot L^{-1}$, values representative of ultra-oligotrophic productivity nearing oligotrophic productivity. In 2016, TP values from water quality samples of both basins ranged from 1.0 to 5.6 $\mu g \cdot L^{-1}$ with a seasonal mean of 2.2 ± 1.4 $\mu g \cdot L^{-1}$ indicating reservoir productivity remained in the ultra-oligotrophic to oligotrophic end of the spectrum (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 $\mu g \cdot L^{-1}$ with a range of 1-2 $\mu g \cdot L^{-1}$. In 2016, SRP ranged from <1 to 1.1 $\mu g \cdot L^{-1}$ throughout the season with a mean of 0.6 ± 0.2 $\mu g \cdot L^{-1}$ (Figure 14). Despite phosphorus additions, most SRP samples (10 of 12 samples or 83%) were below the detection limit of 1 $\mu g \cdot L^{-1}$ suggesting rapid uptake and assimilation of useable phosphorus by phytoplankton.

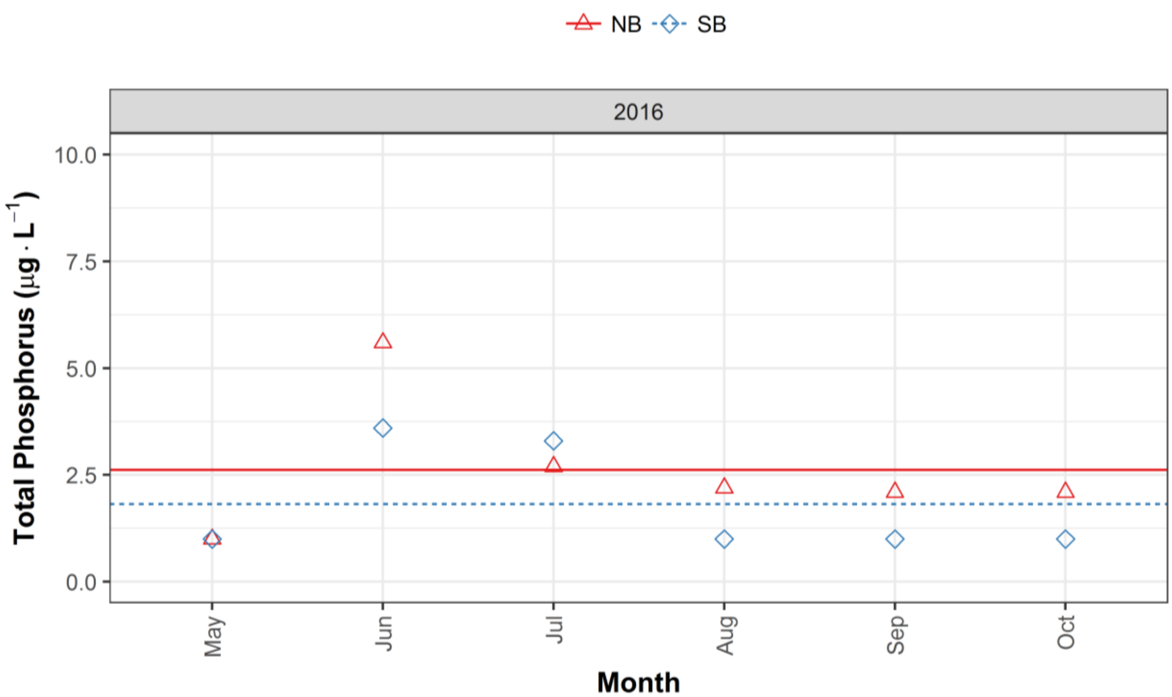

Figure 13. Total phosphorus concentration (µg·L^{-1}) from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to October, 2016, Wahleach Reservoir, BC.

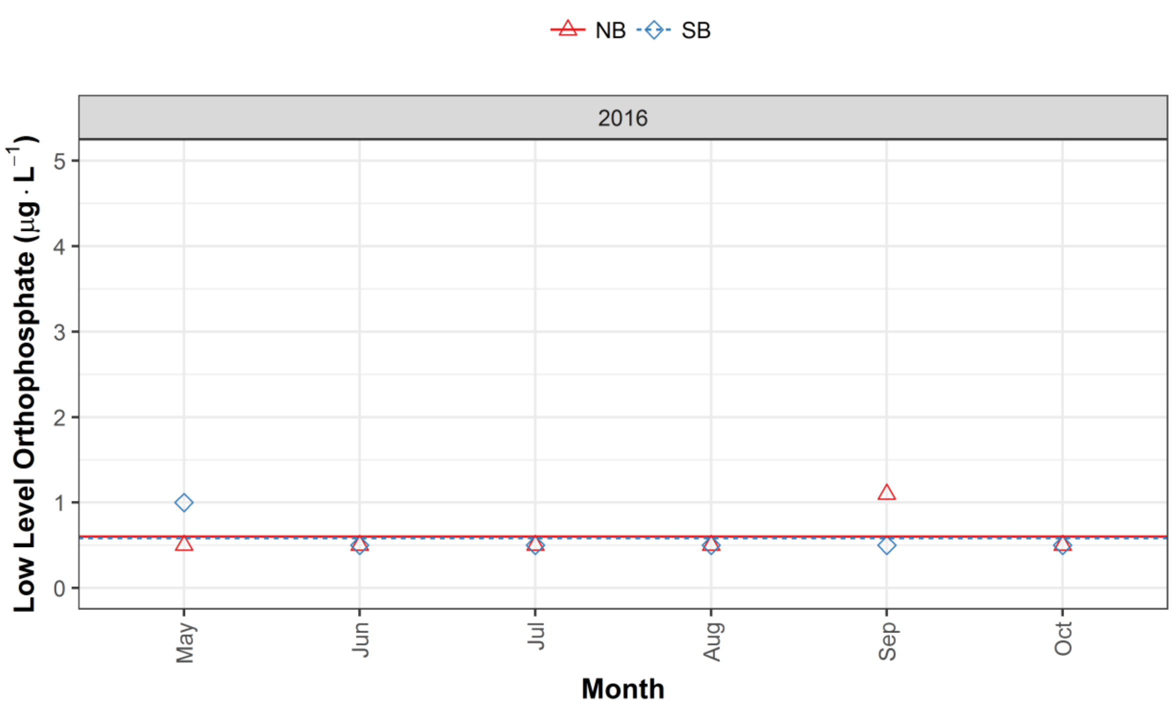

Figure 14. Low level orthophosphate concentrations (µg·L^{-1}) from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May-October, 2016 in Wahleach Reservoir, BC.

Total nitrogen (TN) represents dissolved inorganic forms of nitrogen (i.e. nitrate, nitrite and ammonium) and particulate forms of nitrogen (mainly organic). Epilimnetic TN concentrations were highest in spring, decreased through the summer, and then started to increase in fall (Figure 15). This pattern coincides with the seasonal growth and utilization of nitrogen by phytoplankton in the reservoir's epilimnion. TN concentrations in 2016 were 125 ± 34 $\mu g \cdot L^{-1}$ (83 to 211 $\mu g \cdot L^{-1}$), which on average was higher than baseline values of 112 ± 48 $\mu g \cdot L^{-1}$, (9 to 220 $\mu g \cdot L^{-1}$) (Figure 15).

Nitrate and nitrite-N (NO_3+NO_2-N) are important forms of dissolved inorganic nitrogen supporting algal growth (Wetzel 2001). In 2016, the highest concentrations of NO_3+NO_2 were observed during spring mixing, low concentrations were measured through the summer with a slight increase in concentrations in early fall. Summer NO_3+NO_2 concentrations frequently dropped below the level considered limiting for phytoplankton (<20 $\mu g \cdot L^{-1}$) suggesting strong biological utilization of NO_3+NO_2. The seasonal mean NO_3+NO_2 concentration in 2016 was 20 ± 21 $\mu g \cdot L^{-1}$ (1.6 to 63 $\mu g \cdot L^{-1}$) (Figure 16), which was low compared to baseline levels of 46 ± 14 $\mu g \cdot L^{-1}$ (27 to 72 $\mu g \cdot L^{-1}$) in 1993 and 86 ± 92 $\mu g \cdot L^{-1}$ (0.9 to 426 $\mu g \cdot L^{-1}$) in 1994.

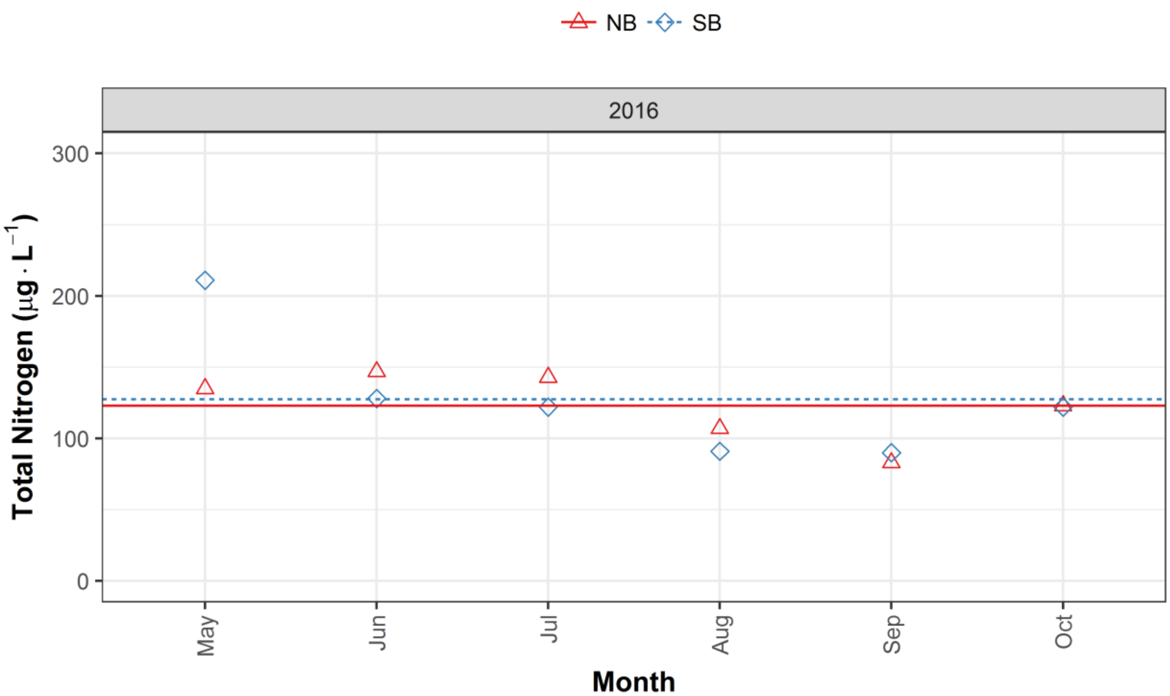

Figure 15. Total nitrogen concentrations ($\mu g \cdot L^{-1}$) from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May-October, 2016 in Wahleach Reservoir BC; horizontal lines represent seasonal means for each station.

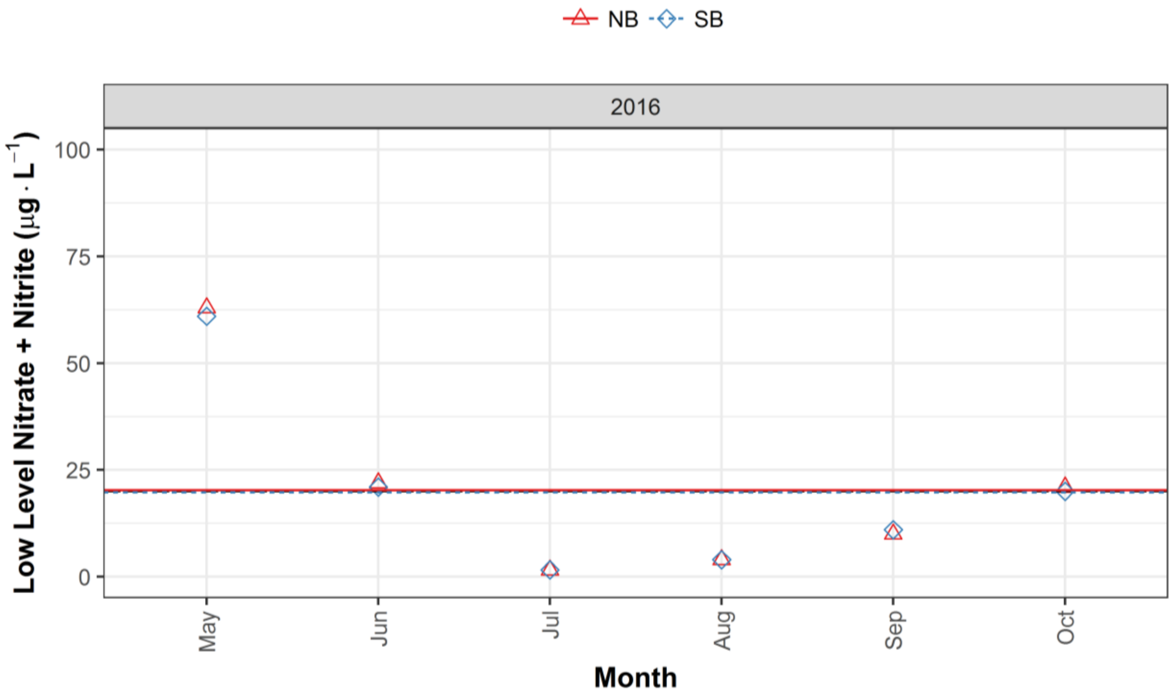

Figure 16 Low level nitrate + nitrite nitrogen concentrations (µg·L^{-1}) from 1 m discrete water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May-October, 2016 in Wahleach Reservoir BC. The black dashed line at 20 µg·L^{-1} represents the limiting concentration for phytoplankton growth.

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 2016 ranged between 26-211 with a mean of 79 ± 54 (Figure 17); seasonally, Wahleach Reservoir was likely in a state of phosphorus limitation during the early and late portions of the growing season. Baseline TN:TP ratios were lower than levels observed in 2016, 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.

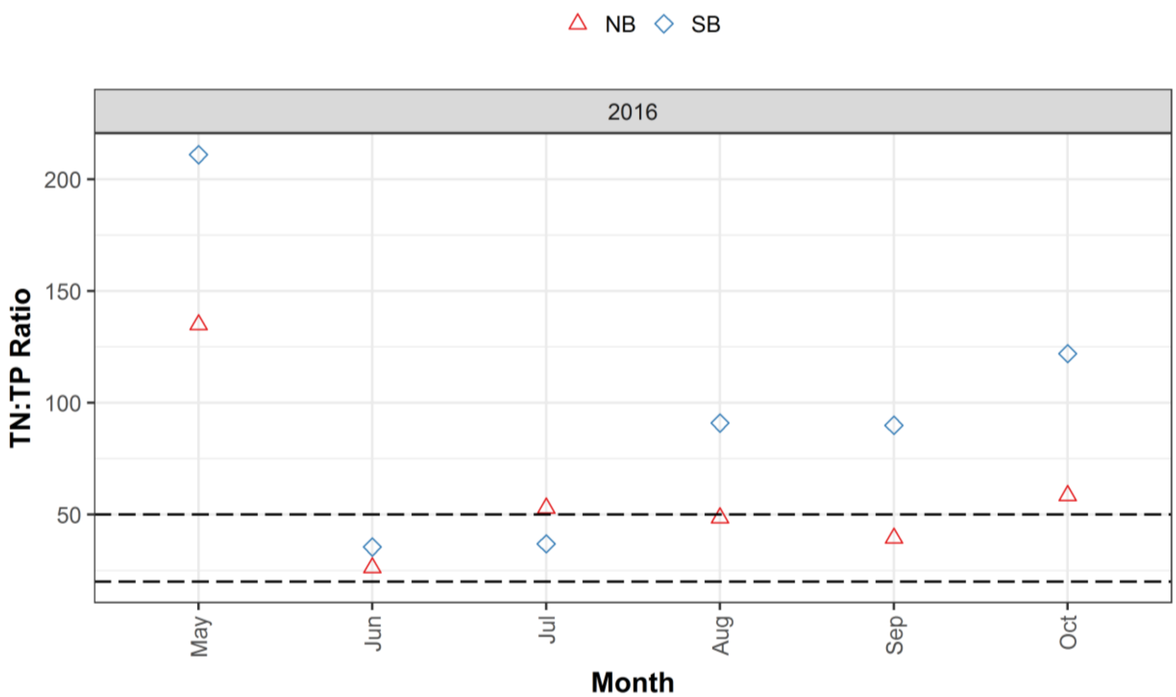

Figure 17. Total nitrogen (TN) to total phosphorus (TP) ratios based on 1 m water chemistry samples from the north basin (NB) and the south basin (SB) limnology stations May-October, 2016, Wahleach Reservoir, BC. Points above dashed line at 50 were likely in a state of P limitation, while points below dashed line at 20 were likely in a state of N limitation (Guildford and Hecky 2000).

4.4 Phytoplankton

A total of 53 phytoplankton species were detected in Wahleach Reservoir during 2016 (Appendix D), which was higher than the 1994 baseline year when only 38 phytoplankton species were detected. Mean phytoplankton abundance in 2016 was the highest on record at 25,789 ± 40,616 cells·mL^{-1} (1,906 to 119,575 cells·mL^{-1}), compared to the 1994 baseline year where phytoplankton abundance was only 8,793 ± 4,929 cells·mL^{-1} (4,632 to 20,093 cells·mL^{-1}). Abundance was driven largely by growth of *Merismopedia* sp. and to a lesser extent *Microcystis* sp. in July and August; both species are small blue-green algae belonging to the class *Cyanophyceae* (Figure 18). Samples from Wahleach in July and August showed *Microcystis* were present in cell form as opposed to colonies, and thus they were considered edible by zooplankton (Figure 19). Flagellates (*Chryso-* & *Cryptophyceae*) were the second most numerically dominant class of phytoplankton in 2016 (Figure 18). Overall, the phytoplankton community was primarily edible species and forms throughout the season (25,431 ± 40,533 cells·mL^{-1}; 1,673 to 118,835 cells·mL^{-1}) (Figure 19); inedible fractions (348 ± 193 cells·mL^{-1}; 112 to 740 cells·mL^{-1}) were much lower in 2016 than in recent years (Sarchuk et al. 2016).

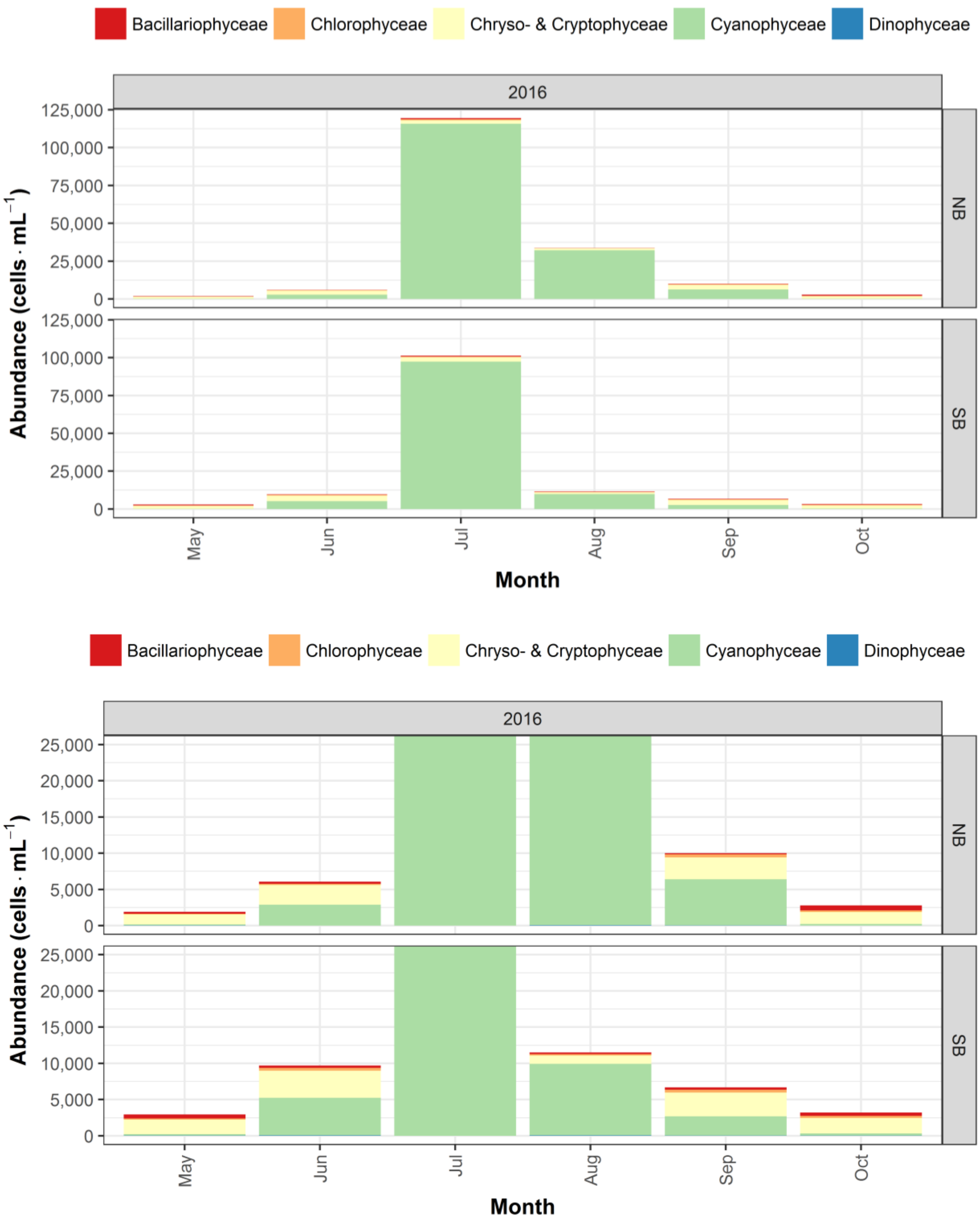

Figure 18. Seasonal phytoplankton abundance (cells·mL^{-1}) by class at the north basin (NB) and south basin (SB) limnology stations May to October, 2016, Wahleach Reservoir BC; lower panel is zoomed in to show distribution of classes with abundance ≤ 25,000 cells.

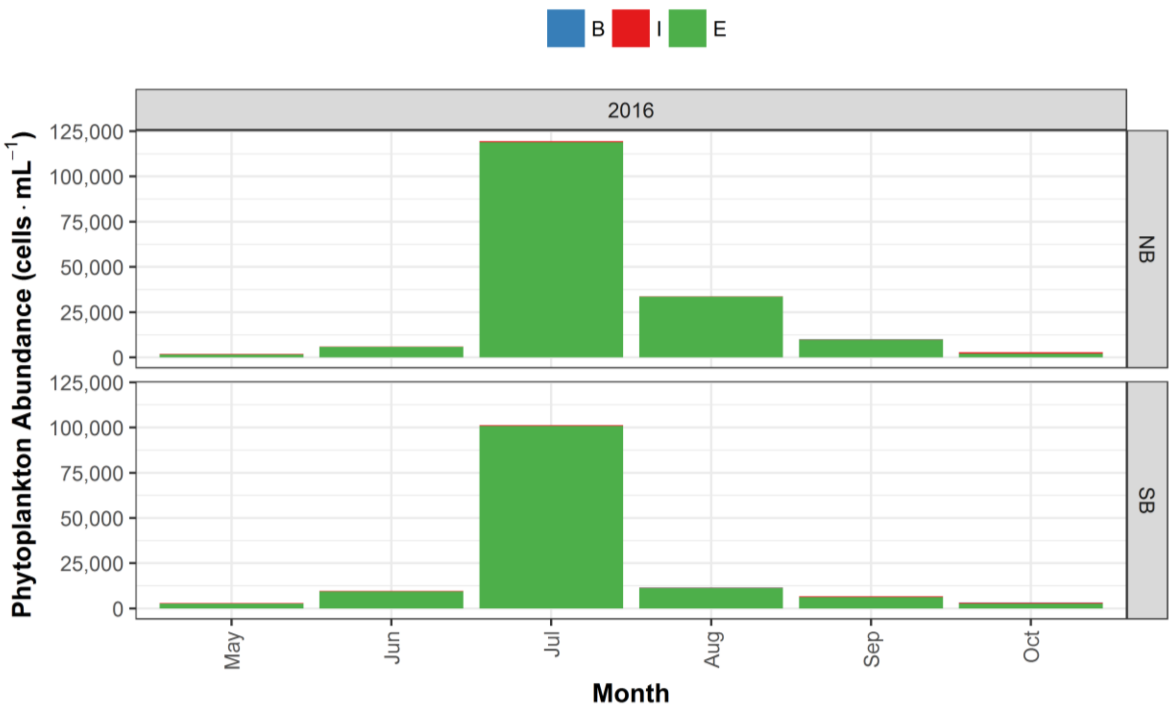

Figure 19. Seasonal phytoplankton abundance (cells·mL^{-1}) by edibility (E=edible, I=inedible, B= both edible and inedible forms) at the north basin (NB) and south basin (SB) limnology station May to October, 2016, Wahleach Reservoir BC.

Phytoplankton biovolume in 2016 (1.02 ± 0.98 mm^3·L^{-1}; 0.19 to 3.26 mm^3·L^{-1}) was near average for the nutrient addition period (0.97 ± 0.96 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 *Merismopedia* sp. Flagellates (*Dinobryon* sp. and *Ochromonas* sp.), together with *Tabellaria fenestrata* (class *Bacillariophyceae*) and *Sphaerocystis* sp. (class *Chlorophyceae*), which were also significant contributors to biovolume results in 2016 (Figure 20). Diatoms (especially *Tabellaria fenestrata*) generally made up the inedible fraction (0.08 ± 0.06 mm^3·L^{-1}; 0.02 to 0.20 mm^3·L^{-1}) of the biovolume, while flagellates, chlorophytes and to a lesser extent, dinoflagellates (class *Dinophyceae*) generally made up the edible fraction (0.94 ± 0.95 mm^3·L^{-1}; 0.18 to 3.06 mm^3·L^{-1}). Phytoplankton biovolume overall consisted mainly of edible species and forms throughout the growing season (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.

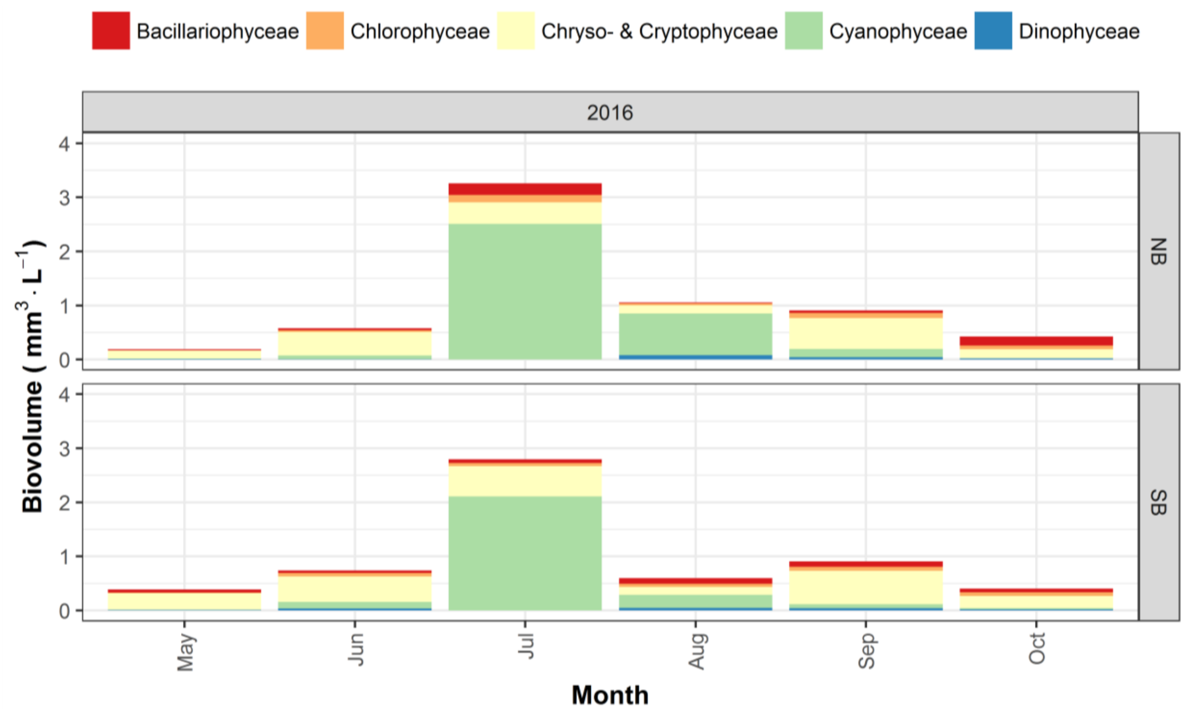

Figure 20. Seasonal phytoplankton biovolume ($mm^3 \cdot L^{-1}$) by class at the north basin (NB) and south basin (SB) limnology stations May-October, 2016, Wahleach Reservoir BC.

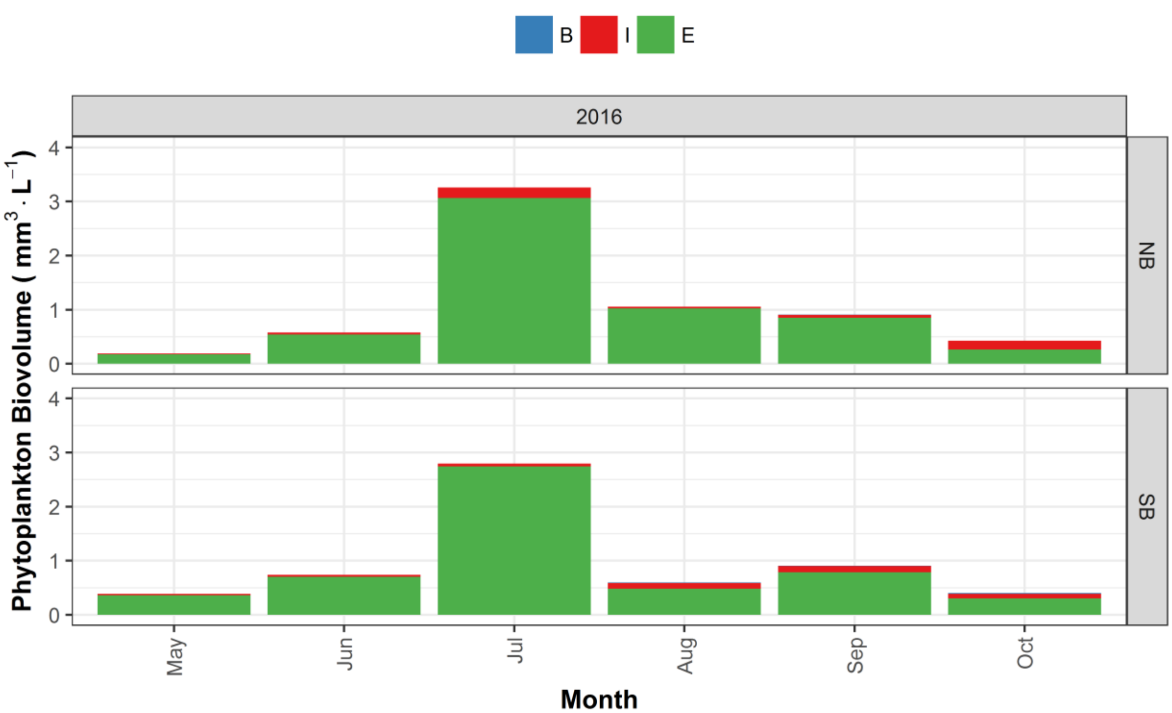

Figure 21. Seasonal phytoplankton biovolume ($mm^3 \cdot L^{-1}$) by edibility (E= edible, I=inedible, B= both edible and inedible forms) at the north basin (NB) and south basin (SB) limnology station May to October, 2016, Wahleach Reservoir BC.

4.5 Zooplankton

Seven *Cladocera* species and two *Copepoda* species were identified in Wahleach Reservoir in 2016 (Appendix E). Species such as *Daphnia rosea* (Sars), *Bosmina longirostris* (O.F.M.), and *Holopedium gibberum* (Zaddach) were common, while others such as *Alona* sp., *Leptodora kindtii* (Focke), *Scapholeberis mucronata* (O.F.M.) and *Chydorus sphaericus* (O.F.M.) were observed sporadically and/or at low densities. *Scapholeberis mucronata* and *Chydorus sphaericus* are generally 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. Interestingly, in 2015 and 2016, the species *Leptodiaptomus ashlandi* was observed in zooplankton samples, though it had not been detected in Wahleach Reservoir since 2008.

Seasonal zooplankton density in 2016 (7.7 ± 5.6 individuals·L^{-1}; 3.1 to 28.7 individuals·L^{-1}) was near average for the nutrient addition period (8.7 ± 8.7 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 the density of the zooplankton community; beginning in July and then continuing for the rest of the season, *Daphnia* were the dominant contributor to density results (Figure 22). Overall in 2016, cladocerans (other than *Daphnia*) contributed 54% of seasonal density, while *Daphnia* made up 35% of density. Seasonal densities of each major zooplankton group are detailed in Table 6**Error! Reference source not found.**.

Seasonal zooplankton biomass was the third greatest on record at 97.7 ± 49.6 µg·L^{-1} (34.7 to 275.6 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 contributor to biomass results (Figure 23). Overall in 2016, cladocerans (other than *Daphnia*) contributed 48% of biomass in 2016, while *Daphnia* made up 51% of biomass. Seasonal biomass for each major zooplankton group is detailed in Table 6**Error! Reference source not found.**.

Table 6. Summary statistics for seasonal zooplankton density and biomass of each major group (*Copepoda*, *Daphnia* and other *Cladocera*), 2016, in Wahleach Reservoir BC.

Taxonomic Group	Density (individuals·L^{-1})				Biomass (µg·L^{-1})			
	Mean	SD	Max	Min	Mean	SD	Max	Min
Copepoda	0.9	0.4	1.8	0.3	1.2	0.6	2.5	0.2
Daphnia	2.7	2.7	10.6	0.1	49.5	46.4	136.8	0.1
Other *Cladocera*	4.2	6.9	28.2	0.2	47.1	66.4	268.4	1.5

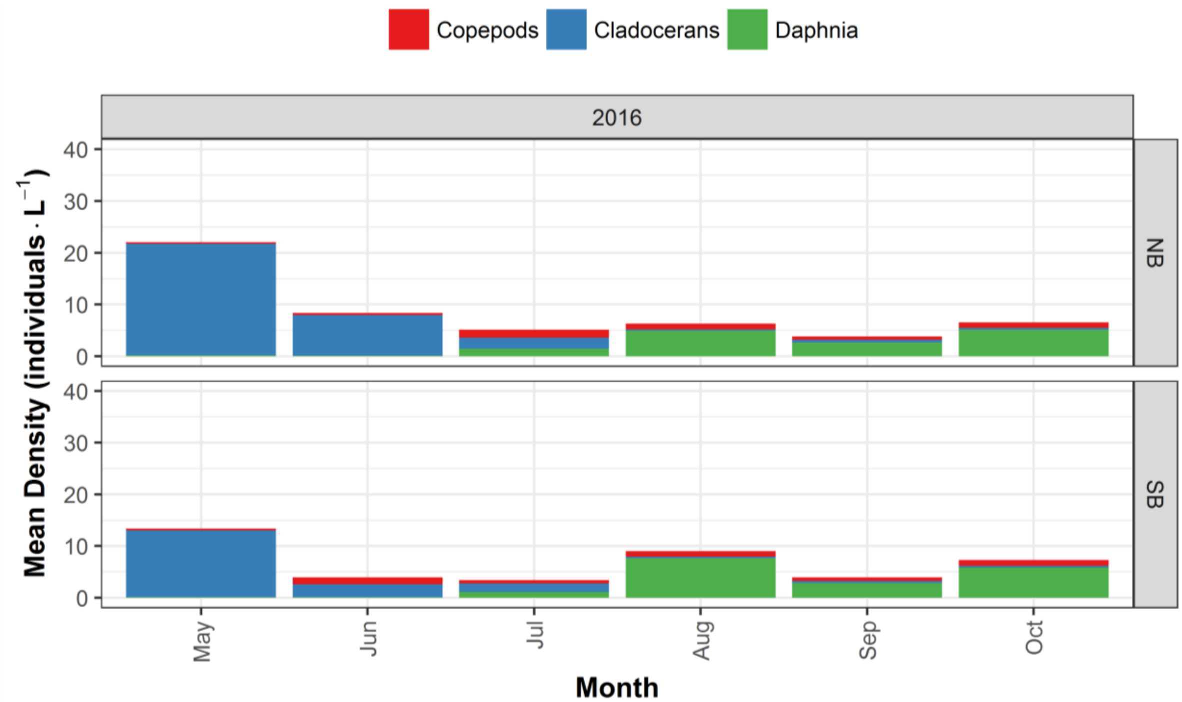

Figure 22. Monthly zooplankton density (individuals·L-1) by major group (*Copepoda*, *Daphnia* and other *Cladocera*) at the north basin (NB) and south basin (SB) limnology stations, 2016, Wahleach Reservoir BC.

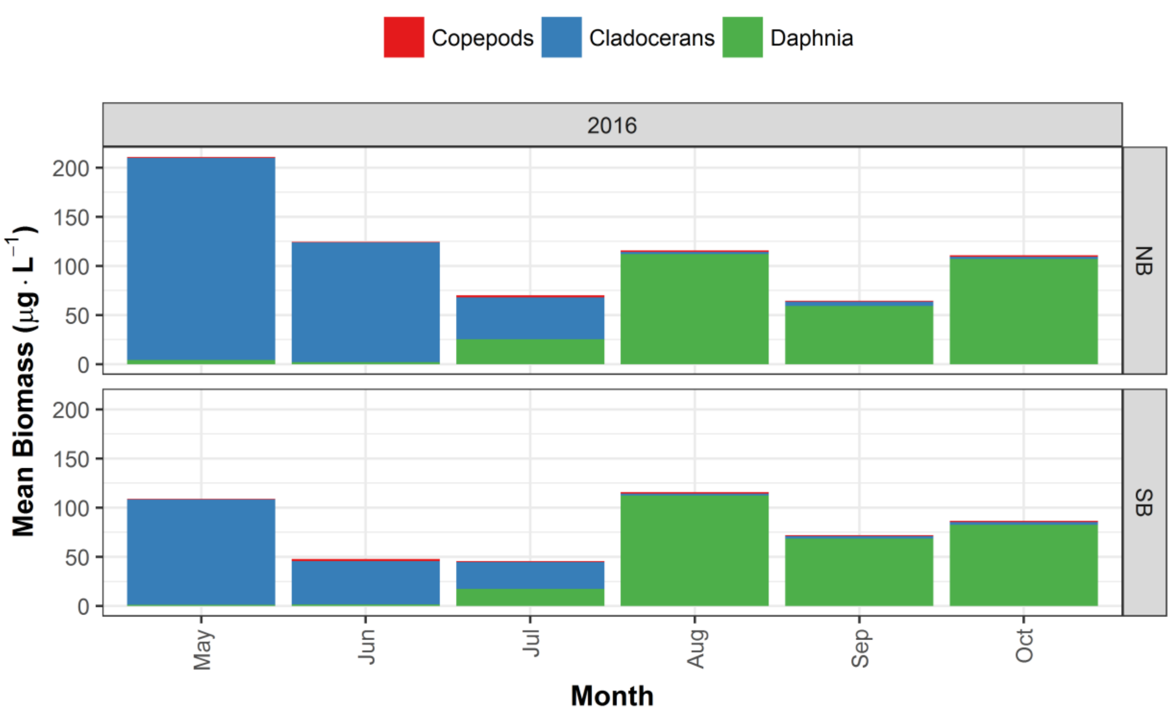

Figure 23. Monthly zooplankton biomass (µg·L^{-1}) by major group (*Copepoda*, *Daphnia* and other *Cladocera*) at the north basin (NB) and south basin (SB) limnology stations, 2016, Wahleach Reservoir BC.

4.6 Fish

4.6.1 Catch & CPUE

Nearshore gillnetting total catch in 2016 was 207, which was higher than previous years (Table 7; Sarchuk et al. 2016). The majority of the catch was Rainbow Trout at 68%, while about 12% were Kokanee (Table 8). In 2014 and onward, a 1.25" panel was added to the standard RISC net. In 2016, about 23% of the total catch was in the 1.25 inch panels (Table 9). Overall, catch-per-unit-effort (CPUE) for all species combined in the nearshore gillnetting was 0.12 fish$\cdot$100m$^{-2}\cdot$hr^{-1} (Table 10). CPUE was the highest in 2016 compared to previous years (Sarchuk et al. 2016).

Table 7. Summary of fall nearshore gillnetting catch for Wahleach Reservoir, 2016. Species include Kokanee (KO), Cutthroat Trout (CT), Rainbow Trout (RB), hybrid Rainbow Trout/Cutthroat Trout (RB/CT), Unknown fish species (UN), and Trout (general) (TR).

Species	2016[1]
CT	33
RB	141
KO	25
RB/CT	3
UN	3
TR	2
Total	207

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

Table 8. Percentage (%) of fish species composition of nearshore gillnetting program catches, 2016, Wahleach Reservoir, BC.

Species	CT	RB	RB/CT	KO	UN	TR
2016	15.9	68.1	1.4	12.1	1.4	1.0

Table 9. Summary of fall nearshore gillnetting catch for Standard vs. 1.25" panel for 2016. The 1.25" panel was added in 2014 and will now be used regularly.

Species	2016 - Standard	2016 - 1.25"
CT	29	4
RB	110	31
KO	14	11
RB/CT	3	0
UN	1	2
TR	2	0
Total	159	48

Table 10. Summary of CPUE (fish·100 $m^{-2}\cdot hr^{-1}$) during annual nearshore gillnetting program, 2016, in Wahleach Reservoir, BC.

Year	Total Fish Captured	Total Net Area (m^2)	Total Hours	CPUE (fish·100 $m^{-2}\cdot hr^{-1}$)
2016[1]	207	1530	116	0.12

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

45 Threespine Stickleback were captured in the littoral minnow trap in 2016, which was higher than in previous years (Sarchuk et al. 2016). No juvenile salmonids were captured. Total soak time was 115 trap hours. CPUE for 2016 was also higher than previous years at 0.39 fish per trap hour (Sarchuk et al. 2016). No fish were caught in the limnetic minnow traps.

4.6.2 Kokanee

Kokanee captured during the fall nearshore gillnetting in 2016 were generally smaller than in recent years (e.g. 2014 and 2015) (Table 11; Sarchuk et al. 2016). No 3+ or 4+ Kokanee were captured during fall nearshore gillnetting program due to the timing of sampling after the spawning period (Figure 24; Figure 25). Similar to 2015, Kokanee caught in 2016 during the fall nearshore gillnetting contained a high frequency of age 1+ compared to the other years (prior to 2014; Sarchuk et al. 2016), which explains the low mean length of the overall catch (Figure 24; Figure 25). When comparing summary statistics of Kokanee size by age class, individuals caught in 2016 were larger and in better condition than during the baseline years (Table 11). In 1993 and 1994 combined, Kokanee caught during fall gillnetting were nearly all age 2+ (n=43) with only 6 age 1+ caught out of a total catch of 52 Kokanee; catch statistics for age 2+ individuals had a mean length of 178 mm, mean weight was 55.5 g, and condition factor of 1.0 (data on file). Furthermore, Kokanee length-weight regressions based on 2016 fall nearshore gillnetting data, as presented in Figure 26 and Table 12, had a slope (b value) greater than 3 indicating a thicker body for a given length; fish that have thin elongated bodies tend to have b values less than 3 (Anderson et al. 1983, Cone 1989).

Table 11. Summary of Kokanee biometric data, including length, weight, condition factor (K) and age, for Wahleach Reservoir during nutrient restoration in 2016.

Year	Species	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)	Mean K	SD K	Mean Age	SD Age
2016	KO	166	18	53.4	20.2	1.1	0.07	1	0.5

Age	Fork Length (mm)				Weight (g)				Condition Factor (K)				n
	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	
1	158	9	176	145	44.1	9.3	66.5	32.5	1.1	0.08	1.22	0.91	19
2	184	20	221	157	70.8	24.1	113.5	43.0	1.1	0.06	1.19	1.02	5

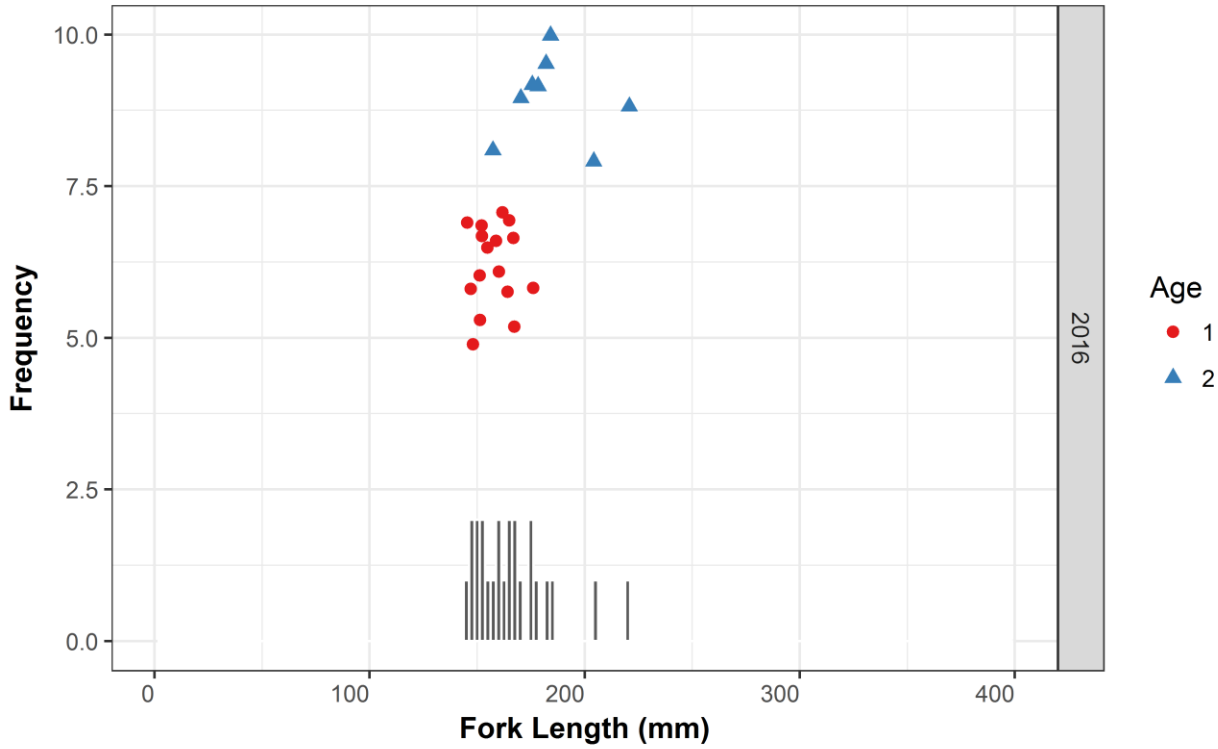

Figure 24. Length frequency and associated age-at-length of Kokanee captured in nearshore gillnet surveys, 2016, Wahleach Reservoir, BC.

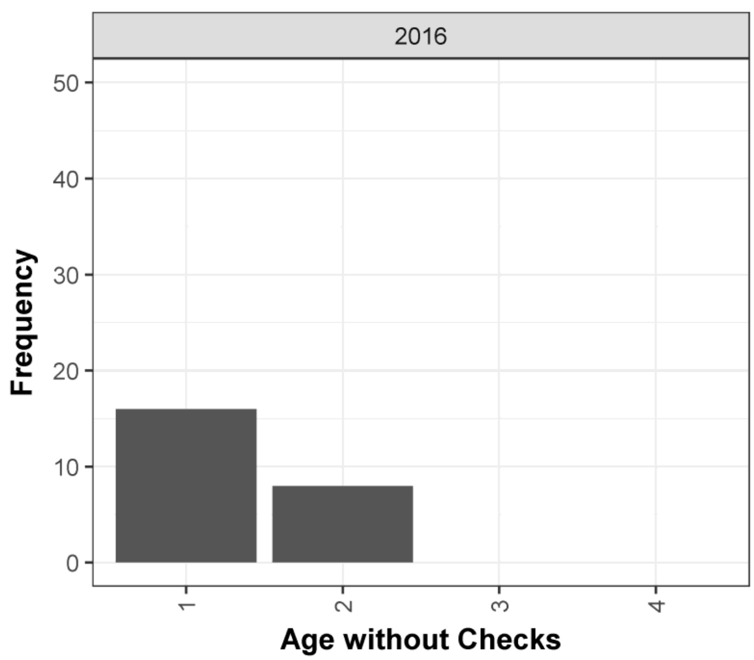

Figure 25. Age Frequency for Wahleach Reservoir Kokanee caught during fall nearshore gillnetting during nutrient restoration in 2016.

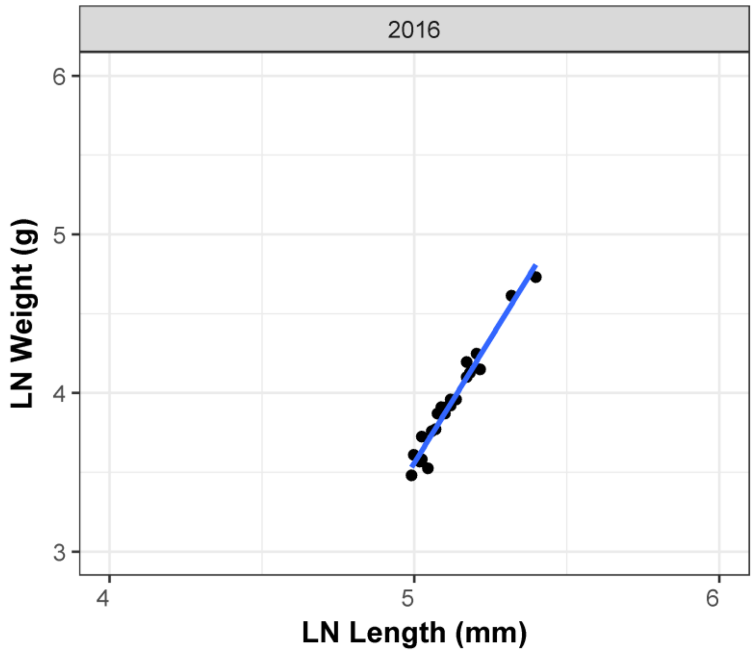

Figure 26. Natural logarithm of length weight linear regression (LN W = LN a * LN Lb) of Kokanee caught in gillnets during nutrient restoration in 2016, Wahleach Reservoir.

Table 12. Summary of variables in R for Kokanee length weight relationships (Ln W = b · Ln L + Ln a) during nutrient restoration in 2016, Wahleach Reservoir.

Year	Equation	R^2
2016	LN.weight.g = 3.14 * LN.length.mm -12.1	0.9608

4.6.2.1 Spawners

Timing of Kokanee spawning in 2016 was similar to previous years. 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 2016 was 7,411. Flat Creek had the most spawners (6,111), followed by Jones Creek (903), and then Boulder Creek (397); this pattern has been observed since 2004 with the exception of 2007 where Jones Creek had the most spawners (data on file; Sarchuk et al. 2016). In pre-treatment years, 1993-1994, Kokanee spawning had largely collapsed from a previous high of more than 16,000 individuals down to 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 205 ± 24 mm (152 to 269 mm) and ranged from age 1+ to 3+ with the majority of spawners aged at 2+ years (Table 13, Figure 28). Length frequency and associated age-at-length data show overlap in the lengths between each of the age classes. Similar to 2015, age-1+ spawners were observed in all three index streams, though in lower numbers than in 2015 (Sarchuk et al. 2016).

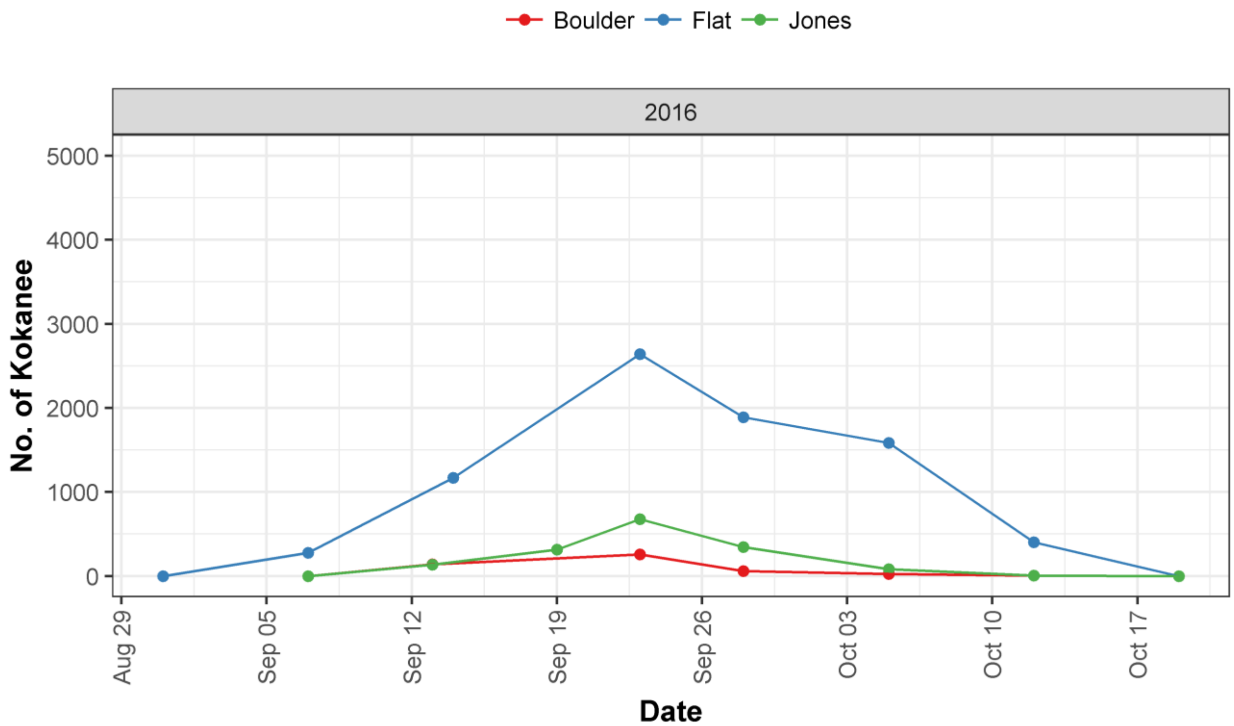

Figure 27. Kokanee spawner counts from each index stream (Boulder Creek, Flat Creek, and Jones Creek) during the 2016 spawning season in Wahleach Reservoir.

Table 13. Summary of Kokanee biometric data during the 2016 spawning season in Wahleach Reservoir. Data are for all three index streams combined: Boulder Creek, Flat Creek, and Jones Creek.

Year	Fork Length (mm)					Age				
	Mean	SD	Max	Min	n	Mean	SD	Max	Min	n
2016	205	24	269	152	98	2	1	3	1	95

Age	Fork Length (mm)				
	Mean	SD	Max	Min	n
1	168	18	199	152	6
2	198	16	238	163	67
3	235	16	269	204	22

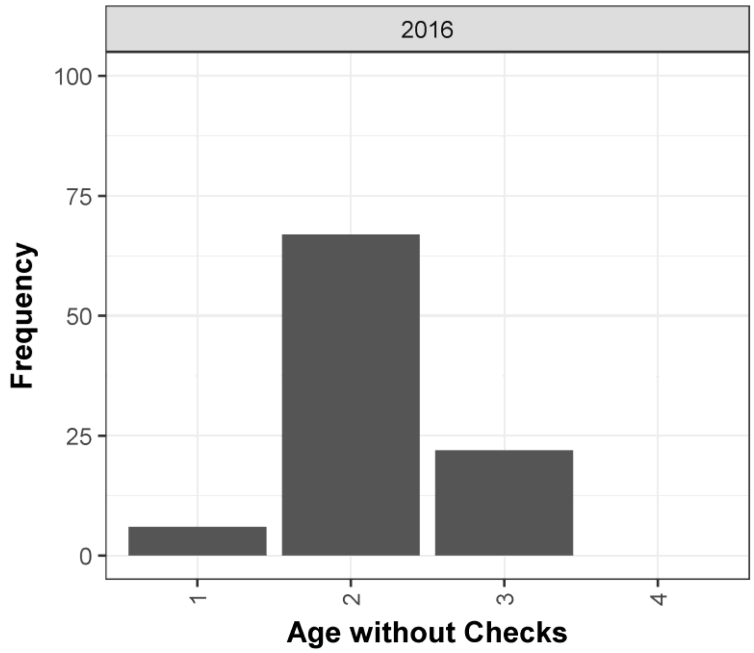

Figure 28. Age frequency of Kokanee spawners caught in index streams (Boulder Creek, Flat Creek and Jones Creek) of Wahleach Reservoir during 2016.

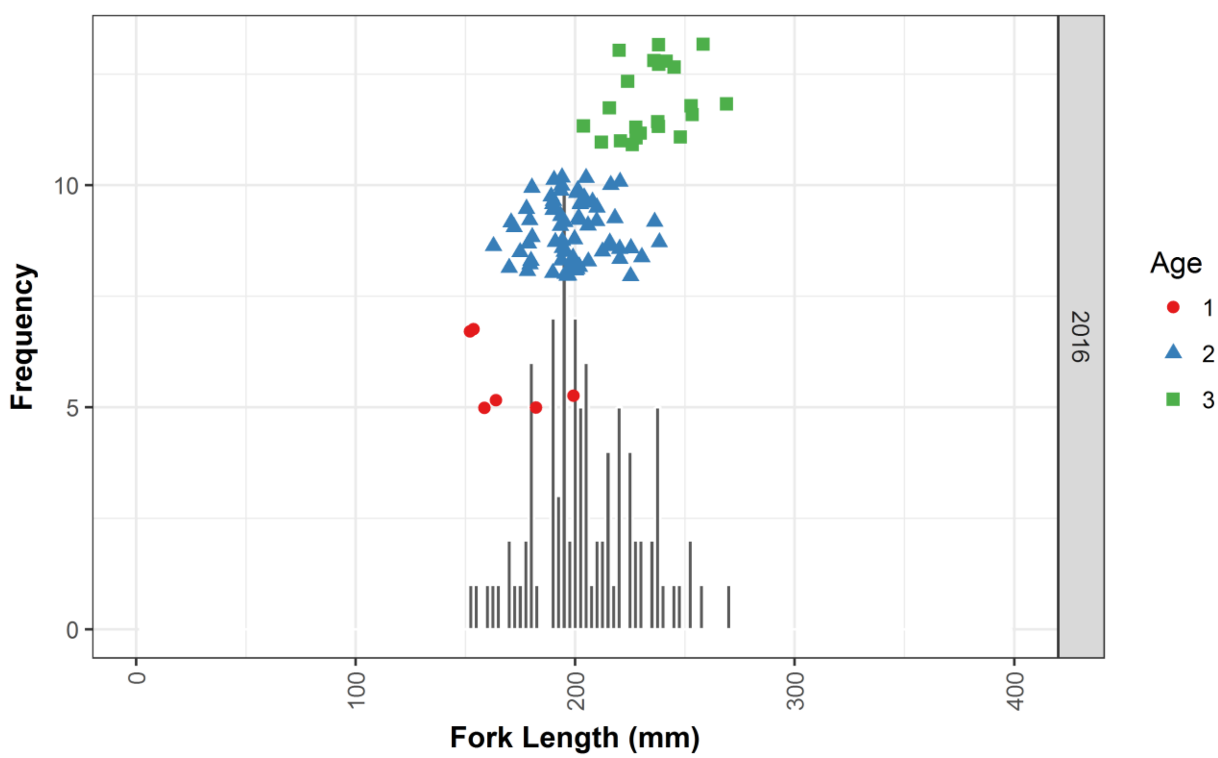

Figure 29. Length frequency and associated age-at-length of Kokanee spawners caught in index streams (Boulder Creek, Flat Creek and Jones Creek) of Wahleach Reservoir during 2016.

4.6.3 Rainbow Trout

In 2016, fall nearshore gillnet sampling captured a total of 141 Rainbow Trout ranging in length from 112 to 285 mm and in weight from 16 to 200 g (Table 14 shows the means and standard deviations). Compared to Rainbow Trout catches during baseline years, lengths of Rainbow Trout were similar with the maximum sizes of fish caught in baseline years being greater than those of 2016; Rainbow Trout catch ranged from 111 to 312 mm (mean 200 ± 53 mm) in 1993 and 118 to 324 mm (mean 182 ± 38 mm) in 1994. Likewise, Rainbow Trout caught during baseline years ranged from 14 to 307 g (mean 87 ± 61 g) in 1993 and 18 to 276 g (mean 70 ± 46 g) in 1994. Looking at the age distribution of Rainbow Trout catch in 2016, age 2+ represented the majority of the catch, and catch of older age classes (age 4+ and 5+) was low (Figure 31, Figure 30); this would account for the lower mean length and weight of overall catch data when compared to baseline years. Summary statistics for Rainbow Trout by age class are shown in Table 14; it is worth noting that one of the age 4+ individuals captured was noted to have spawned that year and had a condition factor of 0.60 which was not typical for the group. Overall, Fulton's condition factor (K) for 2016 Rainbow Trout was 1.0 ± 0.1 indicating healthy somatic growth. Rainbow Trout length-weight regressions based on fall nearshore gillnetting data for 2016 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 program, including length, weight, condition factor (CF) and age, for Wahleach Reservoir during nutrient restoration in 2016.

Year	Species	N	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)	Mean K	SD K	Mean Age (yrs)	SD Age (yrs)
2016	RB	141	189	42	78.5	43.8	1.0	0.10	2	1

Age	Fork Length (mm)				Weight (g)				Condition Factor (K)				n
	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	
1	133	18	164	112	26.1	11.5	49.0	16.0	1.04	0.11	1.18	0.68	23
2	187	26	243	116	72.7	26.3	140.5	17.5	1.07	0.08	1.30	0.93	79
3	244	17	283	220	139.2	25.1	200.0	107.5	0.96	0.06	1.07	0.85	22
4	266	17	285	251	163.3	28.9	195.0	138.5	0.89	0.25	1.07	0.60	3

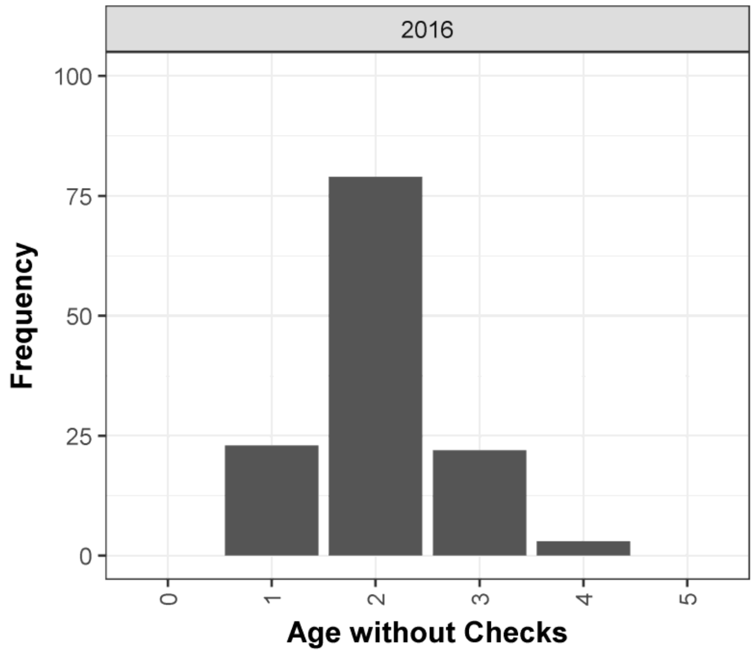

Figure 30. Age frequency of Rainbow Trout caught in fall nearshore gillnets and minnow traps during nutrient restoration years in 2016, Wahleach Reservoir. No Rainbow Trout were caught in minnow traps in 2016.

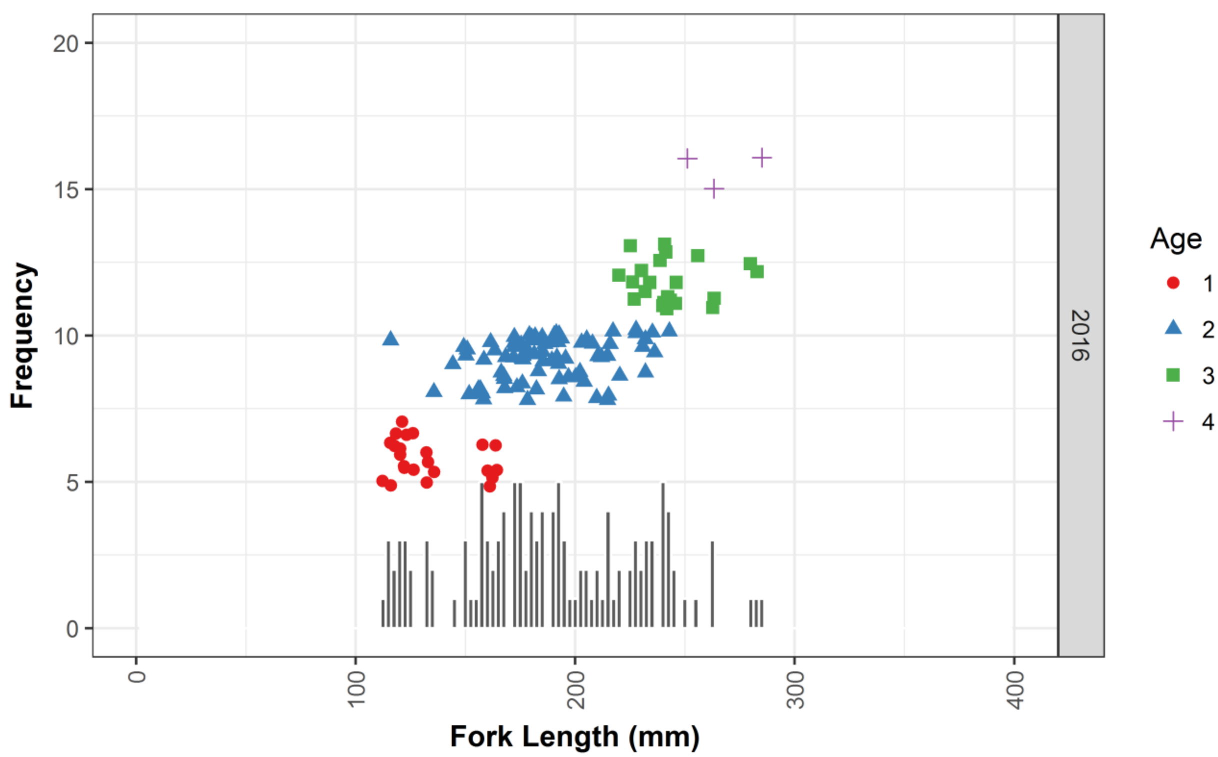

Figure 31. Length frequency and associated age-at-length of Rainbow Trout caught in fall nearshore gillnets and minnow traps during nutrient restoration in 2016, Wahleach Reservoir. No Rainbow Trout were caught in minnow traps in 2016.

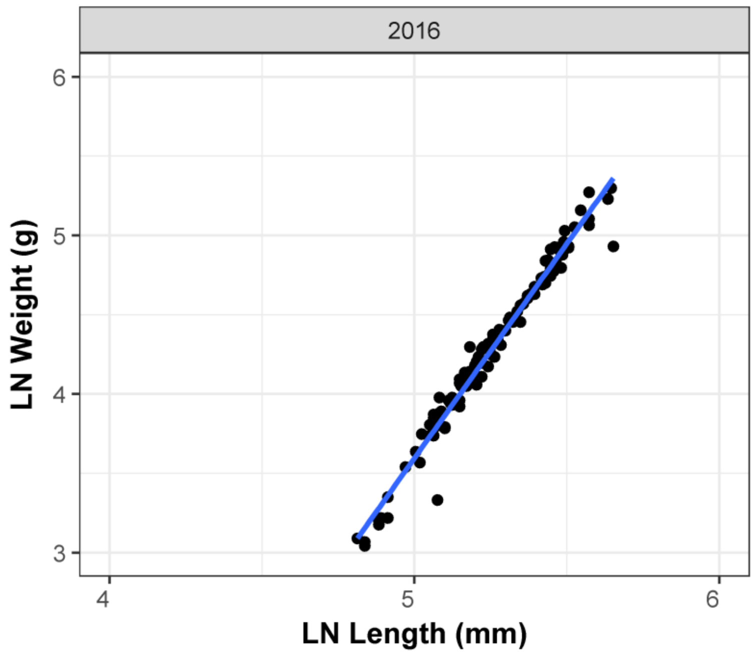

Figure 32. Length weight plot and relationship (Ln W=b . Ln L + Ln a) of Rainbow Trout caught in gillnets and minnow traps[1] during nutrient restoration years in 2016, Wahleach Reservoir. No Rainbow Trout were caught in minnow traps in 2016.

Table 15. Summary of variables in R for Rainbow Trout length weight relationships (Ln W = b · Ln L + Ln a) during nutrient restoration in 2016, Wahleach Reservoir

Year	Equation	R^2
2016	LN.weight.g = 2.81 *LN.length.mm -10.5	0.9798

4.6.4 Cutthroat Trout

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. Fall nearshore gillnet sampling in 2016 resulted in capture of 33 Cutthroat Trout ranging in length from 235 to 535 mm and in weight from 393.3 to 471.7 g (Table 16). Fulton's condition factor (K) had a mean of 1.0 indicating healthy somatic growth. Cutthroat Trout caught during 2016 were relatively evenly distributed amongst size and age, ranging from age 1+ to 6+ with age 2+ and 4+ representing most of the catch (Table 16, Figure 33, Figure 34). The length-weight regression slope (b value) for Cutthroat Trout in 2016 was greater than 3 indicating a thicker body shape (Figure 35; Table 17); b values near 3 are common for fish (Anderson et al. 1983; Cone 1989).

Table 16. Summary of Cutthroat Trout biometric data, including length, weight, condition factor (CF) and age, for Wahleach Reservoir during nutrient restoration in 2016.

Year	Species	n	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)	Mean K	SD K	Mean Age (yrs)	SD Age (yrs)
2016	CT	33	341	81	471.7	393.3	1.0	0.10	3	1

Age	Fork Length (mm)				Weight (g)				Condition Factor (K)				n
	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	
1	280	44	362	235	224.3	141.1	507.0	123.0	0.94	0.08	1.07	0.82	7
2	296	25	331	265	266.2	75.4	402.5	169.0	1.00	0.07	1.11	0.91	9
3	306	65	381	267	287.3	172.5	486.5	187.0	0.94	0.06	0.99	0.88	3
4	409	63	495	320	781.8	452.5	1620.0	345.0	1.04	0.16	1.34	0.86	9
5	435	1	435	434	777.8	39.2	805.5	750.0	0.95	0.04	0.98	0.92	2
6	535	-	-	-	1510.0	-	-	-	0.99	-	-	-	1

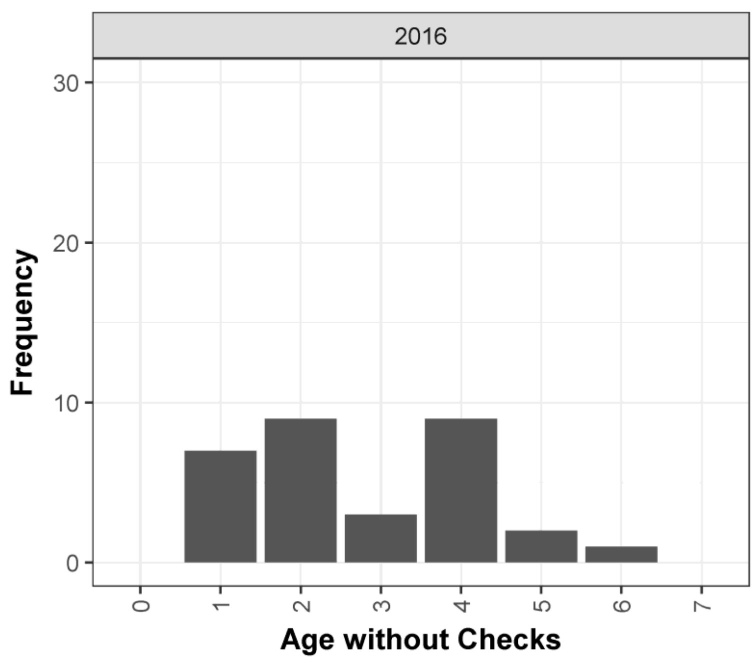

Figure 33. Age Frequency of Cutthroat Trout caught in fall nearshore gillnets during nutrient restoration in 2016, Wahleach Reservoir.

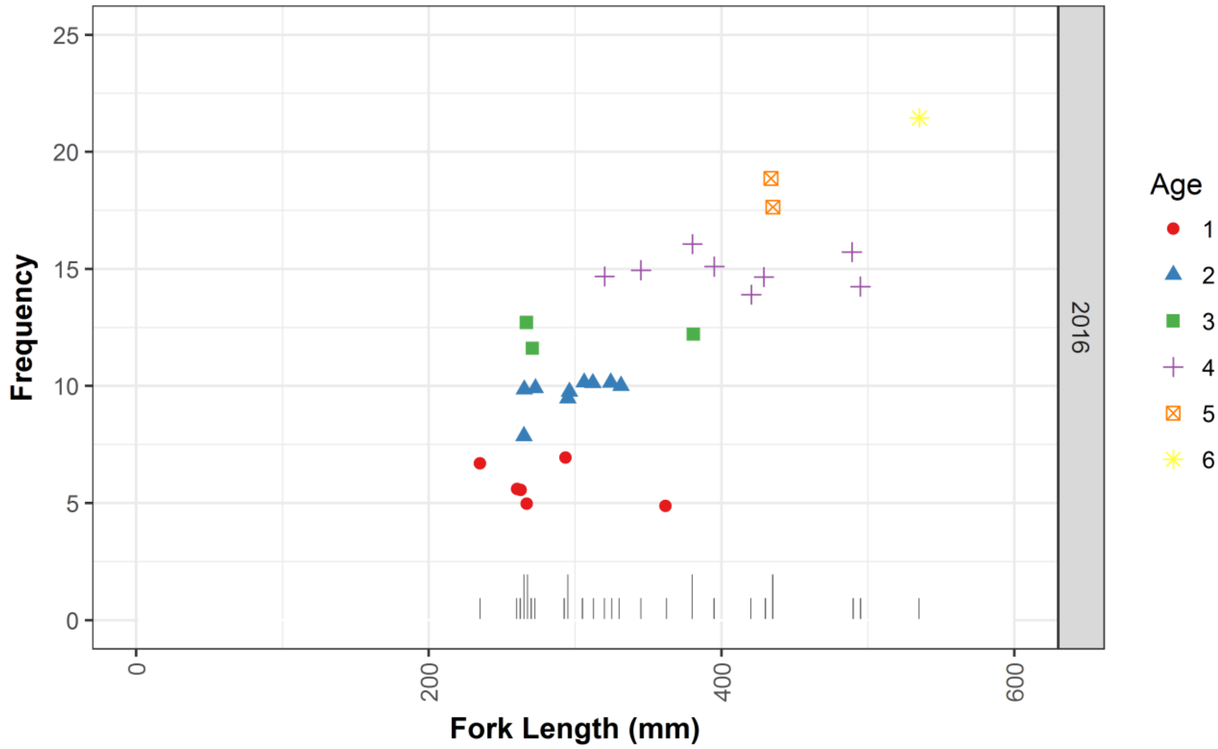

Figure 34. Length frequency and associated age-at-length of Cutthroat Trout caught in fall nearshore gillnets during nutrient restoration in 2016, Wahleach Reservoir.

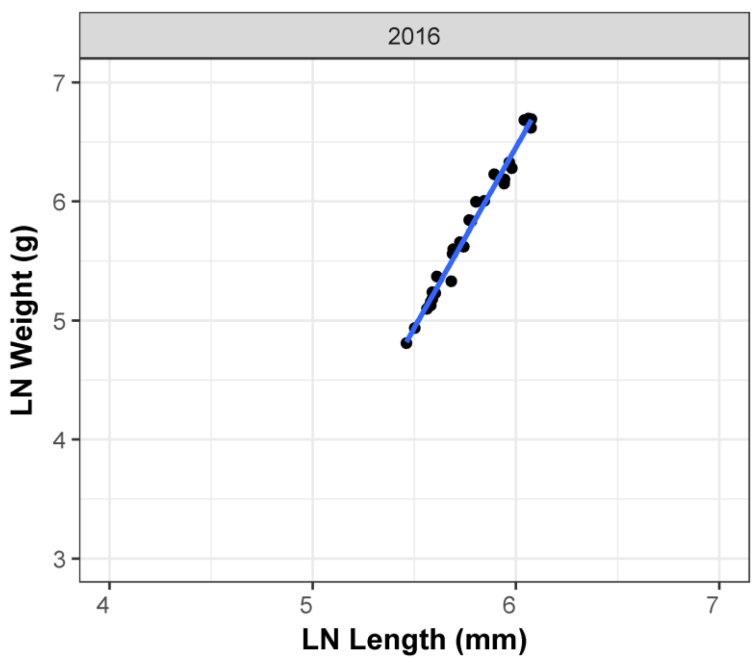

Figure 35. Length weight plot and relationship (Ln W = b · Ln L + Ln a) of Cutthroat Trout caught in gillnets during nutrient restoration years in 2016, Wahleach Reservoir.

Table 17. Summary of variables for Cutthroat Trout length weight relationships (Ln W = b · Ln L + Ln a) during nutrient restoration in 2016, Wahleach Reservoir.

Year	Equation	R^2
2016	LN.weight.g = 3.14 *LN.length.mm -12.3	R^2=0.9849

4.6.5 Threespine Stickleback

Both littoral and limnetic minnow traps were set in 2016; however, only the littoral traps were successful in capturing Threespine Stickleback. Littoral minnow traps captured a total of 45 Threespine Stickleback with a range of 26 to 46 mm in length and 0.2 to 1.1 g in weight (Table 18, Figure 36). Threespine Stickleback catch remained lower than in baseline years (n=65 Threespine Stickleback in 1994); however, the 2016 catch was greater than in recent years (Sarchuk et al. 2016).

Table 18. Summary of Threespine Stickleback length and weight data from minnow trapping on Wahleach Reservoir during nutrient restoration in 2016.

Year	n	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)
2016	45	39	4	0.6	0.2

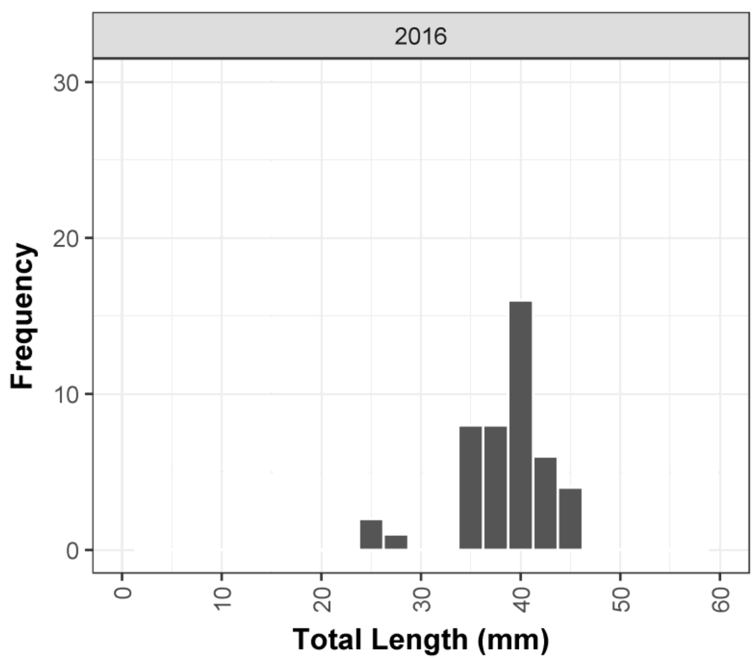

Figure 36. Length frequency of Threespine Stickleback caught in fall 2016, Wahleach Reservoir.

4.6.6 Fish Distribution

Figure 37 illustrates the acoustic target size distribution by the analysis depth range (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 (FLNRO data on file). Trawl catch data also demonstrated size differences between Threespine Stickleback and Kokanee fry that showed Threespine Stickleback are smaller in length than Kokanee fry and so would be represented within the smaller scale of acoustic targets (Appendix G). 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 12 m and 20 m (Figure 38). Small fish had a bimodal distribution with the greatest densities at 12 m and a secondary peak density near the surface at 2 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 F.

Catch data from the trawl survey further demonstrated important differences in species composition by depth within the reservoir despite catch rates being low. As shown in Figure 39 and detailed in Appendix G, Kokanee fry were the dominant catch species at or below 10 m, while Threespine Stickleback were increasingly common in shallower depths. However, it appeared that Threespine Stickleback were also present in deeper areas of the pelagic zone making interpretation of acoustic data more challenging.

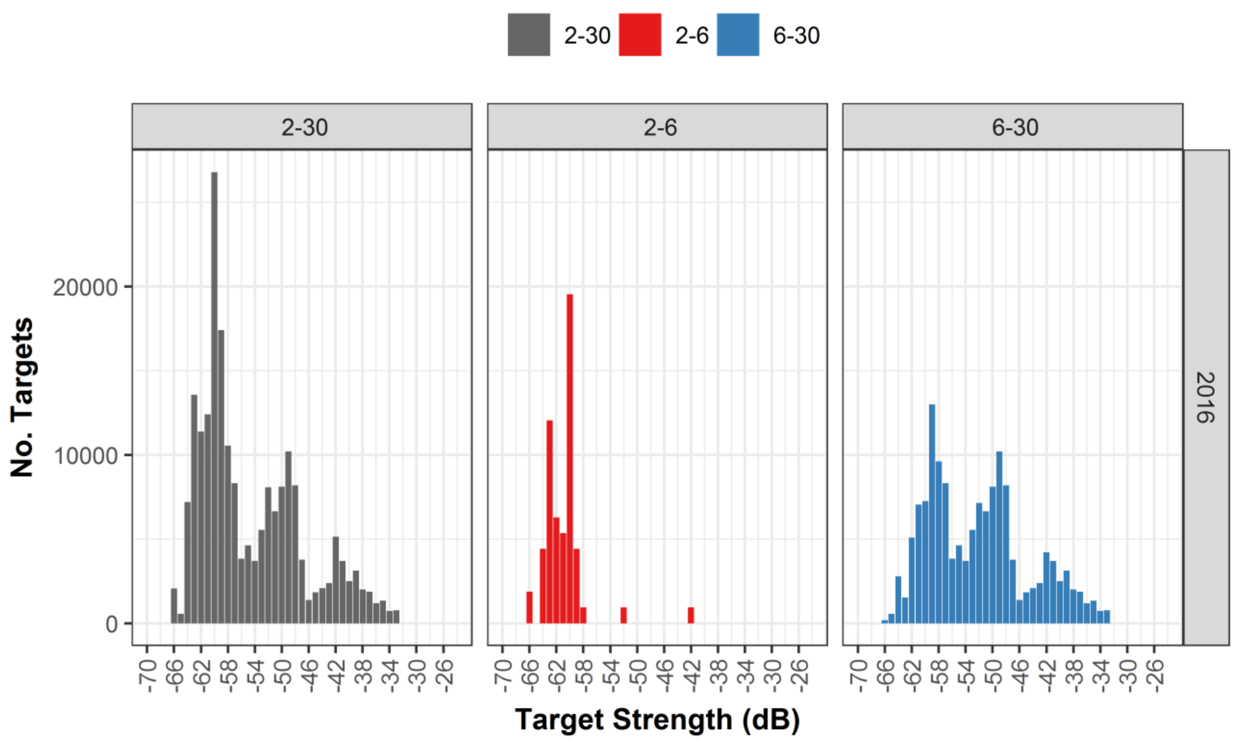

Figure 37. Target strength distributions by depth range (m) from hydroacoustic survey, 2016, Wahleach Reservoir, BC.

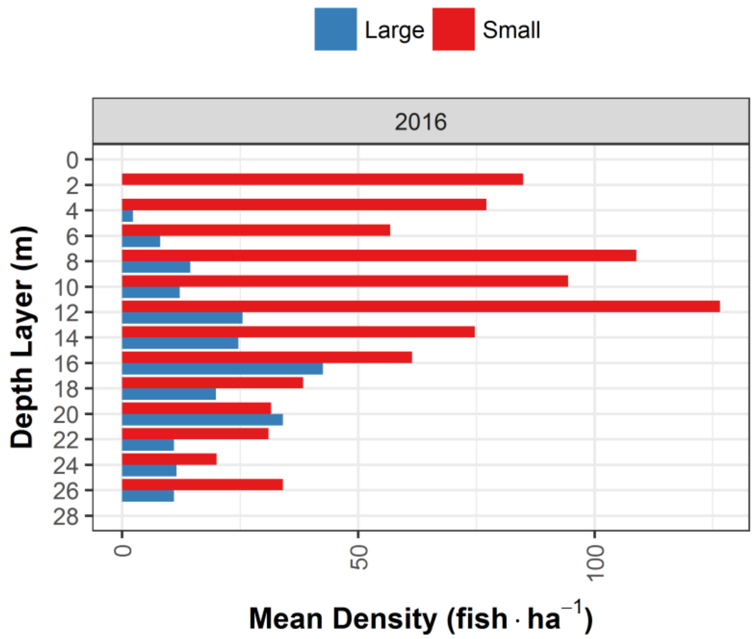

Figure 38. Distribution of fish densities by size group (small = -66 to -47 dB, large ≥ -46 dB) and depth layer based on hydroacoustic survey, 2016, Wahleach Reservoir, BC.

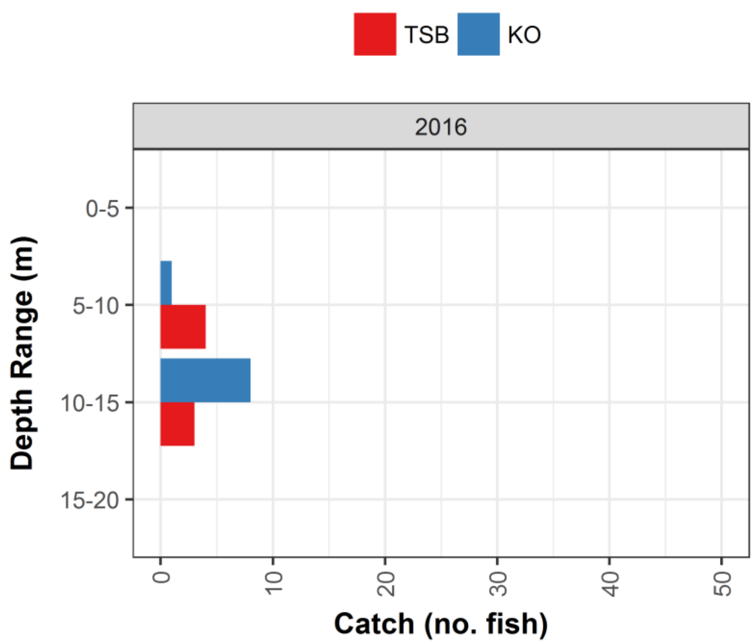

Figure 39. Vertical distribution of fish captured in trawl survey, 2016 in Wahleach Reservoir, BC.

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), fry abundance was between approximately 178,000 and 242,000 individuals, which was within the range seen in 2014 and 2015 (Table 19; Sarchuk et al*.* 2016). Even though Threespine Stickleback were distributed within the shallower portion of the Kokanee analysis depth range, overall trawl catch rates were low. Multiple lines of evidence would suggest the majority of targets at depth were Kokanee fry. The difference between the small fish population estimate and the Kokanee fry population estimate represented Threespine Stickleback populations in the pelagic zone of approximately 57,000 individuals in 2016. Adult Kokanee population estimates are generally more stable and less likely to be confounded by mixed species assemblages as demonstrated by Sarchuk et al. (2016). In 2016, the adult Kokanee population was between approximately 19,000 to 41,000 individuals aged > 1 year, which was less than the record high of approximately 65,000 individuals in 2015 but within the average range observed since 2009 (Table 19; Sarchuk et al. 2016). The total biomass of fish (all species) was estimated at 2,112 kg in 2016, which was within the average since 2009 (Sarchuk et al. 2016). Generally, biomass was driven by the abundance of fish in the large size group, which was primarily made up of adult Kokanee.

Table 19. Population estimates with upper and lower confidence intervals for all fish and kokanee based on hydroacoustic survey, 2016, Wahleach Reservoir, BC.

Year	Analysis Depths (m)	Group	Population Estimate	Lower CI	Upper CI
2016	2-30	All Fish	210,133	177,676	242,408
2016	2-30	Small Fish	179,927	151,090	208,277
2016	2-30	Large Fish	30,509	19,386	41,629
2016	6-30	All KO	152,431	126,934	178,137
2016	6-30	KO Fry	122,749	101,487	144,130
2016	6-30	Adult KO	29,699	18,812	40,715

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). Assessment metrics outlined in the Wahleach Reservoir Nutrient Restoration Project TOR included: zooplankton production, reservoir fish populations and densities, and Kokanee spawner abundance (BC Hydro 2006); assessment of the recreational fishery was added in later years (BC Hydro 2010).

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 ecosystem response (e.g. Schindler et al. 1971; Vollenweider 1976, 1968). 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, 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 2016, Wahleach Reservoir was characterized by ultra-oligotrophic conditions in terms of nutrient concentrations, and exhibited Secchi depths indicative of oligotrophic to mesotrophic conditions (Table 20).

Table 20. Trophic state classification using criteria defined by Wetzel (2001) and Wetzel (1983) during nutrient restoration, 2016, Wahleach Reservoir, BC.

Parameter (Units)	**Mean ± SD (Range)**	**Trophic Classification, Mean (Range)**			
	2016	Ultra-Oligotrophic	Oligotrophic	Mesotrophic	Eutrophic
TP ($\mu g \cdot L^{-1}$)	2.2 ± 1.4 (1.0 to 5.6)	(< 1-5)	8 (3-18)	27 (11-96)	84 (16-386)
TN ($\mu g \cdot L^{-1}$)	125 ± 34 (83 to 211)	(< 1-250)	661 (307-1,630)	753 (361-1,387)	1,875 (396-6,100)
Secchi (m)	5.3 ± 1.2 (3.7 to 7.2)	-	9.9 (5.4-29.3)	4.2 (1.5-8.1)	2.5 (0.8-7.0)

Patterns and concentrations of nitrogen and phosphorus in the epilimnion were consistent with the seasonal growth of phytoplankton and suggested a rapid uptake and assimilation of useable forms of nutrients by phytoplankton. In terms of nutrient loading from fertilizer additions, actual loads deviated from planned loading in response to monitoring results. If nutrient loads were not corrected based on changing reservoir conditions, eutrophication of the system would be a very real possibility in Wahleach Reservoir. Planned nutrient loading strategies will continue to be revised in response to changing reservoir and climatic conditions noted during data reviews, as will actual in-season loading based on incoming monitoring data.

Phytoplankton Edibility & Zooplankton Community

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 is 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 2016 consisted primarily of edible species throughout the season. Abundance was the highest on record (25,789 ± 40,616 cells·mL^{-1}) owing to growth of *Merismopedia* sp. and *Microcystis* sp., small blue-green algae belonging to the class *Cyanophyceae*. Both species were observed in an edible unicellular form, as opposed to inedible colonies (John Stockner, 2017, pers. comm.). As with abundance, biovolume was largely driven by *Merismopedia* sp. growth. Besides the notable bloom of *Merismopedia* sp., a few key species of flagellates, chlorophytes and to a lesser extent, dinoflagellates also contributed to the edible fraction of the phytoplankton community. The diatom *Tabellaria fenestrata* generally made up the inedible fraction of the community. It is common for Wahleach Reservoir, like many other coastal and sub-alpine lakes in BC, to move into low and or limiting nitrogen conditions during peak growing season (Stockner 1981, Stockner and Shortreed 1985). Under these conditions, growth of nitrogen-fixing cyanophytes (e.g. *Microcystis*, *Merismopedia*) and inedible diatoms that are able to store nutrients for later use (e.g. *Tabellaria* sp.) are favoured – as was observed in 2016.

At the zooplankton level, all major taxonomic groups have increased since the nutrient restoration project began. The most significant result has been the appearance of *Daphnia*. In 2016, *Daphnia* densities averaged near 3 individuals·L^{-1} and biomass averaged near 60 µg·L^{-1}. This accounted for 35% of overall zooplankton density and 50% of total zooplankton biomass. Overall, *Daphnia* metrics in 2016 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 2016 season prior to the onset of *Daphnia* growth. The combined outcome was the third greatest zooplankton biomass on record. These results establish that the nutrient restoration program has increased food availability for Kokanee.

Fish Population Response

Methods to determine fish abundance and biomass in Wahleach Reservoir have focused on acoustic-trawl surveys. Due to its smaller size (relative to other large lakes where acoustic-trawl surveys are commonly and successfully used), 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 2016 were consistent with years covered in the recent review report (Sarchuk et al. 2016). Unfortunately, trawl surveys in 2016 were not as successful at producing 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 reexamined during the WUP Order review. Besides the trawl data, known habitat preferences of the species present in Wahleach Reservoir were also used to refine population estimates generated from acoustic data. This method can be consistently applied year over year, and is not subject to the variability that has been seen with the trawl results. Acoustic-trawl surveys were also the basis 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 in order to eventually produce biomass density estimates, the metric most useful for comparisons of Kokanee populations across systems. Current biomass estimates for Wahleach demonstrated that Kokanee biomass generally tracked adult Kokanee abundance, which is true of other BC systems (e.g. Kinbasket and Revelstoke Reservoirs, Sebastian and Weir. 2016). Even though Kokanee fry (and to some extent Threespine Stickleback that would be present in the Kokanee analysis depths) were numerically dominant, they are considerably smaller than the older age classes of Kokanee and so do not contribute much to the system's overall biomass. 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 as a result of increases in undesirable fish species (i.e. Threespine Stickleback). Assessments of Wahleach Reservoirs' fish populations indicate a significant increase in Kokanee abundance and biomass, which were below detection limits and considered extirpated when the project began. The adult Kokanee population in 2016 was estimated at approximately 30,000 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 in 2016 continued to provide evidence of a healthy, self-sustaining Kokanee population in Wahleach Reservoir – a result directly linked to the project's model of nutrient additions and initial stocking. Data from 2016 continued to show Kokanee were in better condition than in baseline years. Similar to 2015, Kokanee caught in 2016 were shorter and lighter compared to previous years; however, Kokanee abundance was high for this system in 2016 suggesting density-dependent growth response.

In 2016, minnow trap catch of Threespine Stickleback was greater than recent years, but remained lower than baseline. Minnow traps were set in both the littoral and limnetic areas of the reservoir in 2016, but only the littoral traps were successful in capturing Threespine Stickleback. Trawl data confirmed that Threespine Stickleback were present in the pelagic areas of Wahleach Reservoir, and that they were smaller than Kokanee fry (Appendix G). Acoustic data for the pelagic area indicated that fish present in the upper 6 m of the water column belonged to small size classes; and when water temperatures were considered, data suggest that this portion of the acoustic population would be primarily Threespine Stickleback. The acoustic population for small fish in the 2-6 m depth strata was approximately 57,000 individuals, which was near the average since 2009 (data on file) and overall was significantly lower than original population estimates of 1.2 million individuals during baseline years of the project (Perrin et al. 2006).

Rainbow Trout

Similar to previous years, Rainbow Trout made up the majority of fish catch in nearshore gillnets. In 2016, catch of older age classes (i.e. 4+ and 5+) was low with age 2+ dominating the catch statistics. Overall, Rainbow Trout catch in 2016 indicated the condition factor, length and age frequency of the population was stable.

Cutthroat Trout

Results of the assessments for Cutthroat Trout in 2016 were similar to previous years and indicated the condition factor of individuals in the population was stable. Sterile Cutthroat Trout have been stocked in Wahleach Reservoir to control Threespine Stickleback numbers, representing the biomanipulation component of the project. A total of 2,050 triploid yearlings were stocked in 2016. Catch of Cutthroat Trout in 2016 continued to demonstrate that individuals were remaining in the population long enough to reach the sizes required to exhibit piscivorous feeding, which was also confirmed though stomach content analysis by Perrin et al. (2006) in the earlier years of the project.

Kokanee Spawning

Kokanee spawner escapement in 2016 was estimated at 7,411 individuals, demonstrating the presence of a restored Kokanee population on Wahleach Reservoir. Like 2015, both spawning and spent age 1+ Kokanee 'jacks' and 'jills' were observed in all three of the index streams (Boulder, Flat, and Jones creeks), though in lower numbers than other age classes present in 2016 and also lower than the frequency of age 1+ spawners seen in recent years (Sarchuk et. al. 2016). 'Jacks' and 'jills' are defined as fish returning after one year and are smaller than the typical spawning population. Although this life history strategy is uncommon, it has been documented in Sockeye Salmon in a number of systems including the Babine (Foote et al. 1997), Fraser and Okanagan (Burgner 1991) and can vary between common and rare depending on the system; though, in general, 'jills' are not commonly reported. One difference is that Sockeye 'jacks' or 'jills' spawn at age 2+ owing to the ocean phase of their lifecycle. Investigation of the factors leading to the incidence of age-1+ spawners would be worth additional attention from a scientific perspective, though this is outside the scope of the current project.

Recreational Fishery

A creel survey was not conducted on Wahleach Reservoir in 2016; the next creel survey is scheduled for 2017. For an overview of recent recreational fishery assessments on this system, refer to Sarchuk et al. (2016). In the absence of recent creel data, we can review data collected from other monitoring programs, as we know that increased size and catch rates for Kokanee are important factors in attracting anglers to recreational fisheries (Askey and Johnston 2013). In 2016, monitoring data indicated that adult Kokanee abundance was stable with 19,000 to 41,000 individuals in the reservoir during the summer with an escapement of over 7,000 spawners. As well, age 2+ and age 3+ Kokanee were above 22 cm fork length, the known minimal threshold size for satisfying angler interest (Askey and Johnston 2013). Overall, provided that anglers are aware of the opportunity and techniques to fish for Kokanee, there is high potential for greater catches of Kokanee in a suitable size range. Furthermore, angling regulations for Wahleach Reservoir now allow the retention of four trout with only one over 40 cm; this provides the opportunity for anglers to catch and retain Rainbow Trout, as well as the possibility of retaining, larger Cutthroat Trout that are present in the reservoir.

6. Conclusion

It is evident that seasonal nutrient addition on Wahleach Reservoir has had a positive effect on the lower trophic levels and ultimately the reservoir's Kokanee population, as demonstrated from program monitoring data and also when considering the evidence from systems across BC (e.g. Alouette Reservoir, see Hebert et al. 2016). 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 at current levels (~2000) and size (yearling) to maintain top-down pressure on the Threespine Stickleback population; stocking decisions should continue to be informed by data collected from the gillnetting, minnow trapping, acoustic and trawl programs.

- Continue to abstain from Kokanee and Rainbow Trout stocking.

Monitoring Programs

Limnology

- Continue monthly limnology sampling to adaptively manage the nutrient restoration program approach.

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

- Complete analysis of chlorophyll *a* samples.

Fish Populations

- Continue the 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 prior to the WUP Order Review to evaluate its efficacy in smaller mixed-species systems.

Recreational Fishery

- Creel surveys to assess the recreational fishery on Wahleach Reservoir should be incorporated into regular program monitoring. One additional creel survey in 2017 is recommended to assess the effects of regulation changes on the fishery. Over the long-term, at least one creel survey completed over each five year cycle should be sufficient to understand how anglers are responding to restoration actions; ideally the creel survey would be completed during year 3 with a contingency budget for a second creel, so if something significant is detected or logistical issues arise (as has often been the case on Wahleach due to difficulties with road access etc.) another survey can be scheduled for the last year of the five year cycle.

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

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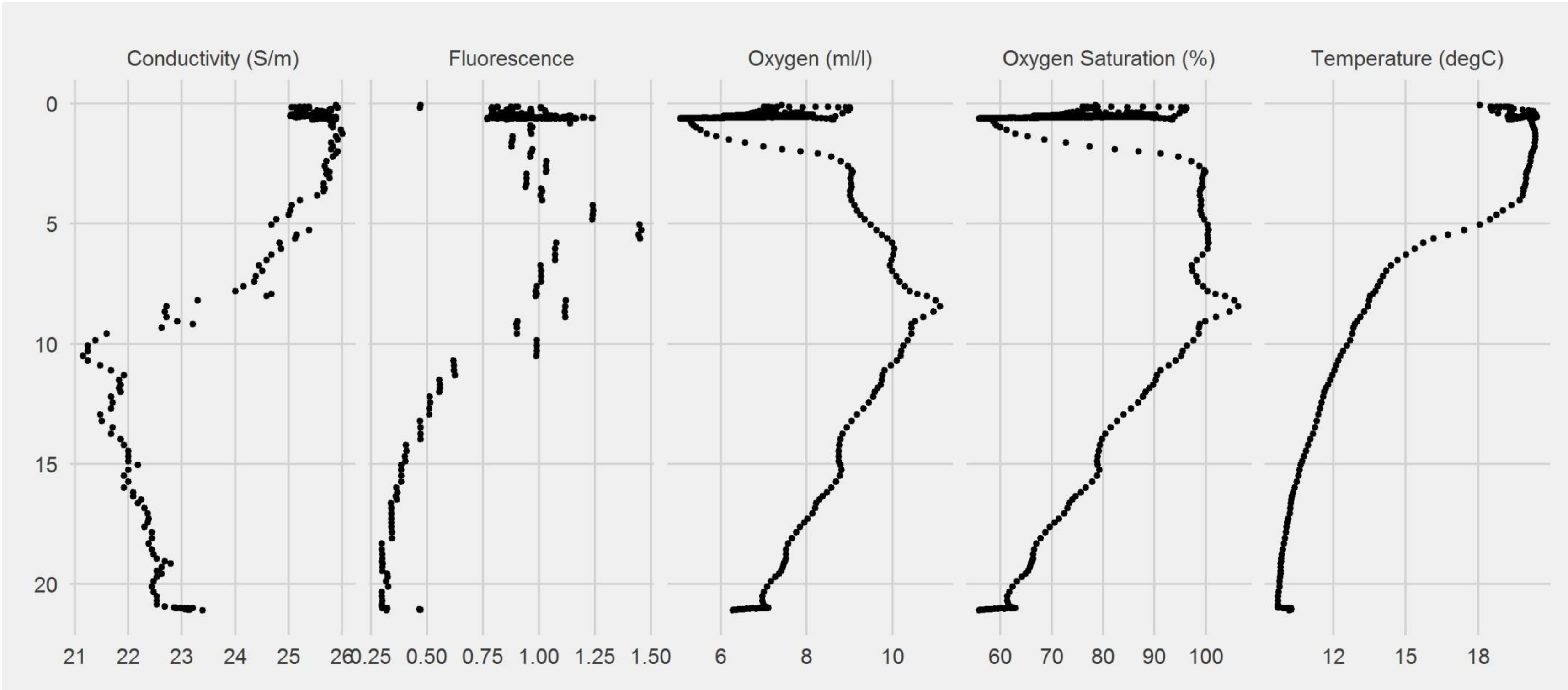
Appendix A. Details of water chemistry samples collected during the limnology field program on Wahleach Reservoir and analysed by ALS Environmental Laboratory, Burnaby, BC, 2016. All parameters were sampled at depths of 1 m, 20 m, and a vertically integrated sample from the surface (0 m) to the mixed layer depth or to a maximum of 20 m if the reservoir was not thermally stratified.

Parameter	Sample Frequency	Preservation	Reportable Detection Limit	Analytical Method
Alkalinity	Monthly Apr-Oct	Cold	1.0 mg $CaCO_3 \cdot L^{-1}$	APHA 2320 Alkalinity
pH	Monthly Apr-Oct	Cold	0.10	APHA 4500-H pH Value
Nitrogen: Nitrate and Nitrite	Monthly Apr-Oct	Cold	3.0 $\mu g \cdot L^{-1}$ Nitrate, 1.0 $\mu g \cdot L^{-1}$ Nitrite	EPA 300.0; EPA 300.1 (mod)
Nitrogen: Total	Monthly Apr-Oct	H_2SO_4	30 $\mu g \cdot L^{-1}$	APHA Method 4500-P (J) / NEMI 5735
Nitrogen: Total Kjeldahl	Monthly Apr-Oct	H_2SO_4	50 $\mu g \cdot L^{-1}$	BC MOE LABORATORY MANUAL (2005)
Phosphorus: Dissolved Orthophosphate	Monthly Apr-Oct	Cold	1 $\mu g \cdot L^{-1}$	APHA 4500-P Phosphorus
Phosphorus: Dissolved	Monthly Apr-Oct	Field filtered 0.45 µm sterile Sartarous filter, H_2SO_4	2 $\mu g \cdot L^{-1}$	APHA 4500-P Phosphorous
Phosphorus: Total	Monthly Apr-Oct	H_2SO_4	2 $\mu g \cdot L^{-1}$	APHA 4500-P Phosphorus
Silicate (as SiO_2)	May, Jun, Aug-Oct	Cold	0.5 $mg \cdot L^{-1}$	APHA 4500-SiO2 E.
Metals: low level Total	Sep only	HNO_3	Various	EPA 200.8
Hardness	Sep only	HNO_3	0.5 mg $CaCO_3 \cdot L^{-1}$	APHA 2340B

Appendix B. Reservoir conditions as shown through profile data taken during hydroacoustic survey, 2016 in Wahleach Reservoir, BC.



Lake	Wahleach
Station	Penstock
Date	2016-07-27
File	ll2016_053.cnv

Appendix C. Detailed equipment specifications and data analysis parameters used for acoustics, 2016, Wahleach Reservoir, BC.

Project Phase	**Category**	**Parameter**	**Value**
Data Collection	Echosounder	Manufacturer	Simrad EK60
		Software	Simrad ER60 ver. 2.2.1
	Transceiver	Frequency	120 kHz
		Max power	100 W
		Pulse duration	0.256 ms
		Band width	8.71 kHz
		Absorption coefficient	4.11 dBKm
		Amplitude threshold	-70 dB (40 Log R TVG)
	Transducer	Type	split-beam
		Depth of face	1.0 m
		Orientation, survey method	vertical, mobile, tow foil
		Sv, TS transducer gain	26.6 dB
		Angle sensitivity	23.0
		nominal beam angle	7.0 deg
		Data collection threshold	-70 dB
		Ping rate	3-5 pps
Analysis	Processing software	-	SONAR 5 version 6.0.0
	Single target filter	Analysis threshold	-66 to -24 dB
		Min echo length	0.7 – 1.3
		Max. phase deviation	0.3 deg.
		Max gain compensation	6 dB

Appendix D. Phytoplankton species detected in samples during 2016 in Wahleach Reservoir, BC.

Species	2016	Species	2016
Achnanthidium sp.	+	Mallomonas sp2	+
Ankistrodesmus sp.	+	Merismopedia sp.	+
Aphanothecae sp.	+	Microcystis sp.	+
Asterionella formosa var1	+	Microcystis sp. (cells)	+
Bitrichia sp.	+	Monoraphidium sp.	+
Botryococcus sp.	+	Navicula sp.	+
Carteria sp.	+	Ochromonas sp.	+
Chlorella sp.	+	Oocystis sp.	+
Chromulina sp1	+	Peridinium spp.	+
Chroomonas acuta	+	Phacus sp.	+
Chrysochromulina sp.	+	Planctosphaeria sp.	+
Chrysococcus sp.	+	Pseudokephrion sp.	+
Coelastrum sp.	+	Pyramimonas sp.	+
Cosmarium sp.	+	Rhizosolenia sp.	+
Cryptomonas sp.	+	Scenedesmus sp.	+
Cyclotella comta	+	Scourfieldia sp.	+
Cyclotella glomerata	+	Small microflagellates	+
Cyclotella stelligera	+	Sphaerocystis sp.	+
Dinobryon sp.	+	Synechococcus sp. (coccoid)	+
Elakatothrix sp3	+	Synechococcus sp. (rod)	+
Fragilaria capucina	+	Synechocystis sp.	+
Gymnodinium sp1	+	Synedra acus	+
Gymnodinium sp2	+	Synedra nana	+
Gyromitus sp.	+	Synedra ulna	+
Isthmochloron sp.	+	Tabellaria fenestrata	+
Kephyrion sp.	+	Tetraedron sp.	+
Komma sp.	+		

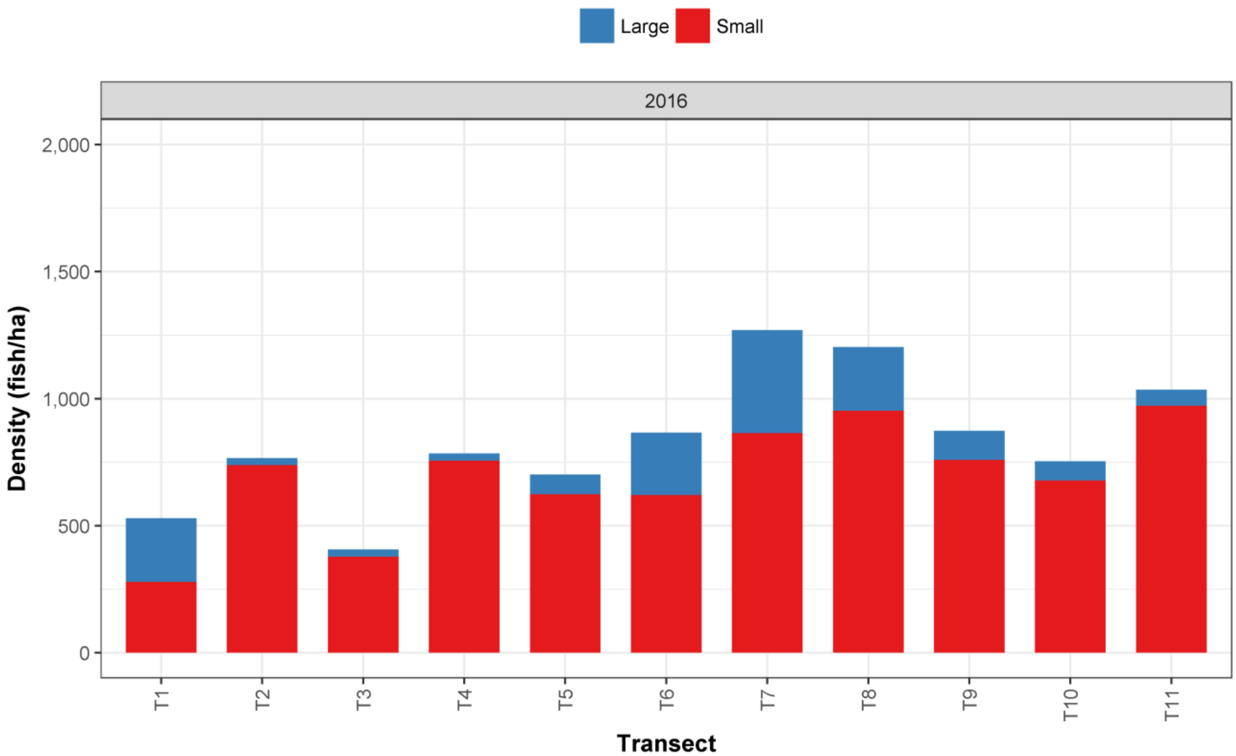
+ = present

Appendix E. Zooplankton species detected in samples during 2016 in Wahleach Reservoir, BC.

Order/Species	2016
CLADOCERA	
Alona sp.	+
Bosmina longirostris	+
Chydorus sphaericus	+
Daphnia rosea	+
Holopedium gibberum	+
Leptodora kindtii	+
Scapholeberis mucronata	+
COPEPODA	
Cyclops vernalis	+
Leptodiaptomus ashlandi	+

r = rare species, + = present

Appendix F. Acoustic density distribution by size group (small = -66 to -47 dB, large ≥ -46 dB) and transect, 2016 in Wahleach Reservoir, BC.



Appendix G. Detailed haul and catch information from trawl surveys, 2016 in 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	
2	10 U	601138	545707	10 U	600761	5453049	Sped up from 2.8 to 3.1 kph at 25 min
3	10 U	600761	5453049	10 U			No ending position indicated

Trawl No	Start Time	Duration (min)	End Time	Cable Length (m)	Net Depth (m)	Target Depth (m)
1	22:22	60	23:22	60	8	8-10.5
2	23:43	25	0:08	69	13	12.5-15
2	0:08	25	0:33	69	11	11-13.5
3	1:00	15	1:15	65	10	10-12.5
3	1:15	15	1:30	87	17	17-19.5
3	1:30	10	1:40	71	14	13.5-16

Trawl No	Sample No	Species	Length (mm)	Weight (g)	Condition Factor
1	1	KO	61.0	2.10	0.93
1	2	TSB	50.0	1.20	0.96
1	3	TSB	51.0	1.20	0.90
1	4	TSB	48.0	0.90	0.81
1	5	TSB	29.0	0.20	0.82
2	6	KO	71.0	3.20	0.89
2	7	KO	52.0	1.40	1.00
2	8	KO	61.0	1.80	0.79
2	9	KO	62.0	2.10	0.88
2	10	TSB	49.0	1.10	0.93
2	11	TSB	22.0	0.10	0.94
3	12	KO	65.0	2.10	0.76
3	13	KO	63.0	2.30	0.92
3	14	KO	60.0	1.80	0.83
3	15	KO	54.0	1.30	0.83
3	16	TSB	33.0	0.30	0.83