Wahleach Project Water Use Plan

Wahleach Reservoir Fertilization Program

Implementation Year 5 - 11

Reference: WAHWORKS-2

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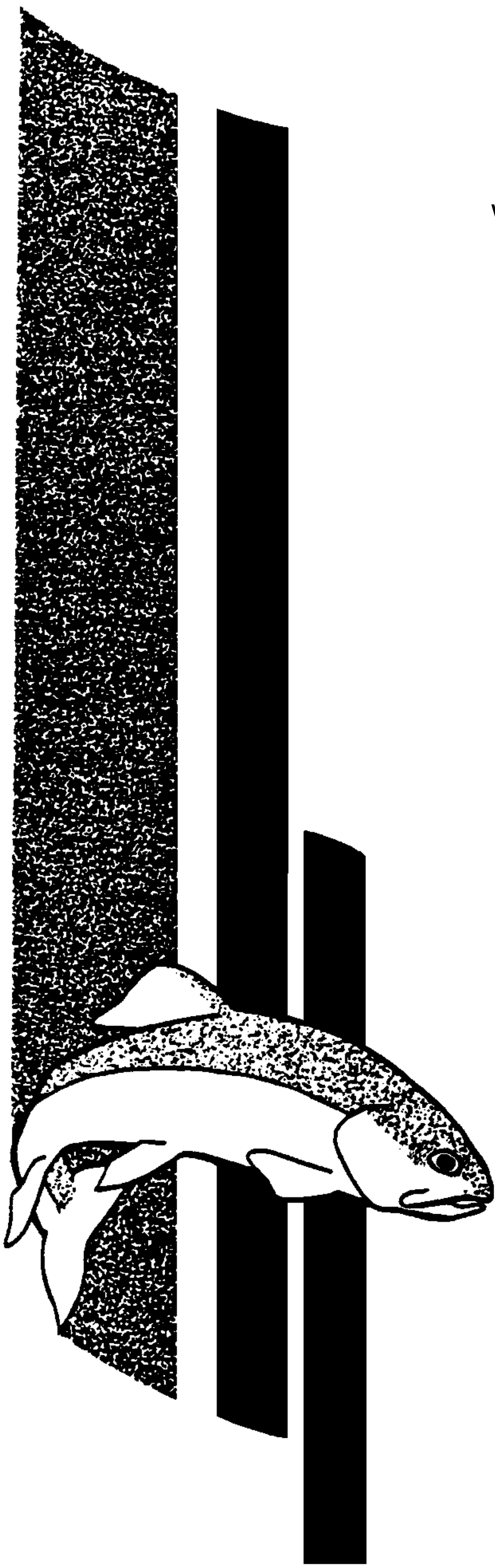

WAHLEACH RESERVOIR NUTRIENT RESTORATION PROJECT, REVIEW REPORT, 2009-2015

by

J.A. Sarchuk, A.S. Hebert, H. Andrusak, S.L. Harris,
T. Weir, and D. Sebastian

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2019

Province of British Columbia
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J.A. Sarchuk[1], A.S. Hebert[1], H. Andrusak[2], S.L. Harris[1], T. Weir[3], and D. Sebastian[4]

1. Ministry of Environment and Climate Change Strategy; Ecocsytems Branch, Conservation Science Section, 315 - 2202 Main Mall, Vancouver, BC V6T 1Z4
2. Redfish Consulting, 5244 Highway A. Nelson, BC V1L 4N6
3. Ministry of Forests, Lands, Natural Resource Operations and Rural Development; Fish, Wildlife and Habitat Management Branch, 4th Floor - 2975 Jutland Road, Victoria, BC V8T 5J9
4. BC Conservation Foundation

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Executive Summary

The restoration of Wahleach Reservoir has focused on nutrient addition in combination with biomanipulation of the food web via stocking of sterile cutthroat trout. The objective of the project is to restore historical populations of Kokanee in the reservoir. Annual monitoring is undertaken to adaptively manage the program and assess the ecosystem response in the reservoir; a suite of physical, chemical and biological parameters were measured from May to October to achieve this end. Data presented are from 2009 to 2015; this report is intended as a summary review report.

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 have also confirmed sterile Cutthroat Trout stocked in Wahleach Reservoir exhibit top-down pressure on the Threespine Stickleback population through predation, which has reduced Threespine Stickleback abundance in the reservoir, and has allowed the Kokanee to take advantage of the improved conditions. Combined restoration efforts have clearly been able to restore and maintain Wahleach Reservoir's Kokanee population over the long-term.

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

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1. Introduction

The Wahleach Reservoir Nutrient Restoration Project is a unique project originally developed as part of a complex fisheries management strategy focused primarily on Kokanee (*Oncorhynchus nerka*) production. The project draws on a significant body of literature from over fifty years of federal and provincial nutrient addition experiments in British Columbia (e.g. Stockner 1981, Stockner and MacIsaac 1996, Wilson *et al*. 2002, Stockner and Ashley 2003, Hebert *et al*. 2015, Schindler *et al*. 2013; Schindler *et al*. 2014). When the first phase of restoration was initiated in 1993, the recreational fishery on Wahleach Reservoir had collapsed; Rainbow Trout (*Oncorhynchus mykiss*) were stunted (<20 cm) and in poor condition, while Kokanee were recorded in low numbers and considered extirpated in 1995. The collapse of 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 the illegal or accidental introduction of a competitor fish species – Threespine Stickleback (*Gasterosteus aculeatus*) (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 restoration project is to restore and maintain Wahleach Reservoir fish populations, specifically Kokanee. The nutrient addition treatment was meant to increase nitrogen and phosphorus concentrations in a way that optimized food resources for higher trophic levels. It is well established that nutrient addition 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 edible phytoplankton and, in turn, increasing zooplankton biomass, specifically *Daphnia* spp. which is a key forage item for planktivorous fish such as Kokanee (Thompson 1999, Perrin and Stables 2000, Perrin and Stables 2001). Stimulation of the lower trophic levels plays a key role in increasing fish populations.
The fish stocking treatment has two purposes: first was the short-term supplementation of Kokanee to re-establish the extirpated population, and 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 effect for Kokanee, as in some systems competition between Kokanee and other fish species counteracts the positive effects of nutrients addition (Hyatt and Stockner 1985). In Wahleach Reservoir, sterile Cutthroat Trout (*Oncorhynchus clarkii*), a known piscivore, were introduced to decrease Threespine Stickleback populations and associated forage pressure on *Daphnia* sp., thus freeing up resources for Kokanee.

The Wahleach Reservoir Nutrient Restoration Project consisted of three phases: baseline data collection completed in 1993 and 1994, nutrient addition treatment from 1995 onward, and fish stocking treatment from 1997 onward. Project funding was provided by BC Hydro from 1993-2002 for delivery of the program by Limnotek Research and Development. While the Water Use Plan (WUP) was in development, limited funding for the 2003 and 2004 field season was provided to MOE 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 maintain 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) will need to continue until completion of the WUP Order Review (scheduled for 2017) 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).

This report presents a comprehensive review of the nutrient restoration project focused on the most recent seven years (2009 to 2015), which covers all years since the last review report (Squires and Stables 2009).

2. Methods

All figures and analyses contained in this report with the exception of Appendices 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. Use of R was intended to reduce error in data manipulations and calculations, increase reproducibility of analysis, and facilitate peer review. Because this is the first Wahleach Reservoir Nutrient Restoration Project report completed using R, some differences in the numbers reported for past years may occur; these differences were primarily a result of undetected error in past data files or analyses, or minor changes in the way data were manipulated. Additional details on the data and analysis for each discipline are described in the sections to follow.

All R figures were produced using the ggplot2 package. For box plots, upper and lower "hinges" represent the first and third quartiles (25th and 75th percentiles). The upper whisker extends from the hinge to the highest value that is within 1.5 * IQR of the hinge, where IQR (inter-quartile range) is the distance between the first and third quartiles. The lower whisker extends from the hinge to the lowest value within 1.5 * IQR of the hinge. Data beyond the end of the whiskers are described as possible outliers and plotted as points using Tukey's Method.

All "long-term" values reported were calculated for the entire duration of the Wahleach Reservoir Nutrient Restoration Project, representing years 1993-2015. Values for comparison to baseline studies were taken from data on file.

2.1 Study Site

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 claimed traditional territory of the Sto:lo Nation. 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 hydroelectric dam at the original lake's outlet stream. Wahleach Reservoir has a surface area of approximately 460 ha, and can hold 66 million m^3 of water at a maximum depth of 29 m; the minimum operating level is 628 m (BC Hydro 2004). The reservoir is dimictic – having two seasons of complete mixing within the water column during spring and fall, and two seasons of thermal stratification during summer and winter. Ice cover on Wahleach Reservoir generally occurs from December through March. Fish species in Wahleach Reservoir include: Kokanee, Rainbow Trout, sterile Cutthroat Trout, and Threespine Stickleback.

Two limnology sampling sites were selected for annual monitoring: one in the north at LS1 (EMS ID#E219070; also known as north basin) and one in the south at LS2 (EMS ID#E219074; also known as south basin) (Figure 1). Nearshore gillnetting and minnow trap sites are shown on Figure 1 with exact coordinates for 2009 to 2015 in Table 1 and Table 2, respectively. The coordinates each year between 2009 and 2015 remained relatively similar for each location.

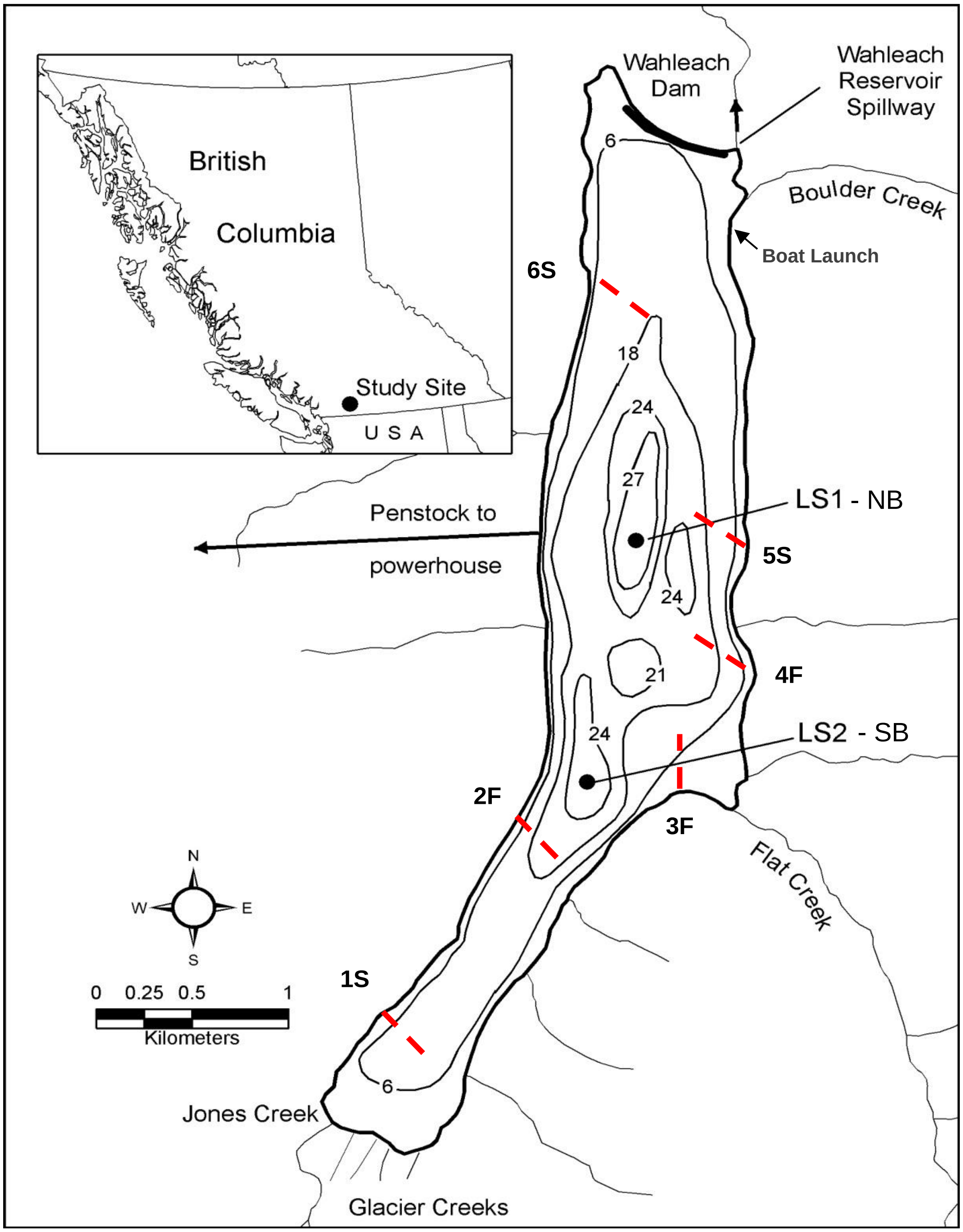

Figure 1 Map of Wahleach Reservoir showing Kokanee spawner index streams (Boulder Creek, Flat Creek, Jones Creek), and limnology sampling sites (LS1=North Basin and LS2=South Basin) Bathymetric contour depths (m) represent the reservoir at full pool.

Table 1 Wahleach Reservoir nearshore gillnet locations, 2009-2015.

Net	Location Coordinates						
	2009	2010	2011	2012	2013	2014	2015
1S	NA	NA	49°12.399 N, 121°38.020 W	NA	49°12.471 N, 121°38.005 W	49°12.463 N, 121°38.002 W	49°12.477 N, 121°37.984 W
2F	NA	NA	49°13.164 N, 121°37.123 W	49°13.088 N, 121°37.255 W	49°13.208 N, 121°37.181 W	49°13.208 N, 121°37.184 W	49°13.206 N, 121°37.179 W
3F	NA	NA	49°13.113 N, 121°36.681 W	49°13.102 N, 121°36.734 W	49°13.054 N, 121°36.689 W	49°13.058 N, 121°36.679 W	49°13.057 N, 121°36.682 W
4F	NA	NA	49°13.568 N, 121°36.433 W	49°13.350 N, 121°36.397 W	49°13.350 N, 121°36.281 W	49°13.392 N, 121°36.257 W	49°13.357 N, 121°36.270 W
5S	NA	NA	49°14.030N, 121°36.310 W	49°14.090 N, 121°36.351 W	49°14.222 N, 121°36.237 W	49°14.222 N, 121°36.868 W	49°14.232 N, 121°36.235 W
6S	NA	NA	49°14.687 N, 121°36.802 W	49°14.673 N, 121°36.732 W	49°14.807 N, 121°36.868 W	49°14.807 N, 121°36.868 W	49°14.818 N, 121°36.846 W

Table 2 Wahleach Reservoir minnow trap locations, 2009-2015.

Trap	Location Coordinates						
	2009	2010	2011	2012	2013	2014	2015
1M	NA	NA	49°12.241 N, 121°37.962 W	49°12.204 N 121°38.030 W	49°12.224 N, 121°38.007 W	49°12.199 N, 121°38.031 W	49°12.211 N, 121°38.015 W
2M	NA	NA	49°12.210 N, 121°38.014 W	49°12.192 N, 121°37.957 W	49°12.203 N, 121°37.934 W	49°12.211 N, 121°38.016 W	49°12.166 N, 121°37.877 W
3M	NA	NA	49°12.186 N, 121°37.914 W	49°13.228 N, 121°37.177 W	49°12.190 N, 121°37.906 W	49°13.372 N, 121°37.143 W	49°13.361 N, 121°37.146 W
4M	NA	NA	49°12.156 N, 121°37.882 W	49°13.290N, 121°37.149 W	49°12.169 N, 121°37.858 W	49°13.373 N, 121°37.146 W	49°13.401 N, 121°37.142 W
5M	-	-	49°13.350 N, 121°37.142 W	49°13.795 N, 121°37.150 W	49°13.372 N, 121°37.143 W	49°13.762 N, 121°37.142 W	49°13.760 N, 121°37.146 W
6M	-	-	49°13.371 N, 121°37.142 W	49°13.960 N, 121°37.112 W	49°13.372 N, 121°37.143 W	49°13.762 N, 121°37.142 W	49°13.818 N, 121°37.148 W
7M	-	-	-	-	49°13.762 N, 121°37.142 W	49°14.823 N, 121°36.850 W	-
8M	-	-	-	-	49°13.762 N, 121°37.142 W	-	-
9M	-	-	-	-	49°13.815 N, 121°37.153 W	-	-
10M	-	-	-	-	49°13.815 N, 121°37.153 W	-	-
11M	-	-	-	-	49°13.125 N, 121°36.386 W	-	-

2.2 Nutrient Loading

Agricultural grade liquid ammonium polyphosphate (10-34-0: N-P2O5-K2O; % by weight) and urea-ammonium nitrate (28-0-0: N-P2O5-K2O; % by weight) were added weekly to Wahleach Reservoir from the first week of June (after thermal stratification) for period of 20 weeks or once the reservoir turns over, whichever comes first. The ammonium polyphosphate and urea-ammonium nitrate were blended on-site immediately prior to dispensing. The exception was in 2011 when only urea-ammonium nitrate was added (i.e. no phosphorus additions) to the reservoir in an effort to prevent persistent blooms of inedible phytoplankton that had been observed in previous years. 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. In-season modifications to nutrient loads were informed by monthly monitoring results and supplemented by a visual inspection of the reservoir.

Typically, planned annual phosphorus loading rates for Wahleach Reservoir were kept near 200 $mg{\cdot}P/m^2$ to improve the production of *Daphnia* sp. as based on recommendations by Perrin *et al*. (2006). All nutrient addition programs in British Columbia (Arrow, Kootenay, Alouette and Wahleach) are adaptively managed based on results obtained from the comprehensive monitoring program delivered in concert to the nutrient additions. In season modifications are made to the fertilizer additions based on *in situ* conditions of the reservoir (i.e. Secchi depth, visual inspection of littoral algal accumulation, weather forecast) and based on results of the limnological monitoring program. While reservoir productivity is largely governed by nutrient loading, climate strongly influences the response of the ecosystem. In response to results obtained by our monitoring program, annual phosphorus loading rates have been modified (Table 3). Nitrogen was added concurrently to keep epilimnetic concentrations above 20 $\mu g{\cdot}L^{-1}$ – the concentration considered limiting to phytoplankton growth (Wetzel 2001) and maintain a suitable N:P ratio. For the 2013-2015 seasons, planned N:P ratios were increased earlier in the season in an effort to prevent nitrogen limitation (Figure 2). In most years, 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. Given the need for thermal stratification of the reservoir in order to fully benefit from the nutrient additions the last few planned loads were often eliminated as thermal stratification in the reservoir had broken down. Weekly areal loading rates of phosphorus reached a maximum of 20 mg $P{\cdot}m^{-2}$ in 2009, 2012 and 2013; while the maximum rates were 7 mg $P{\cdot}m^{-2}$, 17 mg $P{\cdot}m^{-2}$, and 13 mg $P{\cdot}m^{-2}$ in 2010, 2014 and 2015 respectively. For nitrogen, the maximum weekly areal loading rate was typically near 130 mg $N{\cdot}m^{-2}$, except for 2011 when it was 109 mg $N{\cdot}m^{-2}$ and in 2009 when in was 176 mg $P{\cdot}m^{-2}$. Weekly molar N:P ratios, typically peak at 30-40; the peak in 2015 was 97 on week 14 when only 9 gallons of ammonium polyphosphate was added to reservoir before switching to nitrogen only for the remaining weeks (Figure 2).

Table 3 Annual nutrient additions by weight and areal loading, 2009-2015, 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	$mg \cdot m^{-2}$
2009	15-Jun to 5-Oct	3.30	14.83	1,121	122	4,482	1,120
2010	12-Jul to 21-Sep	0.66	11.41	223	24	3,260	815
2011	6-Jul to 14-Sep	0.00	15.92	0	0	4,459	1,115
2012	6-Jun to 10-Oct	3.39	12.54	1,151	126	3,849	962
2013	5-Jun to 24-Sep	2.64	14.49	897	98	4,321	1,080
2014	4-Jun to 24-Sep	3.70	16.59	1,258	137	5,016	1,254
2015	3-Jun to 16-Sep	1.73	16.00	589	64	4,654	1,163

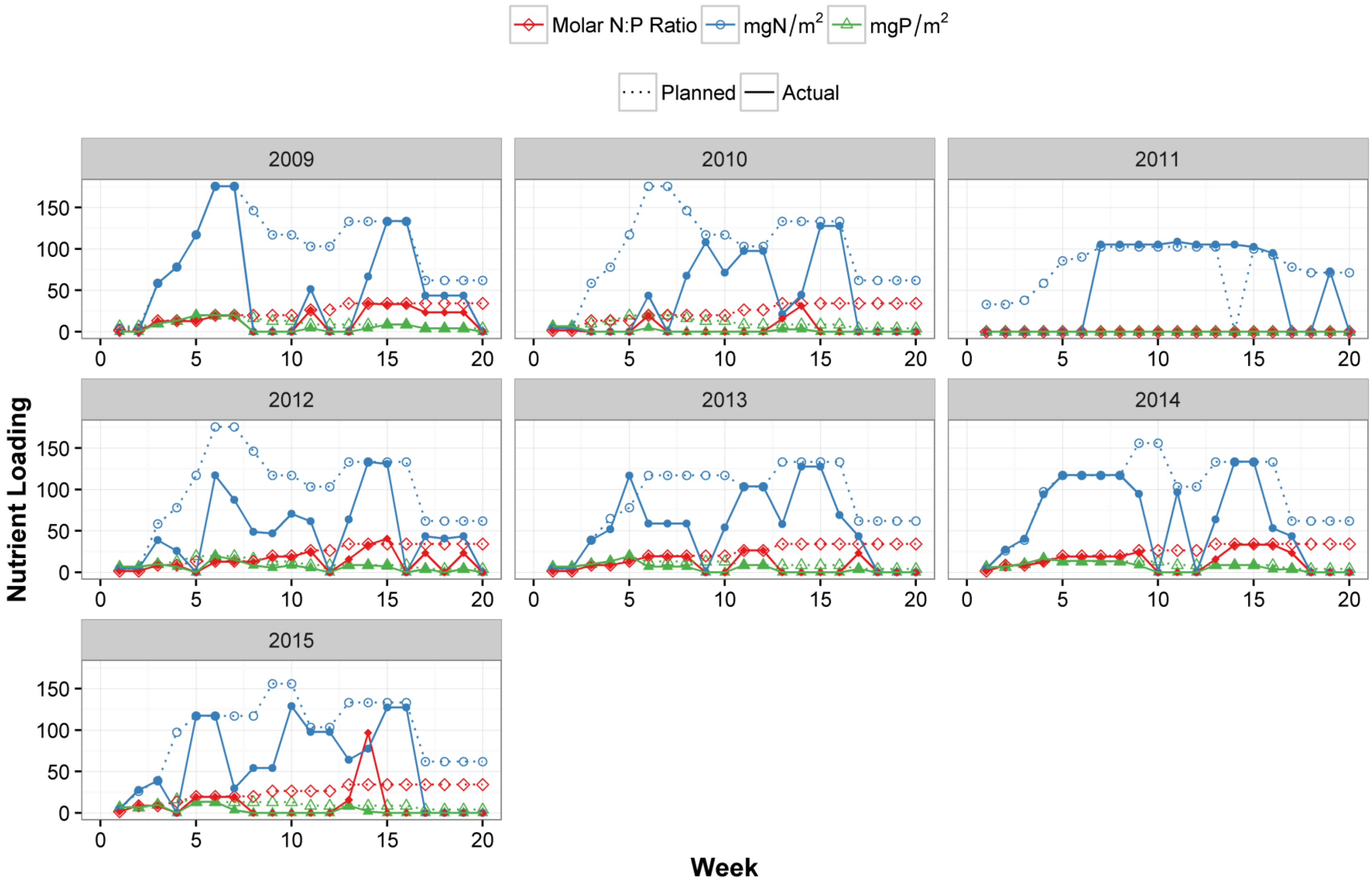

Figure 2 Seasonal planned and actual nutrient additions for Wahleach Reservoir, including areal nitrogen and phosphorus loading as well as molar N:P ratios, 2009-2015; planned values are represented by hollow icons, while actual values are represented by solid icons.

2.3 Hydrometrics and Reservoir Operations

Data were provided by BC Hydro, including day-end reservoir surface elevations, average daily inflow and discharge. Annual drawdown was calculated by taking the difference between the annual maximum and minimum reservoir elevations, and thus does not represent cumulative drawdown.

2.4 Climate

Daily maximum and minimum air temperatures and daily total precipitation data were provided by BC Hydro. An average of the maximum and minimum air temperature for each day was calculated and then used to report annual/seasonal means and associated standard deviations. Reported maxima and minima were taken from raw daily maximum and minimum air temperatures provided by BC Hydro. Box plots represent daily mean temperatures within each month of a given year. For precipitation, daily and monthly summary statistics were reported on for each year/season, as well as the total annual/seasonal precipitation. Box plots represent daily precipitation within each month of a given year.

2.5 Physical and Chemical Limnology

Limnology sampling was conducted monthly from May to October each year generally in the third week of each month; in some instances, circumstances (e.g. weather, access issues, equipment issues etc.) necessitated delays in sampling and so results may show a 'missing' month followed by two sampling sessions in the next month. Vertical profiles of dissolved oxygen ($mg \cdot L^{-1}$) and temperature (ºC) were taken *in situ* at 1 m intervals to a depth of 20 m with a YSI 550A meter, air-calibrated on site. Thermocline depth was identified by the temperature inflection point. Water transparency was measured with a standard 20 cm Secchi disk used without a viewing chamber.

Three water chemistry samples were collected at each station (Figure 1); discrete samples were taken at depths of 1 m and 20 m using a Niskin water sampler and a depth integrated sample was taken from the epilimnion using Tygon tubing. Parameters for analysis included pH, alkalinity, total phosphorus (TP), total dissolved phosphorus (TDP), soluble reactive phosphorus (SRP), total nitrogen (TN), and nitrate + nitrite-nitrogen (NO_3 + NO_2-N). The dissolved fractions were field filtered through a 0.45 µm sterile Sartarous filter. Samples were immediately stored in a cooler with ice until delivery to the laboratory on the same day (<12 h). Lab analyses were completed by Maxxam Analytics and ALS Laboratory in Burnaby, BC. The TP and TDP samples were digested and analysed according to Menzel and Corwin (1965). The TDP values reported included orthophosphate, polyphosphates and organic phosphates (Strumm and Morgan 1981). The SRP sample was analysed using the molybdenum blue method (Murphy and Riley 1962). The SRP values reported included the orthophosphate ion and acid-labile P compounds (Harwood *et al*. 1969), and may overestimate biologically available P (Rigler 1968; Bothwell 1989). The TN sample was analysed using methods outlined in APHA (1998). Nitrate + nitrite-N were analysed using a Technicon autoanalyzer equipped with a long flow cell to attain a detection limit of 0.5 $mg \cdot L^{-1}$ (Stainton *et al*. 1977; Wood *et al*. 1967). Seasonal means ± the standard deviation are reported. Where samples were reported below detection limits, a value of one half the detection limit was assigned for analysis.

Depth integrated chlorophyll *a* (chl *a*) samples were collected from the epilimnion. Samples of 100-500 mL were filtered using parallel filtration onto 47-mm diameter 0.45 µm cellulose acetate filters using a vacuum pressure differential of <100 mm of Hg. Filters were wrapped in aluminum foil and stored at -20°C. Chlorophyll *a* data were not available at the time of writing.

2.6 Phytoplankton

Phytoplankton sampling was conducted during monthly limnology sampling programs from May to October. Phytoplankton enumeration was completed on the integrated sample of the epilimnion collected using tygon tubing, then transferred to glass amber bottles and preserved with acid-Lugol's solution. Samples were stored in a cool and dark location until analysis. Counts of phytoplankton cells by taxa were completed using a Carl Zeiss© inverted phase-contrast plankton microscope. Counting was completed by first examining several random fields (5-10) at low power (250x magnification) for large microplankton (20 to200 μm), such as colonial diatoms, dinoflagellates, and filamentous blue-green algae. Second, all cells were counted within a single random transect 10 to 15 mm long at high power (1,560x magnification). High magnification allowed for quantitative enumeration of minute (<2 μm) autotrophic picoplankton sized cells such as *Cyanophyceae* and small nanoflagellates (2.0-20.0 μm; *Chrysophyceae* and *Cryptophyceae*). A total of 250 to 300 cells were enumerated in each sample to assure statistical accuracy of the results (Lund *et al*. 1958). The compendium of Canter-Lund & Lund (1995) was used as a taxonomic reference. Phytoplankton species detected each year are listed in Appendix A.

Annual species richness (or number of species detected), as well as summary statistics (mean, standard deviation, maximum and minimum) for total abundance ($cells{\cdot}mL^{-1}$) and total biovolume ($mm^3{\cdot}L^{-1}$) were reported. In addition to total abundance and biovolume, phytoplankton results were analyzed according to the edibility of each species detected in samples; the three categories used to classify edibility were inedible, edible, and both (i.e. where both edible and inedible forms of the same species were found in a sample; in those cases, the edible and inedible fractions were not determined quantitatively, thus both is represented as its own distinct category). Box plots and histograms by class and edibility are presented for the north basin and south basin for each year.

2.7 Zooplankton

Zooplankton sampling was conducted during monthly limnology sampling programs from May to October. Zooplankton enumeration was completed on each replicate sample collected at each station using a 157 μm mesh Wisconsin plankton net with a 0.25 m throat diameter and an 80 μm window for straining water from the cod-end. The net was lowered to a depth of 20 m and raised vertically at approximately 0.5 m/sec. Zooplankton were anaesthetized in a wash of Club Soda before being preserved with 70% ethanol. The addition of carbon dioxide prevents egg shedding when the sample is mixed with the preservative. Samples were analyzed for species composition, density, biomass and cladoceran fecundity (data on file). Samples were re-suspended in tap water filtered through a 74 µm mesh and sub-sampled using a four-chambered Folsom-type plankton splitter. Splits were placed in gridded plastic petri dishes and stained with Rose Bengal to facilitate viewing with a Wild M3B dissecting microscope at up to 400x magnification. For each replicate, organisms were identified to species and counted until ≤200 individuals were recorded. If ≥150 individuals were counted by the end of a split, a new split was not started. For biomass calculations, the lengths of up to 30 individuals of each species were measured using a mouse cursor on a live television image. Lengths were converted to biomass (µg dry-weight) using empirical length-weight regressions from McCauley (1984). The number of eggs carried by gravid females and the lengths of these individuals were recorded for use in fecundity estimates. Taxonomic references included Sandercock and Scudder (1996), Pennak (1989), Wilson (1959), and Brooks (1959). *Daphnia* were not identified to species for density counts. Appendix B contains a list of zooplankton species observed during each year.

Annual species richness (or number of species detected), as well as summary statistics (mean, standard deviation, maximum and minimum) for total density ($individuals{\cdot}L^{-1}$) and total biomass ($\mu g{\cdot}L^{-1}$) were reported. Values from stations LS1 (North Basin) and LS2 (South Basin) were combined for calculating annual means. In addition to total density and biomass, results were analyzed according to each major zooplankton group, including *Copepoda*, *Daphnia* and *Cladocera* (not including *Daphnia*). Box plots and histograms by group are presented for each basin and year.

2.8 Fish

For simplification, abbreviated species names are used in tables and graphs including Kokanee (KO), Rainbow Trout (RB), Cutthroat Trout (CT), and Threespine Stickleback (TSB).

2.8.1 Stocking

Table 4 shows fish stocking records for Wahleach Reservoir since 1997. Kokanee have not been stocked since 2004, and Rainbow Trout have not been stocked since 2002. Stocking of sterile (3N) Cutthroat Trout continues as the biomanipulation portion of the project to ensure top down pressure on the Threespine Stickleback population remains. The decision to stock sterile Cutthroat Trout is evaluated annually and is based on the results of the gillnetting program, specifically condition and growth of captured Cutthroat Trout, as well as through the acoustic population estimates.

Table 4 Wahleach Reservoir fish stocking records, 1997-2015.

Year	KO	CT (3N)	RB
1997	50,000	2,273	0
1998	50,000	5,111	2,010
1999	51,682	4,959	0
2000	52,000	3,045	0
2001	0	0	0
2002	35,200	1,000	5,726
2003	50,000	3,493	0
2004	50,000	4,995	0
2005	0	2,994	0
2006	0	3,000	0
2007	0	2,002	0
2008	0	0	0
2009	0	1,007	0
2010	0	0	0
2011	0	1,000	0
2012	0	2,145	0
2013	0	2,000	0
2014	0	2,000	0
2015	0	2,000	0

2.8.2 Gillnet and Minnow Trap Surveys

Standardized annual gillnetting was completed in June in some years, and in September, October and November in others. In the past five years, nearshore gillnetting has occurred in October after spawning

Kokanee have migrated out of the reservoir. Table 5 shows the nearshore gillnetting and minnow trapping dates sampled each year.

Table 5 Nearshore gillnetting and minnow trapping sampling dates, 2009-2015, Wahleach Reservoir, BC.

Year	Gillnetting and Minnow Trapping Dates
2009	28-29 Jun; 4-5 Nov
2010	22-23 Jun; 17-16 Sep
2011	17-18 Oct
2012	23-24 Oct
2013	22-23 Oct
2014	21-22 Oct
2015	26-27 Oct

In 2009 to 2013, gillnets consisted of six panel standard RISC nets (15.2 m long by 2.4 m deep) with a modification of the mesh size order; gillnet panel mesh sizes were: 25 mm, 89 mm, 51 mm, 76 mm, 38 mm, 64 mm (i.e. 1", 3.5", 2", 3", 1.5", 2.5"). Beginning in 2014 and used annually thereafter, the standard gillnets were modified to include a seventh panel with a mesh size of 32 mm (1.25“) to address fishing bias against age-1+ sized Kokanee. In all years, a total of six stations were sampled; three stations consisted of floating nets set at the surface and three stations consisted of sinking nets set on the reservoir bottom. Nets were set near dusk, left overnight, and then retrieved the following morning. Gillnets were set perpendicular to shore with one end tied to shore and the other end anchored with a lead weight and marked with a buoy. In addition, minnow traps targeting Threespine Stickleback were set and retrieved at the same time. Six minnow traps baited with salmon roe and/or moist cat food were set each year for 2011, 2012 and 2015; four traps were set in 2009 and 2010 during both the June and November/September sampling trips; and in an effort to increase sample sizes, eleven traps were deployed in 2013 and seven in 2014. All minnow traps were deployed in littoral habitat in approximately 2 to 3 m of water.

Captured fish were identified to species using McPhail and Carveth (1999) when necessary. Kokanee, Rainbow Trout and Cutthroat Trout were processed using RISC standard methods (RISC 2004); parameters collected included species, fork length (mm), weight (g), sex, maturity, clips/marks and notes. Scales were taken from all individuals for ageing; otoliths were also taken from Cutthroat Trout greater than 300 mm. Scale samples were processed and read using methods described in Ward and Slaney (1988).

Condition factor was calculated for each individual fish using the equation:

$$K = (W \times 10^5)/L^3$$

Where K = condition factor, W = weight in g, and L = fork length in mm.

Threespine Stickleback were processed for total length (mm), weight (g), and notes only.

Annual gillnetting data were used to determine catch-per-unit-effort (CPUE) as individuals per 100 m^2 of net per hour; for 2014 and 2015, CPUE included catch from the added 1.25” mesh panel which was corrected for by calculating CPUE as a function of 100 m^2 net area. Differences in catch between standard RISC nets and the added 1.25” mesh panel were reported. CPUE for minnow trapping was calculated as individuals per hour of trap soak time. Other metrics included length frequency, age at length, age frequency, and length weight regressions. Ages of fish from fall sampling represent years of growth with an additional summer (i.e. ‘+’ growth) owing to sampling timing; however, ages in figures do not show these notations. Length weight regressions were calculated using the natural logarithm (ln) in R using linear model function (lm); equations were reported directly from R output.

2.8.2.1 Pelagic Gillnetting

Pelagic gillnetting was conducted in conjunction with the hydroacoustic survey in 2009, 2012 and 2013. Pelagic nets are generally set between hydroacoustic transect 5 and 8, which is the deepest section of the reservoir near the north basin (LS1-NB) (Figure 3, Figure 1). Data from this program were not compared to past pelagic gillnetting data or fall nearshore gillnetting data. Net types were either standard nets like those used in nearshore netting (see Section 2.8.2), or a small mesh gillnet (WOD). The small mesh gillnet consisted of six panels 15.2 m long by 2.4 m deep with mesh sizes of 25 mm, 19 mm, 13 mm, 19 mm, 19 mm, and 13 mm. Nets were set overnight and retrieved the following morning. Fish sampling methods were as described in Section 2.8.2.

Table 6 Summary of pelagic gillnetting dates, stations, net types and depths from 2009, 2012, and 2013, Wahleach Reservoir, BC. WOD = small mesh gillnet; all others are standard RISC nets.

Year	Dates	Stations[1]	Net Types & Depths	Depths (m)
2009	17- 18 Sep	Station 1	Floating	0
		Station 1	Sinking	15
		Station 2	Floating	0
		Station 2	Sinking	10
		Station 2	Sinking	20
		Station 3	Floating	0
		Station 3	Sinking	10
		Station 3	Sinking	15
2012	19 Jul	Station 1	Floating	0
		Station 1	Sinking	5
		Station 1	Sinking	10
		Station 1	Sinking (WOD) x 1	4
2013	10 Aug	Station 2	Sinking x 2	10
		Station 2	Sinking x1	5
		Station 2	Sinking (WOD) x1	5
		Station 1	Sinking x2	10
		Station 1	Sinking x2	5

1. These stations are not standard gillnetting stations

2.8.3 Kokanee Spawner Surveys

Kokanee spawner escapement in three index streams - Boulder Creek, Flat Creek, and Jones Creek - was estimated using standardized visual survey methods. Live spawners and carcasses were enumerated from the confluence with Wahleach Reservoir to 600 m upstream on Boulder Creek, 1000 m upstream on Flat Creek and 400 m upstream on Jones Creek. Survey end points were standardized based on the habitat characteristics of each stream and the upper limits of spawners observed in earlier years of the project. Kokanee have also been observed spawning in the small Glacier Creeks at the south end of the reservoir; though, these streams were not included in standardized annual surveys. Spawner surveys were conducted weekly on each index stream from the last week of August to late October over about an 8 week period, depending on observed trends in spawner numbers. During each survey, a 2 to 3 person crew walked each index stream in an upstream direction positioned near the right and left banks to increase the overall field of view. Each surveyor counted the number of spawners and carcasses in a defined reach, and then the average was recorded before moving on. Care was taken to avoid spawning substrate and suspected redds. 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 years (2003-2016) when both post-orbital hypural length (POHL) and FL were measured.

Counts provided an estimate of the number of mature Kokanee in each index stream on a survey day. Total escapement estimates were made using a modified area-under-the-curve (AUC) model from Irvine *et al*. (1993) which uses counts, stream residency time, and estimated observed efficiency. Stream residency time was defined as the average number of days a mature fish will spend in a stream during the spawning period (Irvine *et al*. 1993). Stream residency time was originally set at 10 days based on literature estimates for sockeye (*Oncorhynchus nerka*) with the assumption that value for Kokanee would be similar (Greenbank 2002). Literature on Kokanee spawners corroborates this value in which stream residency times ranged from 6 to 15 days with an average of 10.2 days (Andrusak *et al*. 2004). Observer efficiency in the AUC model attempts to account for the fish missed during surveys due to instream cover or spawner density. Observer efficiency was estimated at 90% to be consistent with previous study years. The AUC model involved two calculations – (1) the AUC estimate and (2) the escapement estimate:

(1) $$\text{AUC} = 0.5 \cdot \sum_{i=2}^{n} (t_i - t_{i-1})(p_i + p_{i-1})$$

(2) $$\text{Escapement} = \text{AUC} \cdot rt^{-1} \cdot oe^{-1}$$

> "Where t_i is the number of days from the first survey to the ith survey day inclusive; the survey ranges from the first survey day to the last (nth) survey day when p_i (daily population) and p_n should be equal to zero. Finally, the AUC escapement estimate is calculated, where rt^{-1} is the residency time, oe is the observer efficiency factor [as a decimal percent]." (Irvine *et al*. 1993)

In addition to escapement estimates, a random sample of Kokanee spawners from each index stream was taken for sampling using RISC standard methods (RISC 2004); parameters included fork length (mm), weight (g), sex, maturity, clips/marks and notes. Otoliths were taken from all individuals for ageing.

2.8.4 Hydroacoustic Surveys

Hydroacoustic surveys were conducted at night beginning at least one hour after sunset within one week of the new moon (Table 7). Data were collected along eleven standardized transects (Figure 3) at a speed of approximately 2 $m \cdot s^{-1}$ using a Simrad EK60 120 kHz split beam echosounder with a downward looking transducer. The transducer was towed from the side of a boat at a depth of 1.0 m. Transects were navigated with the aid of a Lowrance LCX27-C GPS, and a spotlight while in close proximity to shore. Acoustic data were monitored on a computer during collection and stored for analysis.

Hydroacoustic data were analyzed using Sonar 5 post processing software (Balk and Lindem 2011). Estimates of fish densities were reported as fish·ha^{-1} by 2 m depth strata. Software provided densities by 47 size groups in 1 decibel (dB) increments from -70 to -24 dB. Detailed data collection and analysis parameters for 2015 are found in Appendix C; parameters for surveys conducted from 2009-2014 are detailed in previous data reports (Harris *et al* 2011, Hebert *et al.* 2013, Hebert *et al.* 2015). Decibel thresholds used to differentiate smaller fry-sized fish from larger adult-sized fish are detailed in Table 7. The presence of Threespine Stickleback as well as Rainbow Trout and Cutthroat Trout that mix with Kokanee in pelagic habitat was a complicating factor for hydroacoustic data interpretation; species differentiation within each size group 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; population estimates assumed targets distributed at depths with water temperatures <17˚C and dissolved oxygen concentrations >5 mg·L^{-1} were mainly Kokanee, as supported by results of pelagic gillnetting and directed trawling (Harris *et al* 2011, Hebert *et al.* 2013, Hebert *et al*. 2015). 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).

Habitat areas used to extrapolate transect fish densities to a whole reservoir population were derived from Perrin and Stables (2000) using 640 m as the benchmark full pool reservoir surface elevation and resulting surface area of 410 ha (Appendix G). Reservoir surface elevations at the time of acoustic surveys each year are shown in Table 7. The average start and end depth of the acoustic transects in 2015 was 6.4 m; this equates to approximately 73 ha of littoral habitat (approximately 20% of reservoir) not surveyed, similar to previous years (Table 7).

Table 7 Summary of equipment, conditions and analysis parameters for hydroacoustic surveys on Wahleach Reservoir, 2009-2015.

Year	Survey Date	Sounder	Reservoir Pool Elevation[1] (m)	Avg Transect End Depth (m)	Analysis Depth Range (m)	Fry-sized Fish dB	Adult-sized Fish dB	All Fish dB
2009	14-Sep	EK60	639.3	4.6	10-20	-61 to -45	≥ -44	≥ -61
2010	14-Sep	EK60	639.5	3.4	10-20	-61 to -46	≥ -45	≥ -61
2011	26-Aug	EK60	639.7	6.0	6-30	-61 to -47	≥ -46	≥ -61
2012	18-Jul	EK60	641.7	6.3	4-30	-66 to -51	≥ -50	≥ -66
2013	08-Aug	EK60	639.7	5.2	6-30	-66 to -47	≥ -46	≥ -66
2014	18-Aug	EK60	639.3	6.0	6-30	-66 to -46	≥ -47	≥ -66
2015	11-Aug	EK60	639.8	6.4	10-30	-66 to -47	≥ -46	≥ -66

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

We estimated fish populations with confidence intervals using a stochastic simulation approach (a Monte Carlo method). For each depth stratum, we calculated 30,000 random realizations of normal distribution with a mean being the stratum mean and the standard deviation being the standard error of the population mean estimate. The 0.025 and 0.975 quantiles were taken as the confidence intervals, while the 0.5 quantile was taken as the population estimate. Simulations were done in R (R Core Team 2016), producing estimates for all fish, as well as for large and small fish within the preferred Kokanee depth ranges for each year; this was unlike in previous reports, where population estimates were generated only for all fish and large-sized fish, and then the estimate for small fish was calculated as the difference.

Initial biomass estimates for Wahleach Reservoir are presented in this report; 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. We estimated biomass from the acoustic distributions by multiplying abundance estimates for each 1dB size increment by the estimated mean weight (g) for the corresponding increment; these were then summed to get total biomass. Estimating the mean weight by dB was done in two stages. First a relationship of acoustic size or target strength (TS) in dB to fish fork length was established by relating visible reference points on the acoustic size distributions with visible reference points from fish length-frequency distributions. We identified seven visible reference points as follows on acoustic distributions: 1) peak of smallest fish; 2) second peak in the fry distribution; 3) cut-off between fry and non-fry; 4) first of two largest peaks beyond the fry cut-off; 5) second peak beyond fry cut-off; 6) inflection point marking upper end of the main “non-fry” distribution, and 7) the largest kokanee captured (Appendix H). These reference points were plotted against corresponding reference points from a cumulative length-frequency for Kokanee and Threespine Stickleback (Appendix H; pooled minnow trap, gillnet and trawl data from Wahleach Reservoir, 2000-2014) to produce the following regression:

$$FL = 5618.8\ e^{\ 0.0884(TS)} \quad R^2 = 0.993$$

where FL is fork length in mm, e= 2.718 and TS = acoustic target strength in dB (Appendix H).

The form of the equation was then revised to conform to equations used by SONAR5 software following Love’s (1971) dorsal aspect formula: $TS = A * \log_{10} (FL) + B$.

By plotting known values for TS on Log_{10} (FL in cm) from Equation 1 above, we were able to solve for slope “A” and coefficient “B” using a linear regression. The resulting TS:FL relation for Wahleach Reservoir fish (primarily KO and TSB) was:

$$TS = 25.878 \log_{10} (FL\ cm) - 71.445 \quad R^2 = 0.992 \quad \text{(Appendix H).}$$

Next a generalized relationship of fork length to mean fish weight was determined from the combined catches of all species in Wahleach Reservoir. Because the largest Kokanee appeared to fit the combined regression line (KO, CT and TSB) better than the kokanee regression, we decided to use the combined regression line to represent all fish in order to prevent an over estimate of biomass based on small numbers of large fish (Appendix H). Equation 3 (below) was used to calculate mean weight by 1 dB intervals for corresponding estimates of FL from equation 2 above:

$$WT\ (g) = 0.0102\ (FL\ in\ cm)^{\ 3.0090} \quad R^2 = 0.97\ (n = 1055) \quad \text{(Appendix H).}$$

Once biomass in kg was determined for each survey, estimates of biomass density ($kg{\cdot}ha^{-1}$) were calculated by dividing biomass by habitat area. For all fish, the habitat area at 4 m was used. For Kokanee, the area corresponding with the annual acoustic depth analysis range (Table 7) was used to calculate biomass density as this was where the highest densities of Kokanee were typically found.

It is important to note that acoustic surveys in earlier years (specifically 2009 and 2010) were completed part way through the Kokanee spawning period (Table 7), so abundance and biomass estimates generated from acoustic data would not account for the entire population.

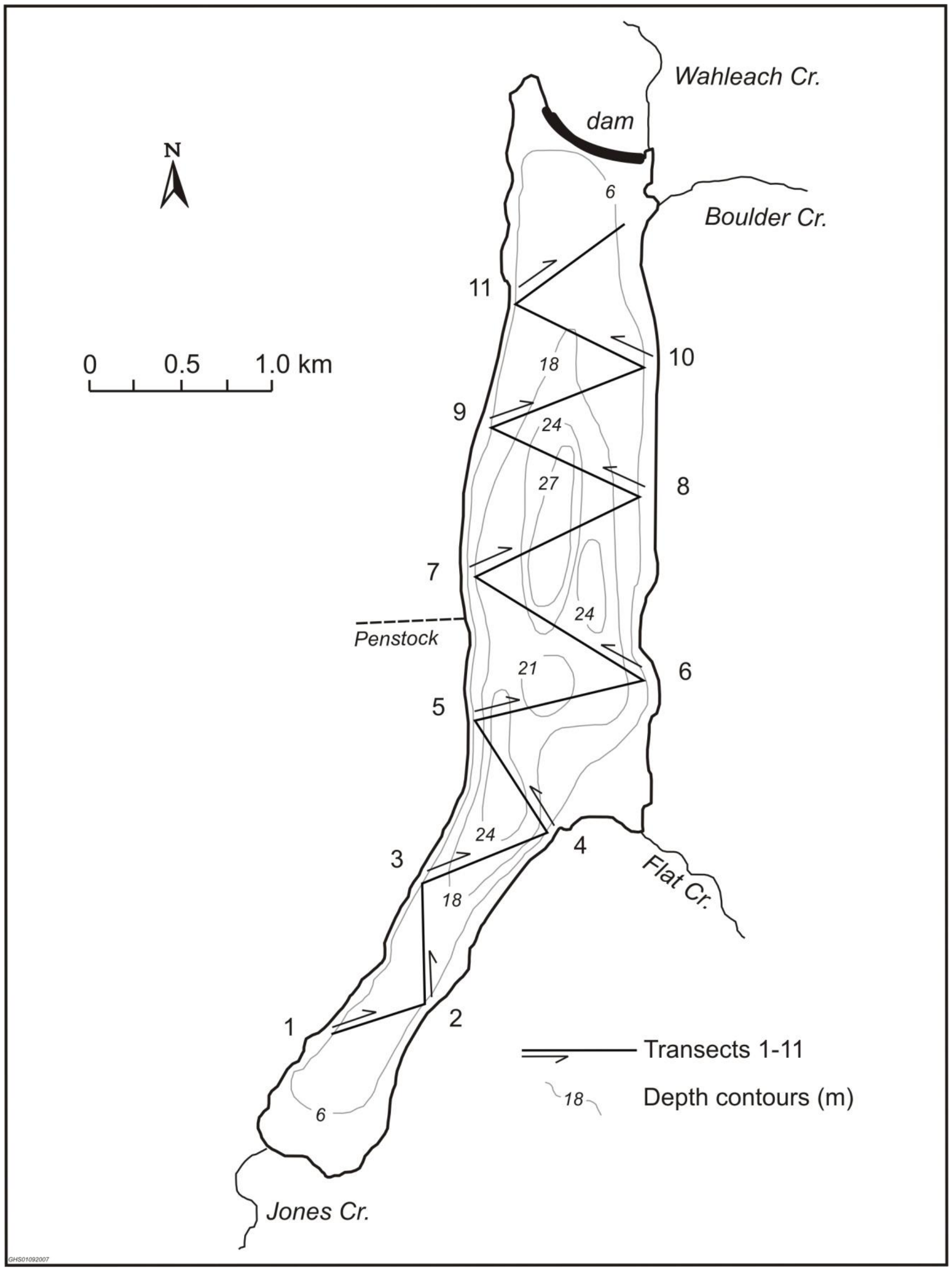

Figure 3 Map of Wahleach Reservoir showing standardized hydroacoustic transect locations.

2.8.5 Trawl Surveys

Trawl surveys were conducted annually, except in 2010 or 2012, to evaluate fish species distribution, specifically between Kokanee fry and Threespine Stickleback. Typically, trawl sampling occurred the night after the acoustic survey at approximately 1.5 hours after sunset. Trawls were directed at the highest target fish 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 8. We assumed Kokanee fry and all age classes of Threespine Stickleback were equally vulnerable to the trawl gear.

Trawl equipment and methodology in 2015 was the same as in 2014; prior to that there were minor differences in net specifications and equipment amongst years, detailed in previous reports and summarized in Table 8. The 2015 trawl set-up followed the system described by Gjernes (1979), using a 12 m long beam-trawl net with an opening of 2.5 × 2.5 m towed at a target speed of 0.8-1.0 $m \cdot s^{-1}$. The net consisted of four graduated mesh panels 50.8 mm, 25.4 mm, 12.7 mm, and 3 mm in size as described in order moving towards the cod-end. A gas powered capstan winch was secured to the back of the boat and used to retrieve the net. A Notus trawl sensor was attached to the top bar of the net to provide real time net depth information. Captured fish were kept in labelled packages on ice and sampled for species, length (mm) and weight (g).

Table 8 Summary of equipment and effort for trawl surveys on Wahleach Reservoir, 2009-2015.

Year	Survey Date	Net Size (l×w×h in m)	No. Hauls	Haul Depth Range (m)	Haul Time Range (min)	Method Reference(s)
2009	15-Sep	12 × 2.5 × 2.5	6	5.5-10.5	10-40	Harris *et al*. 2011
2010[1]	-	-	-	-	-	-
2011	20-Sep	5.4 × 2 × 2	4	8-15	40	Hebert *et al*. 2013
2012[1]	-	-	-	-	-	-
2013	09-Aug	7.5 × 2 × 2	2	5.5-10.5	50-55	MacLellan and Hume 2010; Hebert *et al*. 2015
2014	19-Aug	12 × 2.5 × 2.5	3	6.5-17	33-40	Gjernes 1979; Hebert *et al*. 2015
2015	12-Aug	12 × 2.5 × 2.5	3	8-15.5	40-53	Gjernes 1979; Hebert *et al*. 2015

1. No trawl survey conducted; acoustic survey only

To illustrate the vertical distribution of fish based on trawl surveys, catch data was pooled by year (2009-2015) and 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 in a figure.

2.8.6 Creel Survey

A random stratified survey design (Pollock *et al.* 1994) was used to conduct seasonal angler surveys on Wahleach Reservoir during three years (2009, 2013, 2014) of the current review period. While methods were generally kept consistent to facilitate comparison of results, some changes to interview questions were made based on input from regional and provincial Biologists. Changes involved adding questions and clarifying how angler responses were recorded. Interviews consisted of four parts: (1) creel data including questions on catch, harvest, effort etc; (2) fishing behavior including questions on catch preferences, reasons for fishing on Wahleach etc; (3) demographics including age, license type, angler origin etc; and (4) general comments from the angler. One interview questionnaire (on file) was filled out per party (i.e. angler boat). If anglers had limited time, creel data and select behavioral questions were prioritized over other parts of the interview. In addition to the interview, all harvested fish (with permission of the angler) were identified to species and sampled for length, weight, clips, and ageing structures (i.e. scales).

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

2.9 Summary of Methods

A summary of the various sampling programs completed in each year from 2009-2015 on Wahleach Reservoir is presented in Table 9.

Table 9 Summary of sampling programs completed on Wahleach Reservoir, 2009-2015.

Category	2009	2010	2011	2012	2013	2014	2015
Nutrient Addition	X	X	X	X	X	X	X
Fish Stocking	X	-	X	X	X	X	X
KO	-	-	-	-	-	-	-
CT	x	-	x	x	x	x	x
RB	-	-	-	-	-	-	-
Limnology Sampling	X	X	X	X	X	X	X
Temp-DO Profiles	X	X	X	X	X	X	X
Secchi Depths	X	X	X	X	X	X	X
Water Chemistry	X	X	X	X	X	X	X
Chlorophyll-a	X	X	X	X	X	X	X
Phytoplankton	X	X	X	X	X	X	X
Zooplankton	X	X	X	X	X	X	X
Nearshore Gillnetting	X	X	X	X	X	X	X
spring	x	x	-	-	-	-	-
summer	-	-	-	-	-	-	-
fall	x	x	x	x	x	x	x
Spawner Survey	X	X	X	X	X	X	X
Pelagic Gillnetting	X	-	-	X	X	-	-
spring	-	-	-	-	-	-	-
summer	-	-	-	x	x	-	-
fall	x	-	-	-	-	-	-
Hydroacoustic Survey	X	X	X	X	X	X	X
Trawl Survey	X	-	X	-	X	X	X
Littoral Minnow Trapping	X	X	X	X	X	X	X
Limnetic Minnow Trapping	-	-	-	-	-	-	-
Creel Survey	X	-	-	-	X	X	-

3. Results

3.1 Hydrometrics and Reservoir Operations

3.1.1 Inflow

Summary statistics values for the past seven years (2009 to 2015) are shown in Table 10, which varied to the long term (1993 to 2015) mean daily inflow of 6.2 ± 5.5 $m^3 s^{-1}$. In 2009, 2010, 2013 and 2015 mean daily inflows were lower than the long term mean daily inflow mentioned above, whereas, in 2011, 2013 and 2014 values were higher than the mean. In general, peak inflows were seen in the winter (Figure 4).

Table 10 Annual summary statistics of daily inflow ($m^3 \cdot s^{-1}$), 2009-2015, Wahleach Reservoir BC

Year	Mean ($m^3 \cdot s^{-1}$)	SD ($m^3 \cdot s^{-1}$)	Max ($m^3 \cdot s^{-1}$)	Min ($m^3 \cdot s^{-1}$)
2009	5.5	4.7	27.5	0.0
2010	5.5	3.9	31.9	0.5
2011	7.3	6.1	50.6	0.0
2012	7.2	5.9	42.0	0.6
2013	5.7	4.6	32.6	0.0
2014	7.3	5.2	43.1	0.8
2015	5.8	5.4	44.7	0.0

3.1.2 Discharge

Summary statistics values for the past seven years (2009 to 2015) are shown in Table 11, which varied to the long term (1993 to 2015) mean daily inflow of 6.2 ± 4.6 m^3 s^{-1}. In 2009, 2010, 2013 and 2015 mean daily outflows were lower than the long term mean daily inflow mentioned above, whereas, in 2011, 2012 and 2014 values were higher than the mean. Figure 5 shows annual patterns in flow, which was highly variable.

Table 11 Annual summary statistics of daily outflow ($m^3 \cdot s^{-1}$), 2009-2015, Wahleach Reservoir BC

Year	Mean ($m^3 \cdot s^{-1}$)	SD ($m^3 \cdot s^{-1}$)	Max ($m^3 \cdot s^{-1}$)	Min ($m^3 \cdot s^{-1}$)
2009	5.5	4.3	13.1	0.0
2010	5.9	4.6	13.5	0.0
2011	6.8	5.9	28.1	0.0
2012	7.5	5.0	23.0	0.0
2013	5.2	4.4	16.6	0.0
2014	7.4	4.1	12.7	0.0
2015	5.9	4.9	12.8	0.0

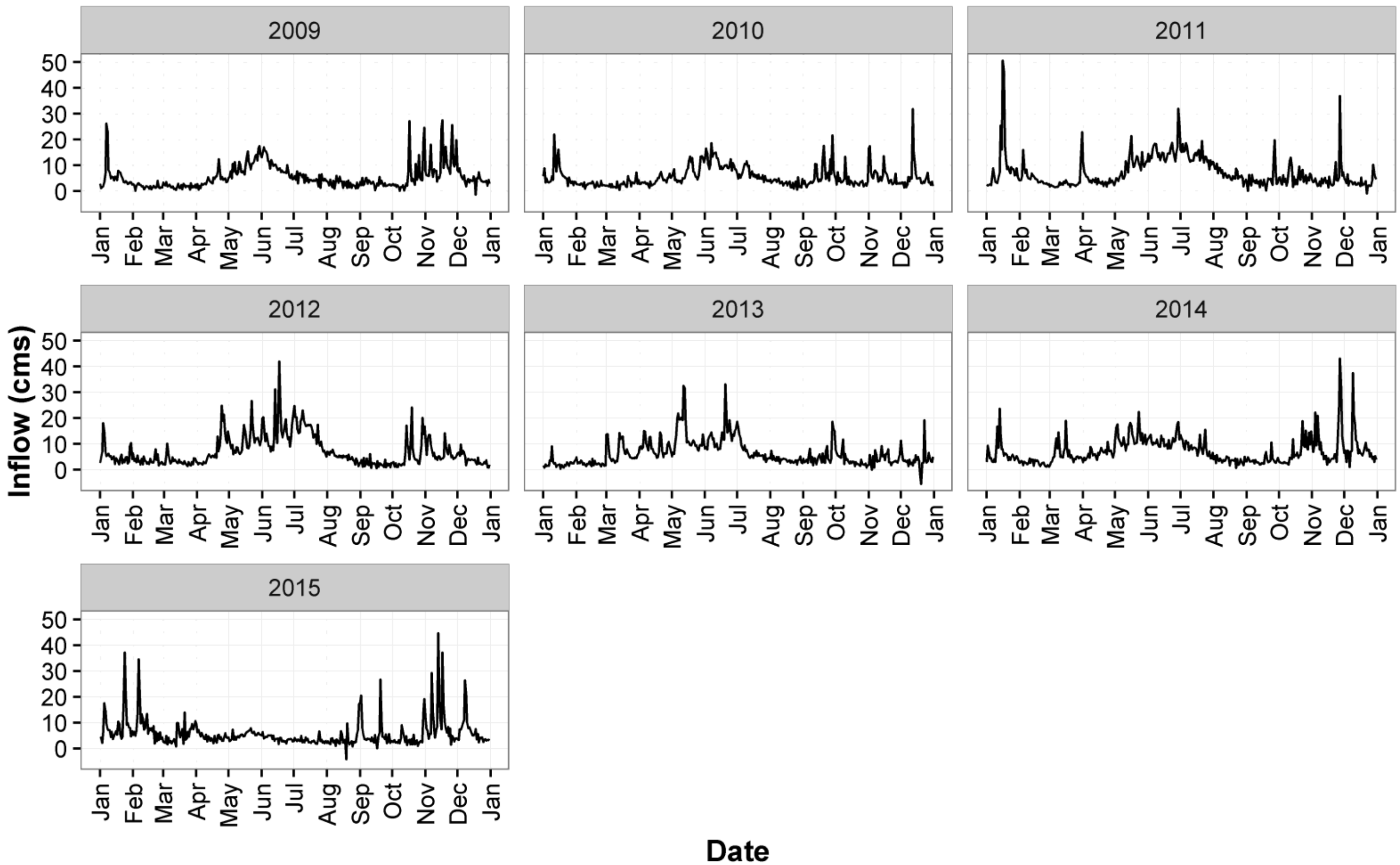

Figure 4 Daily inflow ($m^3 \cdot s^{-1}$) into Wahleach Reservoir, 2009-2015.

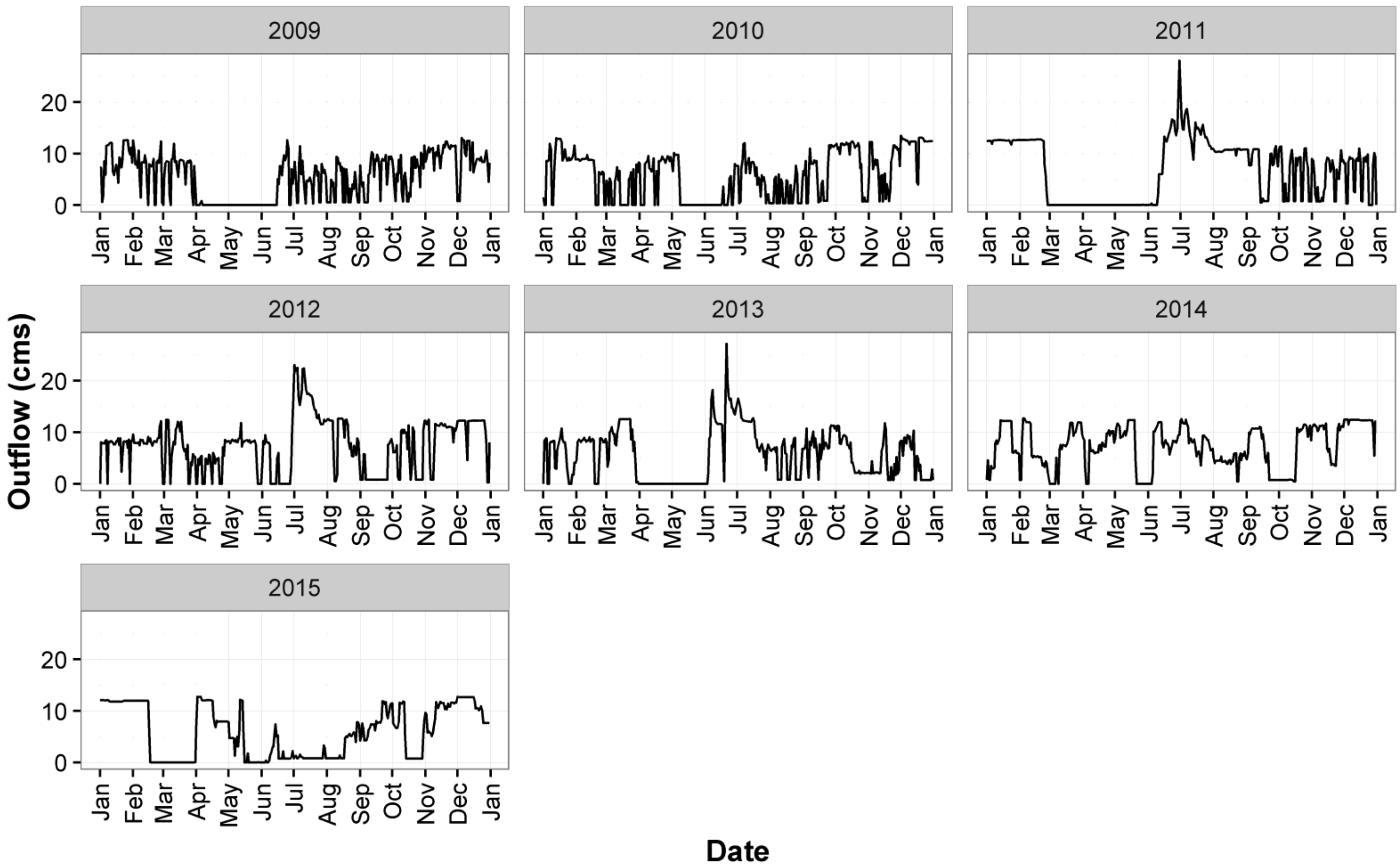

Figure 5 Daily outflow ($m^3 \cdot s^{-1}$) from Wahleach Reservoir, 2009- 2015.

3.1.3 Reservoir Elevation

Of the years studied, the reservoir elevations have stayed above the minimum standard operating level of 628 m, with the exceptions of the following years; 2009, 2011 and 2013 (Figure 6). In 2009, 2011 and 2013 the reservoir elevation dropped below the 628 m minimum operating level by 2.6 m, 3.7 m and 3.6 m, respectively and below the minimum elevation recommended by Perrin and Stables (2000) to protect Rainbow Trout spawning habitat. Drawdown of Wahleach Reservoir generally begins in late summer or early fall. The reservoir reaches its lowest level around April; and then is recharged during freshet with the maximum water surface elevation occurring in June which corresponds with the start of nutrient additions.

Reservoir elevation summary statistics are shown in Table 12. During 2009 to 2015, annual drawdowns varied between the highest on record since the beginning of the project of 17.7 m in 2011 to the lowest of 5.8 m in 2015.

Table 12 Annual summary statistics of daily reservoir elevation (m, Geodetic Survey of Canada), 2009-2015, Wahleach Reservoir BC.

Year	Mean (m)	SD (m)	Max (m)	Min (m)	Annual Drawdown (m)
2009	635.5	4.5	640.5	625.4	15.1
2010	635.4	3.7	640.5	628.2	12.3
2011	635.2	5.2	642.0	624.3	17.7
2012	636.1	3.8	642.1	629.1	12.9
2013	635.1	4.8	641.8	624.1	17.6
2014	637.1	1.9	639.7	633.5	6.2
2015	637.5	1.6	640.2	634.4	5.8

Figure 6 Daily reservoir surface elevation (m, Geodetic Survey of Canada), 2009-2015, Wahleach Reservoir. Open circles represent limnology sampling dates. Red dashed line represents minimum operating level of 628 m.

3.2 Climate

3.2.1 Air Temperature

Seasonal air temperature patterns are the highest in July and August and lowest in December and January (Figure 7). The long term (1993 to 2015) mean daily temperature was 7.1 ± 6.0 °C. The minimum temperature on record during the whole study period was -22.3 °C (1997), while the maximum temperature was 33.9 °C (2014). Overall, the mean daily temperature was slightly warmer (7.5 ± 6.7 °C) than the long term average in the last three years (2013 to 2015). Annual summary statistics of daily air temperatures for 2009 to 2015 are shown in Table 13.

Table 13 Summary statistics of daily air temperatures (°C), 2009-2015, Wahleach Reservoir, BC.

Year	Daily Mean (°C)	Daily SD (°C)	Daily Max (°C)	Daily Min (°C)
2009	6.8	7.5	33.8	-18.8
2010	7.1	6.2	30.4	-14.2
2011	6.1	6.4	29.6	-19.6
2012	6.9	6.8	30.9	-19.3
2013	7.7	7.1	32.0	-14.4
2014	8.0	7.1	33.9	-12.7
2015	9.1	6.5	30.2	-8.9

For the nutrient addition period only (June to September), summary statistics of daily air temperatures are shown in Table 14. The long term (1993 to 2015) mean daily temperature during the nutrient period was 14.1 ± 3.8°C, with a range of 0.8 to 33.9 °C. The mean daily temperature was slightly warmer in the last three year (2013 to 2015) compared to the long term mean daily temperature. Also, the nutrient season of 2015 (15.7 ± 4.2) and 2014 (15.6 ± 3.7) were the warmest and second warmest on record.

Table 14 Summary statistics of daily air temperatures (°C) during nutrient addition period, June to September, 2009-2015, Wahleach Reservoir, BC.

Year	Daily Mean (°C)	Daily SD (°C)	Daily Max (°C)	Daily Min (°C)
2009	15.2	4.1	33.8	3.5
2010	13.5	3.8	30.4	3.9
2011	13.4	3.3	29.6	4.8
2012	14.2	4.1	30.9	3.5
2013	15.3	3.8	32.0	3.6
2014	15.6	3.7	33.9	5.3
2015	15.7	4.2	30.2	3.5

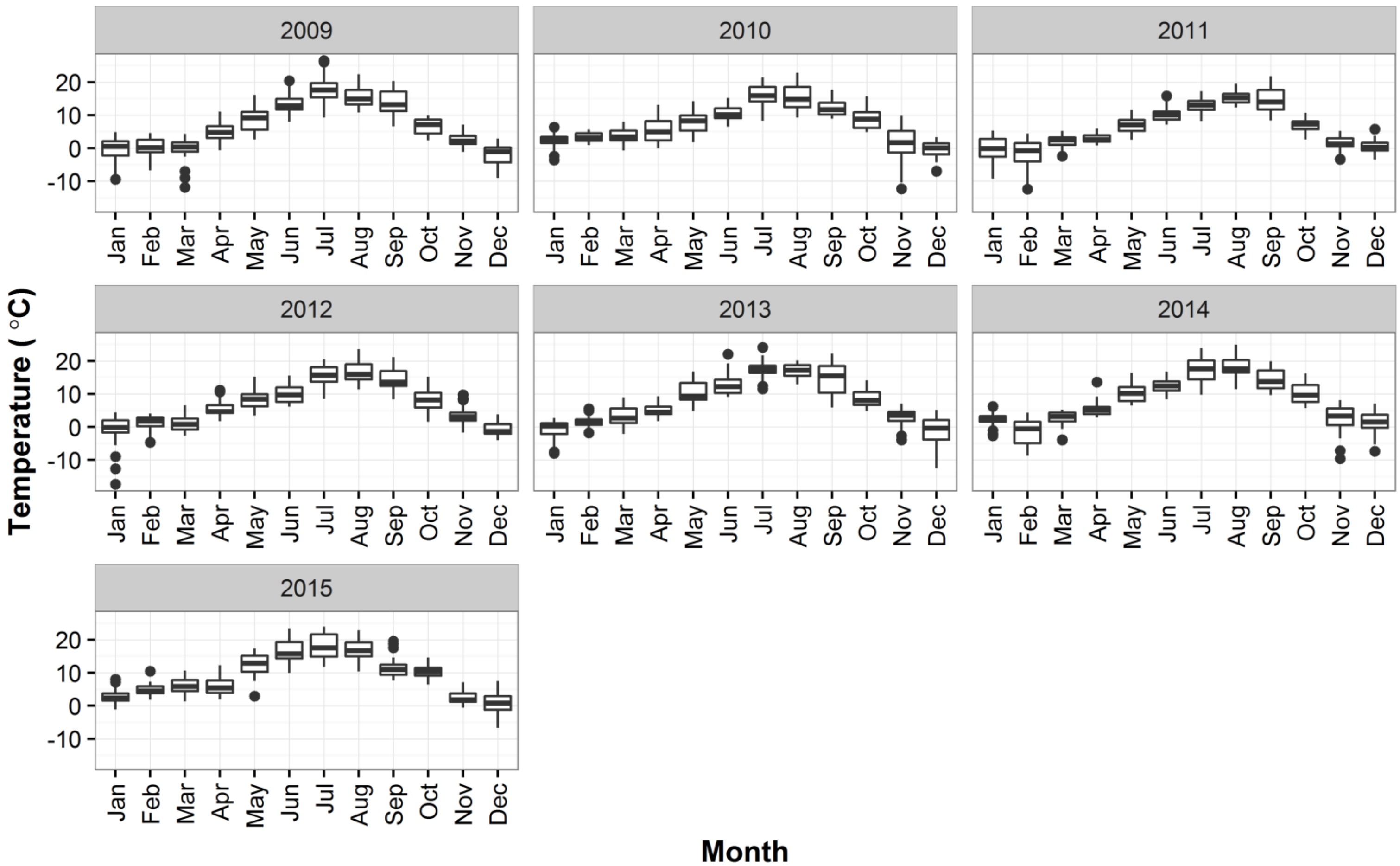

Figure 7 Boxplot of daily mean air temperatures (°C) during each month, 2009-2015, Wahleach Reservoir, BC.

3.2.2 Precipitation

Seasonal patterns in precipitation generally followed the inverse trend of air temperature; typically, July and August had the lowest precipitation while November through January had the highest precipitation with another peak in March (Figure 8). Annual summary statistics of daily and monthly precipitation for 2009 to 2015 are shown in Table 15. The long term (1993 to 2015) mean daily precipitation was 7 ± 13 mm with a range of 0 to 130 mm and the long term monthly mean was 218 ± 110 mm. In terms of total annual precipitation, the wettest year on record was 2011 (3124 mm) and the driest year on record was 1993 (2102 mm). Monthly and daily precipitation means show the same patterns (Table 15).

Table 15 Annual summary statistics of daily, monthly and total precipitation (mm), 2009-2015, Wahleach Reservoir BC.

Year	Daily Mean (mm)	Daily SD (mm)	Daily Max (mm)	Daily Min (mm)	Monthly Mean (mm)	Monthly SD (mm)	Monthly Max (mm)	Monthly Min (mm)	Annual Total (mm)
2009	7	13	83	0	206	158	618	70	2466
2010	7	12	77	0	206	107	335	20	2466
2011	9	16	130	0	260	154	614	37	3124
2012	8	13	66	0	237	136	429	10	2847
2013	7	12	81	0	210	117	390	8	2522
2014	8	13	63	0	253	124	485	59	3032
2015	7	12	71	0	207	110	373	36	2478

Summary statistics for the nutrient addition season (June to September, inclusively) from 2009 to 2015 are shown in Table 16. During the nutrient addition season, long term (1993 to 2015) mean daily precipitation was 4 ± 9 mm with a range of 0 to 114 mm and the long term monthly mean was 127 ± 77 mm. Overall, from 2009 to 2015, daily and monthly precipitation means during the nutrient addition season were similar to the long term average. The wettest nutrient addition season on record had 687 mm total seasonal precipitation (2004) and the driest had 280 mm total season precipitation (2003).

Table 16 Annual summary statistics of daily, monthly and total precipitation (mm) during the nutrient addition season, 2009-2015, Wahleach Reservoir BC.

Year	Daily Mean (mm)	Daily SD (mm)	Daily Max (mm)	Daily Min (mm)	Monthly Mean (mm)	Monthly SD (mm)	Monthly Max (mm)	Monthly Min (mm)	Annual Total (mm)
2009	3	7	35	0	94	30	138	70	375
2010	5	9	46	0	153	140	335	20	611
2011	4	9	60	0	116	68	186	37	464
2012	4	10	59	0	115	134	305	10	458
2013	4	11	78	0	132	126	304	8	527
2014	4	9	51	0	129	56	179	59	515
2015	4	10	65	0	125	82	201	36	499

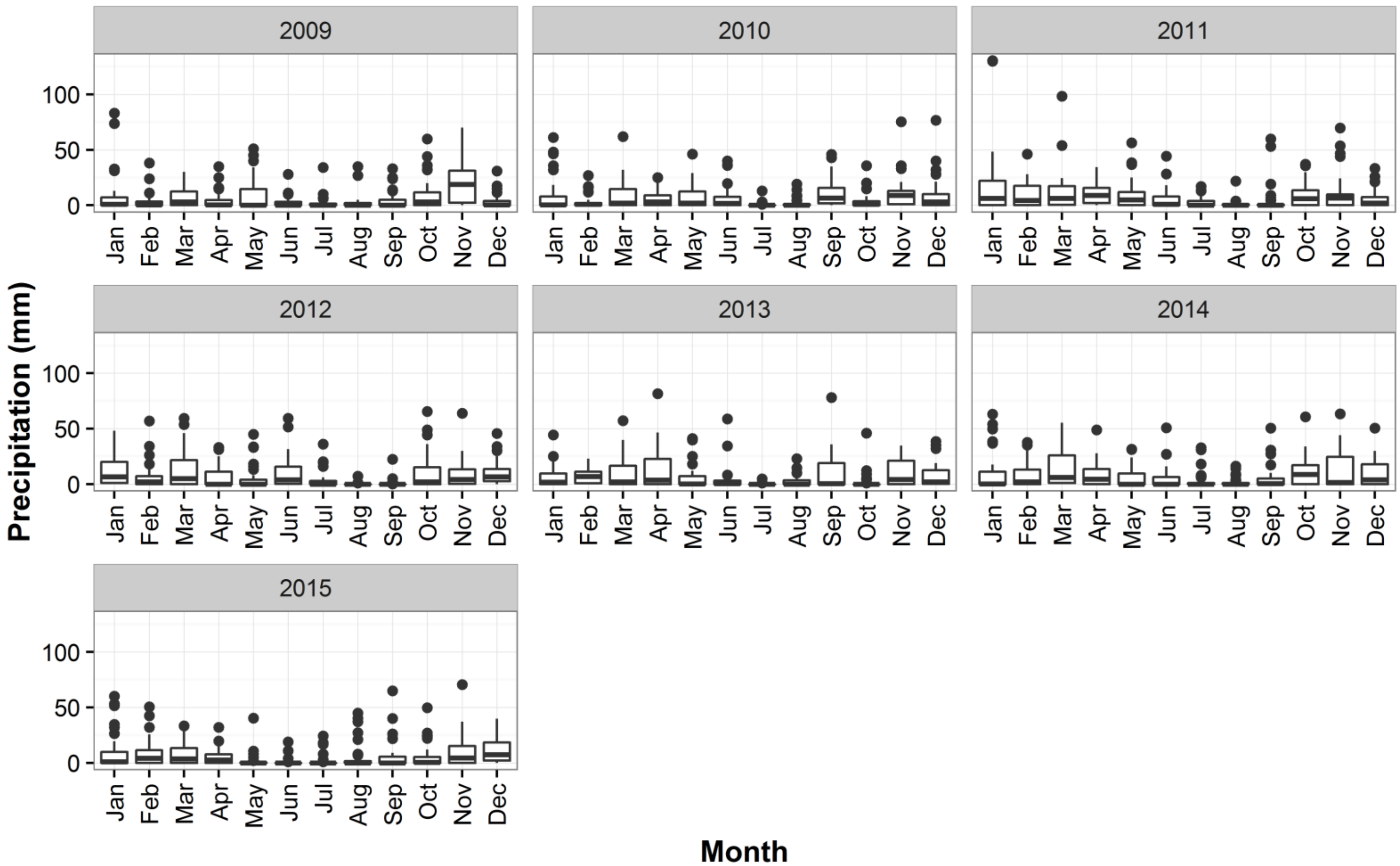

Figure 8 Boxplot of daily total precipitation (mm) during each month, 2009-2015, Wahleach Reservoir, BC.

3.3 Physical and Chemical Limnology

Wahleach Reservoir experiences a seasonal pattern of thermal stratification typical of temperate systems (Wetzel 2001) as shown in Figure 10 and Figure 11 for the north and south basins, respectively. The thermocline begins to develop in June with strong thermal stratification in July and August, and then a weakening of the stratification by September. In general, in the spring (May) and fall (October), the water column is well mixed showing and isothermal profile. Thermocline depth was generally between 4-8 m (Figure 10, Figure 11).

Annual summary statistics of water temperature and dissolved oxygen in both the north and south basins are shown in Table 17. Seasonal mean and maximum water temperatures for the north basin and south basin are shown in Figure 9. Water temperatures were similar in the north basin and the south basin. Prior to 2009, maximum water temperatures were below 20°C (with the exception of 2005) and after 2009, maximum water temperatures were above 20°C (with the exceptions of 2012 and 2014). The warmest water temperatures on record were in 2009 in both basins (Figure 9). In 2009, several data points were over 25°C (water temperatures were above 25°C down to 2 m in July in NB and down to 3 m in August in SB), which is lethal for most salmonid species (Ford *et al*. 1995). The coolest mean water temperatures on record were observed in 2012

As expected, patterns in dissolved oxygen were opposite of temperature (Figure 10, Figure 11). From 2009 to 2015, mean dissolved oxygen ranged from 7.5 to 10.5 mg·L^{-1} (Table 17). Both basins showed orthograde oxygen profiles indicative of oligotrophic conditions (Figure 10, Figure 11). Federal guidelines for dissolved oxygen in cold water lakes are 9.5 mg·L^{-1} for early life stages and 6.5 mg·L^{-1} for other life stages (CCME 1999). All mean dissolved oxygen temperatures were above 6.5 mg·L^{-1}.

Table 17 Annual summary statistics of water temperature (°C) and dissolved oxygen (mg·L^{-1}) at the north basin (NB) and south basin (SB) limnology sampling stations, 2009-2015, Wahleach Reservoir, BC.

Year	Basin	Temperature (°C)				Dissolved Oxygen (mg·L^{-1})			
		Mean	SD	Max	Min	Mean	SD	Max	Min
2009	NB	16.4	4.0	27.3	10.3	7.5	1.3	10.4	4.5
2009	SB	16.5	4.2	26.8	10.6	7.8	1.1	10.1	4.4
2010	NB	15.6	3.2	24.7	12.0	7.8	1.0	10.0	4.1
2010	SB	15.2	3.0	23.7	12.1	7.9	0.8	9.5	5.2
2011	NB	13.2	2.9	22.8	9.3	9.8	1.2	13.1	6.6
2011	SB	13.2	2.9	22.8	9.2	9.7	1.2	11.4	5.3
2012	NB	10.3	3.0	17.3	6.4	10.5	1.4	14.2	6.9
2012	SB	10.7	3.2	17.2	6.4	10.3	1.3	12.8	7.2
2013	NB	11.7	3.8	21.1	7.2	9.5	1.3	11.2	4.5
2013	SB	11.7	3.8	21.5	7.3	9.5	1.2	11.4	5.5
2014	NB	12.3	3.5	19.9	6.6	10.0	1.4	12.2	5.3
2014	SB	12.3	3.4	20.3	6.6	10.1	1.2	11.7	5.5
2015	NB	13.5	3.9	21.8	7.8	8.7	1.5	11.1	3.9
2015	SB	13.6	3.9	22.4	7.8	8.7	1.4	10.7	4.1

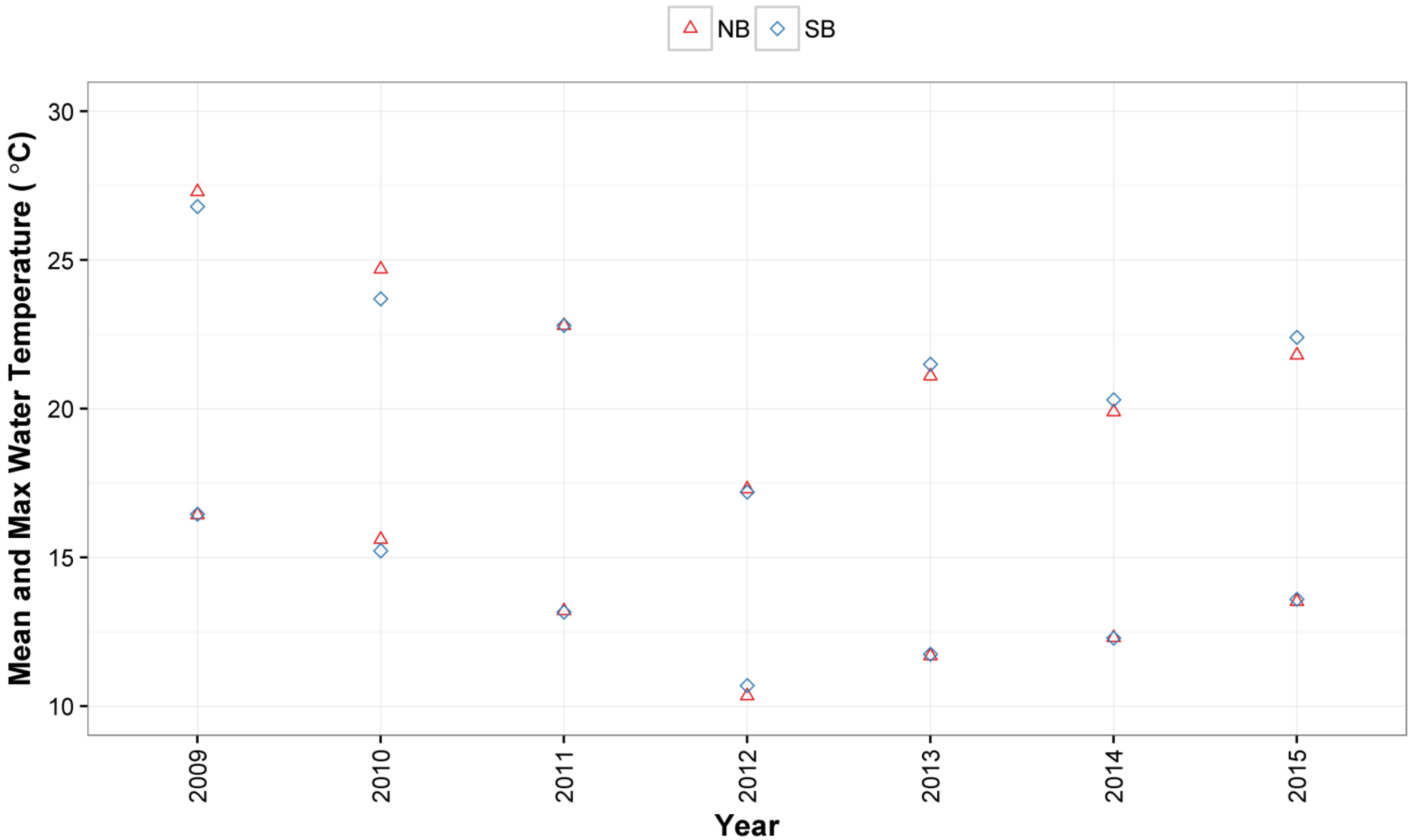

Figure 9 Seasonal (May to October) mean and maximum water temperatures (°C) at the north basin (NB) and south basin (SB) limnology sampling stations, 2009-2015, Wahleach Reservoir, BC.

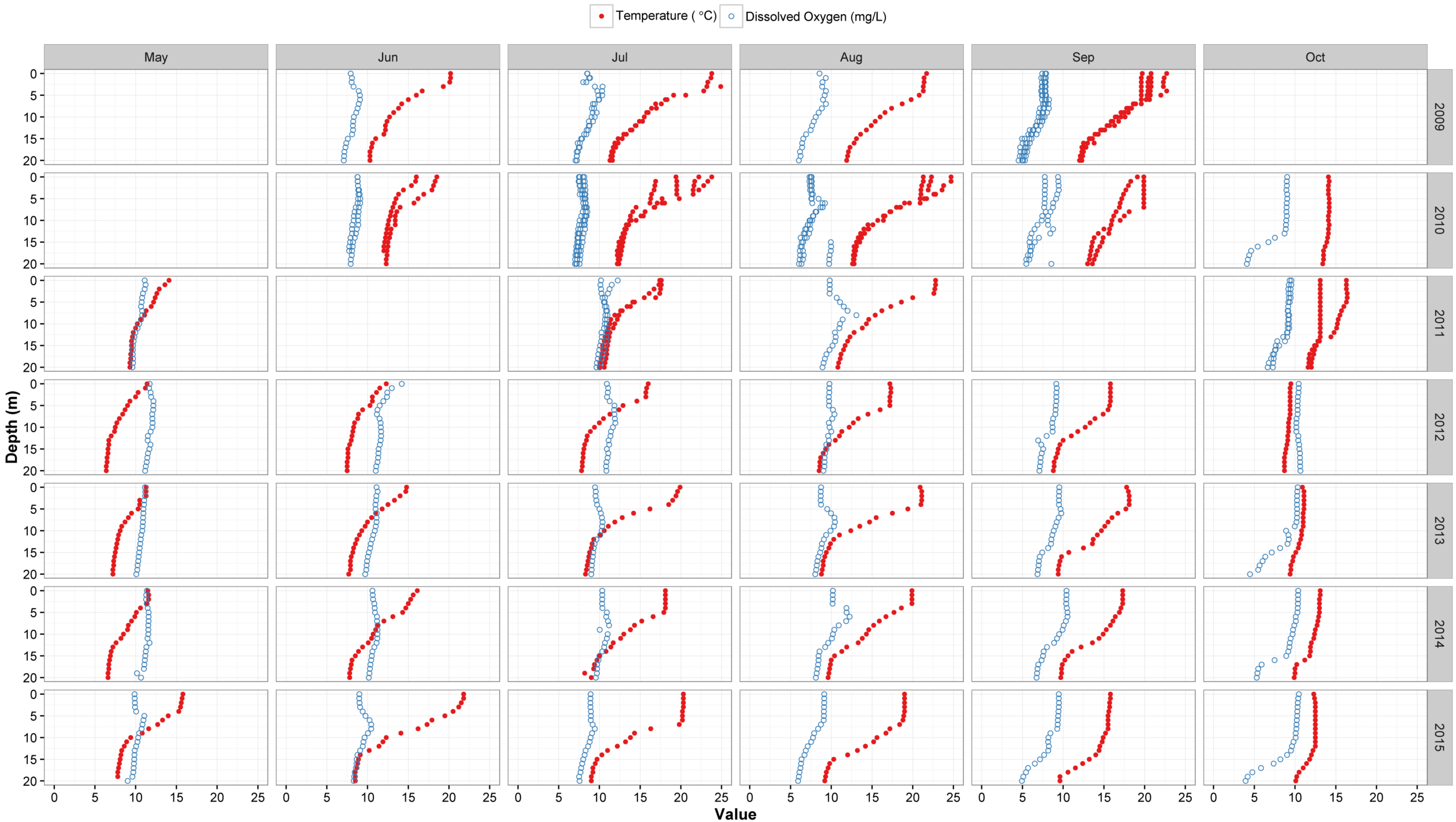

Figure 10 Water temperature (°C) and dissolved oxygen (mg·L^{-1}) profiles taken at the north basin (NB) limnology sampling station May to October, 2009-2015, Wahleach Reservoir, BC.

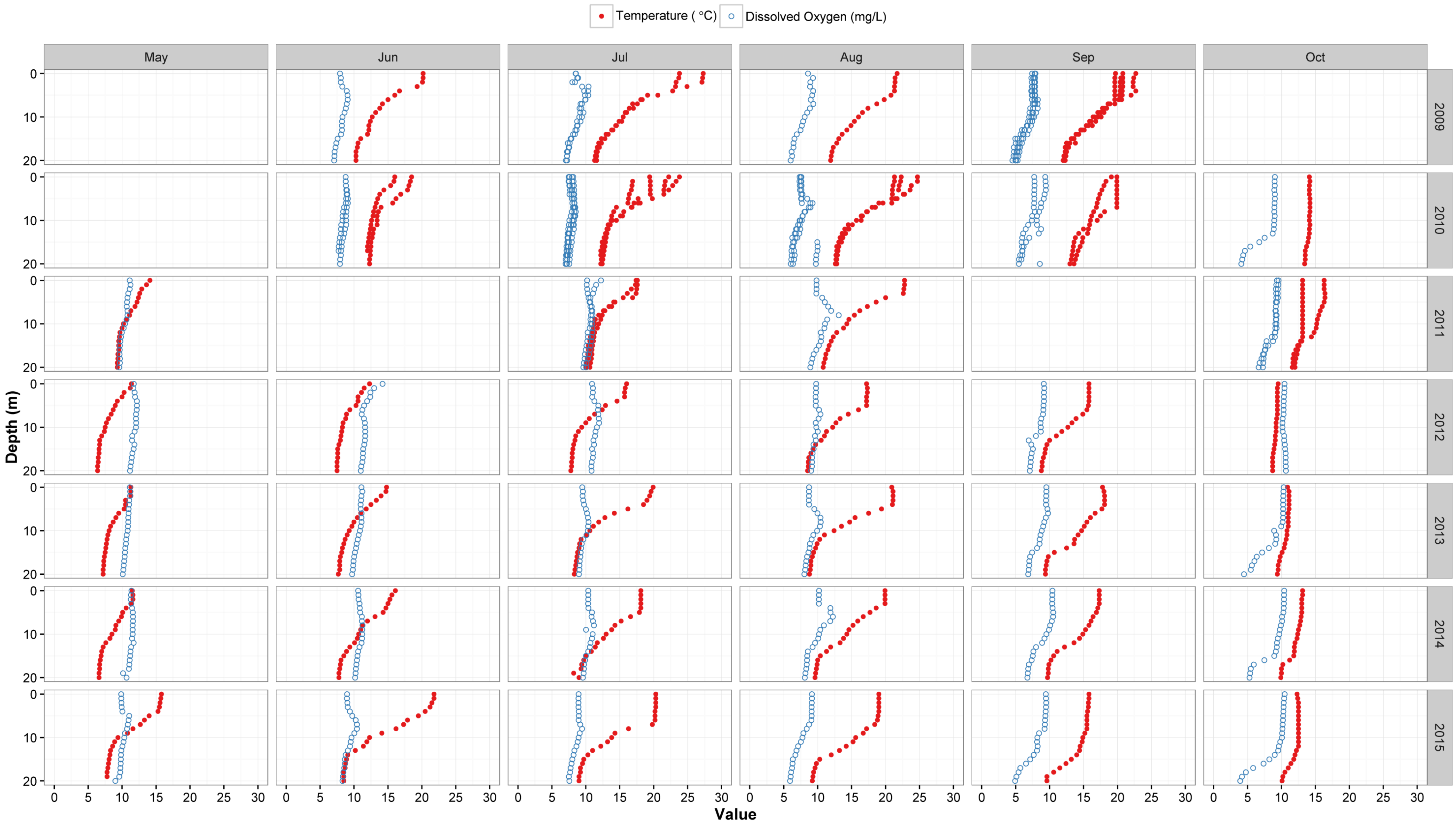

Figure 11 Water temperature (°C) and dissolved oxygen (mg·L^{-1}) profiles taken at the south basin (SB) limnology sampling station May to October, 2009-2015, Wahleach Reservoir, BC.

Secchi depth, an indicator of water transparency, has increased over the last seven years as shown in Figure 12 and annual summary statistics in Table 18. Secchi depths generally ranged from 6-8 m early in the season to 2-4 m (with the exceptions of 2014 and 2015, which were deeper) during peak growing season (Figure 12). Secchi depths recorded in both the north basin (NB) and south basin (SB) were similar.

Table 18 Annual summary statistics of Secchi depths (m), 2009-2015, Wahleach Reservoir, BC.

Year	Secchi Depth (m)			
	Mean	SD	Max	Min
2009	3.8	1.7	6.2	2.0
2010	3.5	0.9	4.8	2.1
2011	4.3	1.6	6.6	1.8
2012	4.9	1.4	7.1	3.1
2013	4.0	1.4	6.0	2.0
2014	5.8	1.2	7.8	4.3
2015	5.7	1.5	7.4	2.9

Summary statistics from 2009 to 2015 for pH and alkalinity are shown in Table 19. The pH in Wahleach Reservoir is neutral with an annual mean ranging from 6.5-7.5 (Figure 13). 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 generally ranged between 8-10 mg $CaCO_3 \cdot L^{-1}$, with the exception of the mean alkalinity for 1993 at 14 mg $CaCO_3 \cdot L^{-1}$ (data on file; Figure 14).

Table 19 Annual summary statistics of pH and alkalinity (mg $CaCO_3 \cdot L^{-1}$) from 1m water chemistry sample, 2009-2015, Wahleach Reservoir, BC.

Year	pH				Alkalinity (mg $CO^{3} \cdot L^{-1}$)			
	Mean	SD	Max	Min	Mean	SD	Max	Min
2009	-	-	-	-	10.0	0.8	12.0	8.7
2010	7.2	0.0	7.2	7.2	10.3	1.0	12.0	8.7
2011	7.0	0.1	7.2	6.8	9.0	1.2	11.0	7.5
2012	7.1	0.1	7.2	6.8	8.5	1.0	9.5	6.1
2013	7.1	0.1	7.3	6.9	9.0	0.7	10.0	7.4
2014	7.2	0.1	7.4	7.1	9.5	0.8	10.5	8.0
2015	7.2	0.1	7.4	7.1	10.8	1.1	11.8	8.3

Dashes (-) indicate no data present

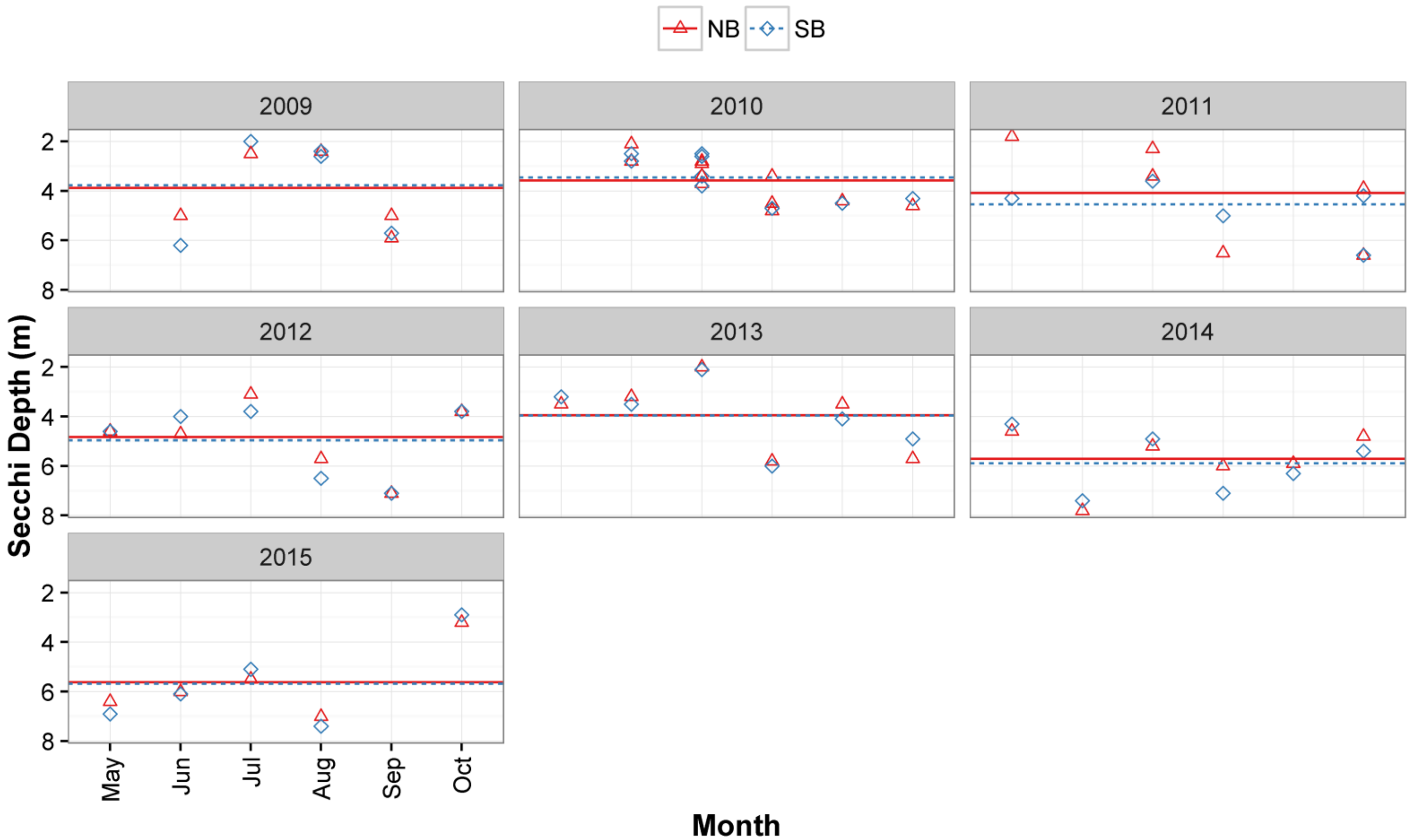

Figure 12 Secchi depths (m) taken at the north basin (NB) and south basin (SB) limnology sampling stations, 2009-2015, Wahleach Reservoir, BC. Horizontal bars represent seasonal mean for each station.

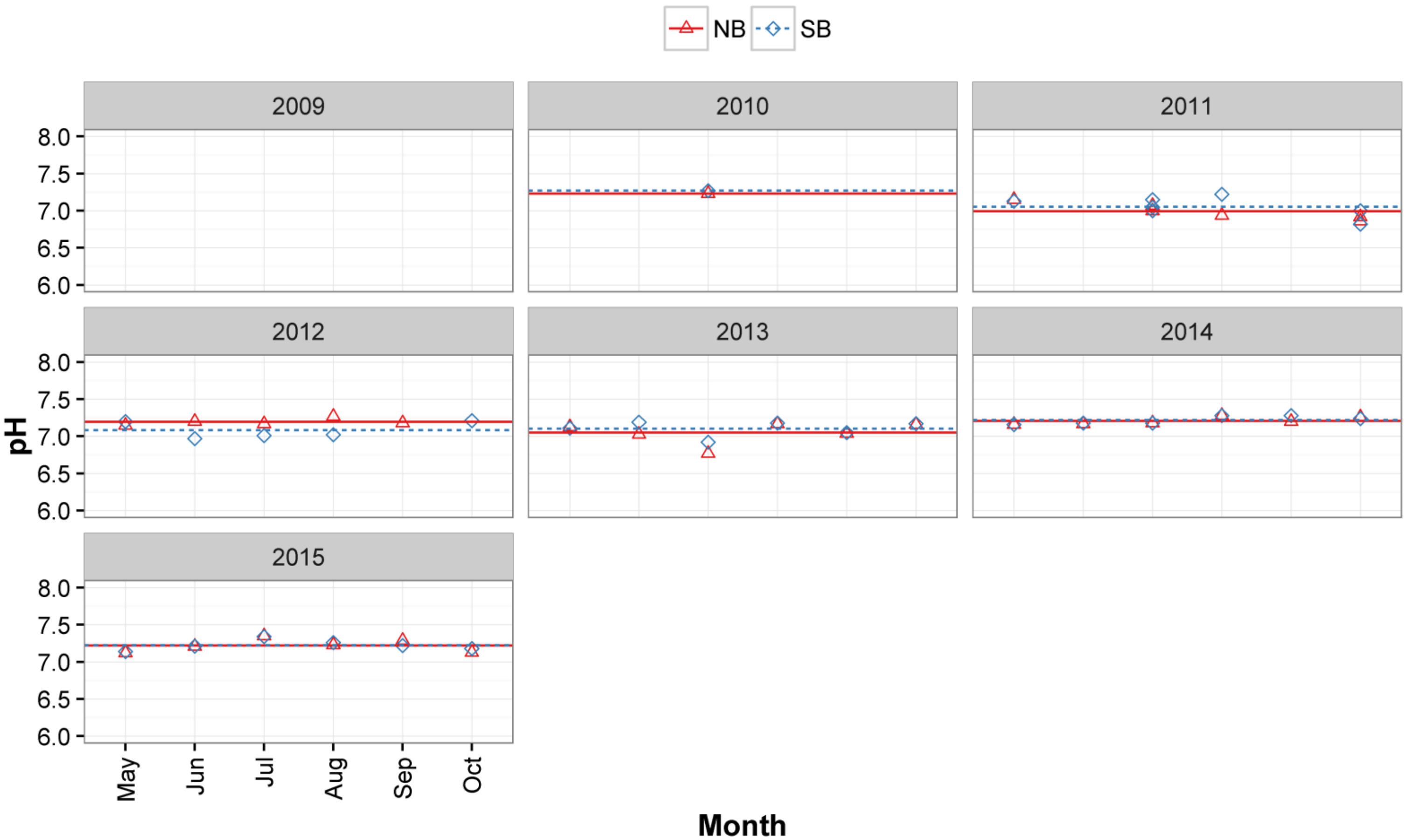

Figure 13 pH values from 1m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May-October, 2009-2015, Wahleach Reservoir, BC. Horizontal bars represents seasonal mean for each station. Note: no pH was taken in 2009.

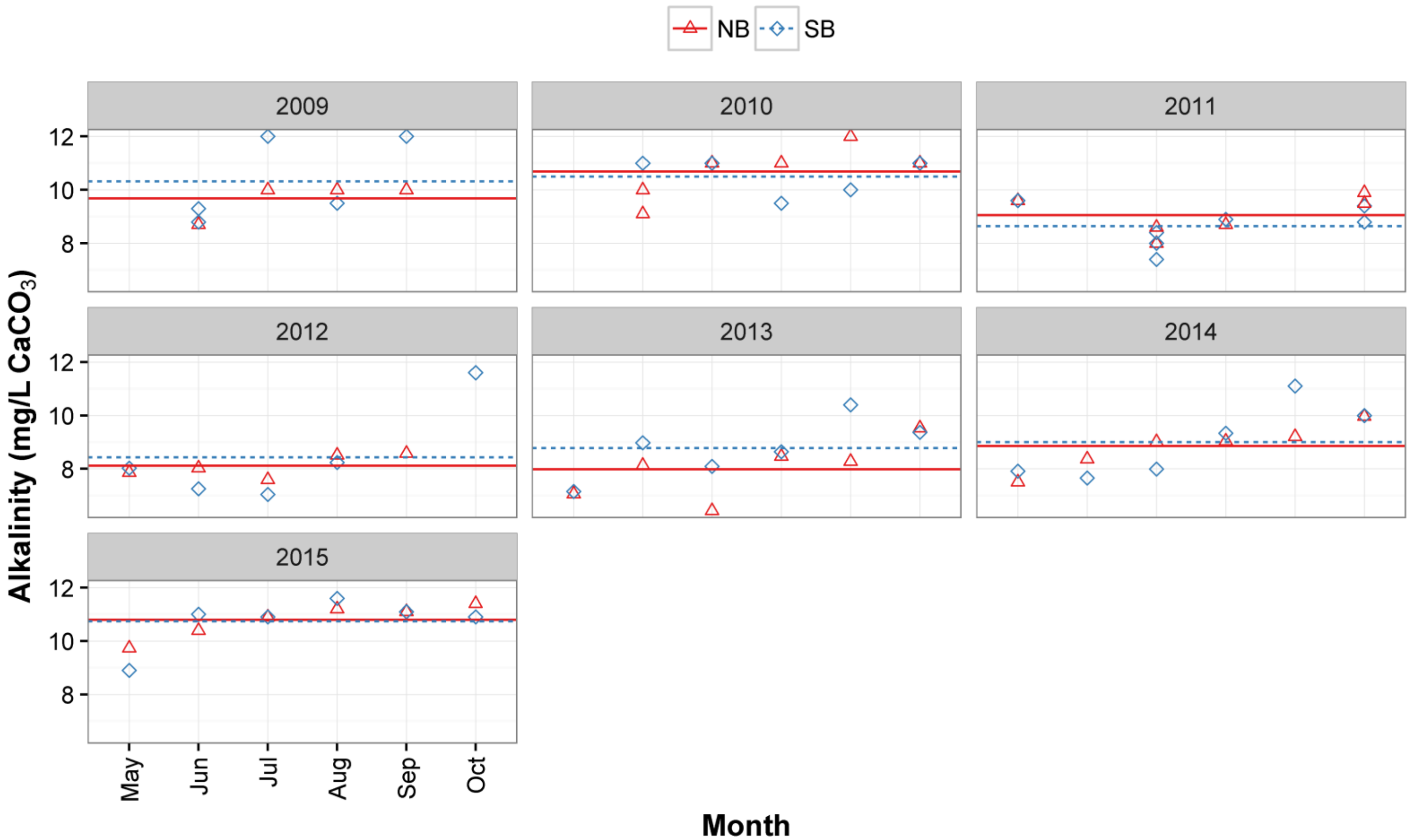

Figure 14 Alkalinity (mg $CaCO^{3}{\cdot}L^{-1}$) values from 1m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May-October, 2009-2015, Wahleach Reservoir, BC. Horizontal bars represents seasonal mean for each station.

In studying the relationship between total phosphorus (TP) and lake productivity, 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 2.9-12.0 $\mu g \cdot L^{-1}$ indicative of ultra-oligotrophic productivity nearing oligotrophic productivity. From 2009 to 2015, seasonal mean TP values ranged from 2.2-5.5 $\mu g \cdot L^{-1}$ (Table 20, Figure 15). Overall, TP values ranged between concentrations indicative of ultra-oligotrophic and oligotrophic productivity.

Soluble reactive phosphorous (SRP), a measurement of low level orthophosphate, is the form of phosphorous readily available to phytoplankton. SRP levels during baseline years were 1.1 ± 0.3 $\mu g \cdot L^{-1}$ with a range of 1-2 $\mu g \cdot L^{-1}$ (Table 20, Figure 16). From 2009 to 2015, seasonal mean SRP levels were similar to levels observed during baseline years. Several soluble reactive phosphorus (SRP) samples (47%) were below detection limits of 1 $\mu g \cdot L^{-1}$ from 2009 to 2015, despite weekly phosphorus additions suggesting rapid uptake and assimilation of useable phosphorus by phytoplankton.

Table 20 Annual summary statistics of total phosphorus (TP; $\mu g \cdot L^{-1}$) and low level orthophosphate (PO_4 $\mu g \cdot L^{-1}$) from 1m water chemistry samples, 2009-2015, Wahleach Reservoir, BC.

Year	TP ($\mu g \cdot L^{-1}$)				Low Level PO4 ($\mu g \cdot L^{-1}$)			
	Mean	SD	Max	Min	Mean	SD	Max	Min
2009	2.7	0.9	4.0	1.0	1.0	0.6	2.0	0.5
2010	4.0	1.2	6.0	2.0	1.3	0.8	3.0	0.5
2011	3.5	1.0	5.0	1.0	1.5	1.0	4.0	0.5
2012	4.7	1.3	6.8	3.4	1.4	0.6	2.0	0.5
2013	5.5	3.2	12.1	1.0	1.2	1.2	4.6	0.5
2014	3.6	1.0	5.6	2.4	1.2	0.9	3.3	0.5
2015	2.2	1.4	4.5	1.0	0.5	0.1	1.0	0.5

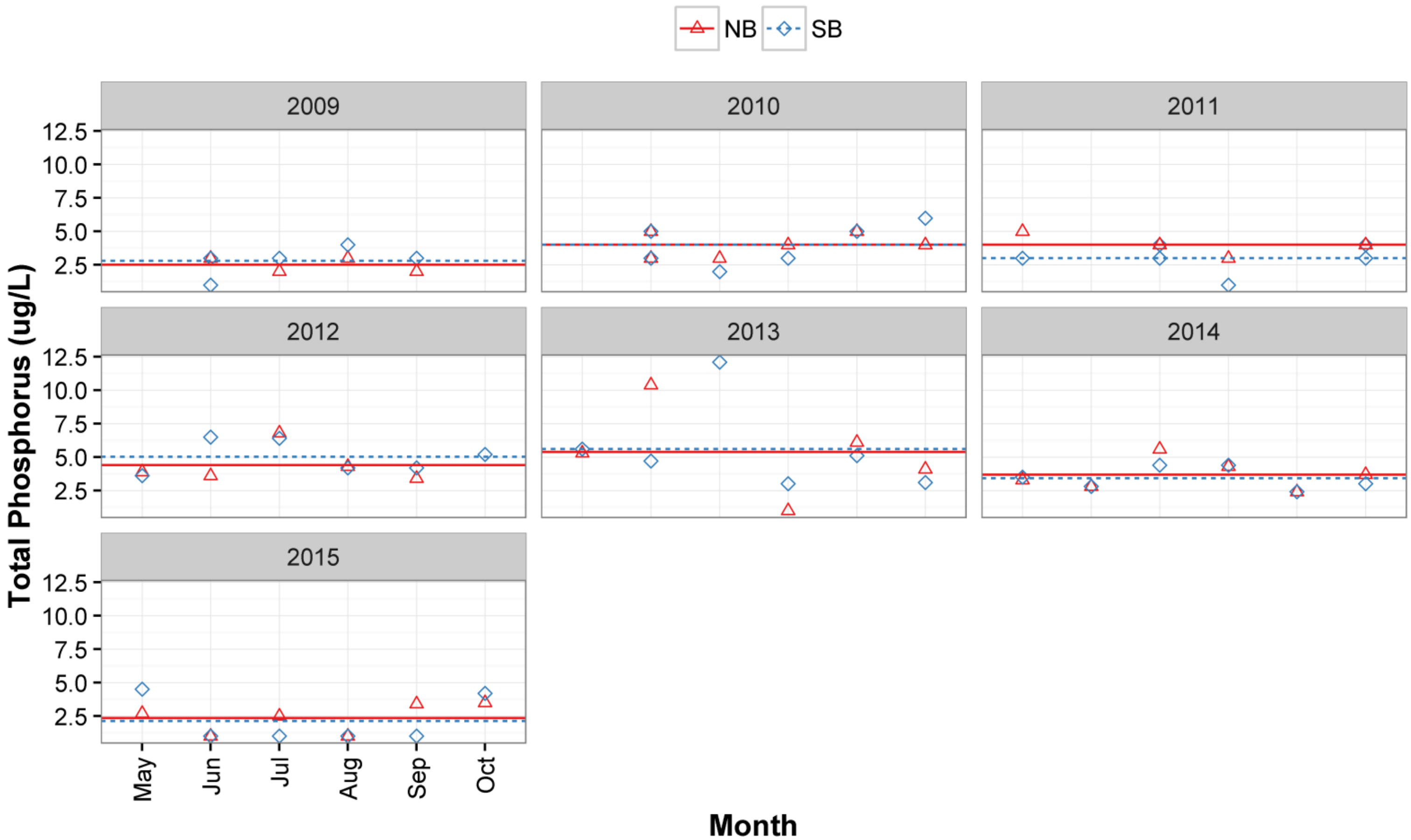

Figure 15 Total phosphorus concentration (µg·L^{-1}) from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to October, 2009-2015, Wahleach Reservoir, BC.

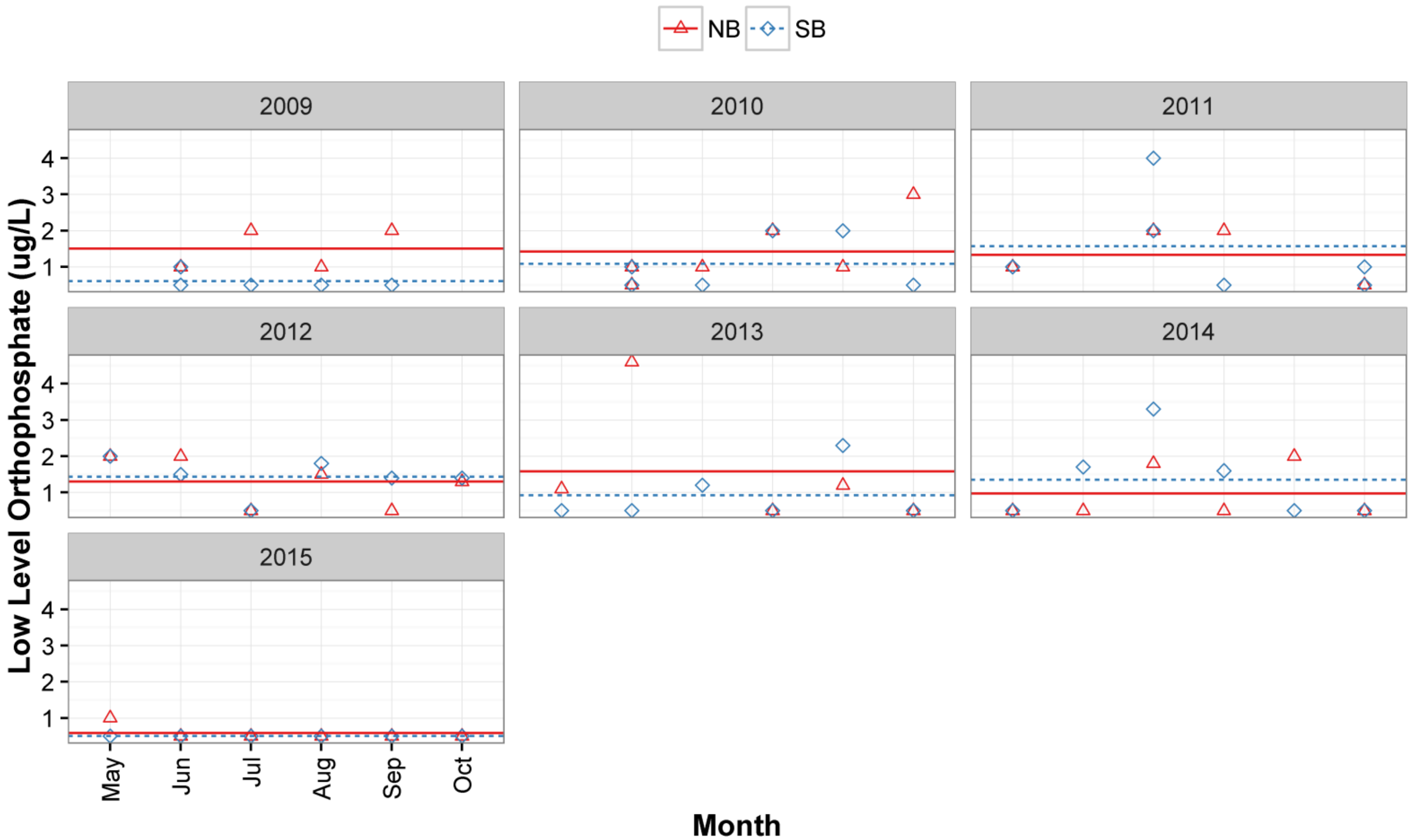

Figure 16 Low level orthophosphate concentrations (µg·L^{-1}) from 1m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May-October, 2009-2015, Wahleach Reservoir BC.

Total nitrogen (TN) represents dissolved inorganic forms of nitrogen (i.e., nitrate, nitrite and ammonia) and particulate forms of nitrogen (mainly organic). Seasonally, epilimnetic TN concentrations were generally highest in spring, decreased through the summer and then started to increase in fall (Figure 17). This pattern coincides with the seasonal growth and utilization of nitrogen by phytoplankton in the reservoir's epilimnion. Total nitrogen (TN) concentrations in 2009 to 2015 were greater than baseline years (112 ± 48 $\mu g \cdot L^{-1}$, range 9-220 $\mu g \cdot L^{-1}$) (Figure 17, Table 21), with 2015 TN values near baseline values.

Nitrate + nitrite-N (NO_3+NO_2-N) are an important form of dissolved nitrogen supporting algal growth (Wetzel 2001). In Wahleach Reservoir, the highest concentrations of NO_3+NO_2 were typically observed at spring turnover while NO_3+NO_2 decreased through summer and then increase in early fall. Although summer NO_3+NO_2 concentrations drop below the level considered limiting for phytoplankton (<20 $\mu g \cdot L^{-1}$) in both eras, the drop is more pronounced during nutrient restoration years (Figure 18) suggesting strong biological utilization of NO_3+NO_2 during these years. In 2009 to 2015 during nutrient restoration, seasonal mean NO_3+NO_2 concentrations were lower than baseline (57 ± 38 $\mu g \cdot L^{-1}$) with a range from 19±32 $\mu g \cdot L^{-1}$ in 2013 to 53±46 $\mu g \cdot L^{-1}$ in 2009 $\mu g \cdot L^{-1}$ (Table 21).

Table 21 Annual summary statistics of total nitrogen (TN; $\mu g \cdot L^{-1}$) and low level nitrate + nitrite (NO_3 + NO_2; $\mu g \cdot L^{-1}$) from 1m water chemistry samples, 2009-2015, Wahleach Reservoir BC.

Year	TN ($\mu g \cdot L^{-1}$)				Low Level NO_3 + NO_2 ($\mu g \cdot L^{-1}$)			
	Mean	SD	Max	Min	Mean	SD	Max	Min
2009	159	51	240	80	53	46	124	4
2010	127	67	280	13	23	25	81	2
2011	182	93	390	80	39	31	97	1
2012	207	50	273	135	46	56	143	1
2013	175	77	330	102	19	32	84	1
2014	147	33	188	89	38	37	98	1
2015	113	29	147	72	22	23	65	2

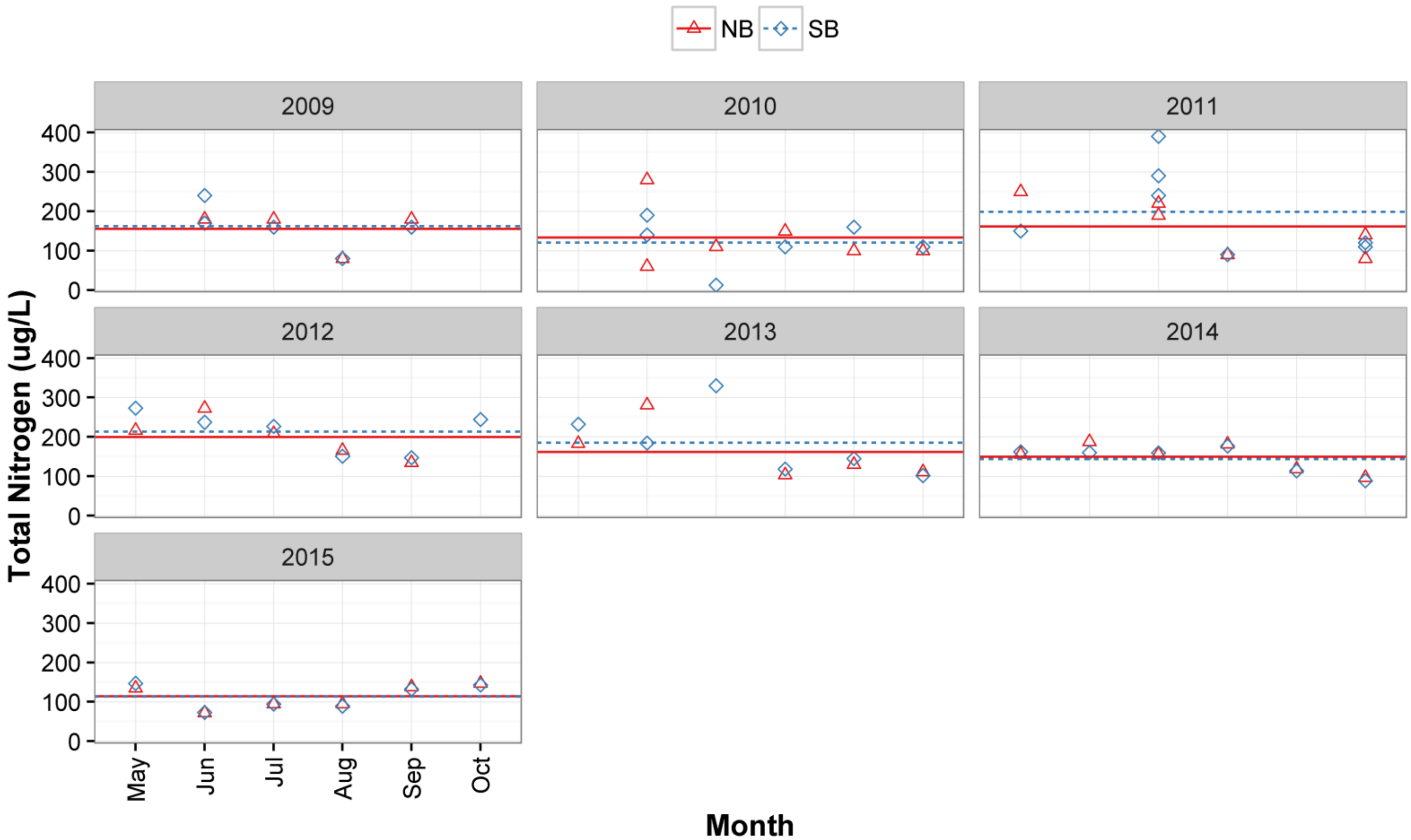

Figure 17 Total nitrogen concentrations (µg·L^{-1}) from 1m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May-October, 2009-2015, Wahleach Reservoir BC; horizontal lines represents seasonal means for each station.

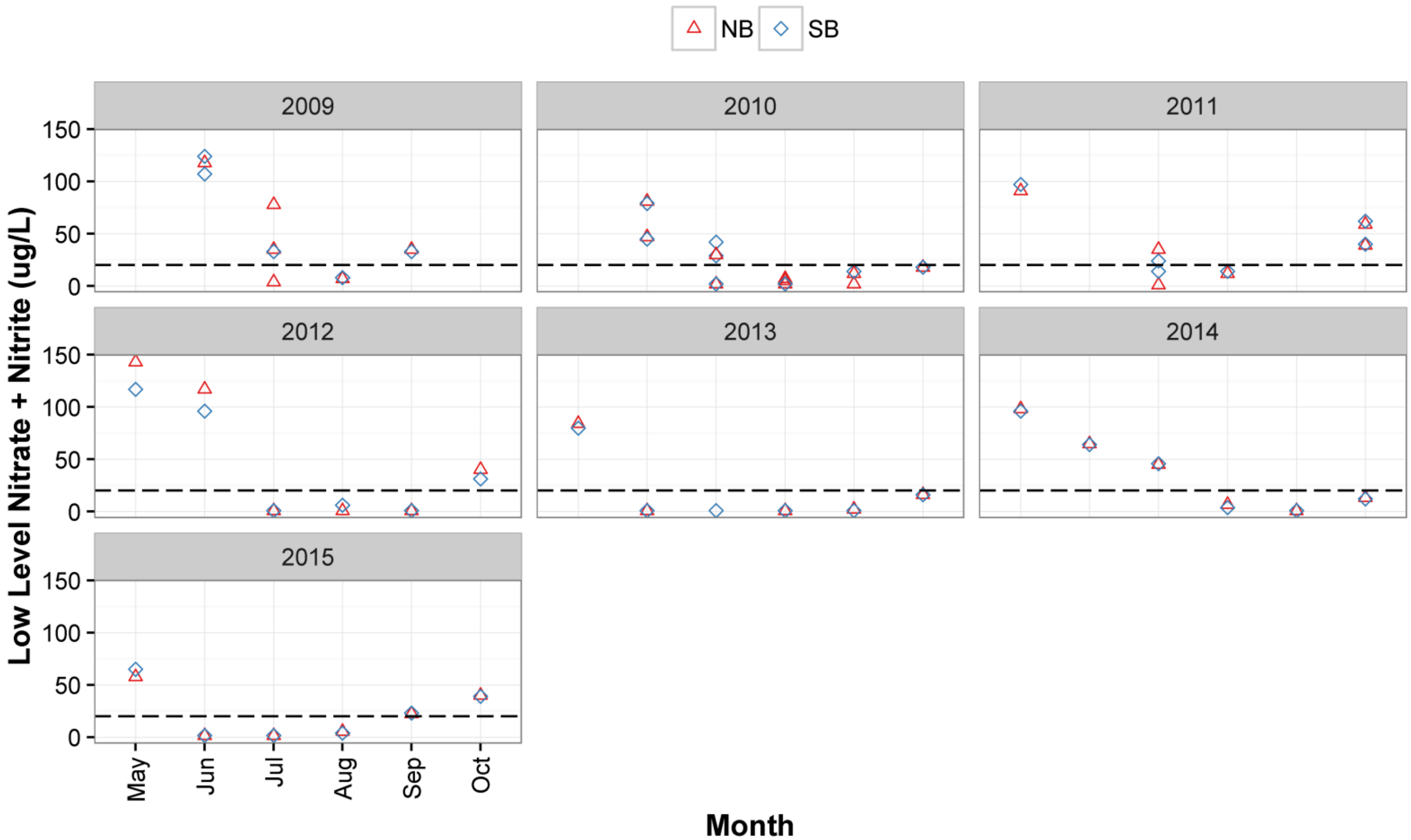

Figure 18 Low level nitrate + nitrite nitrogen concentrations (µg·L^{-1}) from 1 m discrete water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May-October, 2009-2015, Wahleach Reservoir BC; black dashed line at 20 µg·L^{-1} represents the limiting concentration for phytoplankton growth.

Ideal TN:TP ratios for phytoplankton growth are between 20-50; ratios above 50 are likely in a state of phosphorus limitation while ratios below 20 are likely in a state of nitrogen limitation (Guildford and Hecky 2000). Mean TN:TP ratios for 2009-2015 ranged between 31-77 (Table 22). During the past seven years, TN:TP ratios rarely went below 20 with the exception of 2010 which was below 20 in July (Figure 19).

Table 22 Annual summary statistics of total nitrogen (TN) to total phosphorus ratios (TP) from 1 m water chemistry samples, 2009-2015, Wahleach Reservoir, BC.

Year	TN:TP Ratio			
	Mean	SD	Max	Min
2009	77	66	240	20
2010	31	14	56	7
2011	55	27	98	20
2012	46	16	76	31
2013	38	23	104	21
2014	43	12	67	26
2015	66	32	132	33

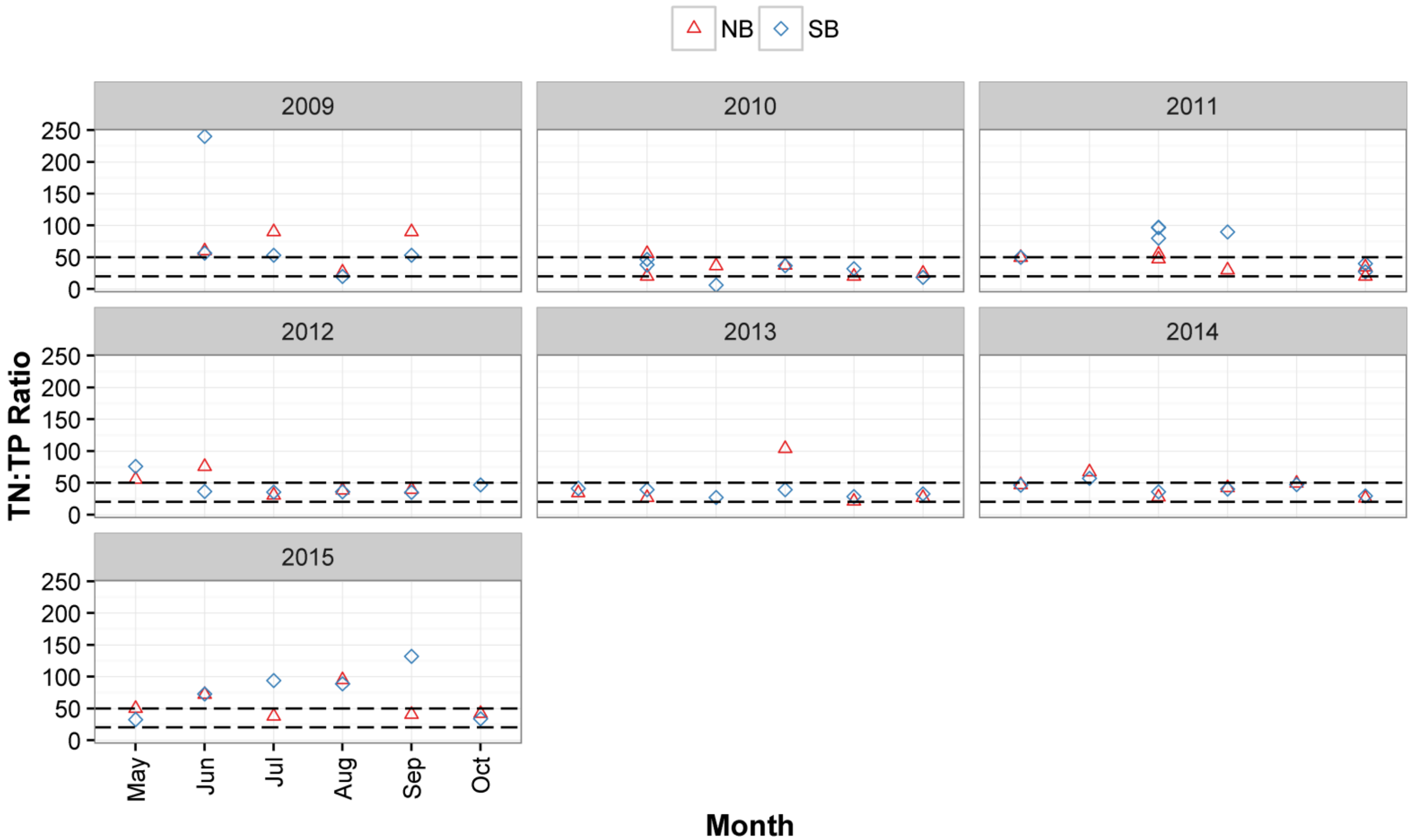

Figure 19 Total nitrogen (TN) to total phosphorus (TP) ratios based on 1 m water chemistry samples from the north basin (NB) and the south basin (SB) limnology stations May-October, 2009-2015, Wahleach Reservoir, BC. Points above dashed line at 50 were likely in a state of P limitation, while points below dashed line at 20 were likely in a state of N limitation (Guildford and Hecky 2000).

3.4 Phytoplankton

Phytoplankton species richness in 2015 was the highest on record with consistent increasing trend in the number of species detected (Figure 20). Phytoplankton species present in each year are shown in Appendix A.

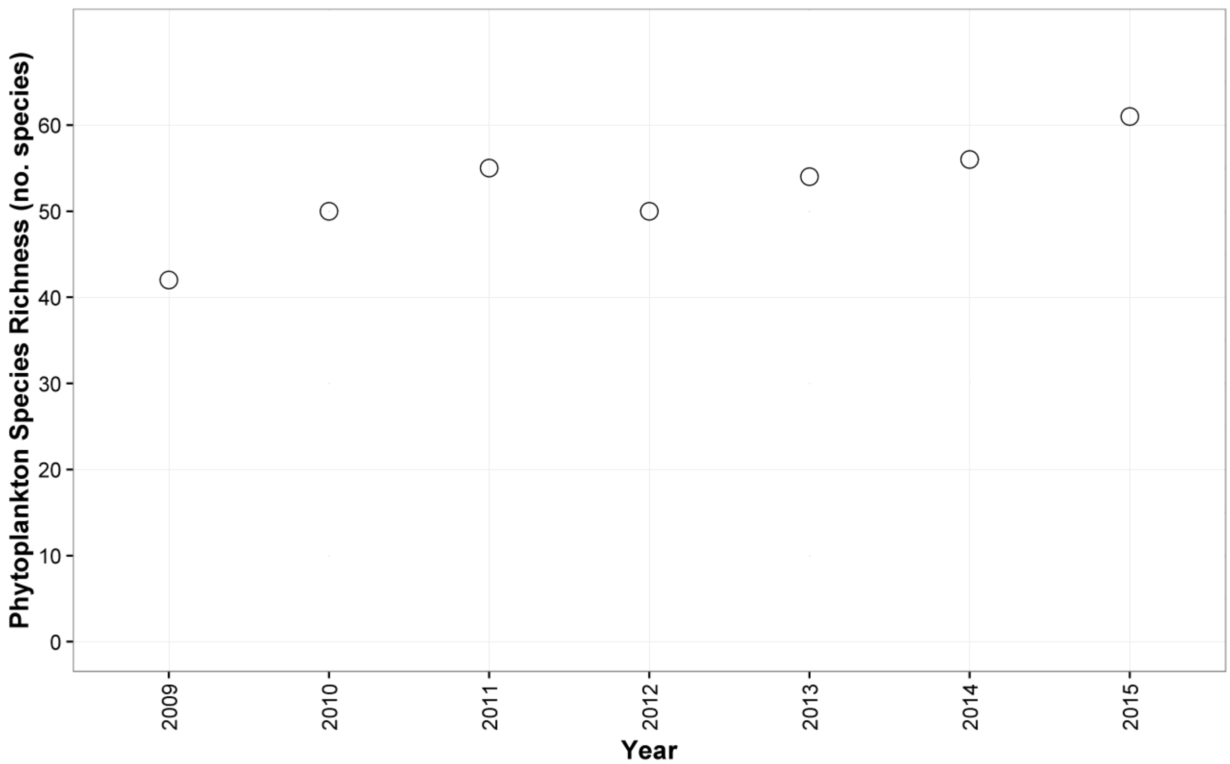

Figure 20 Phytoplankton species richness (number of species detected), 2009-2015, Wahleach Reservoir, BC.

Annual summary statistics of phytoplankton abundance between 2009 and 2015 are shown in Table 23. Summary statistics broken down by edibility are shown in Table 24. Annual distributions of phytoplankton abundance are shown in Figure 21. Mean phytoplankton abundance during the baseline study year (1994) was 8,793 ± 4,929 cells per mL, while the mean during whole reservoir nutrient additions (1995-2015) was 9,055 ± 11,052 cells per mL (data on file). In the last seven years, phytoplankton abundance was the highest on record in 2010. The abundance was high in the north basin primarily as a result of a summer (August) *Microcystis* sp. bloom (a small, largely inedible blue-green belonging to the class *Cyanophyceae*). Figure 23 shows seasonal abundance of the phytoplankton community by class, while Figure 24 shows seasonal abundance by edibility. Overall, recent years have experienced increased phytoplankton abundance largely resulting from summer blue-green algal blooms – particularly inedible *Microcystis* sp. – which is also reflected in increased abundance of the inedible fraction versus earlier years of the study (data on file, Figure 22). From 2010 to 2015, blue-greens were the numerically dominant class of the phytoplankton community but they were mainly edible species such as *Merismopedia* sp. (Figure 24). In 2015, inedible fractions were lower than previous years and the edible fraction was the highest of the review period (Table 24).

Table 23 Annual summary statistics of phytoplankton abundance (cells·mL^{-1}), 2009-2015, Wahleach Reservoir, BC.

Year	Abundance (cells.mL^{-1})			
	Mean	SD	Max	Min
2009	2,165	502	3,122	1,561
2010	18,554	22,159	98,392	4,339
2011	12,573	10,707	39,965	4,440
2012	10,454	9,513	33,642	3,061
2013	7,573	5,513	23,910	2,808
2014	15,373	15,103	46,275	1,774
2015	15,973	19,965	62,970	1,875

Table 24 Annual summary statistics of phytoplankton abundance (cells.mL^{-1}) by edibility (B=both edible and inedible forms, E=edible, I=inedible), 2009-2015, Wahleach Reservoir, BC.

Year	Edibility	Abundance (cells.mL^{-1})			
		Mean	SD	Max	Min
2009	B	79	24	112	61
2009	I	761	675	1,812	152
2009	E	1,359	831	2,139	122
2010	B	49	29	96	10
2010	I	11,833	23,842	96,194	57
2010	E	6,685	5,637	20,253	852
2011	B	16	10	28	10
2011	I	2,099	2,840	8,946	41
2011	E	10,470	10,843	39,924	2,848
2012	B	17	7	28	10
2012	I	4,435	6,383	16,916	51
2012	E	6,008	4,654	16,726	2,239
2013	B	60	55	142	10
2013	I	2,199	1,977	7,258	51
2013	E	5,344	5,207	20,869	2,108
2014	B	80	56	162	10
2014	I	5,215	6,527	18,145	253
2014	E	10,112	10,538	35,499	1,470
2015	B	24	6	30	20
2015	I	1,727	2,145	6,325	223
2015	E	14,198	19,786	61,713	1,206

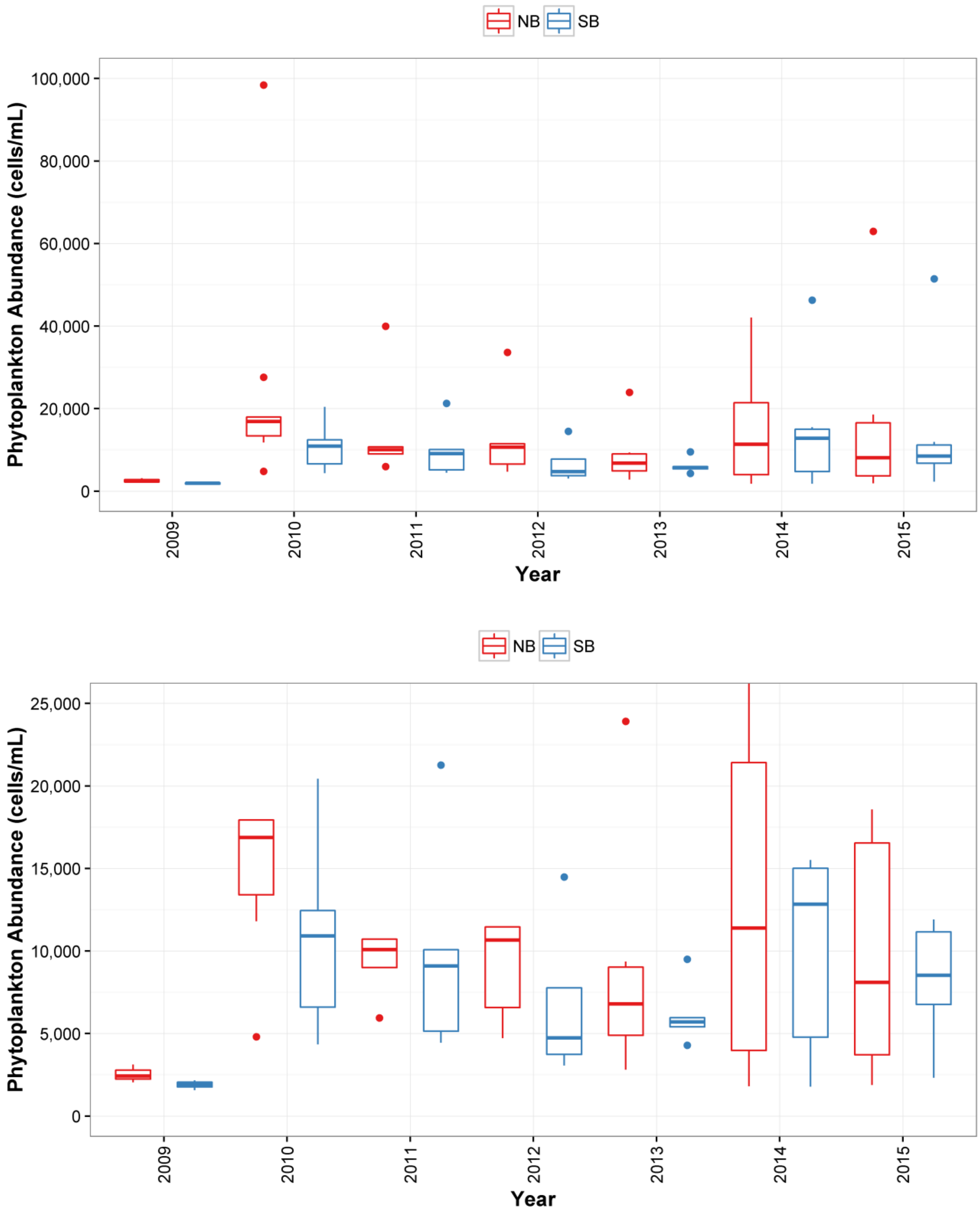

Figure 21 Boxplots of annual (May-October) phytoplankton abundance (cells·mL^{-1}) at the north basin (NB) and south basin (SB) limnology stations, 2009-2015, Wahleach Reservoir BC; lower panel is zoomed in to show distribution from 0-25,000 cells·mL^{-1}.

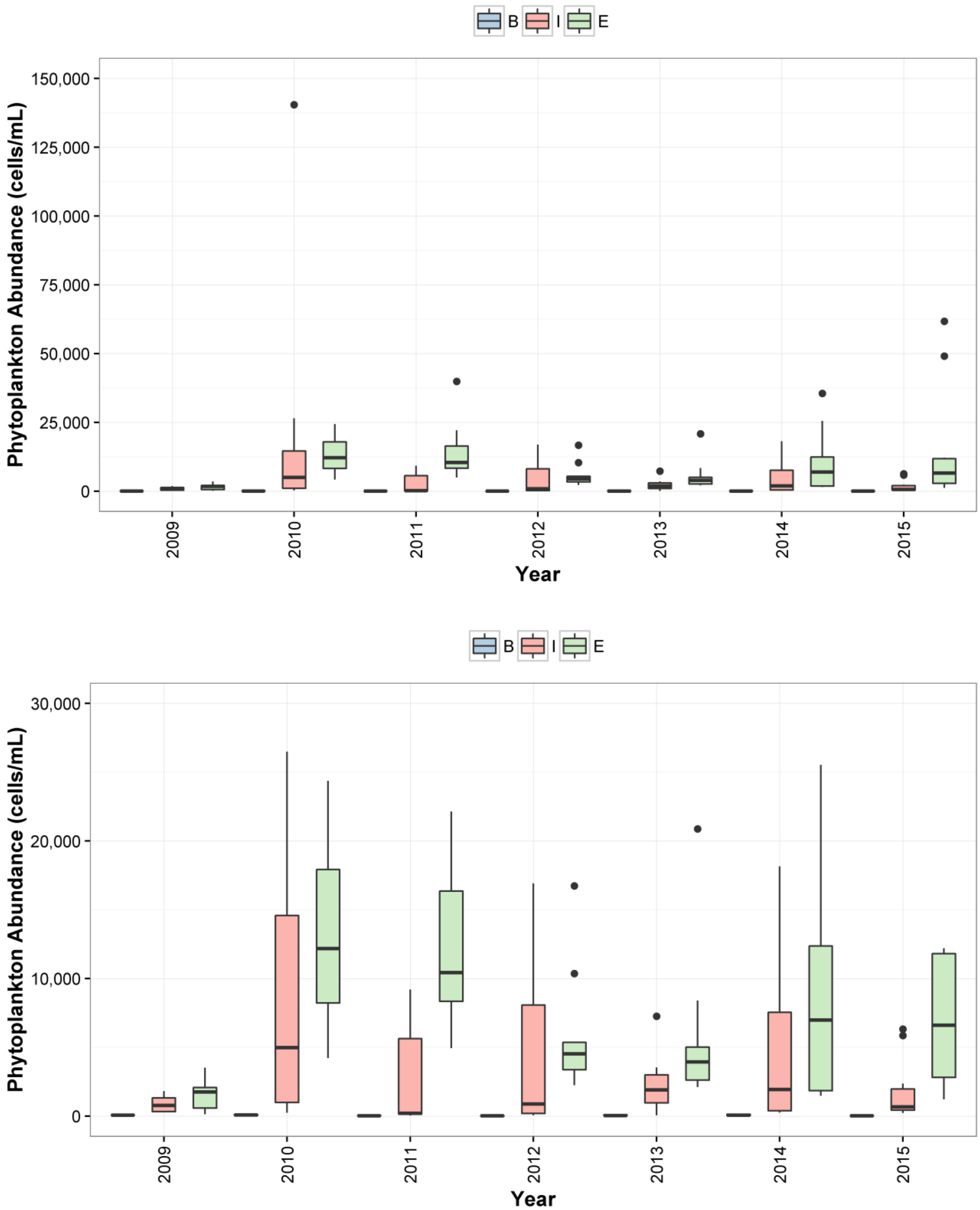

Figure 22 Boxplots of annual (May-October) phytoplankton abundance (cells·mL^{-1}) by edibility (I = inedible, E = edible, B = both edible and inedible forms), 2009-2015, Wahleach Reservoir BC; lower panel is zoomed in to show distribution from 0-30,000 cells·mL^{-1}.

Figure 23 Seasonal phytoplankton abundance (cells·mL^{-1}) by class at the north basin (NB) and south basin (SB) limnology stations May to October, 2009-2015, Wahleach Reservoir BC.

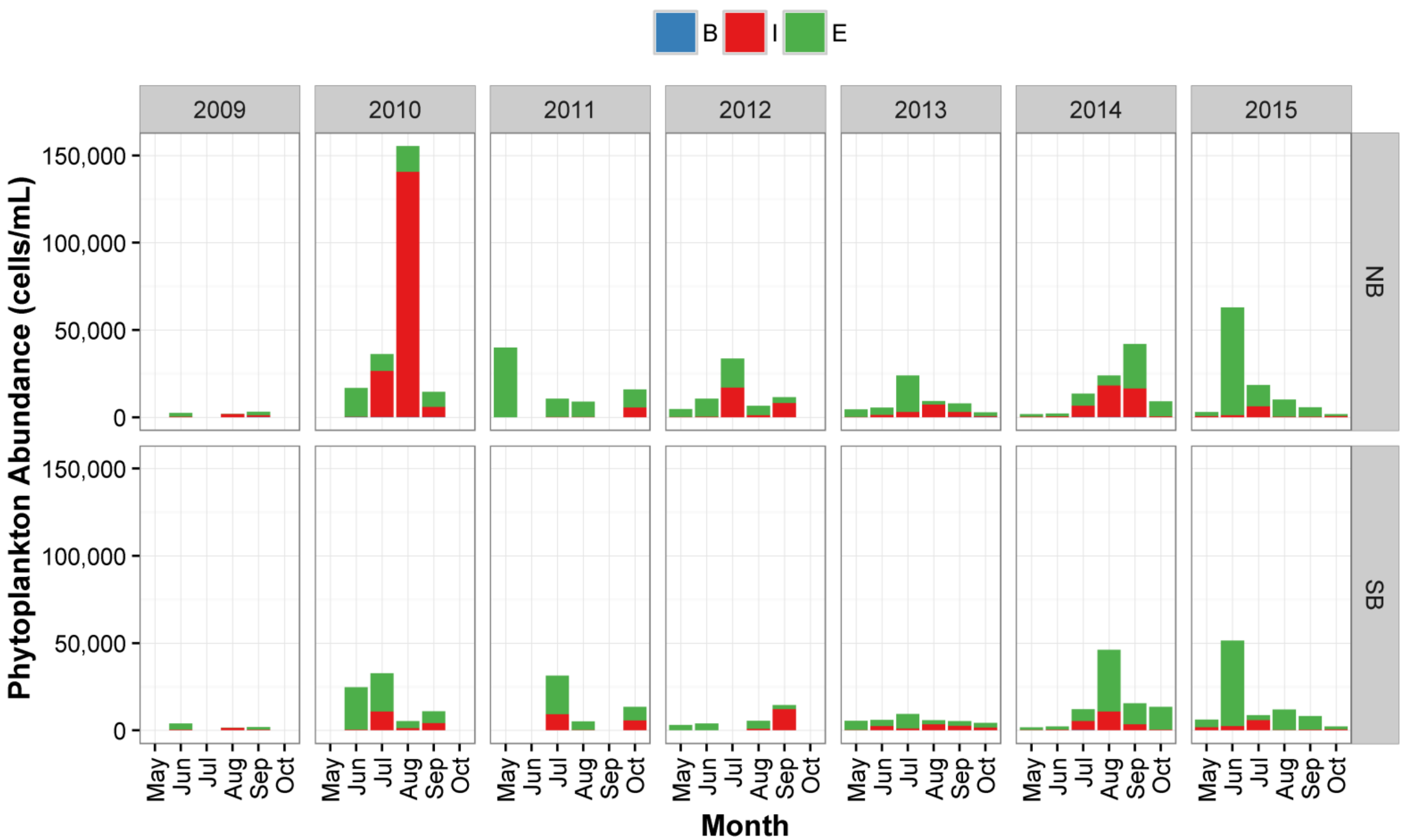

Figure 24 Seasonal phytoplankton abundance (cells·mL^{-1}) by edibility (I=inedible, B= both edible and inedible forms, E=edible) at the north basin (NB) and south basin (SB) limnology station May to October, 2009-2015, Wahleach Reservoir BC.

Summary statistics of phytoplankton biovolume for 2009-2015 are shown in Table 25. Annual patterns in biovolume are shown in Figure 25. Mean phytoplankton biovolume during the baseline study year (1994) was 0.88 ± 0.51 $mm^3 \cdot L^{-1}$, while the long-term mean during whole reservoir nutrient additions (1995-2015) was 0.97 ± 0.96 $mm^3 \cdot L^{-1}$ (data on file). Phytoplankton biovolume was higher than the long-term mean during 2009 to 2015, with the exceptions of 2009 and 2014. The highest phytoplankton biovolume on record was in 2011 (data on file; Table 25). Phytoplankton biovolume has been below average in the last two years, 2014 and 2015 (Table 25).

Figure 27 shows seasonal biovolume of the phytoplankton community by class, while Figure 28 shows seasonal biovolume by edibility. Edible biovolume was highest in 2010 and 2011 (Table 26, Figure 26). In 2010, large biovolumes were a result of a summer bloom (June-July) of edible flagellates (*Dinobryon* sp.). In 2011, high biovolume largely resulted from a spring (May) bloom of edible flagellates (*Ochromonas* sp.) in the north basin. In 2012 and 2013, flagellate (*Ochromonas* sp.) biovolume was also high in the north basin. In 2015, peak biovolume occurred in July owing to a bloom of inedible diatoms and edible flagellates. There appeared to be a shift in the phytoplankton community composition with flagellates occurring as the dominant group in high biovolumes (Figure 27); that pattern was not evident in 2014 and 2015. In early years of the study, the majority of community biovolume was from dinoflagellates (data on file).

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.

Table 25 Annual summary statistics of phytoplankton biovolume (mm^3L^{-1}), 2009-2015, Wahleach Reservoir, BC.

Year	Biovolume (mm^3L^{-1})			
	Mean	SD	Max	Min
2009	0.660	0.412	1.351	0.288
2010	1.280	1.103	4.076	0.205
2011	2.231	2.651	9.475	0.521
2012	1.395	1.099	3.980	0.350
2013	1.303	1.260	4.838	0.387
2014	0.557	0.389	1.328	0.134
2015	0.806	0.619	1.877	0.150

Table 26 Annual summary statistics of phytoplankton biovolume ($mm^3 \cdot L^{-1}$) by edibility (B = both edible and inedible forms, E = edible, I = inedible), 2009-2015, Wahleach Reservoir BC.

Year	Edibility	Biovolume ($mm^3 L^{-1}$)			
		Mean	SD	Max	Min
2009	B	0.0311	0.0262	0.0690	0.0121
2009	I	0.4570	0.5096	1.3152	0.0284
2009	E	0.1850	0.1135	0.2918	0.0175
2010	B	0.0130	0.0088	0.0278	0.0022
2010	I	0.1700	0.1432	0.4772	0.0440
2010	E	1.1001	1.1288	4.0124	0.1235
2011	B	0.0251	0.0382	0.0691	0.0010
2011	I	0.0383	0.0417	0.1390	0.0076
2011	E	2.1849	2.6671	9.4678	0.4865
2012	B	0.0121	0.0145	0.0415	0.0046
2012	I	0.2995	0.4410	1.1995	0.0025
2012	E	1.0871	1.1753	3.9635	0.3078
2013	B	0.0133	0.0103	0.0305	0.0051
2013	I	0.4100	0.5175	1.6046	0.0071
2013	E	0.8863	1.2638	4.6627	0.1675
2014	B	0.0109	0.0087	0.0243	0.0010
2014	I	0.1367	0.1630	0.5919	0.0157
2014	E	0.4137	0.2690	0.9500	0.1180
2015	B	0.0050	0.0053	0.0111	0.0020
2015	I	0.2120	0.4354	1.5313	0.0069
2015	E	0.5853	0.4475	1.3881	0.1159

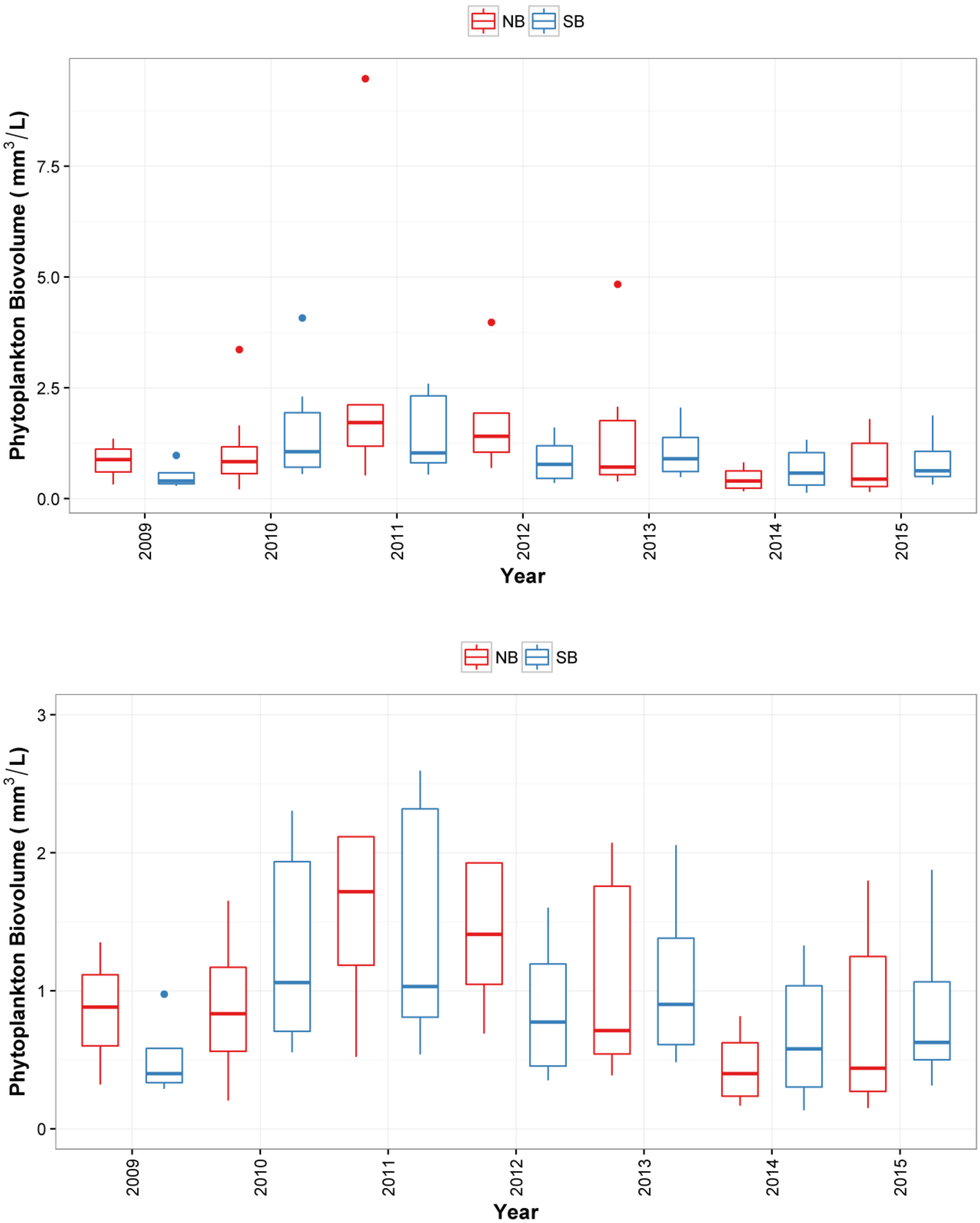

Figure 25 Boxplots of annual (May-October) phytoplankton biovolume ($mm^3 \cdot L^{-1}$)) at the north basin (NB) and south basin (SB) limnology stations, 2009-2015, Wahleach Reservoir BC; lower panel is zoomed in to show distribution from 0-30,000 $mm^3 \cdot L^{-1}$.

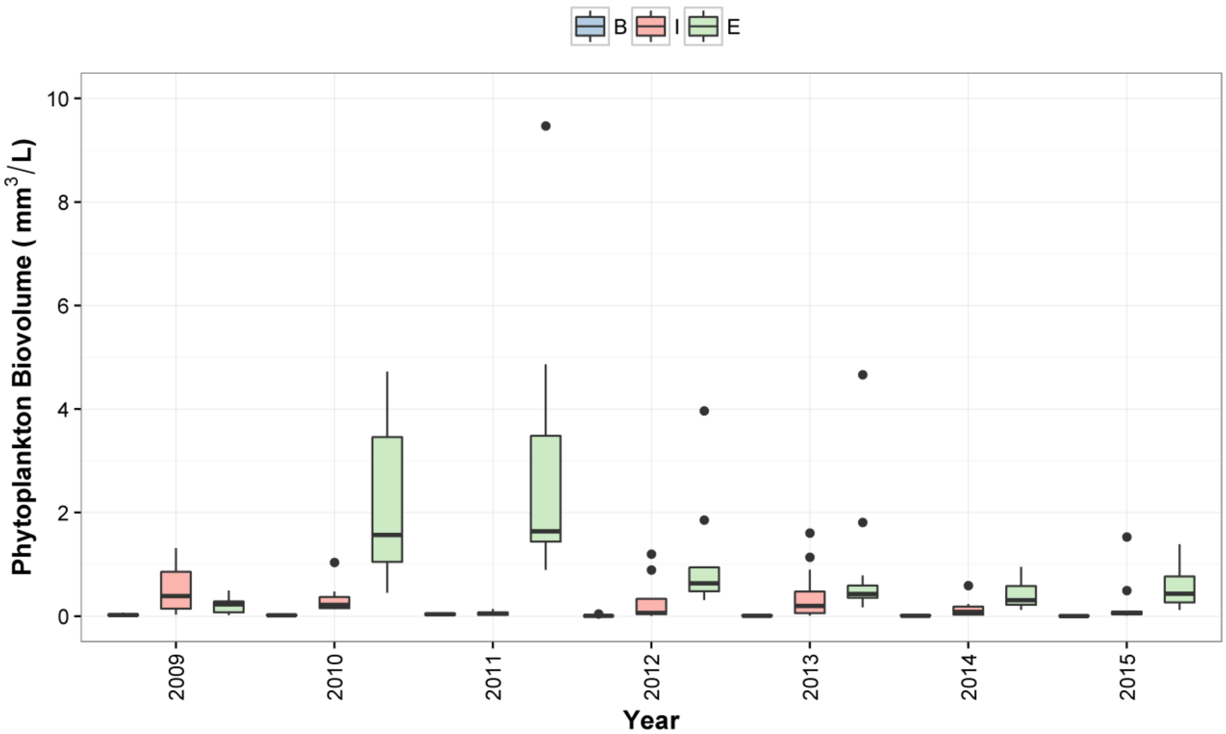

Figure 26 Boxplots of annual (May-October) phytoplankton biovolume (mm^3 per L^{-1}) by edibility (I = inedible, E = edible, B = both edible and inedible forms), 2009-2015, Wahleach Reservoir BC.

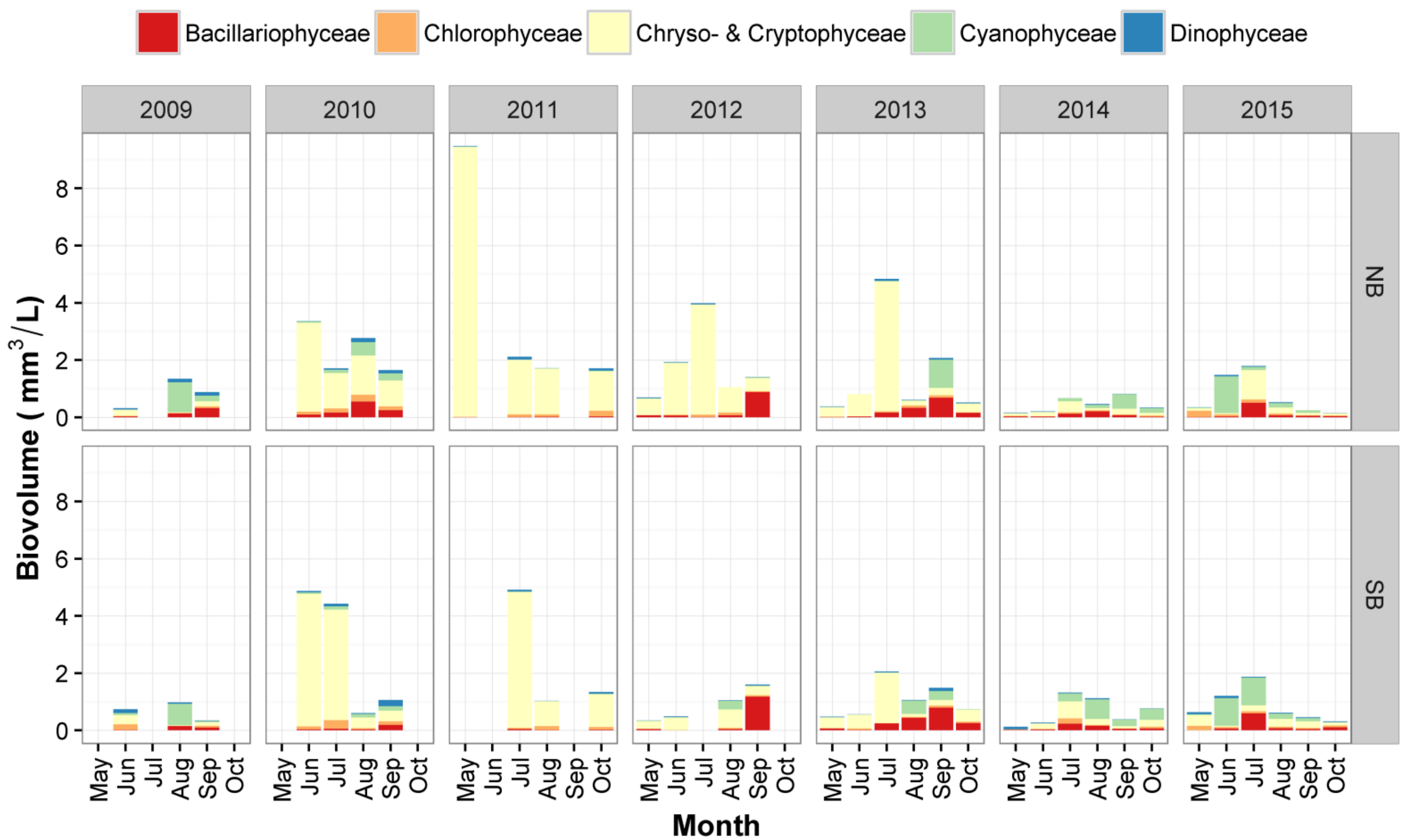

Figure 27 Seasonal phytoplankton biovolume ($mm^3.L^{-1}$) by class at the north basin (NB) and south basin (SB) limnology stations May-October, 2009-2015, Wahleach Reservoir BC.

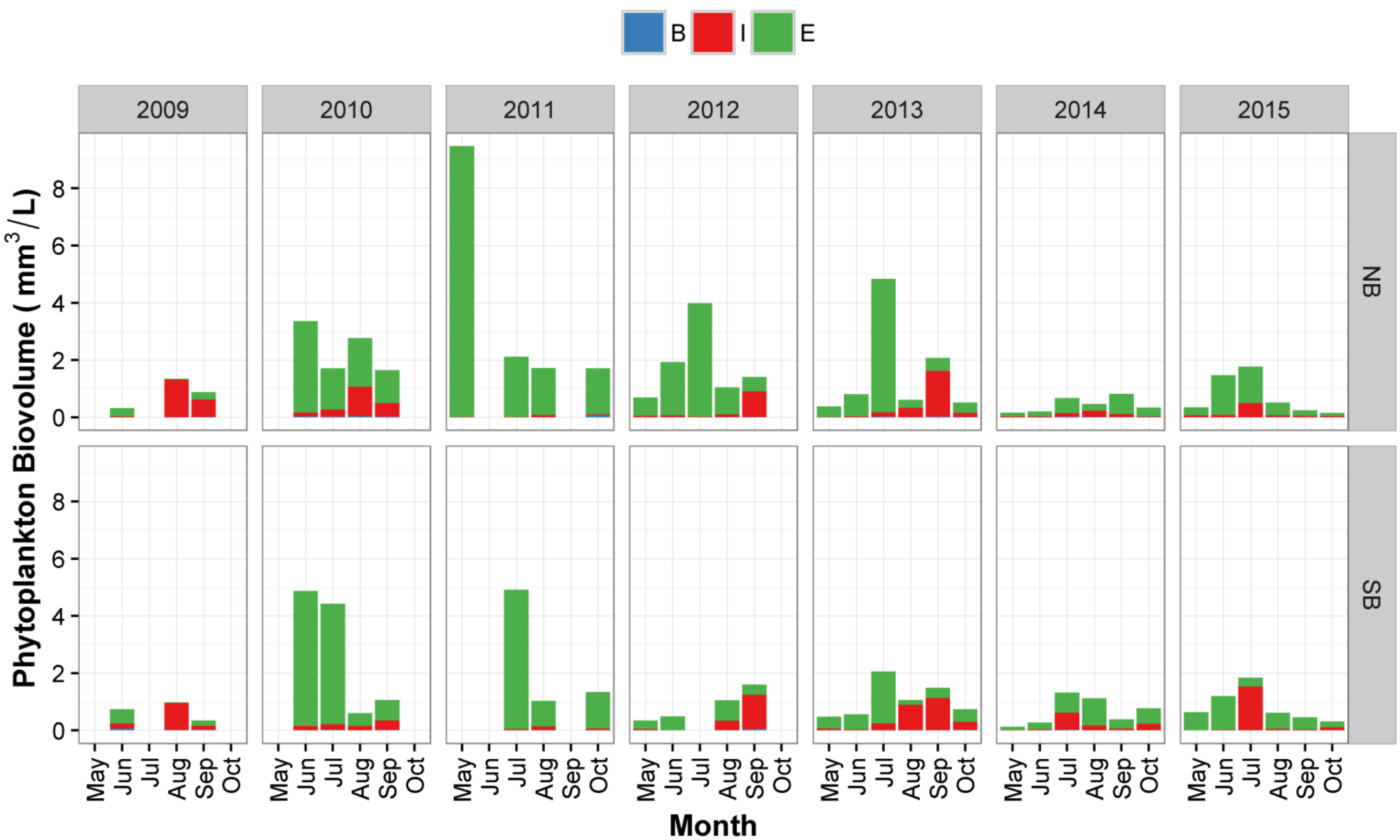

Figure 28 Seasonal phytoplankton biovolume ($mm^{3}\cdot L^{-1}$) by edibility (I=inedible, B= both edible and inedible forms) at the north basin (NB) and south basin (SB) limnology station May to October, 2009-2015, Wahleach Reservoir BC.

3.5 Zooplankton

Ten Cladocera and three Copepoda have been identified in Wahleach Reservoir from 2009 to 2015. Appendix B contains zooplankton species occurrence for each year. *Daphnia rosea* (Sars), *Bosmina longirostris* (O.F.M.), *Holopedium gibberum* (Zaddach) were common while other species 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* (O.F.M.) and *Chydorus sphaericus* (O.F.M.) are more commonly found in littoral habitats but given the close coupling between littoral and pelagic habitat in Wahleach Reservoir it is not surprising to find low densities of these two species in the pelagic habitat. In 2012, *Pleuroxus* sp. was found in the sample for the first time and in 2014, *Diaphanosoma birgei* was found in samples for the first time. In 2015 *Leptodiaptomus ashlandi* was found in the sample and it has not been present since 2008.

Both total zooplankton density and biomass have increased well above baseline levels since baseline years. Zooplankton densities after pre-treatment era were higher than those measured in 1993-1994 (baseline) where densities increased from 1.0 ± 1.0 individuals/L in the pre-treatment era compared to 8.8 ± 8.8 individuals/L (data on file). In 2011, zooplankton densities were the highest on record (21.2 ± 13.3 individuals/L) (Figure 29). Biomass data of the major zooplankton groups were not recorded during baseline studies. Mean annual zooplankton biomass for Wahleach Reservoir between 2010 and 2011 was higher than previous years (Table 27, Figure 29). The 2009 year had the highest zooplankton biomass on record at 104.4 ± 63.7 $\mu g \cdot L^{-1}$ and in 2013, it was the second highest biomass on record at 100.4 ± 68.1 $\mu g \cdot L^{-1}$ (Table 27, Figure 29). Both basins showed similar values from year to year in both densities and biomass with the north basin typically slightly higher values than the south basin.

The density of *Daphnia*, the zooplankton species largely favoured by Kokanee remained static since 2000. It is important to note that *Daphnia* were absent from the zooplankton community in 1993 and 1994 (and until 1997) and now account for a large relative contribution to the zooplankton community (Figure 31, Figure 32). The highest *Daphnia* contribution to total zooplankton density was in 2012 at 58%. *Daphnia* densities from 2010 to 2015 have been near 3.0 individuals/L with the exception of 2011 which was near 2.0 individuals/L and in 2009 near 5.0 individuals/L (the highest on record) (Table 28). In 2011, densities of *Daphnia* were lower; however, the density of other *Cladocera* (especially *Holopedium gibberum*) was highest on record (20.8 ± 13.3 individuals/L).

From 2009 to 2015, the vast majority of the mean annual biomass was accounted for by *Daphnia* and by other Cladocera (Figure 32). During these study years, Copepods were a minor component of the zooplankton community with an increase in 2015 (Figure 31, Table 28). Overall during this time *Daphnia* biomass accounted for 29% to 86%, with 2011 being the lowest at 29%. The highest *Daphnia* contribution to total zooplankton biomass was in 2014 at 86% at 78.1 ± 93.1 $\mu g \cdot L^{-1}$.

Overall, the zooplankton community in Wahleach Reservoir from 2009 to 2015 represent a significant increase in food availability for planktivores relative to baseline years.

Seasonal, Copepods, *Daphnia* and other Cladocerans have varied from year to year. From 2009 to 2015, at the beginning of sampling seasons in May, moderate densities of zooplankton were found with the exception of 2012 which had low densities (Figure 33). In general, *Daphnia* densities peaked in August or September, whereas all other Cladocerans peaked in June or July. However, in 2015, peaks were earlier – July for *Daphnia* and May for other Cladocerans. Copepods were present throughout the sampling season in generally low densities; in 2014 and 2015, copepod densities increased to over 20% in both years. The seasonal cycle of total biomass closely reflects the seasonal pattern just described for zooplankton densities. Biomass is generally low at the beginning of the season (Figure 34). Biomass peaked in September.

Table 27 Annual summary statistics of zooplankton density (individuals·L^{-1}) and biomass (µg·L^{-1}) 2009-2015, Wahleach Reservoir.

Year	Total Density (individuals·L^{-1})				Total Biomass (µg·L^{-1})			
	Mean	SD	Max	Min	Mean	SD	Max	Min
2009	9.7	6.3	25.3	0.0	104.4	63.7	193.3	0.2
2010	8.0	6.6	25.2	2.5	63.7	48.8	187.4	7.7
2011	21.2	13.3	46.7	3.4	90.0	57.4	207.4	11.2
2012	4.4	2.6	9.4	0.2	67.7	57.7	175.0	0.5
2013	7.5	4.0	14.6	1.8	100.4	68.1	246.2	15.7
2014	6.5	4.3	16.0	2.9	91.1	89.8	304.7	12.6
2015	7.3	3.4	18.8	3.2	80.7	50.4	229.0	27.1

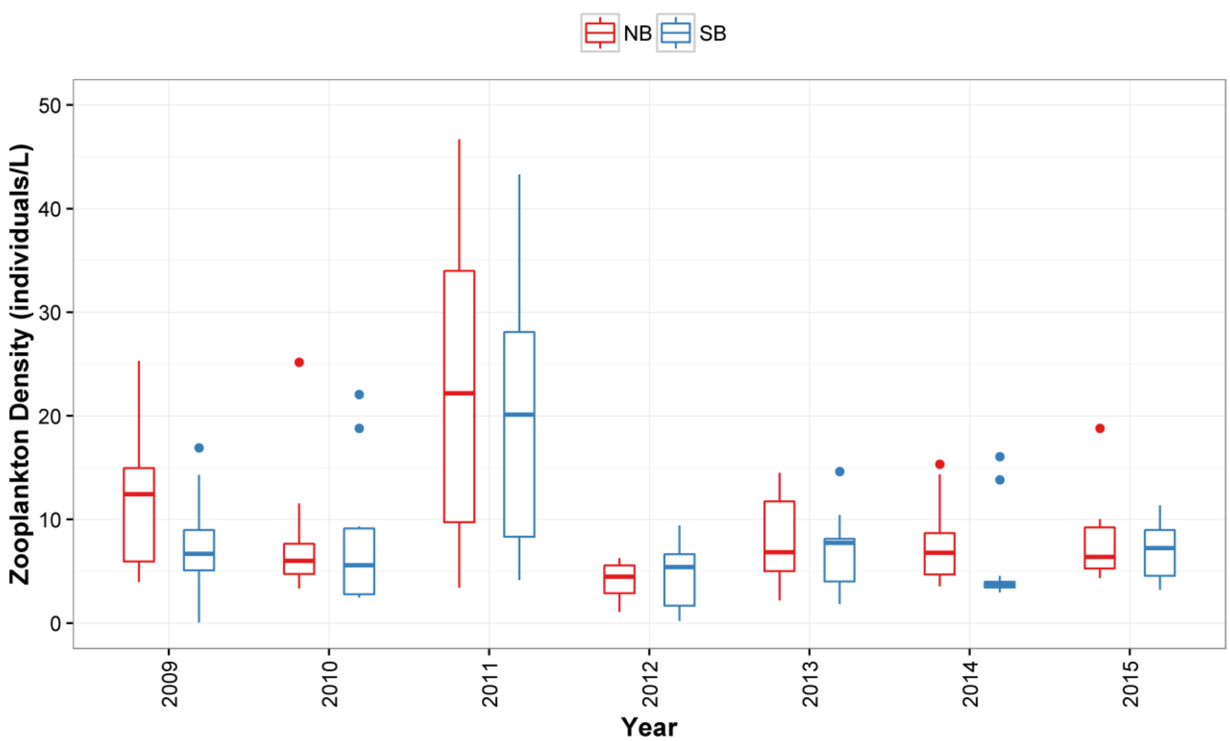

Figure 29 Boxplots of annual (May to October) zooplankton density (individual.L^{-1}) at the north basin (NB) and south basin (SB) limnology stations, 2009-2015, Wahleach Reservoir, BC.

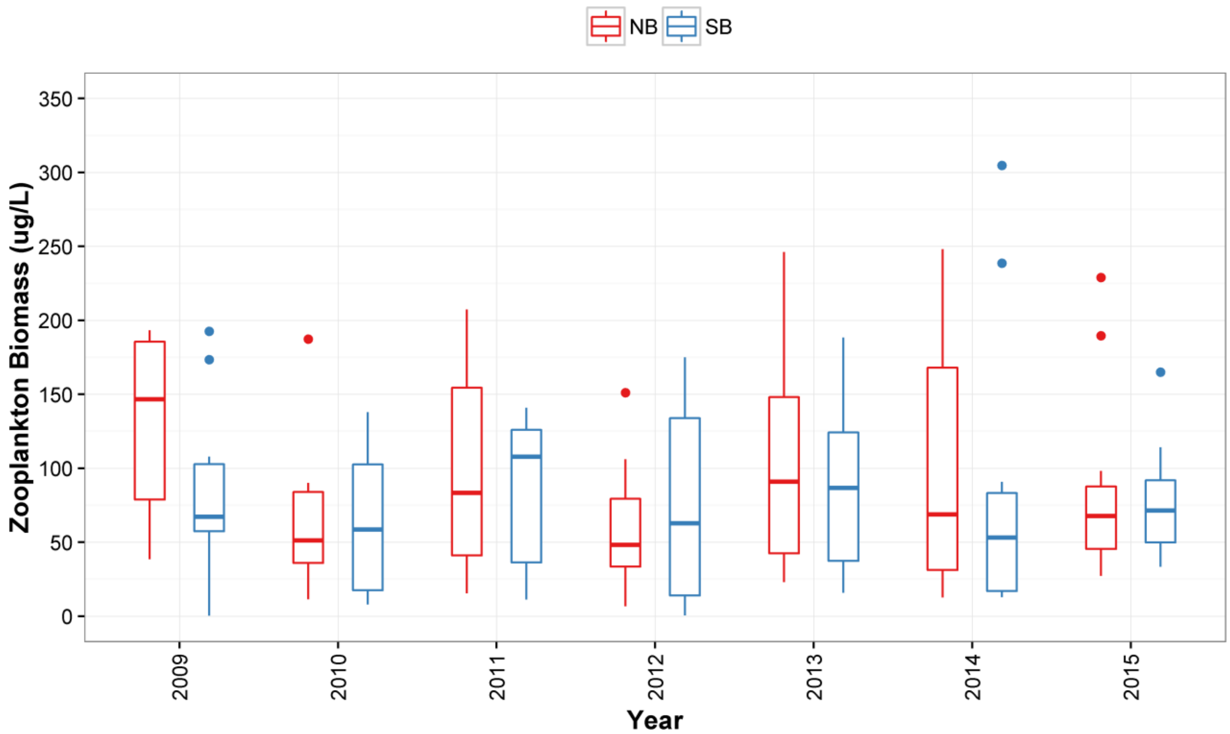

Figure 30 Boxplots of annual (May to October) zooplankton biomass (µg·L^{-1}) at the north basin (NB) and south basin (SB) limnology stations, 2009-2015, Wahleach Reservoir, BC.

Table 28 Annual summary statistics of Copepod, *Daphnia,* and Other Cladoceran density (individual·L^{-1}), 2009-2015, Wahleach Reservoir, BC.

Year	Copepods				*Daphnia*				Other Cladocerans			
	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min
2009	0.8	0.5	1.7	0.0	5.0	4.5	13.5	0.0	8.9	6.3	24.3	0.0
2010	1.2	0.8	2.6	0.1	3.0	2.8	8.0	0.1	6.9	7.1	25.0	0.7
2011	0.4	0.3	1.1	0.0	1.9	2.0	8.4	0.1	20.8	13.3	46.2	3.4
2012	0.3	0.3	0.9	0.1	3.2	2.7	8.9	0.0	4.0	2.6	8.9	0.1
2013	0.8	0.7	2.2	0.1	3.2	3.4	12.3	0.1	6.7	3.7	14.5	1.6
2014	1.4	1.3	4.7	0.3	3.2	3.7	11.3	0.1	5.1	3.1	11.6	2.4
2015	1.8	1.3	4.7	0.1	3.1	1.9	7.8	0.2	5.5	3.6	18.7	1.6

Table 29 Annual summary statistics of Copepod, *Daphnia*, and Other Cladoceran biomass (µg·L^{-1}), 2009-2015, Wahleach Reservoir, BC.

Year	Copepods				*Daphnia*				Other Cladocerans			
	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min
2009	0.9	0.5	2.0	0.0	72.8	67.0	189.4	0.0	103.5	63.6	192.8	0.2
2010	1.5	1.1	3.5	0.0	42.2	41.8	120.5	0.8	62.2	49.2	187.2	6.0
2011	0.5	0.4	1.4	0.0	25.8	29.2	130.4	0.5	89.5	57.2	206.1	11.1
2012	0.5	0.5	1.5	0.1	75.0	65.1	171.6	0.0	67.2	57.6	173.8	0.4
2013	1.5	1.5	5.1	0.1	74.4	73.9	241.1	1.2	98.9	66.9	242.1	15.5
2014	1.7	1.2	4.9	0.4	78.1	93.1	299.9	0.7	89.4	88.7	300.8	11.9
2015	3.2	2.0	6.7	0.0	58.9	50.8	223.9	2.4	77.5	50.4	224.5	24.9

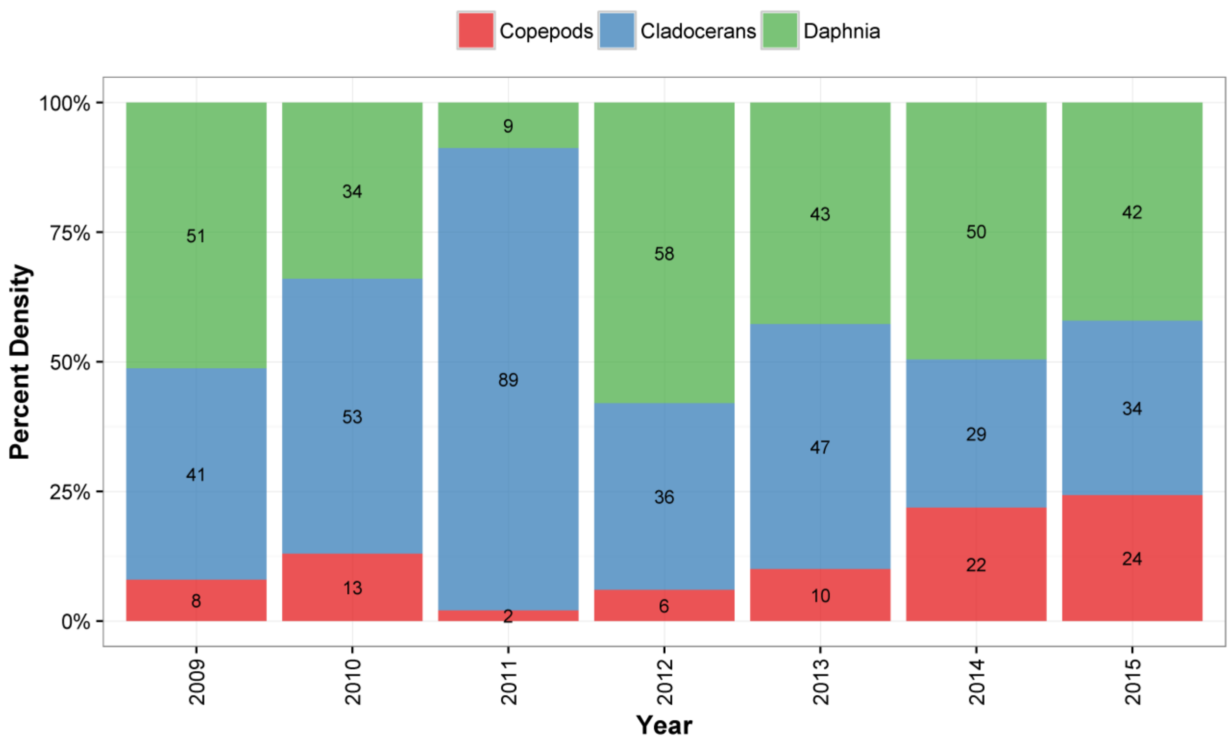

Figure 31 Relative contribution (%) of each major group (Copepods, *Daphnia* and other Cladocerans) to annual (May-October) zooplankton density, 2009-2015, Wahleach Reservoir BC.

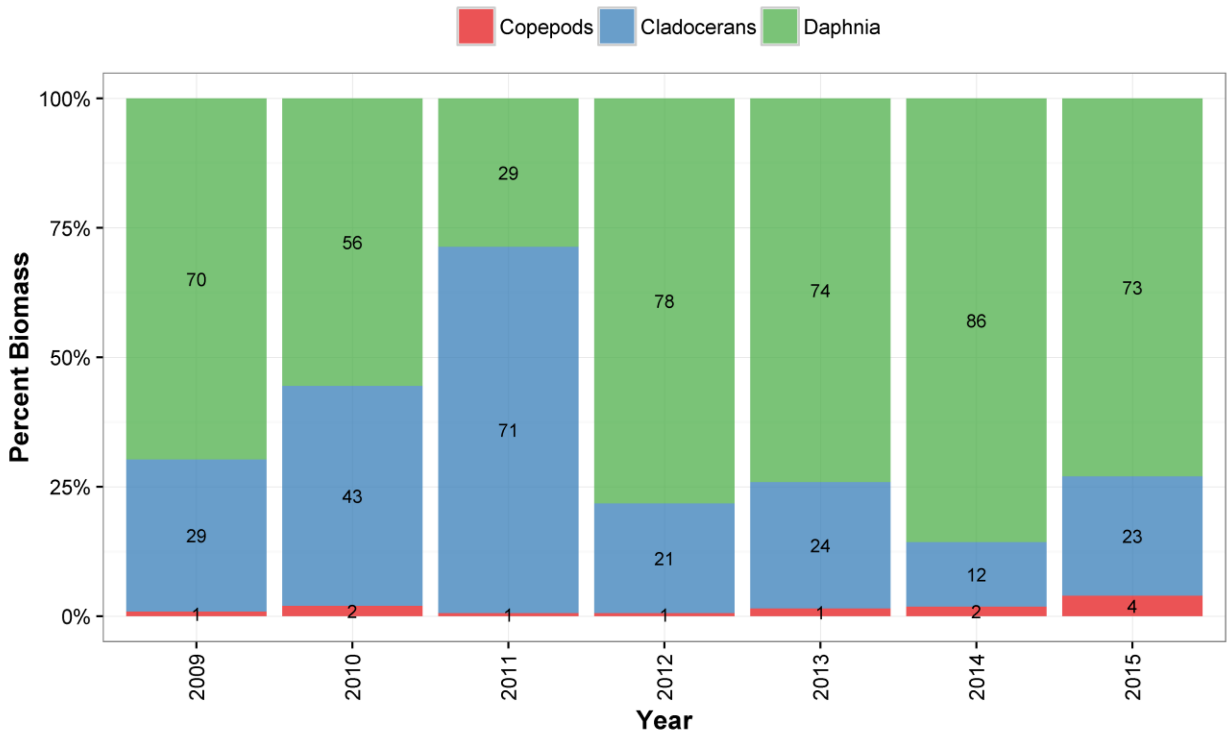

Figure 32 Relative contribution (%) of each major group (Copepods, *Daphnia* and other Cladocerans) to annual (May-October) zooplankton biomass, 2009-2015, Wahleach Reservoir BC.

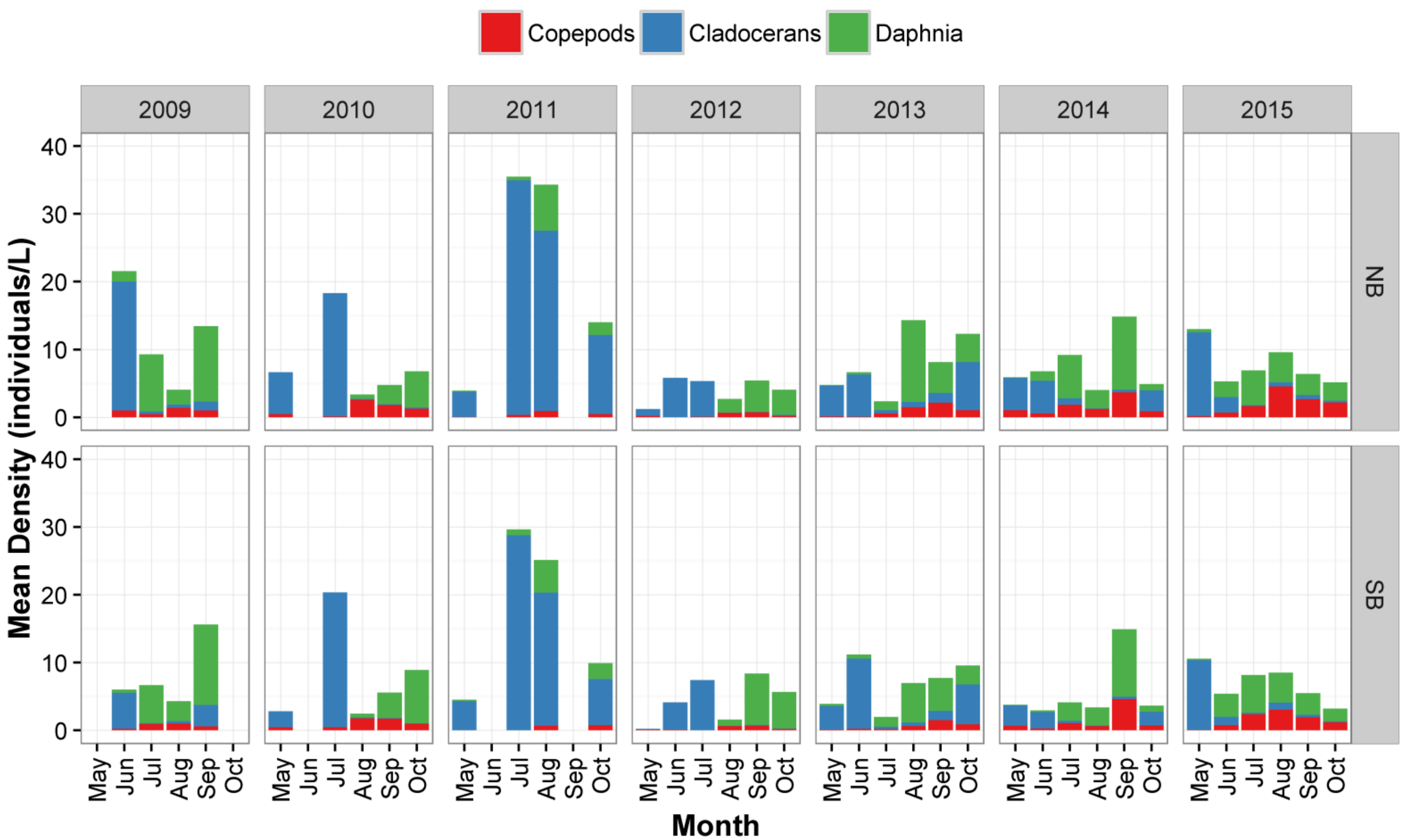

Figure 33 Monthly mean zooplankton density (individuals·L^{-1}) by major group (Copepoda, *Daphnia* and other Cladocera) at the north basin (NB) and south basin (SB) limnology stations, 2009-2015, Wahleach Reservoir BC.

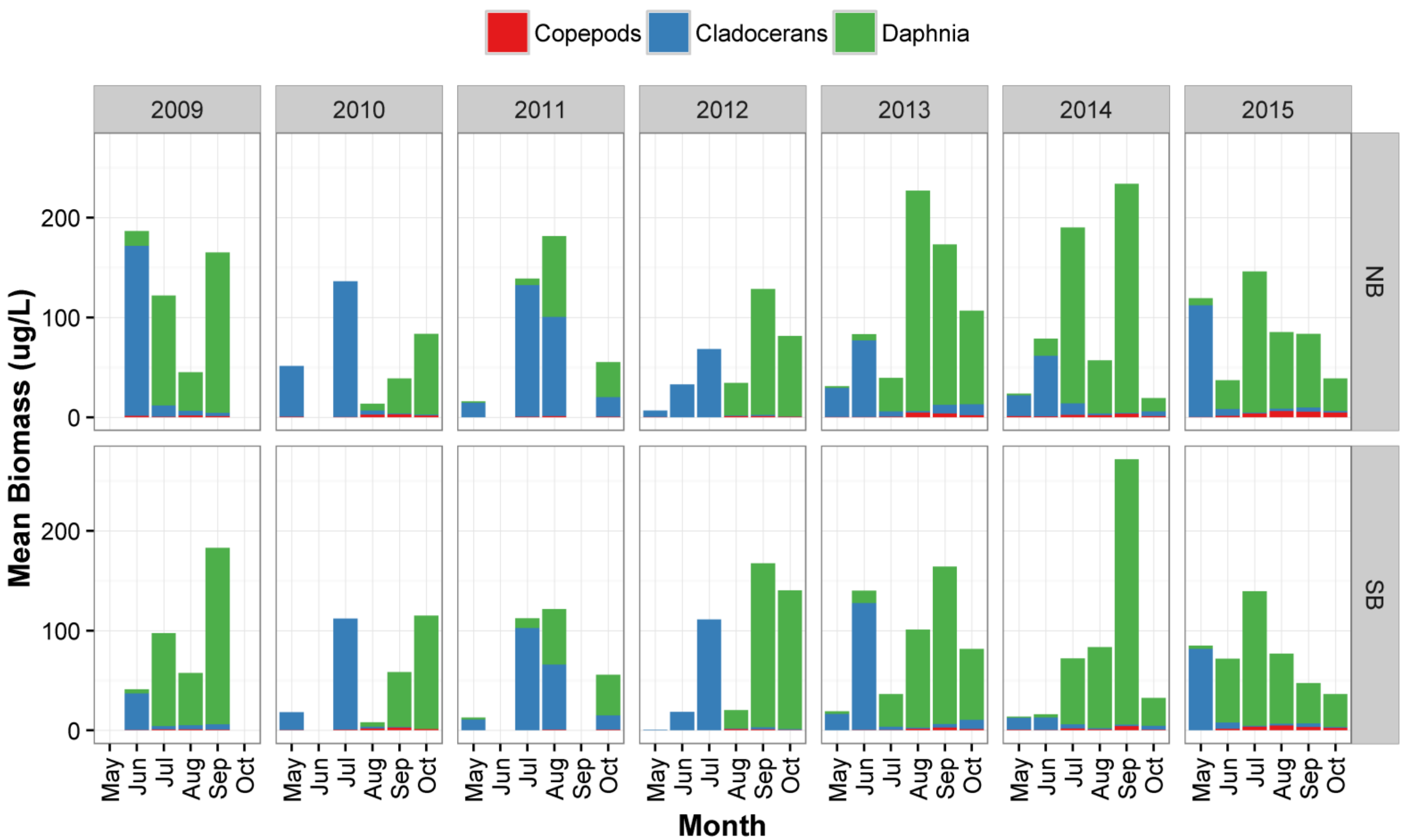

Figure 34 Monthly mean zooplankton biomass ($\mu g \cdot L^{-1}$) by major group (Copepoda, *Daphnia* and other Cladocera) at the north basin (NB) and south basin (SB) limnology stations, 2009-2015, Wahleach Reservoir BC.

3.6 Fish

3.6.1 Catch & Catch-per-unit-effort

Nearshore gillnetting results have been variable from 2009 to 2015 ranging from a low of 81 fish in 2013 to a high of 182 in 2015 during fall surveys (Table 30). The majority of the catch during the last seven years have been Rainbow Trout at 54%, while 22% were Kokanee (Table 32). Overall, catch-per-unit-effort (CPUE) for all species combined in the nearshore gillnetting ranged from 0.06 to 0.10 fish $100m^{-2} \cdot hr^{-1}$ (Table 33). CPUE was the highest in 2011 and 2015, whereas CPUE was the lowest in 2012 and 2013. The change in the standardized net composition beginning in 2014 to increase capture efficiency of age-1+ Kokanee did not result in many more fish being captured in 2014, but accounted for the majority of kokanee captured during the 2015 sampling year (Table 31).

Table 30 Summary of fall nearshore gillnetting catch for Wahleach Reservoir, 2009-2015. Species include Kokanee (KO), Cutthroat Trout (CT), Rainbow Trout (RB), hybrid Rainbow Trout/Cutthroat Trout (RB/CT), Unknown fish species (UN), and Threespine Stickleback (TSB).

Species	2009	2010	2011	2012	2013	2014[1]	2015[1]
CT	35	19	9	25	31	20	54
RB	52	68	123	32	32	88	70
KO	50	21	13	29	15	6	58
RB/CT	0	0	0	0	1	0	0
UN	0	0	0	1	2	0	0
TSB	0	0	2	0	0	0	0
Total	137	108	147	87	81	114	182

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

Table 31 Summary of catch comparing the previous standardized gillnet to the 1.25" mesh gillnet panel that was added to standardized gillnets beginning in 2014. Data are from the fall nearshore gillnetting program on Wahleach Reservoir.

Species	2014 - Standard	2014 - 1.25"	2015 - Standard	2015 - 1.25"
CT	17	3	35	19
RB	81	7	46	24
KO	3	3	15	43
RB/CT	0	0	0	0
UN	0	0	0	0
TSB	0	0	0	0
Total	101	13	96	86

Table 32 Percentage (%) of fish species composition of nearshore gillnetting program catches, 2009-2015, Wahleach Reservoir, BC.

Species	CT	RB	RB/CT	KO	UN	TSB
2009	25.5	38.0	0.0	36.5	0.0	0.0
2010	17.6	63.0	0.0	19.4	0.0	0.0
2011	6.1	83.7	0.0	8.8	0.0	1.4
2012	28.7	36.8	0.0	33.3	1.1	0.0
2013	38.3	39.5	1.2	18.5	2.5	0.0
2014	17.5	77.2	0.0	5.3	0.0	0.0
2015	29.7	38.5	0.0	31.9	0.0	0.0
TOTAL	22.5	54.3	0.1	22.4	0.3	0.2

Table 33 Summary of CPUE (fish·100 $m^{-2}\cdot hr^{-1}$) during annual nearshore gillnetting program, 2009-2015, Wahleach Reservoir, BC.

Year	Total Fish Captured	Total Net Area (m^2)	Total Hours	CPUE (fish·100 $m^{-2}\cdot hr^{-1}$)
2009	137	1338	112	0.09
2010	108	1338	112	0.07
2011	145	1338	112	0.10
2012	87	1338	106	0.06
2013	81	1338	102	0.06
2014	114	1560	104	0.07
2015	182	1560	120	0.10

Minnow Trapping catches have been low from 2009 to 2015 ranging from a low of 1 fish in 2012 to a high of 29 in 2013 (Table 34). The majority of the catch during the last seven years in the minnow traps have been Threespine Stickleback and a few Rainbow Trout juveniles (Table 34). Overall, CPUE for all species combined in the minnow trapping ranged from 0.01 to 0.15 fish per trap hour (Table 35).

Table 34 Summary of minnow trap catch, 2009-2015, Wahleach Reservoir, BC.

Species	2009	2010	2011	2012	2013	2014	2015
CT	0	0	0	0	0	0	0
RB	1	3	0	0	4	0	5
KO	0	0	0	0	0	0	0
RB.CT	0	0	0	0	1	0	0
UN	0	0	0	0	0	0	0
TSB	0	19	10	1	24	19	4
TOTAL	1	22	10	1	29	19	9

Table 35 Summary of CPUE (fish·trap hr^{-1}) during annual minnow trapping, 2009-2015, Wahleach Reservoir, BC.

Year	Total Fish Captured	Total Hours	CPUE (fish·trap hr^{-1})
2009	1	75	0.01
2010	3	72	0.04
2011	10	123	0.08
2012	1	105	0.01
2013	29	196	0.15
2014	19	126	0.15
2015	9	132	0.07

3.6.2 Kokanee

Fall nearshore gillnetting captured Kokanee during 2009 to 2015 with a range in mean length from 165-216 mm and a mean weight with a range from 52.1-128.2 g (Table 36). Kokanee caught in 2015 were the shortest with a mean length of 165 mm and lightest with mean weight of 52.1 g, whereas, Kokanee caught in 2013 were the longest at 216 mm and the heaviest with a mean 128.2 g. Fulton's condition factor (K) indicated a slight variability in condition over this time period, ranging from 1.1-1.2. During pre-treatment (1993-1994), mean Kokanee length was 177 and 148 mm; mean weight was 54.1 and 36.3 g; and K was 1.0 in both years (data on file).

As expected due to the timing of sampling after the spawning period, very few 3+ or 4+ Kokanee were captured during 2009 to 2015 fall nearshore gillnetting programs (Figure 35, Figure 36). In 2009, one 4+ and two 3+ were captured; in 2010, one 4+ was captured; and in 2012, two 3+ were captured. Due to the timing of the netting in late October, we expect the majority of older age classes would have left the reservoir to spawn; however, in 2009 and 2010 the timing slightly varied and occurred in November and September respectively, which might have accounted for the few older fish. Kokanee caught in 2015 during the fall nearshore gillnetting had the highest frequencies of age 1+ compared to the other years (2009 to 2014), which likely explains the low mean length (Figure 35, Figure 36).

Table 36 Summary of Kokanee biometric data, including length, weight, condition factor (CF) and age, for Wahleach Reservoir during nutrient restoration in 2009-2015.

Year	Species	N	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)	Mean K	SD K	Mean Age	SD Age
2009	KO	50	210	38	116.5	66.3	1.2	0.10	1	0.7
2010	KO	21	189	41	83.3	57.8	1.1	0.14	1	0.7
2011	KO	13	174	25	62.4	28.2	1.1	0.11	1	0.4
2012	KO	29	195	17	88.2	26.5	1.2	0.07	2	0.6
2013	KO	15	216	32	128.2	62.3	1.2	0.07	1	0.5
2014	KO	6	207	47	116.6	74.5	1.1	0.07	1	0.5
2015	KO	58	165	22	52.1	22.8	1.1	0.08	1	0.3

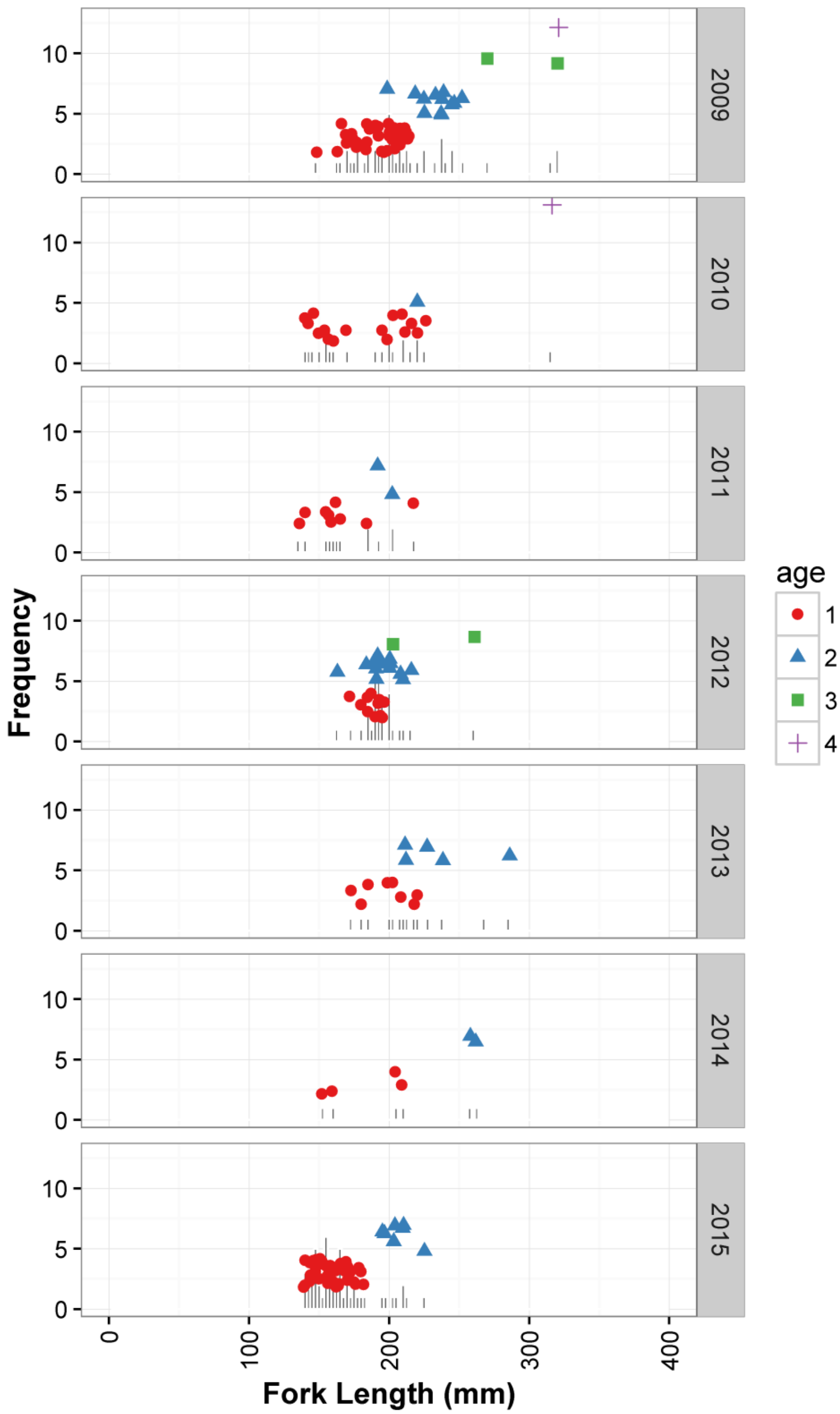

Figure 35 Length frequency and associated age-at-length of Kokanee captured in nearshore gillnet surveys, 2009-2015, Wahleach Reservoir, BC.

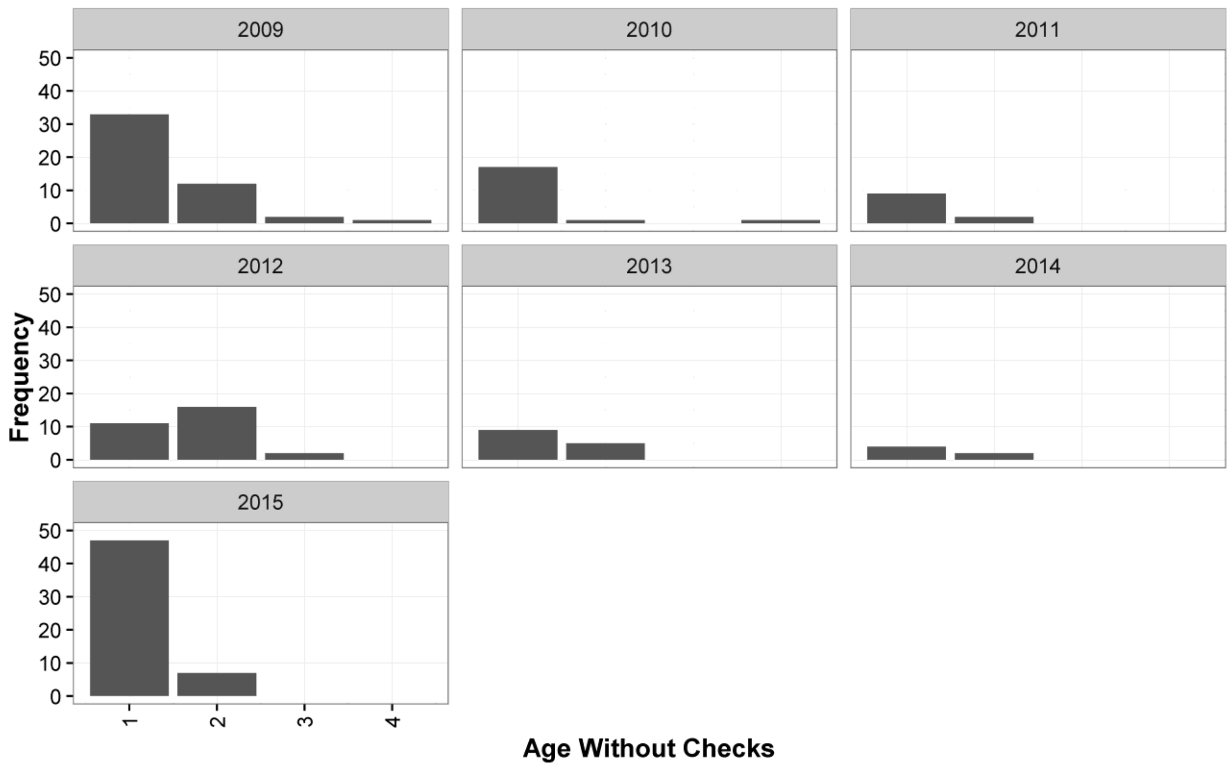

Figure 36 Age Frequency for Wahleach Reservoir Kokanee caught during fall nearshore gillnetting during nutrient restoration in 2009-2015.

Kokanee length-weight regressions were based on fall nearshore gillnetting data. Figure 37 shows the length-weight regressions for 2009 to 2015 for Kokanee. A regression slope of 3 is common for fish (Anderson *et al*. 1983, Cone 1989). All of the length-weight regression slopes were near 3.0, with some years below and some years above. In 2010, the length-weight regression slope was the lowest at 2.82 (Figure 37, Table 37).

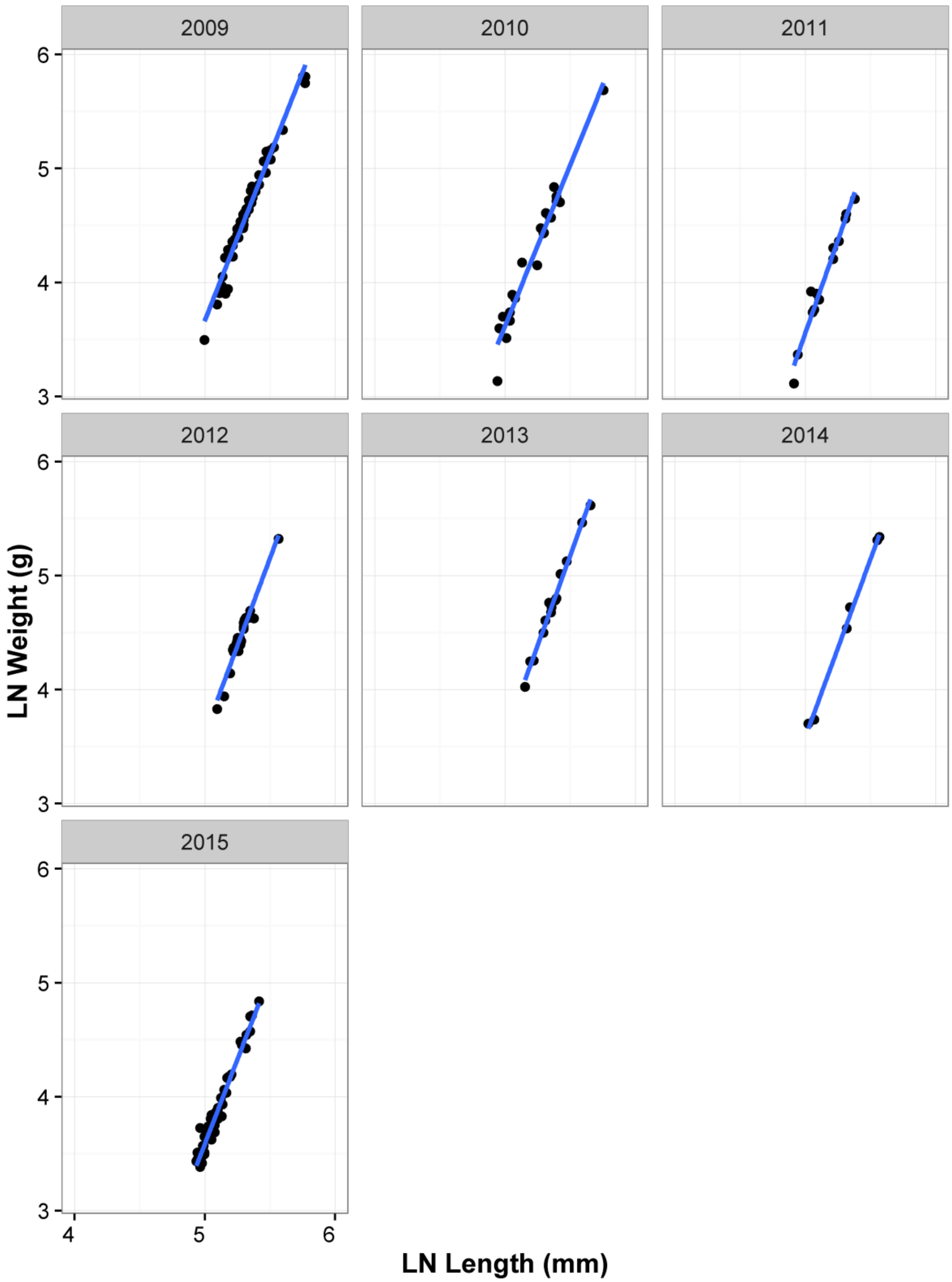

Figure 37 Natural logarithm of length weight linear regression (LN W = LN a * LN Lb) of Kokanee caught in gillnets during nutrient restoration in 2009 to 2015, Wahleach Reservoir.

Table 37 Summary of variables in R for Kokanee length weight relationships (Ln W = b · Ln L + Ln a) during nutrient restoration in 2009-2015, Wahleach Reservoir.

Year	Equation	R^2
2009	LN.weight.g = 2.91 * LN.length.mm -10.9	0.9705
2010	LN.weight.g = 2.82 * LN.length.mm -10.5	0.9583
2011	LN.weight.g = 3.25 * LN.length.mm -12.7	0.9672
2012	LN.weight.g = 3.07 * LN.length.mm -11.7	0.9466
2013	LN.weight.g = 3.16 * LN.length.mm -12.2	0.988
2014	LN.weight.g = 3.12 * LN.length.mm -12.0	0.9953
2015	LN.weight.g = 2.96 * LN.length.mm -11.2	0.9591

3.6.2.1 Spawners

Timing of Kokanee runs was similar from year to year during 2009 to 2015; Kokanee were observed in index streams by the second week of September with peak numbers in late September, and most of the spawning was completed by early October (Figure 38). Flat Creek had the highest number of spawners present compared to Boulder and Jones creeks (Figure 39). Extremely turbid stream conditions on September 11, 2013 resulted in low viewer efficiency and the low count was likely not representative of an actual decrease in spawner numbers (Figure 38).

In pre-treatment years, 1993-1994, Kokanee spawners had collapsed from a high of over 16,000 in 1980 to 953 and 568, respectively (data on file). Kokanee escapement from 2009 to 2015 ranged from 14,863 fish in 2013 to 2,606 fish in 2012 (Figure 39). In all seven years, Flat Creek had the most spawners, followed by Jones Creek, and then Boulder Creek; this pattern has been observed since 2004 with the exception of 2007 where Jones Creek had the most spawners (data on file). Escapement results over the past decade showed a dominant Kokanee run every four years; there was a peak run in 2010 and so the next peak would have been expected in 2014. As Figure 39 shows, the peak came in 2013, one year earlier than expected; age 2+ fish made up approximately 40% of the run in 2013 (Figure 40) which is greater than has been typically seen in Wahleach Reservoir (Hebert *et al*. 2013) and likely resulted in the shift in timing of the peak run.

Kokanee samples 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 ranged from a low of 187 ± 18 mm in 2011 to a high of 273 ± 16 mm in 2014 (Table 38). Kokanee spawner samples ranged from age 1+ to 4+ with overlaps in lengths between age 2+, 3+, and 4+ Kokanee during most years (Figure 40, Figure 41). Overall, the majority of spawners from 2009 and 2015 were age 3+, with the exception of 2010, 2013 and 2015 when there was a greater proportion of age 2+ fish (Figure 40, Figure 41). Age 1+ spawners were observed in Boulder, Flat and Jones Creeks for the first time in 2015.

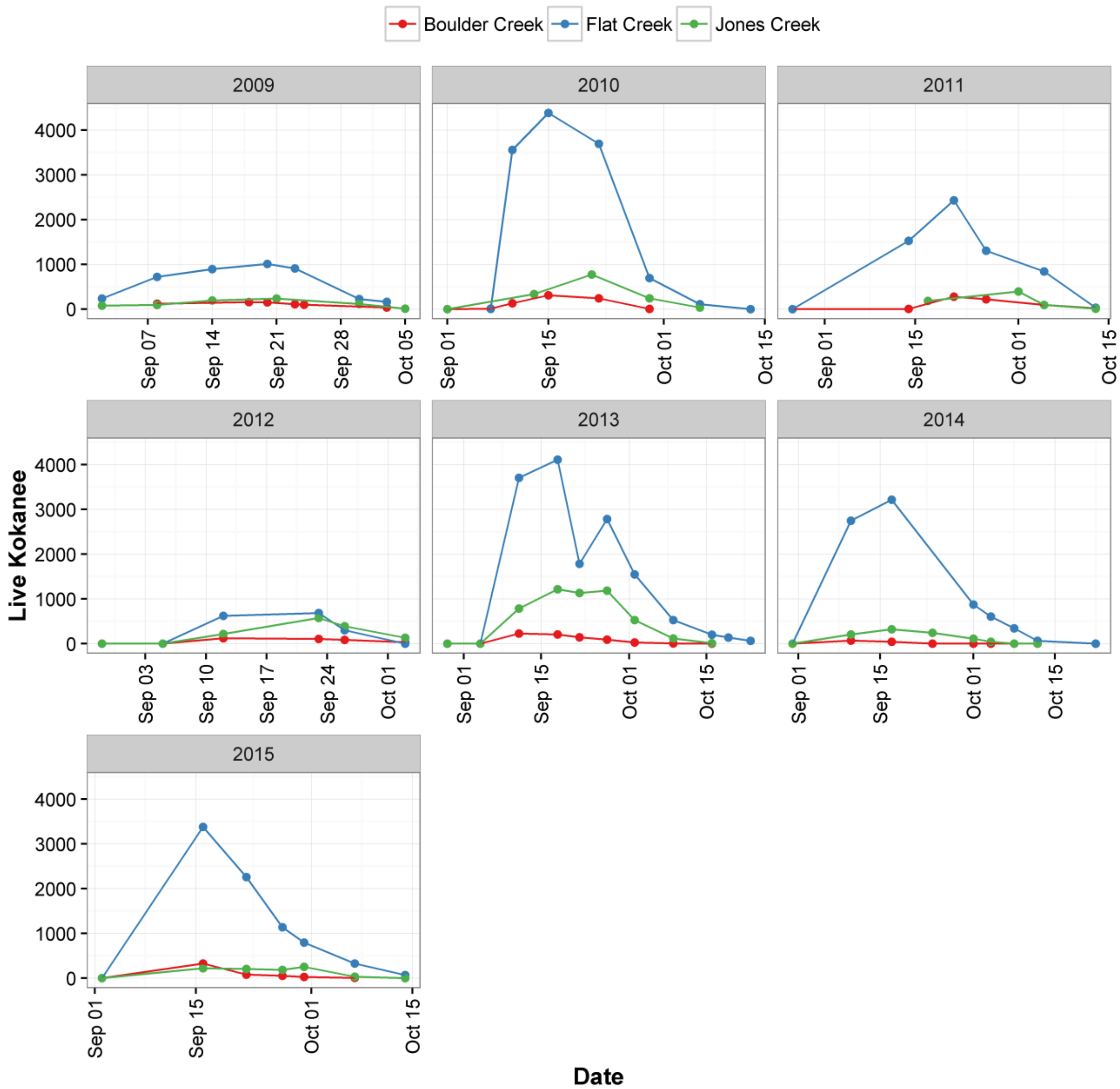

Figure 38 Kokanee spawner counts from each index stream (Boulder Creek, Flat Creek, and Jones Creek) during the 2009-2015 spawning seasons in Wahleach Reservoir. Note the date scales are slightly different from year to year.

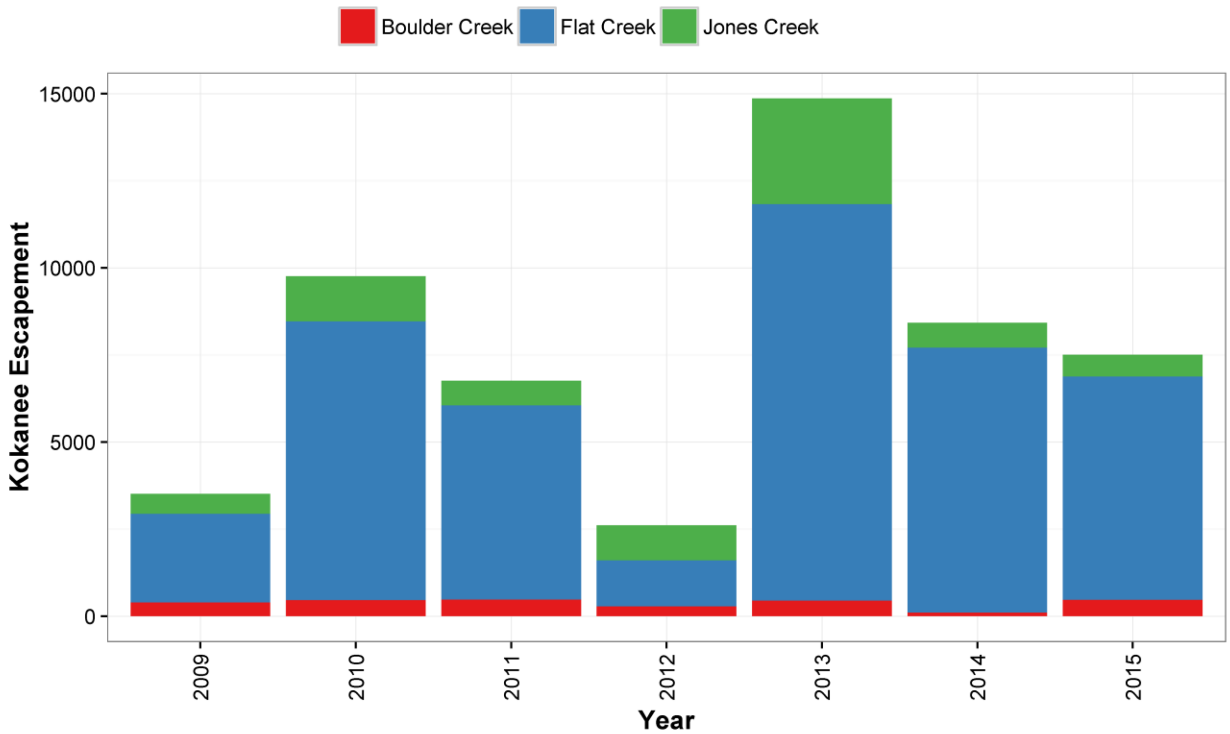

Figure 39 Annual Kokanee escapement estimates from 2009-2015, Wahleach Reservoir, BC.

Table 38 Summary of Kokanee biometric data during the 2009 to 2015 spawning seasons in Wahleach Reservoir. Data are for all three index streams combined: Boulder Creek, Flat Creek, and Jones Creek (and Glacier Creek in 2013).

Year	Fork Length (mm)					Age				
	Mean	SD	Max	Min	n	Mean	SD	Max	Min	n
2009	271	46	433	168	91	3	0	3	2	86
2010	216	27	297	187	18	2	0	2	2	50
2011	187	18	240	134	93	3	1	4	2	40
2012	206	12	232	178	20	3	0	4	2	17
2013	240	23	361	209	77	3	1	4	2	77
2014	273	16	310	236	64	3	1	4	2	59
2015	235	47	322	141	77	2	1	4	1	76

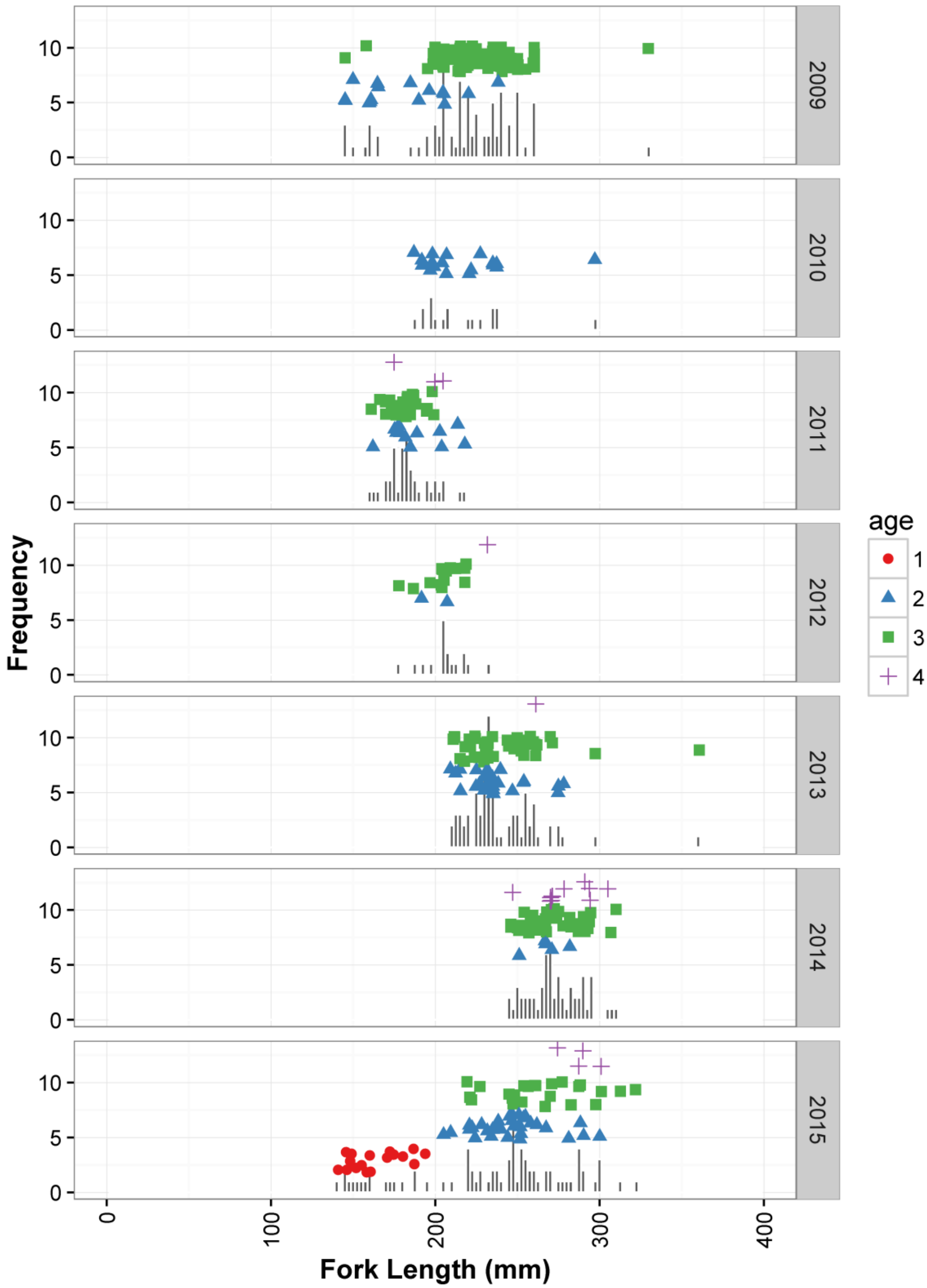

Figure 40 Length frequency and associated age-at-length of Kokanee spawners caught in index streams (Boulder Creek, Flat Creek and Jones Creek) of Wahleach Reservoir during 2009-2015.

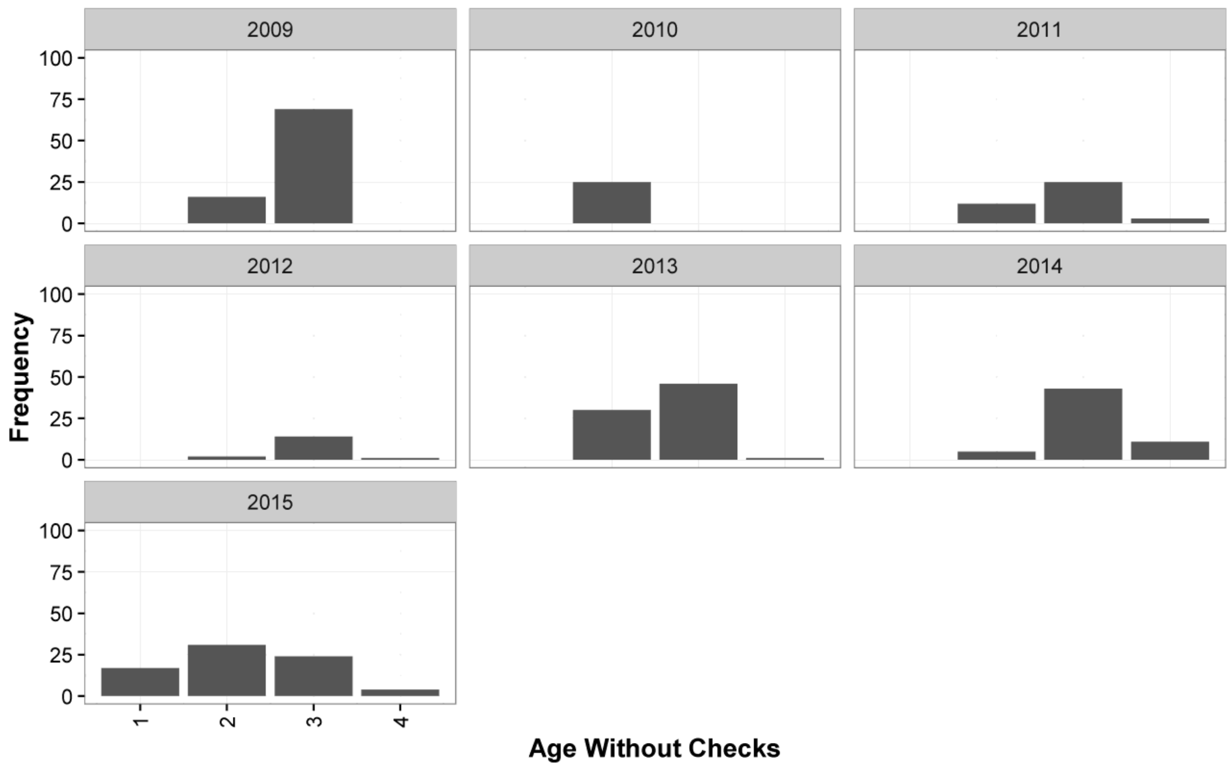

Figure 41 Age frequency of Kokanee spawners caught in index streams (Boulder Creek, Flat Creek and Jones Creek) of Wahleach Reservoir during 2009-2015

3.6.3 Rainbow Trout

Fall nearshore gillnetting captured Rainbow Trout during 2009 to 2015 with a range in mean length from 182-238 mm and a mean weight with a range from 85.3-163.6 g (Table 39). Rainbow Trout caught in 2010 were the shortest with a mean length of 182 mm and Rainbow Trout caught in 2011 were the lightest with mean weight of 55.3 g, whereas, Rainbow Trout caught in 2009 were the longest at 238 mm and the heaviest with a mean 163.6 g. Fulton's condition factor (K) indicated a slight variability in condition over this time period, ranging from 1.0-1.1. Rainbow Trout caught in minnow traps in 2009, 2010, 2013, 2015 had a range in mean length from 79-123 mm and a range in mean weight from 5.5-18.0 g (Table 40). Rainbow Trout caught in minnow traps had a similar conditions factor as rainbows caught in the gillnets. Additional, mean age of Rainbow Trout caught in minnow traps had a range of age from 0+ to 1+, but this is expected based on the sampling gear used (minnow traps versus gillnetting). Some of the differences in mean length and weights might be attributed to the frequency of age classes caught during each year. Particularly in 2014, more 3+ and 4+ Rainbow Trout were caught compared to the other years (Figure 42Figure 43). Rainbow trout caught during 2009 to 2015 were relatively evenly distributed amongst size and age classes, with the exceptions of 2011 and 2012; however, as noted above there were lower catches in these years (Figure 42). Rainbow Trout length-weight regressions were based on fall nearshore gillnetting data. Figure 44 shows the length-weight regressions for 2009 to 2015 for Rainbow Trout. A regression slope of 3 is common for fish (Anderson *et al*. 1983; Cone 1989). All of the length-weight regression slopes were near 3.0, with a range of 2.82 to 2.92 (Figure 44, Table 41).

Table 39 Summary of Rainbow Trout biometric data from fall nearshore gillnetting programs, including length, weight, condition factor (CF) and age, for Wahleach Reservoir during nutrient restoration in 2009 to 2015.

Year	Species	N	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)	Mean CF	SD CF	Mean Age	SD Age
2009	RB	52	238	65	163.6	101.0	1.0	0.07	2	1
2010	RB	68	182	65	87.7	73.7	1.1	0.11	2	1
2011	RB	123	184	61	85.3	74.4	1.0	0.10	2	1
2012	RB	32	220	55	132.4	83.2	1.1	0.11	3	1
2013	RB	32	218	67	135.4	92.5	1.1	0.07	2	2
2014	RB	88	227	66	151.7	96.0	1.1	0.10	2	1
2015	RB	70	202	57	105.1	82.1	1.1	0.09	2	1

Table 40 Summary of Rainbow Trout biometric data from minnow trapping programs, including length, weight, condition factor (CF) and age, for Wahleach Reservoir during nutrient restoration in 2009 to 2015.

Year	Species	N	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)	Mean CF	SD CF	Mean Age	SD Age
2009	RB	1	123	-	18	-	1.0	-	-	-
2010	RB	2	98	1	10.8	0.4	1.0	0.14	1	0
2011	RB	-	-	-	-	-	-	-	-	-
2012	RB	-	-	-	-	-	-	-	-	-
2013	RB	4	107	20	12.8	5.9	1.1	0.43	0	0
2014	RB	-	-	-	-	-	-	-	-	-
2015	RB	5	79	14	5.5	2.5	1.1	0.12	0	0

Dashes (-) indicate no data. No RB were caught in minnow traps in 2011, 2012 and 2014.

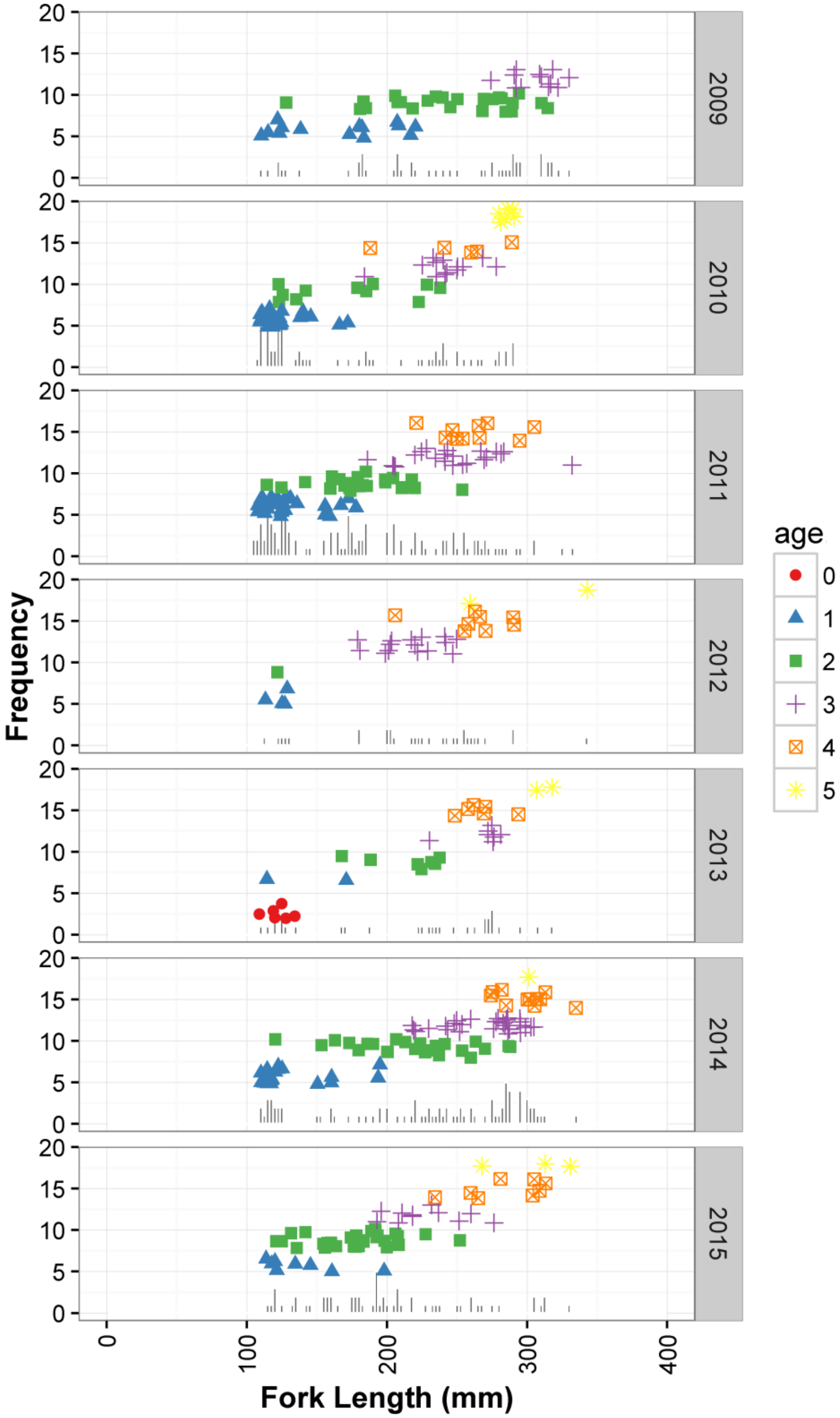

Figure 42 Length frequency and associated age-at-length of Rainbow Trout caught in fall nearshore gillnets and minnow traps during nutrient restoration in 2009-2015, Wahleach Reservoir.

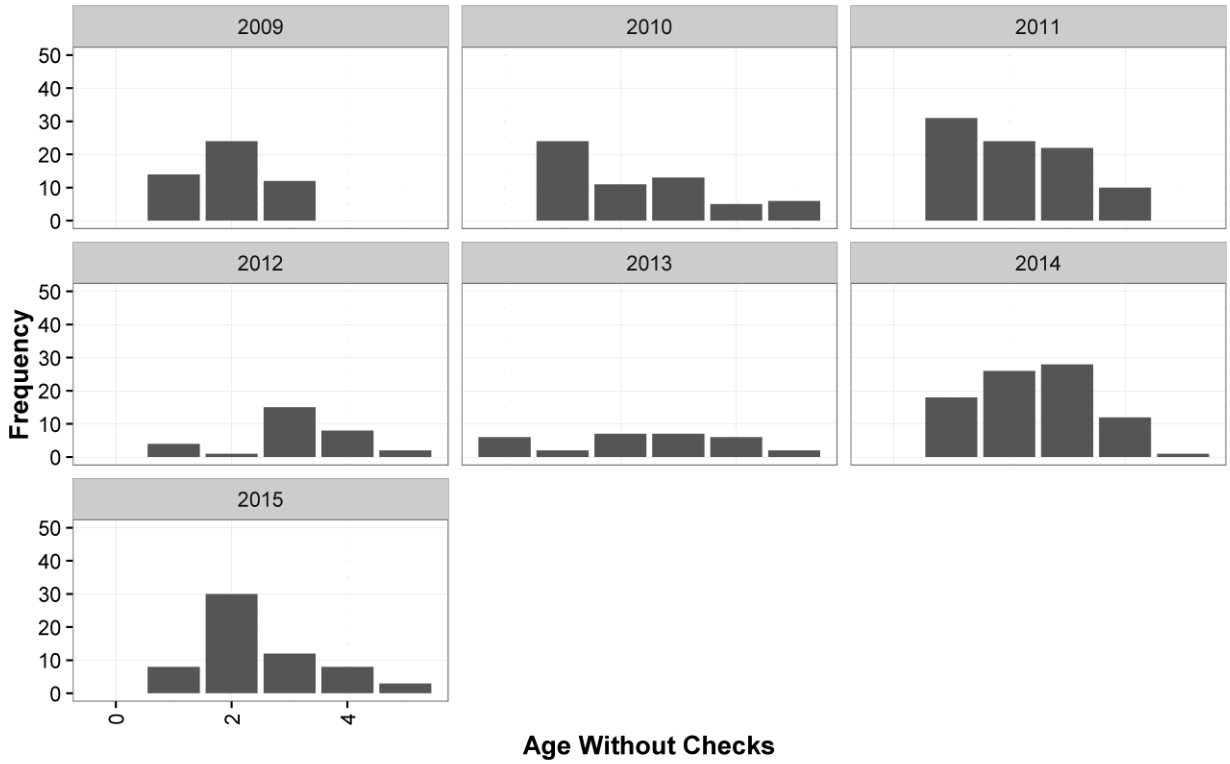

Figure 43 Age frequency of Rainbow Trout caught in fall nearshore gillnets and minnow traps during nutrient restoration years in 2009 to 2015, Wahleach Reservoir.

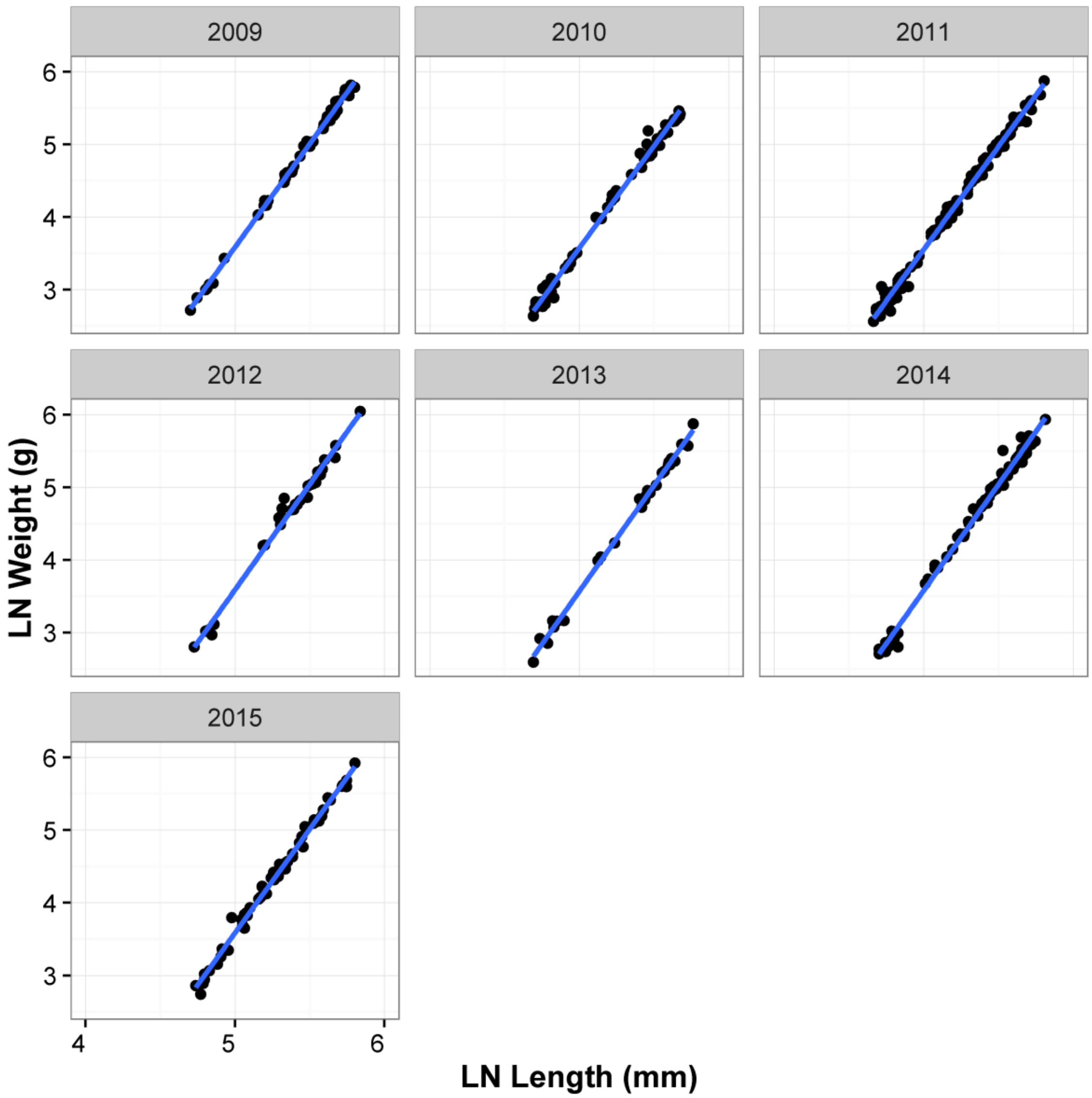

Figure 44 Length weight plot and relationship (Ln W=b·Ln L + Ln a) of Rainbow Trout caught in gillnets and minnow traps during nutrient restoration years in 2009 to 2015, Wahleach Reservoir.

Table 41 Summary of variables in R for Rainbow Trout length weight relationships (Ln W = b · Ln L + Ln a) during nutrient restoration in 2009 to 2015, Wahleach Reservoir

Year	Equation	R^2
2009	LN.weight.g = 2.84 *LN.length.mm -10.6	0.9972
2010	LN.weight.g = 2.82 *LN.length.mm -10.5	0.9933
2011	LN.weight.g = 2.83 *LN.length.mm -10.6	0.9937
2012	LN.weight.g = 2.90 *LN.length.mm -10.9	0.9864
2013	LN.weight.g = 2.91 *LN.length.mm -11.0	0.9964
2014	LN.weight.g = 2.92 *LN.length.mm -11.0	0.9929
2015	LN.weight.g = 2.86 *LN.length.mm -10.7	0.9912

3.6.4 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 gillnetting captured Cutthroat Trout during 2009 to 2015 with a range in mean length from 289-362 mm and a mean weight with a range from 261.6-529.9 g (Table 42). Cutthroat Trout caught in 2015 were the shortest with a mean length of 289 mm and lightest with mean weight of 261.6 g, whereas, Cutthroat Trout caught in 2010 were the longest at 362 mm and the heaviest at 529.9 g. Fulton's condition factor (K) indicated a slight variability in condition over this time period, ranging from 0.9-1.0. Cutthroat Trout caught during 2009 to 2015 were relatively evenly distributed amongst size and age classes in 2015 only; the other years (2009-2014) were spread out in their distributions (Figure 45). Comparing age of Cutthroat Trout between 2009 and 2015, 2015 had the highest frequency of age 1+, whereas the other years had fewer 2+ or 3+ (Figure 46). Very few 4+, 5+ and 6+ Cutthroat Trout were caught throughout 2009 to 2015 (Figure 46). Figure 47 shows the length-weight regressions for 2009 to 2015 for Cutthroat Trout. A regression slope of 3 is common for fish (Anderson *et al*. 1983; Cone 1989). All of the length-weight regression slopes were near 3.0, with a range of 2.79 to 3.13 (Figure 47, Table 43).

Table 42 Summary of Cutthroat Trout[1] biometric data, including length, weight, condition factor (CF) and age, for Wahleach Reservoir during nutrient restoration in 2009 to 2015.

Year	Species	N	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)	Mean CF	SD CF	Mean Age	SD Age
2009	CT	35	317	81	378.7	246.8	1.0	0.07	2	1
2010	CT	19	362	103	529.9	330.0	1.0	0.12	3	2
2011	CT	9	359	33	449.5	133.5	0.9	0.07	4	1
2012	CT	25	330	100	391.8	385.8	1.0	0.09	3	1
2013	CT	31	293	78	294.8	294.8	0.9	0.17	2	1
2014	CT	20	335	66	398.8	254.2	1.0	0.29	3	1
2015	CT	54	289	61	261.6	171.3	1.0	0.25	2	1

1. Cutthroat Trout were not present in Wahleach Reservoir prior to nutrient restoration.

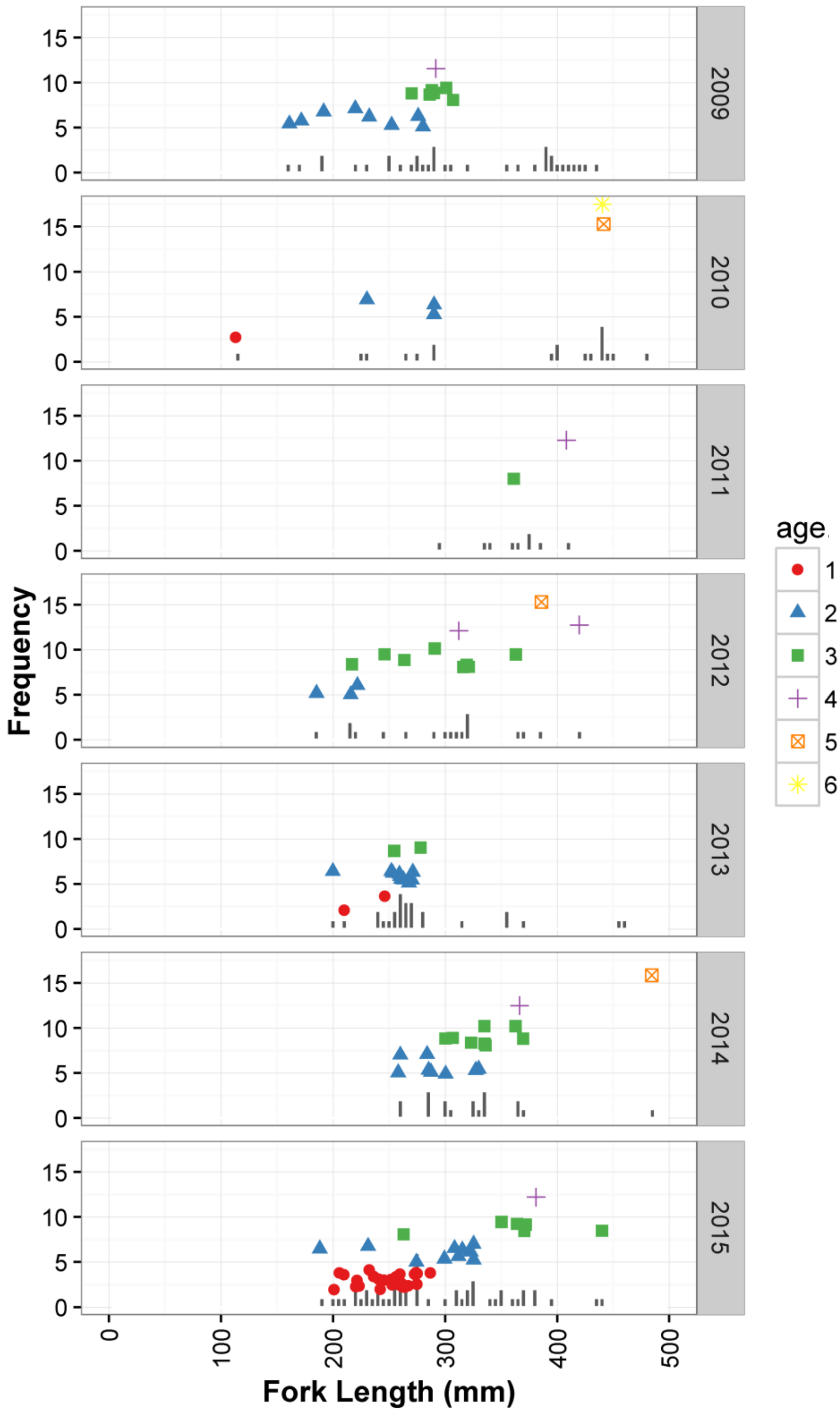

Figure 45 Length frequency and associated age-at-length of Cutthroat Trout caught in fall nearshore gillnets during nutrient restoration in 2009-2015, Wahleach Reservoir.

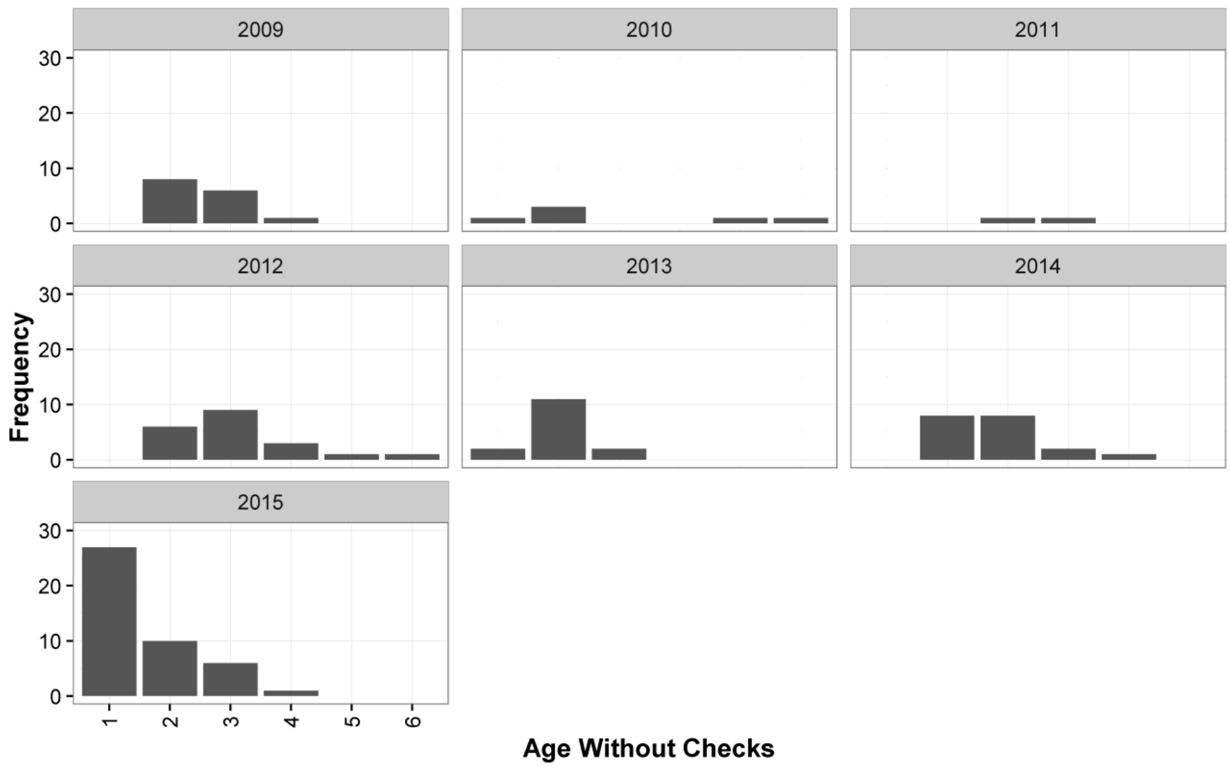

Figure 46 Age Frequency of Cutthroat Trout caught in fall nearshore gillnets during nutrient restoration in 2009-2015, Wahleach Reservoir.

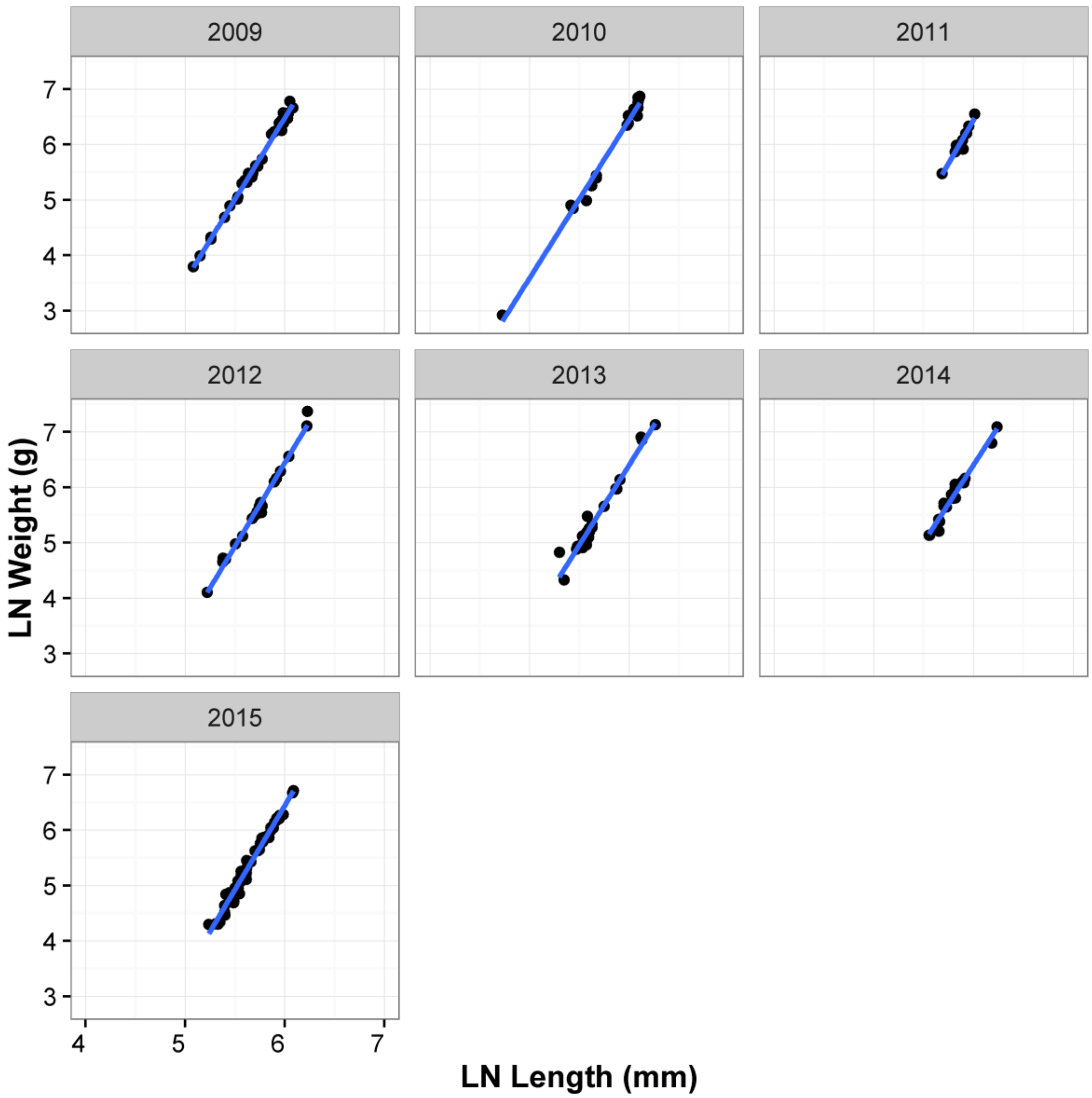

Figure 47 Length weight plot and relationship (Ln W = b · Ln L + Ln a) of Cutthroat Trout caught in gillnets during nutrient restoration years in 2009 and 2015, Wahleach Reservoir.

Table 43 Summary of variables in R for Cutthroat Trout[1] length weight relationships (Ln W = b · Ln L + Ln a) during nutrient restoration in 2009 to 2015, Wahleach Reservoir.

Year	Equation	R^2
2009	LN.weight.g = 2.94 *LN.length.mm -11.2	R^2=0.9933
2010	LN.weight.g = 2.86 *LN.length.mm -10.7	R^2=0.9888
2011	LN.weight.g = 3.13 *LN.length.mm -12.3	R^2=0.9263
2012	LN.weight.g = 3.01 *LN.length.mm -11.6	R^2=0.9879
2013	LN.weight.g = 2.89 *LN.length.mm -10.9	R^2=0.9599
2014	LN.weight.g = 2.79 *LN.length.mm -10.4	R^2=0.9666
2015	LN.weight.g = 3.03 *LN.length.mm -11.8	R^2=0.9784

1. Cutthroat Trout were not present in Wahleach Reservoir prior to nutrient restoration.

3.6.5 Threespine Stickleback

Fall minnow trapping captured Threespine Stickleback during 2010 to 2015 (no TSB captured during 2009 fall minnow trapping) with a range in mean length from 37-47 mm and a mean weight with a range from 0.5-2.0 g (Table 44). During some of the years between 2010 and 2015, numerous Threespine Stickleback samples had large tapeworms in their gut, so actual fish weights would be overestimated in Table 44. Furthermore, Threespine Stickleback catch has dramatically decreased since the beginning of the study were 65 Threespine Stickleback were caught in 1994 (data on file; note sample size (n) in Table 44).

Table 44 Summary of Threespine Stickleback length and weight data from minnow trapping on Wahleach Reservoir during nutrient restoration in 2009 to 2015.

Year	N	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)
2009[1]	-	-	-	-	-
2010	1	39	NA	0.5	NA
2011	10	37	6	0.6	0.3
2012	1	47	NA	2.0	NA
2013	24	37	4	0.5	0.2
2014	19	42	5	0.7	0.3
2015	4	47	3	1.1	0.2

1. 2009 – no TSB caught in MT in fall sampling.

3.6.6 Fish Distribution

Appendix D illustrates the acoustic target size distributions partitioned by the analysis depth range; once partitioned, the distribution of acoustic targets within the preferred Kokanee depths more closely resembles Kokanee-only distributions found in other lakes in BC (FLNRO data on file). Acoustic density distributions by transect and depth are detailed in Appendix E. Across all years transect densities have generally been highest towards the center of the reservoir (generally transects 6-8) which is where depths are greatest and trawl and pelagic gillnet surveys were best performed.

Catch from trawl and pelagic gillnet surveys demonstrates important differences in species composition by depth within the reservoir and assists with interpretation of acoustic data. In earlier years, equipment issues, low fish densities and less than optimal fish distributions resulted in variable success rates in terms of producing reliable species distribution data from trawl surveys; in more recent years, however, changes in methods along with suitable fish densities have produced encouraging results as catch rates improved with >30 Kokanee fry captured in each year in 2014 and 2015 – which made up over 90% of the catch from trawls within the depth ranges targeting Kokanee (Figure 48).

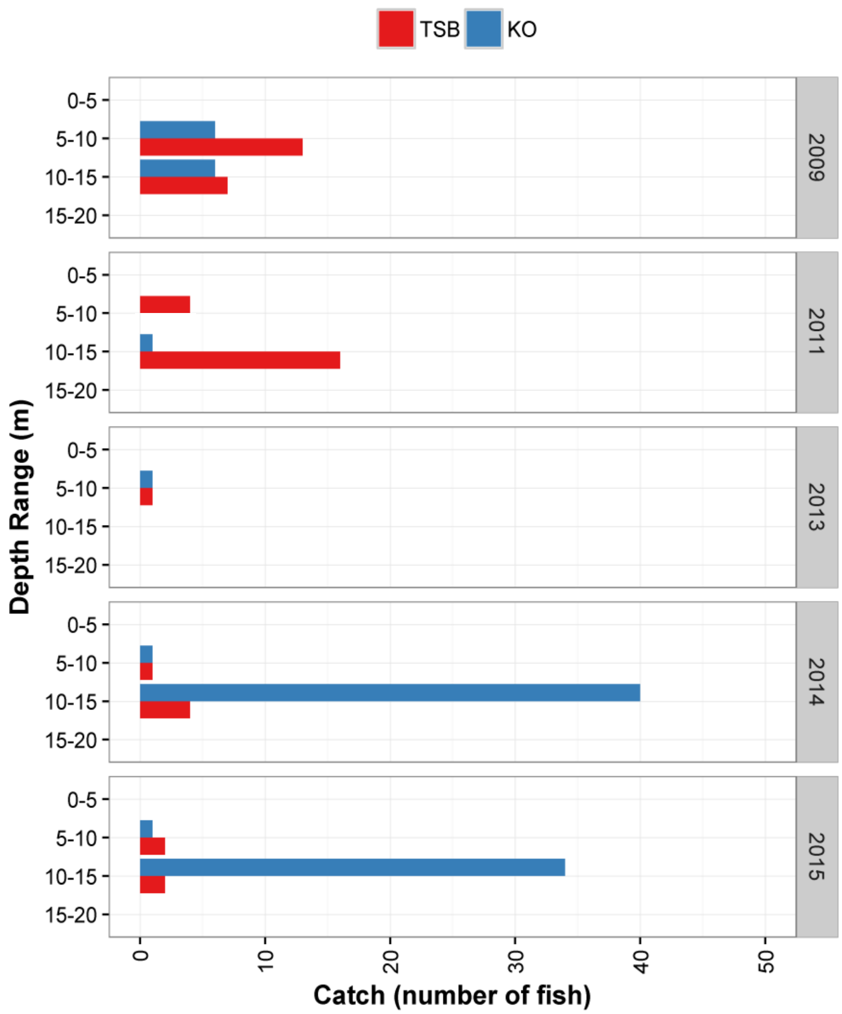

Figure 48 Vertical distribution of fish species caught in trawl surveys on Wahleach Reservoir, 2009-2015.

Furthermore, pelagic gillnetting data resulted in a catch that was over 90% Kokanee at depths below 5 m with 80% of the surface catch being Rainbow Trout (Figure 49). So even though the majority of Kokanee were within the same size range as Rainbow Trout (data on file), these species were generally separated by depth. And while the depth range between Kokanee and Cutthroat Trout overlapped (with Cutthroat Trout distributed almost equally between surface nets and nets below 5m), the size range of Cutthroat Trout was distinct from Kokanee (data on file). Threespine stickleback caught in pelagic nets had the same size characteristics as those captured in trawl surveys (data on file) and made up only 1% of the gillnet catch overall.

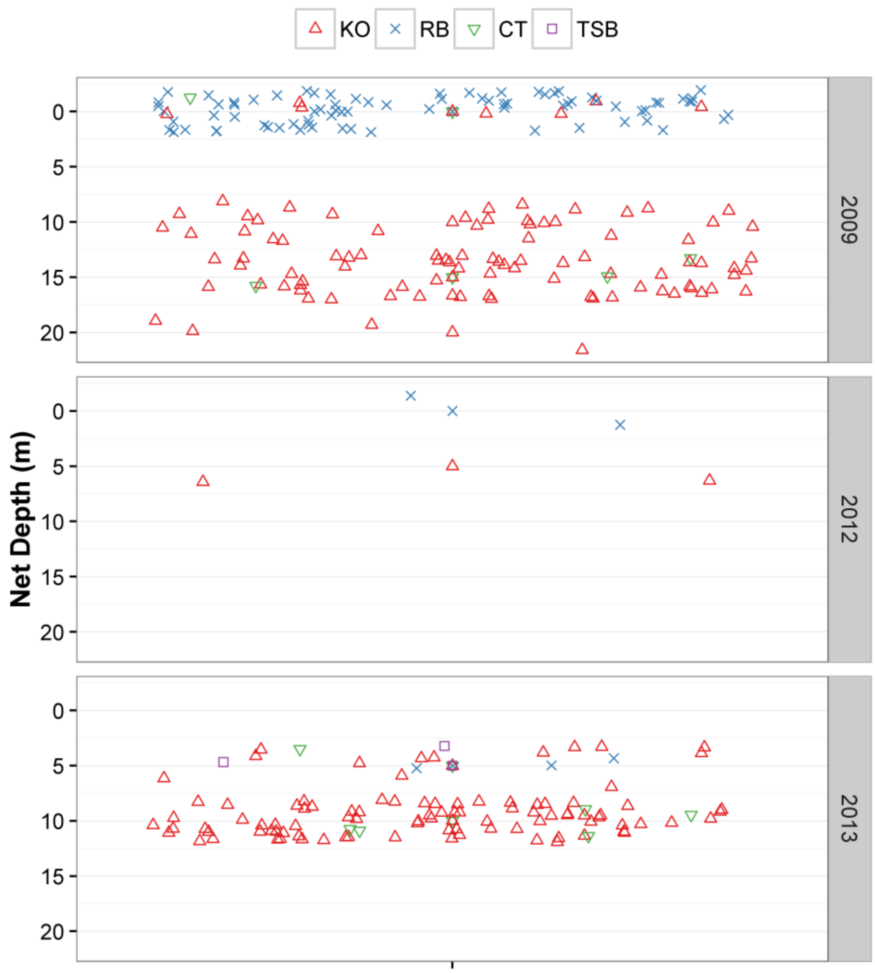

Figure 49 Vertical distribution of fish species caught in pelagic gillnets on Wahleach Reservoir, 2009-2015.

3.6.7 Population Estimates

Total fish abundance by size group for all depths is illustrated in Figure 50 and thus represents a mixed species assemblage. Within the Kokanee depth layer, abundance of fry and adults behaved as we would expect over time – with greater variability in Kokanee fry estimates, and relatively stable abundance of adult Kokanee represented age classes >1 (Figure 51). Abundance of Kokanee fry ranged from 53,696 individuals in 2013 to 123,289 in 2014 (Figure 51). Adult Kokanee abundance was generally in the 15,000-25,000 range, except in 2015 which had 65,140 individuals – the greatest abundance on record (Figure 51).

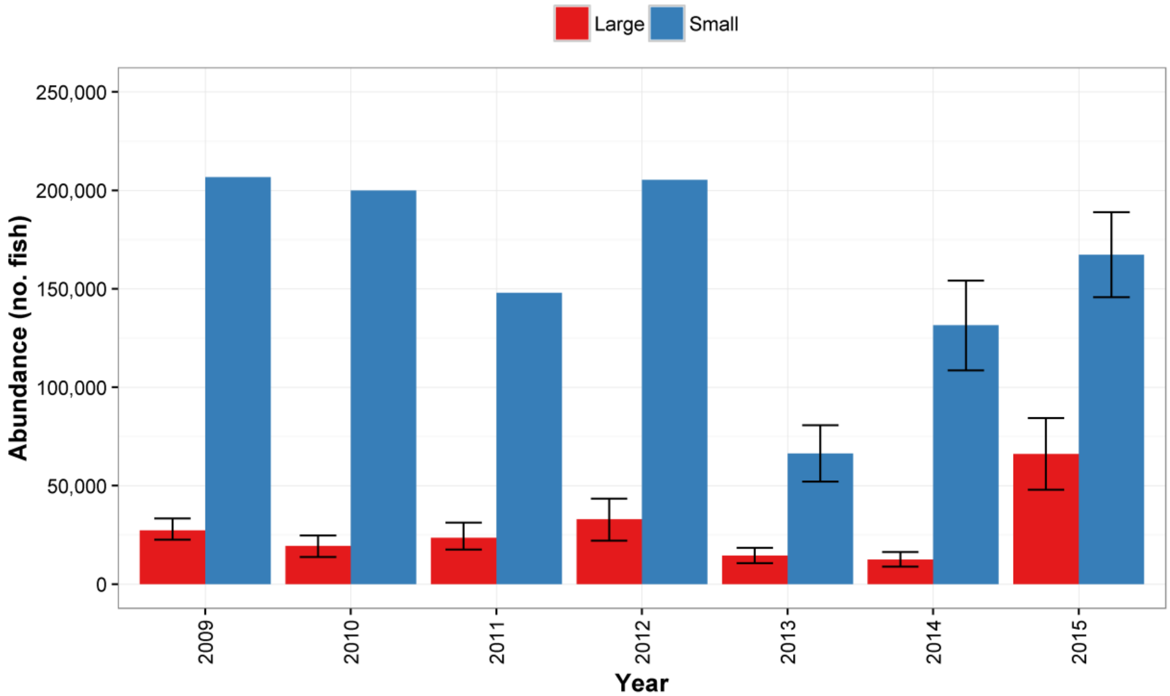

Figure 50 Acoustic population estimates by size group for all fish at all depths for Wahleach Reservoir, 2009-2015.

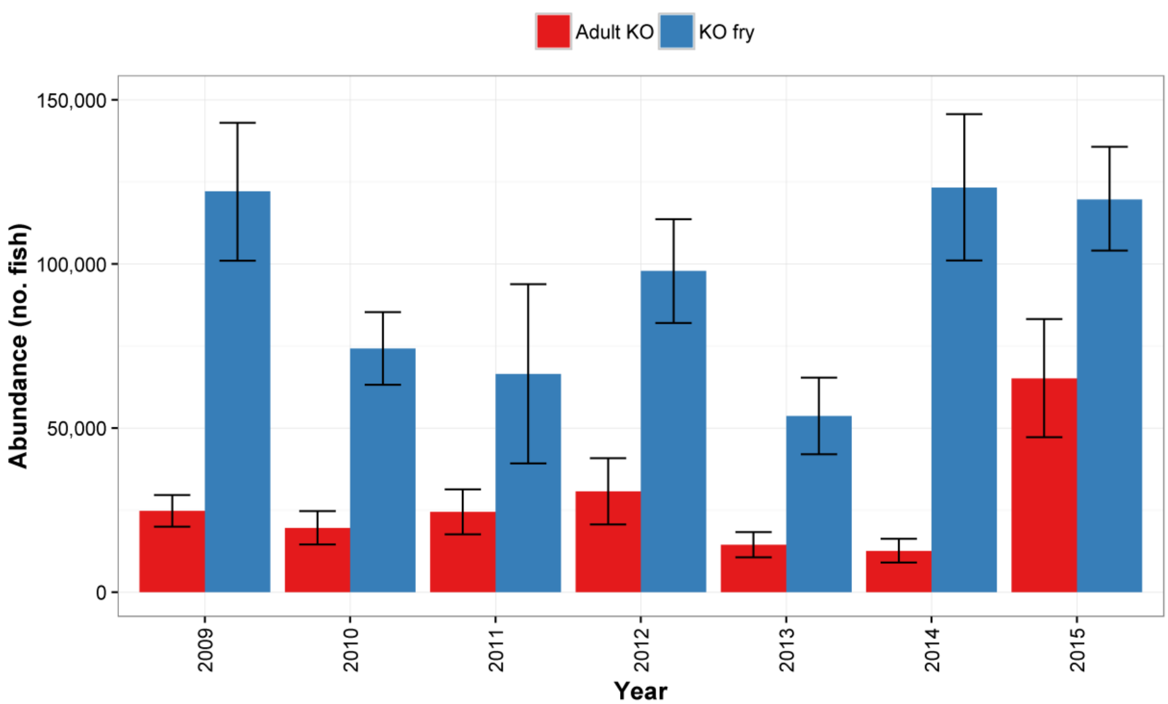

Figure 51 Acoustic population estimate by size within the depth range preferred by Kokanee, Wahleach Reservoir, 2009-2015.

The total biomass of fish (all species) ranged from a low of 590 kg in 2013 to a high of 4,264 kg in 2015, while the average for the seven consecutive years of survey (2009-2015) was 1,950 kg (Figure 52). For Kokanee, the biomass ranged from a low of 506 kg in 2013 to 3,093 kg in 2015, while the average was 1,507 kg (Figure 52). Kokanee biomass was driven largely by adult (age >1) abundance. It is worth noting that 2012 sampling occurred in July, which is one month earlier in the growing season relative to other years; so we would expect to see a lower biomass estimate driven by the relatively smaller body size of fish at that time even though fish abundance was greater.

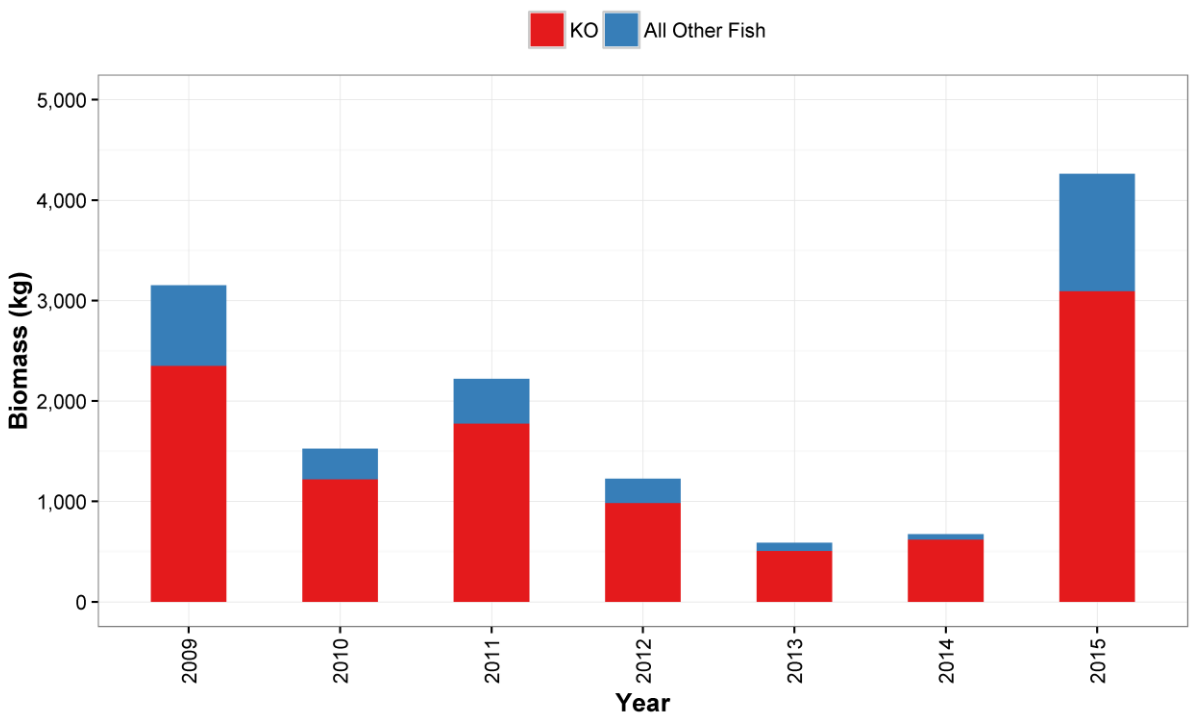

Figure 52 Total fish biomass by species group (as determined by depth analysis) in Wahleach Reservoir, 2009-2015.

3.6.1 Recreational Fishery

The recreational fishery on Wahleach Reservoir is seasonal with highest effort during the summer months gradually declining by late summer. Most anglers were casual fishers seeking “anything” and often were fishing the reservoir for the first time. Despite the presence of Kokanee in reasonable numbers (see section 3.6.2 Kokanee) most anglers caught trout – either Rainbow or Cutthroat with the majority of anglers not able to distinguish the difference. Trolling was by far the method of choice for anglers who fished the surface waters using a variety of lures.

The 2009 survey was conducted from June through to September with estimated angler effort highest in August followed by June with lowest effort in July (Figure 53). Total estimated effort for the four months was 2159 rod hours. Average effort was 3.0 hours per angler day, thus an estimated 720 angler days were expended over the four survey months. Species of the fish that were captured was not recorded in 2009; however, this information was collected during the 2013 and 2014 surveys (detailed below), and in both surveys the catch composition was virtually identical (18% Kokanee, 18% Rainbow Trout, 64% Cutthroat Trout). Based on these ratios and total estimated catch of 536 in the 2009 survey then potentially 96 Kokanee, 96 Rainbow Trout and 344 Cutthroat were caught during the four surveyed months in 2009.

The 2013 survey was limited to June-August with the reservoir inaccessible during September due to the main access road closed for repair. During the three survey months some 2268 rod hours were spent catching an estimated total of 1204 fish. Effort was highest during July (Figure 53). Average hours fished per day was 3.6 therefore 630 angler days expended during the three months. By species the catch was estimated to be: 214 Kokanee, 223 Rainbow and 767 Cutthroat Trout. The division between the trout species catch is somewhat arbitrary as most anglers could not distinguish between the two. Total effort for the three months was far greater than the 2009 estimate that included the additional month of September (see discussion below).

The 2014 survey was conducted from May-September and the effort pattern was more typical of most small lake fishing in the lower mainland area. That is, effort was highest during the spring months declining as the summer advanced with a slight increase in September (Figure 53). Total estimated effort for the 5 months surveyed was just over 3100 rod hours that equates to about 1058 angler days based on an average of 2.9 rod hours per day. An estimated total of 1797 fish were caught with about 325 being Kokanee, 335 Rainbow Trout and 1135 Cutthroat Trout (small differences due to rounding). Again it should be noted the division between the trout species is somewhat arbitrary.

For all three survey years, trout (Rainbow and Cutthroat) dominated the catch with Kokanee as only a small contributor (Figure 54).

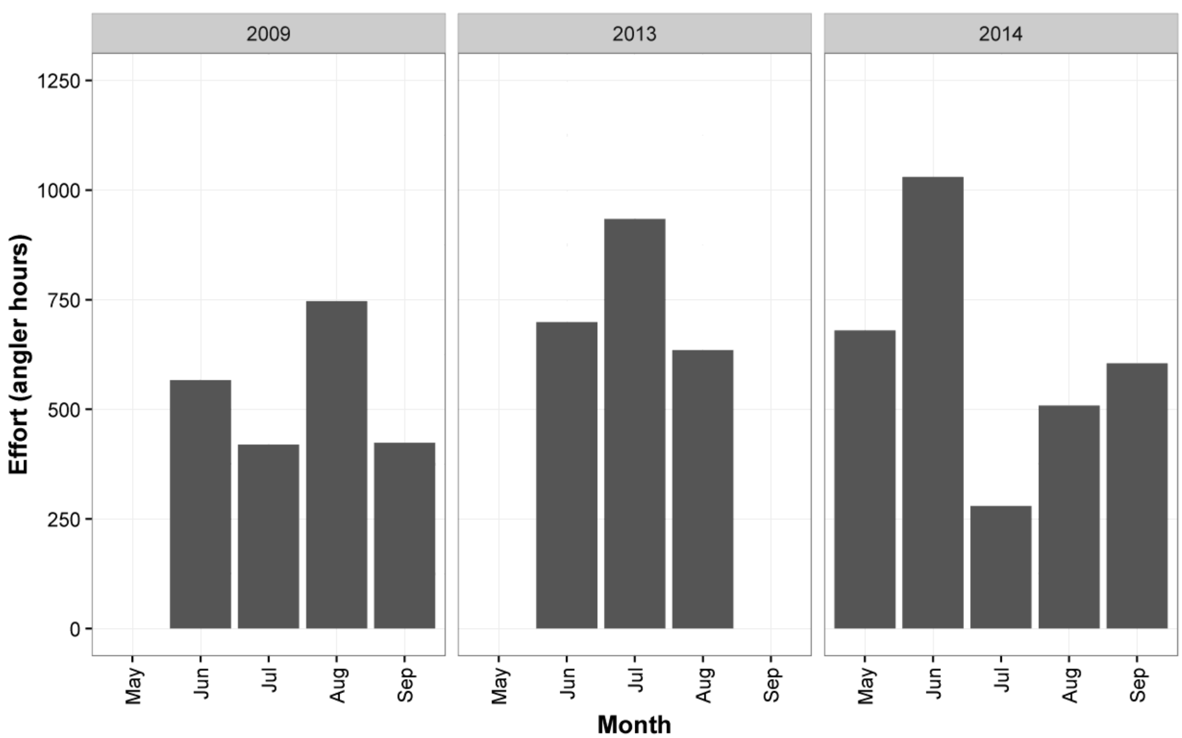

Figure 53 Total monthly angler effort on Wahleach Reservoir in 2009, 2013 and 2014.

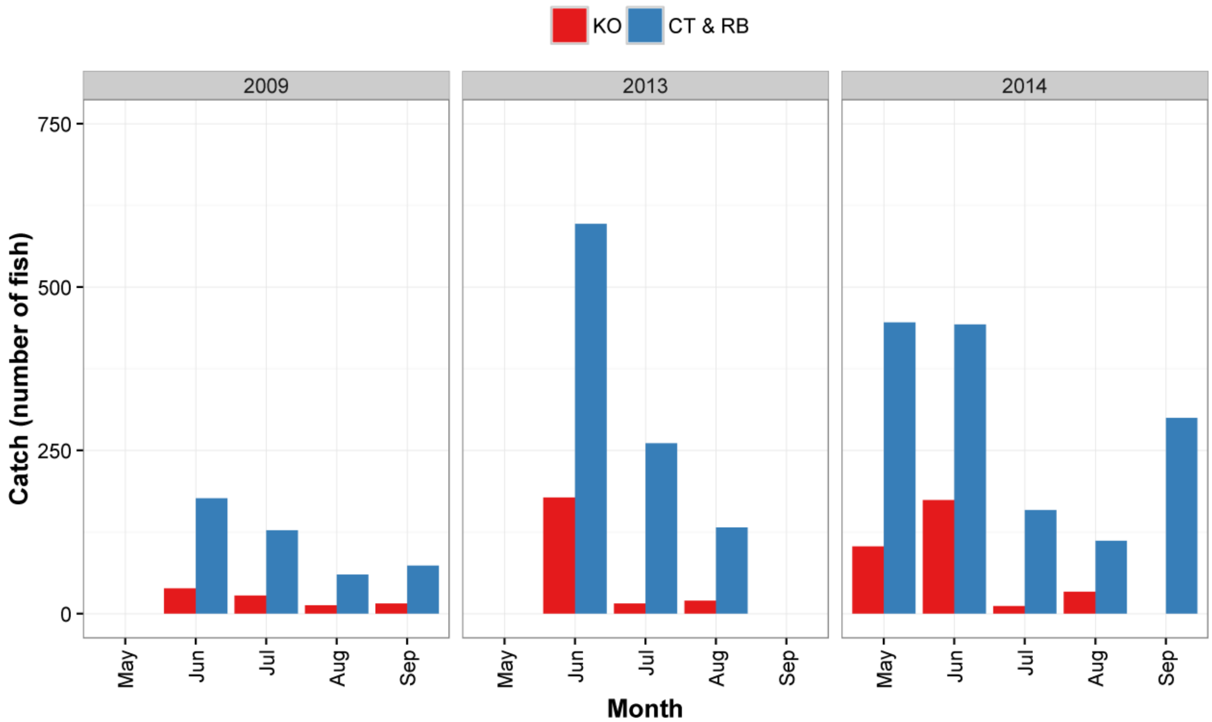

Figure 54 Monthly catch estimates of Kokanee and trout (Rainbow and Cutthroat) in the recreational fishery on Wahleach Reservoir in 2009, 2013 and 2014.

In terms of angler effort, analysis of comparable months surveyed indicated angler effort has increased only slightly (Figure 55) whereas catch and angler success have increased substantially (Figure 56, Figure 54). The seasonal trout catch has doubled since 2009 and the Kokanee catch, albeit still very low appears to be increasing (Figure 56). Moreover, catch-per-unit-effort (CPUE) has doubled since the 2009 survey (Figure 57). The issue for the fishery is that trout are typically too small for anglers to keep. For example, the release rates were high at 90-95% in 2013 and 2014 respectively (Figure 58).

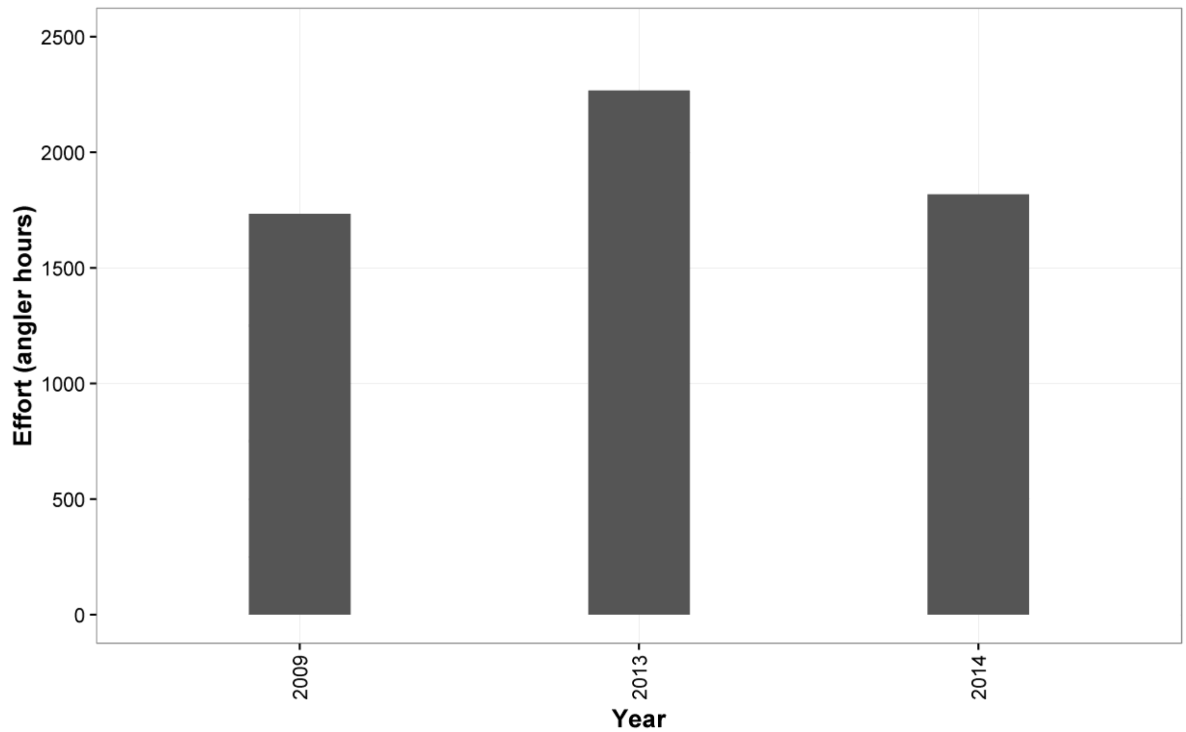

Figure 55 Comparable (June-August) estimate of angler effort on Wahleach Reservoir in 2009, 2013 and 2014.

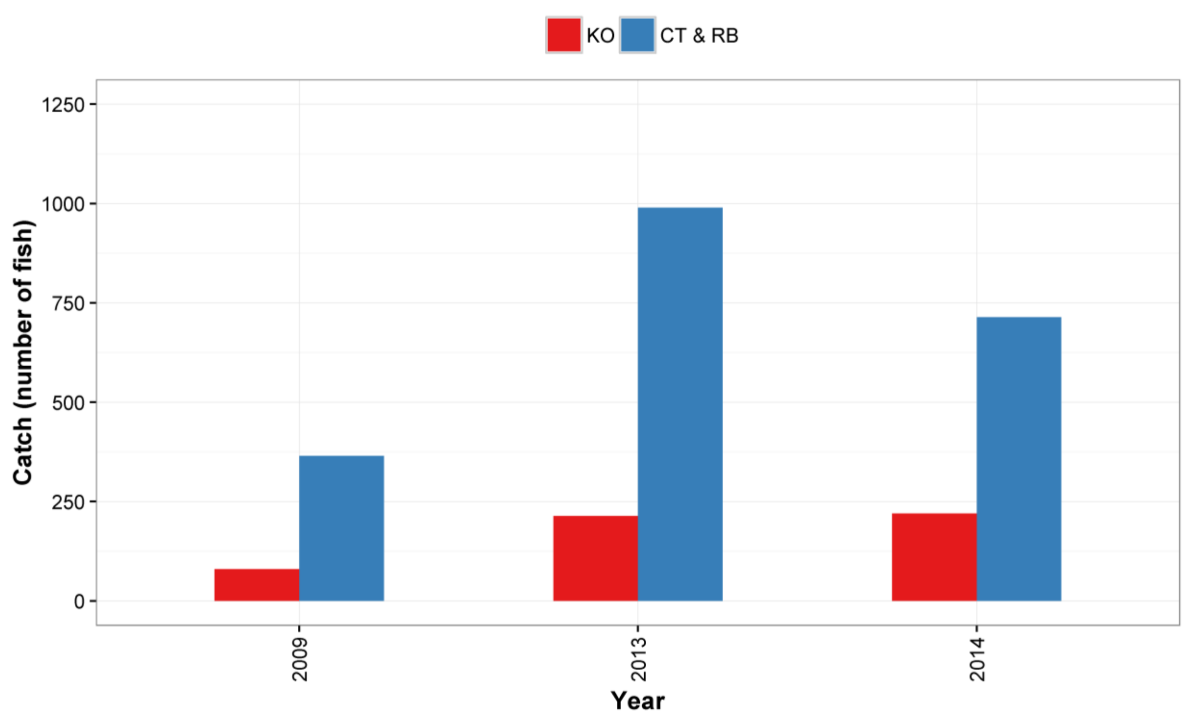

Figure 56 Total seasonal catch estimates of Kokanee and trout (Rainbow and Cutthroat) in the recreational fishery on Wahleach Reservoir in 2009, 2013 and 2014.

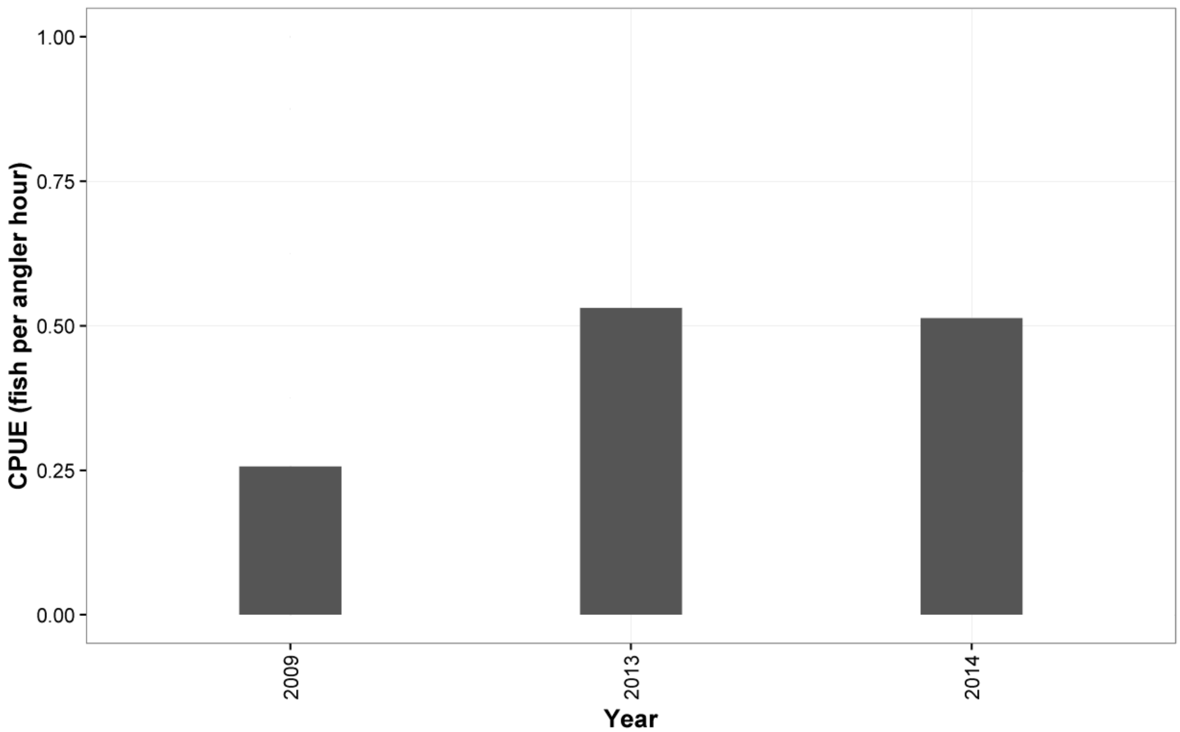

Figure 57 Catch-per-unit-effort (CPUE) for all three sport fish species (Kokanee, Rainbow Trout, Cutthroat Trout) in the recreational fishery on Wahleach Reservoir in 2009, 2013 and 2014.

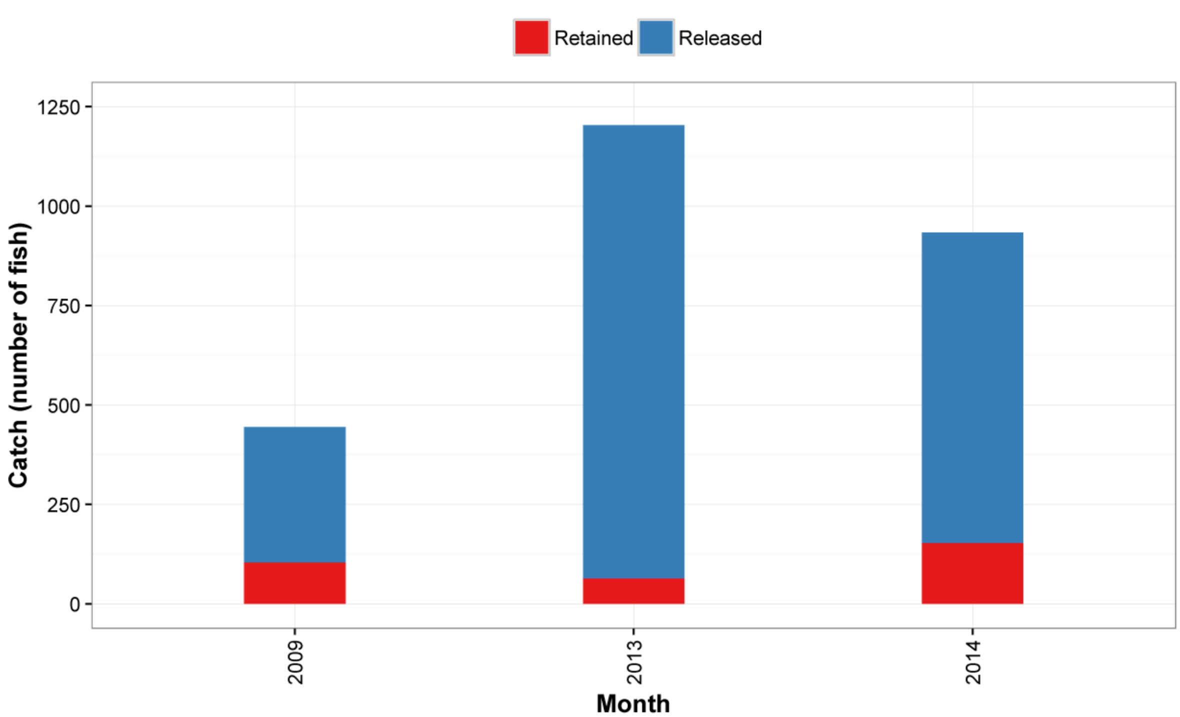

Figure 58 Total number of fish caught, retained and released in the recreational fishery during comparable months (June-August) on Wahleach Reservoir in 2009, 2013 and 2014.

4. 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

The Wahleach Reservoir Nutrient Restoration Project was based on known links between nutrient availability and productivity. There is an overwhelming amount of evidence supporting the relationship between the quantity of nitrogen and phosphorus entering a lake and the measured biological response to that input. Vollenwieder (1976) developed a quantitative relationship describing the trophic conditions that result from a nutrient load and has shown unequivocally that increased phosphorus loading leads to higher productivity lakes. 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 BC 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. Over the review period, Wahleach Reservoir was characterized by ultra-oligotrophic conditions in terms of nutrient concentrations, yet exhibited Secchi depths in the range of oligotrophic to mesotrophic (Table 45).

Table 45 Trophic state classification of Wahleach Reservoir during nutrient restoration years, 2009-2015, using criteria defined by Wetzel (2001) and Wetzel (1983).

Parameter	Results from Nutrient Restoration Limnological Assessments, Mean ± SD						
	2009	2010	2011	2012	2013	2014	2015
TP ($\mu g \cdot L^{-1}$)	2.7±0.9	4.0 ± 1.2	3.5 ± 1.0	4.7 ± 1.3	5.5 ± 3.2	3.6 ± 1.0	2.2 ± 1.4
TN ($\mu g \cdot L^{-1}$)	159±51	127 ± 67	182 ± 93	207 ± 50	175 ± 77	147 ± 33	113 ± 29
Secchi (m)	3.8±1.7	3.5 ± 0.9	4.3 ± 1.6	4.9 ± 1.4	4.0 ± 1.4	5.8 ± 1.2	5.7 ± 1.5

Parameter	Trophic Classification, Mean (Range)			
	Ultra-Oligotrophic	Oligotrophic	Mesotrophic	Eutrophic
TP ($\mu g \cdot L^{-1}$)	(< 1-5)	8 (3-18)	27 (11-96)	84 (16-386)
TN ($\mu g \cdot L^{-1}$)	(< 1-250)	661 (307-1,630)	753 (361-1,387)	1,875 (396-6,100)
Secchi (m)	-	9.9 (5.4-29.3)	4.2 (1.5-8.1)	2.5 (0.8-7.0)

Earlier in the project, Perrin *et al*. (2006) recommended annual phosphorus loading of 200 $mg \cdot m^{-2}$ to promote *Daphnia* production. In recent years, actual nutrient loading has deviated significantly from planned loading in response to monitoring results; and over the review period, no more than 137 $mg \cdot m^{-2}$

of phosphorus has been added to reservoir in any given year. It is well known that lake sediment can play a major role in the nutrient dynamics of lakes and reservoirs (William and Mayer 1972). Generally there is a net flux of phosphorus to the sediments in lakes but under particular physical, chemical and biological conditions, phosphorus can be released into the water column (Wetzel 2001). This exchange of phosphorus bound in the sediment is extremely complex and dynamic but it has been shown that phosphorus can be remobilized from oxygen rich sediments when water temperatures are above 10-15ºC (Wetzel 2001). While phosphorus dynamics have not been studied in Wahleach it is possible that internal loading associated with nutrient return from deeper sediments and recycling of nutrients from littoral area, particularly in warm water conditions may occur (William and Mayer 1972). In addition, nitrogen concentrations within Wahleach Reservoir have consistently decreased throughout the summer and early fall growing seasons entering into very low and sometimes extended limitation periods. Though this is common in many coastal and sub-alpine BC lakes (Stockner 1981, Stockner & Shortreed 1985), such conditions can promote growth of nitrogen-fixing cyanophytes (e.g. *Microcystis*, *Merismopedia*) and inedible diatoms that are able to store nutrients for later use (e.g. *Fragilaria* sp, *Tabellaria* sp.) – as was also observed in some years on Wahleach Reservoir. Increased biomass of inedible species that sink to the hypolimnion can intensify conditions that increase 'internal' nutrient loading rates. Recognizing this possibility, phosphorus addition to Wahleach Reservoir was completely suspended in 2011 to 'reset' the system. If actual nutrient loads were not corrected for changing reservoir conditions, eutrophication of the system would be a very real possibility. Planned nutrient loading strategies will continue to be revised in response to changing reservoir and climatic conditions noted during annual data reviews, as will actual in-season loading based on incoming monitoring data.

<u>Phytoplankton Edibility & Zooplankton Community</u>

When examining the response of the phytoplankton and zooplankton community it is important to keep the dynamic nature of these two trophic levels in mind. The aim of nutrient addition is to stimulate the production of edible phytoplankton so energy if efficiently transferred to the production of desirable zooplankton species, particularly *Daphnia* - a large bodied zooplankter that is the preferred forage for Kokanee (Thompson 1999). Ideally, phytoplankton are quickly ingested and assimilated by *Daphnia*, leaving little trace of enhancement at the phytoplankton trophic level. Monthly sampling allows us to track a fast changing ecosystem to ensure the species we are stimulating will in turn lead to desired outcomes.

Generally, no consistent trend was observed when comparing phytoplankton densities and biovolume between baseline and treatment years. Over the review period, edible phytoplankton have been observed in greater abundances and biovolumes than inedible fractions. 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*. A closer examination of *Daphnia* dynamics shows that densities have been consistently > 3 individuals$\cdot L^{-1}$ and biomass was generally at 60 $\mu g \cdot L^{-1}$. *Daphnia* have accounted for 30-50% of overall zooplankton density and approximately 70% of total zooplankton biomass. These results establish that the nutrient restoration program has increased food availability for Kokanee.

<u>Fish Population Response</u>

Methods to determine fish abundance and biomass in Wahleach Reservoir has focused on acoustic-trawl surveys in combination with pelagic gillnetting in some years. Due to its smaller size (relative to 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. Consequently, a variety of sampling approaches have been used over the years. In recent years, surveys were conducted in August when conditions were expected to be most favorable – i.e. when there would be a strong thermocline and warm surface temperatures to separate Kokanee fry and Threespine Stickleback according to habitat preferences, and when all age classes of Kokanee would be in the reservoir, specifically the spawning portion of the population. Refinement of trawl methods has also resulted in successive years of catches greater than 30 fish – data which are used to validate fish distributions. Overall, acoustic-trawl methods in the most recent years have shown positive results in terms of generating reliable estimates. Initial biomass estimates for Wahleach demonstrate that Kokanee biomass generally tracks adult Kokanee abundance; even though fry are numerically dominant, they are considerably smaller than the older age classes and so do not contribute much to overall population biomass. It should be noted that biomass estimates have been developed using a novel method that will be refined in upcoming years.

Stimulation of the lower trophic levels has translated into increased fish abundance and biomass since the program's inception. Assessments of Wahleach Reservoirs' fish populations generally indicate a significant increase in abundance and overall biomass since the start of nutrient restoration – particularly for Kokanee, which were below detection limits and considered extirpated when the project began. Over the review period, Kokanee fry abundance has ranged from one of the lowest on record for Wahleach Reservoir in 2013 (tracking the low Kokanee spawner escapement in 2012) to one of the highest on record in 2014 (following the very high Kokanee escapement in 2013). While sub-adult and adult Kokanee abundance has generally been more stable ranging from approximately 15,000 to 30,000 fish. Of note, is the particularly large cohort coming from the 2013 spawners that has resulted in record adult abundance (i.e. fish age >1) in 2015 at nearly three times the average from earlier years (2009-2014).
These oscillations in Kokanee abundance over time are not surprising. Changes in Kokanee populations are most often regulated by compensatory changes in growth, survival and reproduction due to changes in densities (Rieman and Myers 1992, Askey and Johnston 2013). It is likely that the Kokanee population in Wahleach Reservoir is regulated by compensatory processes, similar to those observed in many large lake/reservoirs throughout BC (Andrusak 2016, Schindler *et al*. 2013, 2014).

Furthermore, fall nearshore gillnetting from 2009 to 2015 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 2009 to 2015 showed Kokanee were in better condition than in baseline years. In general, Kokanee were larger based on length-at-age data, and had greater body weights for a given length. In 2015, Kokanee caught were shorter and lighter; however, the Kokanee abundance was at record highs for this system suggesting density dependency. After the initial response of the nutrient enrichment, Kokanee size declined as abundance increased similar to what has been observed in other systems in BC (i.e. Alouette Lake, Kootenay Lake and Arrow Lakes Reservoir) (Hebert et. al. 2015, Schindler *et al*. 2013, 2014). The overall increased body size and condition of Kokanee during nutrient restoration years are evidence of increased food availability for Kokanee within the zooplankton community.

Rainbow Trout

Rainbow Trout caught in 2009 to 2015 monitoring programs indicate the condition factor of individuals in the population is stable. In a stomach content analysis completed by Perrin and Stables (2000), it suggested that two food webs exist on Wahleach Reservoir. Rainbow Trout are insectivores, thus select terrestrial food that is introduced to the reservoir from the forest canopy or as drift from inflow of tributaries. Also, Rainbow Trout select larger aquatic insects which are part of the benthic invertebrate community. Similarly, Johnson et. al (1999) determined that Rainbow Trout in Twin Lakes (nearby lakes in the Fraser Valley) obtained 66% of their body carbon from benthic invertebrates. The extent of interaction between nutrient additions, periphyton growth, benthic invertebrate production, and growth of Rainbow Trout is unknown and would require further study to be resolved. Looking at the benthic invertebrate community is not part of the current monitoring program.

A separate concern has been the potential for operations to affect the Rainbow Trout population; in three years during the review period (2009, 2011, 2013) there were large drawdowns where the reservoir was over 2.5 m below the allowable operating limit of 628 m. Perrin and Stables (2000) suggested similar drawdowns may negatively affect Wahleach Reservoir's Rainbow Trout population. The concern is that operation of Wahleach Reservoir below 628 m elevation may reduce access or block migration of Rainbow Trout to tributary streams; other possible effects may be reduced availability of spawning habitat within the drawdown zone, as well as egg mortality by exposing spawning habitat during the incubation phase. Rainbow Trout are of key concern as their spawning window coincides with typical low reservoir elevations in the spring. Rainbow Trout migrate to their spawning grounds from March to April, while spawning occurs from April to June (Greenbank 2002, Ford *et al* 1995, Scott and Crossman 1973); Inglis (1995) however, observed peak Rainbow Trout spawning on Wahleach Reservoir as early as April 1. Low reservoir elevations during the review period occurred in March through early April, overlapping with the migration period and potentially the spawning period. Risk of negative effects on migration success would be increased further if low stream flows and low reservoir elevations occurred at the same time – as was the case in 2009 and 2011; while risks of exposing spawning habitat would be greater if low reservoir elevations occurred after spawning. As well, the dynamic nature of stream channels, particularly within the drawdown zone, means that migration barriers and fish passage ability may change over time; on Wahleach Reservoir, we would expect Flat Creek to be the most at risk as its channel is not entrenched within the drawdown zone, its confluence with the reservoir is situated in a shallow area, and it is prone to sediment loading events. One approach to specifically address this issue on Wahleach Reservoir would be to develop an assessment to rigorously determine what the implications of large drawdowns and low reservoir elevations are on the Rainbow Trout population, similar to Arrow Lakes Reservoir studies for example (see Hawes *et al*. 2014).

Cutthroat Trout & Threespine Stickleback

Results of the assessments for Cutthroat Trout in 2009 to 2015 were similar and indicate the condition factor of individuals in the population is stable. Sterile Cutthroat Trout were stocked in Wahleach Reservoir to control Threespine Stickleback numbers, representing the biomanipulation component of the project. Threespine Stickleback have been known to counteract the effects of nutrient addition by competing with Kokanee (Hyatt and Stockner 1985). Earlier work by Perrin *et al*. (2006), confirmed piscivory of Cutthroat Trout on Threespine Stickleback in Wahleach Reservoir in addition to an assortment of aquatic and terrestrial insects. It is important to note that the prey composition of Cutthroat Trout over multiple seasons and years in Wahleach Reservoir did not include juvenile Kokanee (Perrin *et al*. 2006). Thus far, the project's top-down strategy to control Threespine Stickleback appears effective as indicated by the success of the Kokanee population and low Threespine Stickleback catches in recent years. It should be noted that minnow trapping data representing nearshore/littoral stickleback populations data does not account for pelagic populations. Pelagic species specific abundance estimation remains a challenge for Wahleach Reservoir.

Kokanee Spawning

Kokanee spawner escapement between 2009 and 2015 varied from year to year; with 2010 and 2013 being highest and 2009 and 2012 lowest. Because Kokanee have not been stocked in the reservoir since 2004, Kokanee populations beginning in 2009 were entirely the result of natural recruitment. Spawner escapement in 2013 was one of the highest on record (14,862 fish) owing to the large proportion of age 2+ spawners even though reservoir abundance was lower than usual. In 2015, spawning and spent 1+ Kokanee 'jacks' and 'jills' were observed in all three of the index streams (Boulder, Flat, and Jones creek). '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 on the Babine in BC (Foote *et al*. 1997).There is no documented research explaining as to why this life history strategy occurs; however, one possibility might be attributed to the record high Kokanee abundance detected in the reservoir during the hydroacoustic surveys, which might have triggered Kokanee to spawn early.

Kokanee spawners from 2009 and 2015 exhibited an oscillating shift in mean fork length with 2014 having the longest (273±16 mm) and 2011 having the shortest (187±18 mm). Overall, Kokanee were in better condition than in baseline years, were significantly larger based on length-at-age data, and had greater body weights for a given length. The increased body size and condition of Kokanee during nutrient restoration years are evidence of increased food availability for Kokanee within the zooplankton community.

Recreational Fishery

Currently, Wahleach Reservoir supports a modest recreational sport fishery, as evidenced by the relatively low angler effort in the 2009, 2013 and 2014 angler surveys. Recovery of the naturalized Rainbow Trout and Kokanee populations and associated sport fishery, since their depressed state in 1995, will likely take many years. Nevertheless, total catch for small-size fish has been quite high and survey results recorded improvements in the success of anglers. For example, CPUE and combined trout catch has doubled since the 2009 survey. Kokanee catch may be increasing, but still remains low.

Anglers consistently reported their catches were simply too small to keep. Regulations introduced earlier in the project (i.e. retention of 2 trout, none over 40 cm) were meant to protect stocked Cutthroat Trout and allow them to reach a size where they would exhibit piscivory on Threespine Stickleback. However, data from recent fish assessments indicated Rainbow Trout were largely not over 30 cm and therefore could not be retained by anglers. Fisheries management biologists have recently addressed this issue by changing regulations on Wahleach Reservoir to allow the retention of 4 trout of any size with only 1 allowed over 40 cm. This change will allow anglers to keep Rainbow Trout while protecting larger piscivorous Cutthroat Trout that prey on Threespine Stickleback; recent data indicates that large-sized Cutthroat Trout are present but likely in relatively low numbers.

Improved fishing for larger size Kokanee is also possible. Increased size and catch rates for Kokanee are important factors in attracting anglers to recreational fisheries (Askey and Johnston 2013). Wahleach Kokanee have increased in size since the nutrient program commenced and today they are quite large when they enter the streams to spawn at mean sizes of 24-27 cm in 2013 and 2014 respectively with some individuals > 30 cm. Escapements in recent years have ranged from about 3,000-15,000 yet sport catch from the three recent surveys has been < 400. Kokanee catches were highest in the spring months and declined as the summer(s) advanced, which is similar to angler effort at the lake. There is high potential for greater catches of Kokanee that exceed 22 cm, the known minimal threshold size for satisfying angler interest (Askey and Johnston 2013). Anglers need to be informed that larger Kokanee are available in Wahleach Reservoir and angling techniques need to change to take advantage of these larger fish. As the reservoir stratifies, Kokanee move from surface waters to deeper in the water column; therefore, during the day they are usually found below the thermocline. Instead of surface trolling, anglers need to change their techniques by switching their gear to fish in deeper water and troll near the thermocline that in most years develops by mid-June at about 5 m in depth. Kokanee are also very susceptible to certain trolling gear such as small pink or red lures including “wedding rings”, small apex lures or glow hooks. Brochures or knowledge transfer provided through creel surveys or information signs installed at boat launches would help to better inform anglers of specific techniques for catching Kokanee.

5. Conclusion

It is evident that seasonal nutrient addition on Wahleach Reservoir has had a positive effect on the Kokanee population, as demonstrated from program monitoring data and multiple lines of evidence from systems across BC (e.g. Alouette Reservoir, see Hebert *et al*. 2015). Moreover, Perrin *et al*. (2006) and continued monitoring data confirmed sterile Cutthroat Trout stocked in Wahleach Reservoir exhibit top-down pressure on the Threespine Stickleback population allowing Kokanee to take advantage of improved conditions. These combined restoration efforts have clearly been able to maintain Wahleach Reservoir’s Kokanee population over the long-term.

6. Recommendations

<u>Restoration Treatments</u>

- Continue to adaptively manage seasonal nutrient additions. The planned nitrogen loading rate during early and late summer should be increased to manage the growth of inedible phytoplankton species.

- Continue stocking of marked, 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.

<u>Monitoring Programs</u>

Limnology

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

- Complete an additional sampling trip early in the growing season if limnological results suggest the need to do so to allow for closer tracking of nitrogen concentrations and fast growing phytoplankton.

- Complete analysis of chlorophyll *a* samples.

Fish Populations

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

- Continue annual Kokanee spawner surveys on Boulder Creek, Flat Creek and Jones Creek index streams.

- Complete analysis of stream temperature data and accumulated thermal units to estimate fry emergence and compare with reservoir conditions at that time; ideally this would be included in future reports.

- Continue with hydroacoustic and trawl program in August during favorable field conditions when the thermal stratification is strongest and Kokanee spawners are still present in the reservoir, which will also ensure consistency with more recent time-series data.

- Complete a thorough review of the hydroacoustic program to evaluate its efficacy in smaller, mixed-species systems.

- Complete pelagic gillnetting using small mesh gillnets set at depth to determine the species assemblage of a secondary peak evident within the small fish group in hydroacoustic data. Gillnetting or minnow trapping would be preferred methods since trawl sampling this close to the bottom is unsafe.

Recreational Fishery

- Creel surveys to assess the recreational fishery on Wahleach Reservoir should be incorporated into regular program monitoring. A creel survey in 2017 is recommended to assess the effects of recent regulation changes on the fishery. All creel surveys should collect fish species catch and effort data, as well as angler demographic information. Over the long-term, one or two creel surveys completed over each five-year cycle should be sufficient to understand how anglers are responding to regulatory and restoration actions. The first creel survey would be completed during year 2 or 3 with a contingency budget for an additional survey during the last year if something significant is detected.

- It is recommended that creel survey technicians inform anglers of the opportunity to fish for Kokanee through knowledge transfer or by providing them with a field card that explains the nutrient restoration program, Kokanee feeding behaviour, where to find Kokanee in the reservoir, and how to catch them. This information should also be included on the BC Hydro website, and on public information signage at the two public boat launches and camp sites together with information on the nutrient restoration project.

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Appendix A List of phytoplankton species found in Wahleach Reservoir, 2009-2015.

Class	Species	2009	2010	2011	2012	2013	2014	2015
Bacillariophyceae (diatoms)	Achnanthidium spp.			+	+	+	+	+
Bacillariophyceae	Asterionella formosa	+	+		+	+	+	+
Bacillariophyceae	Cyclotella comta	+	+	+	+	+	+	+
Bacillariophyceae	Cyclotella glomerata		+	+	+	+	+	+
Bacillariophyceae	Cyclotella stelligera	+	+	+	+	+	+	+
Bacillariophyceae	Eunotia sp.							+
Bacillariophyceae	Fragilaria capucina			+	+	+	+	+
Bacillariophyceae	Fragilaria construens				+	+		+
Bacillariophyceae	Navicula sp.	+		+	+	+	+	+
Bacillariophyceae	Rhizosolenia sp.	+	+	+	+	+	+	+
Bacillariophyceae	Synedra acus var angustissima			+		+		+
Bacillariophyceae	Synedra acus	+	+	+	+			+
Bacillariophyceae	Synedra nana		+	++	+	+		+
Bacillariophyceae	Synedra ulna				+	+		
Bacillariophyceae	Suriella spp.	+						
Bacillariophyceae	Tabellaria fenestrata	+	+	+	+	+	+	+
Bacillariophyceae	Tabellaria flocculosa				+			+
Chlorophyceae (coccoid greens, desmids, etc.)	Ankistrodesmus sp.	+	+	+	+	+	+	+
Chlorophyceae	Arthrodesmus sp.							+
Chlorophyceae	Botryococcus sp.	+	+		+	+	+	+
Chlorophyceae	Carteria sp.			+			+	+
Chlorophyceae	Chlorella sp.	+	+	+	+	+	+	+
Chlorophyceae	Clamydocapsa sp.	+	+		+	+		+
Chlorophyceae	Coccomyxa sp.				+			
Chlorophyceae	Coelastrum sp.	+	+	+	+	+	+	+
Chlorophyceae	Cosmarium sp.		+	+	+	+	+	+
Chlorophyceae	Closterium sp.			+				
Chlorophyceae	Crucigenia sp.	+	+				+	+
Chlorophyceae	Dichtyosphaerium	+						
Chlorophyceae	Elakatothrix sp.		+	+	+		+	+
Chlorophyceae	Euglena sp.			+	+			
Chlorophyceae	Gleotila sp.		+	+		+		
Chlorophyceae	Golenkinia sp.	+				+		
Chlorophyceae	Gyromitus sp.	+		+	+	+	+	+
Chlorophyceae	Monomastic sp.		+	+		+	+	+
Chlorophyceae	Monoraphidium sp.		+					+
Chlorophyceae	Nephroselmis sp.		+	+		+	+	+
Chlorophyceae	Oocystis sp.		+	+		+	+	+

Class	Species	2009	2010	2011	2012	2013	2014	2015
Chlorophyceae	Phacus sp.		+	+			+	+
Chlorophyceae	Planctosphaeria sp.	+	+	+		+	+	+
Chlorophyceae	Planctonema sp.			+				
Chlorophyceae	Pyramimonas sp.			+	+	+		
Chlorophyceae	Quadrigula sp.							+
Chlorophyceae	Scenedesmus sp.		+	+	+		+	+
Chlorophyceae	Scourfieldia sp.			+	+	+	+	+
Chlorophyceae	Sphaerocystis sp.	+	+	+	+	+		
Chlorophyceae	Spondylosium sp.	+	+			+		
Chlorophyceae	Staurastrum sp.					+	+	+
Chlorophyceae	Stichococcus minutissimus			+				
Chlorophyceae	Tetraedron sp.		+	+	+	+	+	+
Chryso- & Cryptophyceae (flagellates)	Bitrichia sp.	+		+			+	
Chryso- & Cryptophyceae	Boda spp.	+	+	+				
Chryso- & Cryptophyceae	Chromulina sp.	+	+	+	+	+	+	+
Chryso- & Cryptophyceae	Chroomonas acuta			+	+	+	+	+
Chryso- & Cryptophyceae	Chryptomonas spp.	+	+	+	+	+	+	+
Chryso- & Cryptophyceae	Chrysocapsa planktonica (colony)	+						
Chryso- & Cryptophyceae	Chrysochromulina sp.	+	+	+	+	+	+	+
Chryso- & Cryptophyceae	Chrysococcus sp.			+	+	+	+	+
Chryso- & Cryptophyceae	Chrysoikos sp.						+	+
Chryso- & Cryptophyceae	Dinobryon sp.	+	+	+	+	+	+	+
Chryso- & Cryptophyceae	Isthmochloron sp.		+					
Chryso- & Cryptophyceae	Kephyrion sp.		+	+	+	+	+	+
Chryso- & Cryptophyceae	Komma sp.			+	+	+	+	+
Chryso- & Cryptophyceae	Mallomonas sp.	+		+	+	+	+	+
Chryso- & Cryptophyceae	Ochromonas sp.	+	+	+	+	+	+	+
Chryso- & Cryptophyceae	Pseudokephrion sp.		+			+	+	+
Chryso- & Cryptophyceae	Small microflagellates	+	+	+	+	+	+	+
Chryso- & Cryptophyceae	Uroglena sp.	+						
Cyanophyceae (blue-greens)	Anabaena spp.	+	+		+	+	+	+
Cyanophyceae	Aphanothecae sp.	+	+	+		+	+	+
Cyanophyceae	Chroococcus sp.		+				+	+
Cyanophyceae	Gomphosphaeria sp.	+				+	+	
Cyanophyceae	Lyngbya sp.						+	
Cyanophyceae	Merismopedia sp.		+	+	+	+	+	+
Cyanophyceae	Microcystis sp.	+	+	+	+	+	+	+
Cyanophyceae	Synechococcus sp (rod)	+	+	+	+	+	+	+

Class	Species	2009	2010	2011	2012	2013	2014	2015
Cyanophyceae	Synechococcus sp. (coccoid)	+	+	+	+	+	+	+
Cyanophyceae	Synechocystis sp.	+	+	+	+	+	+	+
Dinophyceae (dinoflagellates)	Ceratium hirundinella					+		
Dinophyceae	Ceratium hirundinella	+						
Dinophyceae	Gymnodinium sp. (large)	+	+	+	+	+	+	+
Dinophyceae	Gymnodinium sp. (small)	+	+	+	+	+	+	+
Dinophyceae	Peridinium spp.	+	+	+	+	+	+	+

Appendix B List of zooplankton species identified in Wahleach Reservoir, 2009-2015.

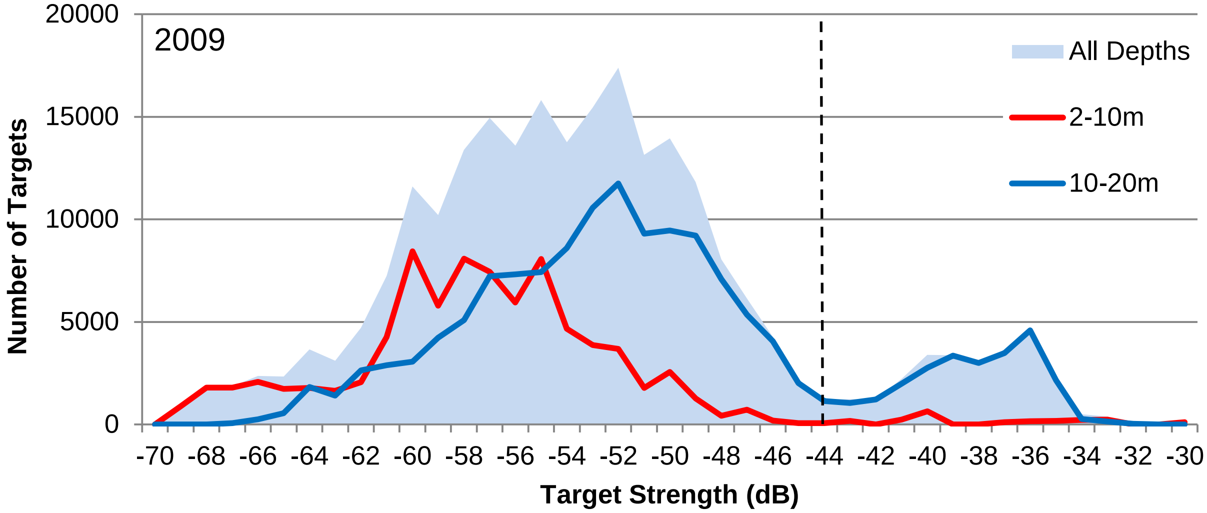
Order/Species	2009	2010	2011	2012	2013	2014	2015
Cladocera							
Alona sp.	r	r	r	r	r	r	r
Alonella nana				r			r
Bosmina longirostris	+	+	+	+	+	+	+
Chydorus sphaericus	r	r	r	r	+	+	+
Daphnia rosea	+	+	+	+	+	+	+
Diaphanosoma birgei						r	
Holopedium gibberum	+	+	+	+	+	+	+
Leptodora kindtii	+	+	+	+	+	+	+
Pleuroxus sp.				r			
Scapholeberis mucronata	r	r	r	r	r	r	r
Copepoda							
Cyclops vernalis	+	+	+	+	+	+	+
Macrocyclops fuscus	r	r	r	r			
Leptodiaptomus ashlandi							r

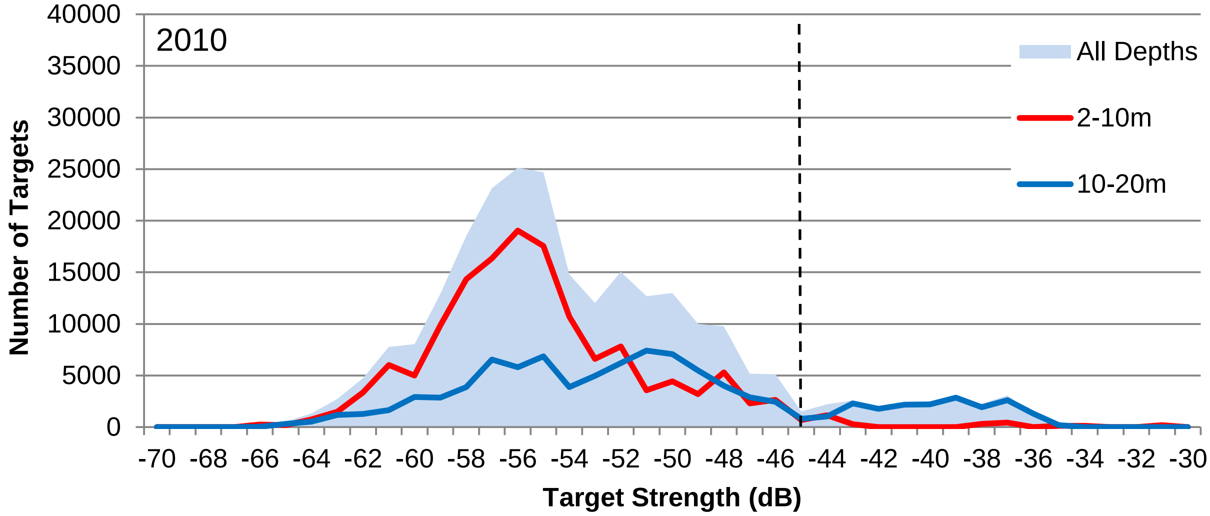
r = rare species, + = present

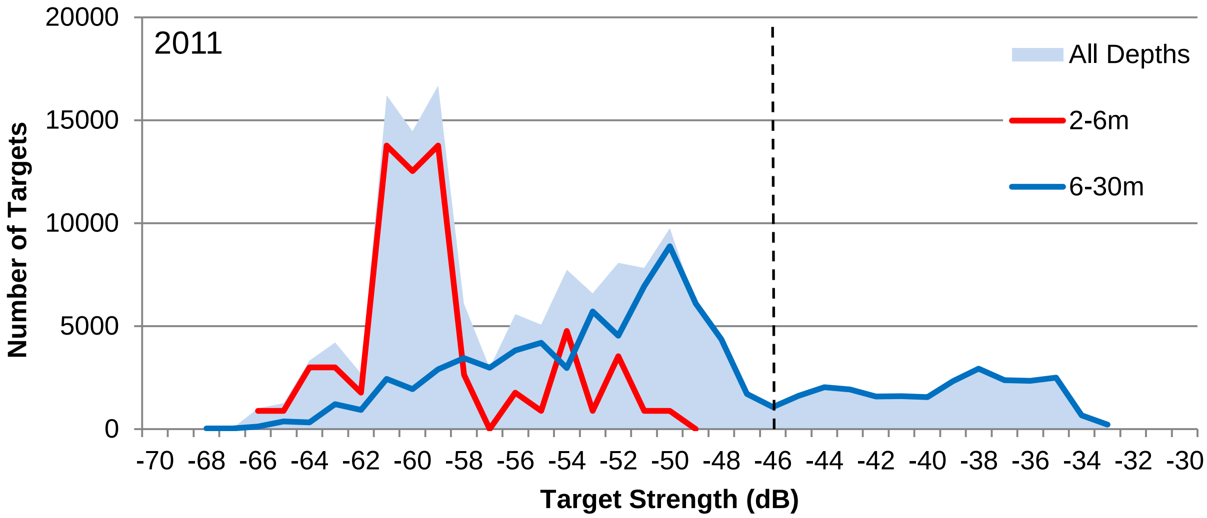
Appendix C Detailed equipment specifications and data analysis parameters used for Wahleach Reservoir hydroacoustic surveys, 2009-2015.

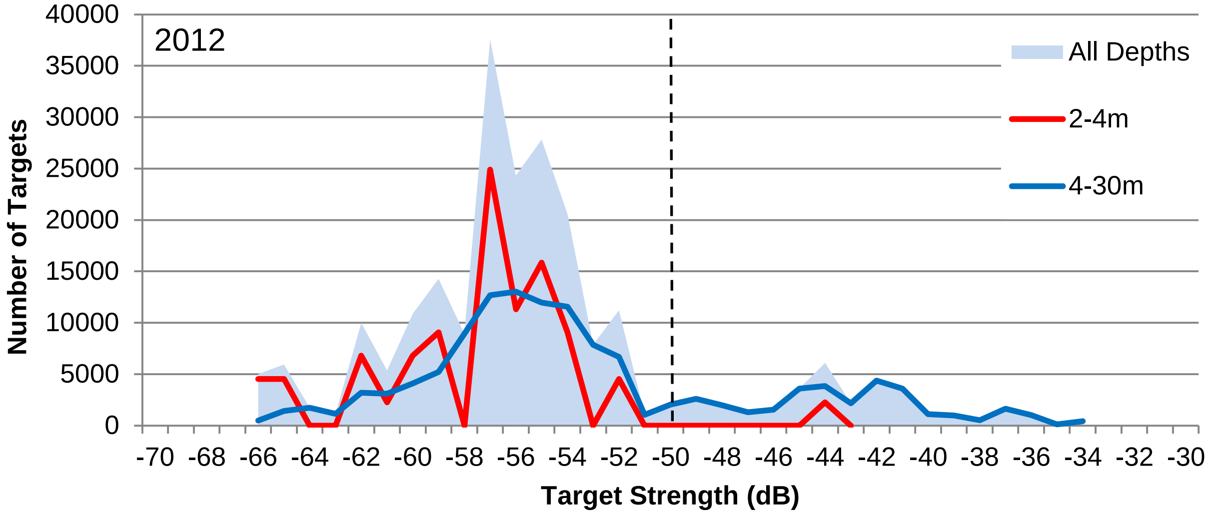
Project Phase	Category	Parameter	Value
Data Collection	Echosounder	Manufacturer	Simrad EK60
		Software	Simrad ER60 ver. 2.2.1
	Transceiver	Frequency	120 kHz
		Max power	100 W
		Pulse duration	0.256 ms
		Band width	8.71 kHz
		Absorption coefficient	4.11 dBKm
		Amplitude threshold	-70 dB (40 Log R TVG)
	Transducer	Type	split-beam
		Depth of face	1.0 m
		Orientation, survey method	vertical, mobile, tow foil
		Sv, TS transducer gain	27.0 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	2009 analysis threshold	-61 to -26 dB
		2010 analysis threshold	-61 to -26 dB
		2011 analysis threshold	-61 to -26 dB
		2012 analysis threshold	-66 to -26 dB
		2013 analysis threshold	-66 to -26 dB
		2014 analysis threshold	-66 to -26 dB
		2015 analysis threshold	-66 to -26 dB
		Min echo length	0.7 – 1.3
		Max. phase deviation	0.2 deg.
		Max gain compensation	6 dB
	Target tracking	Minimum no. echoes	3
		Max range change	0.20 m
		Max ping gap	1

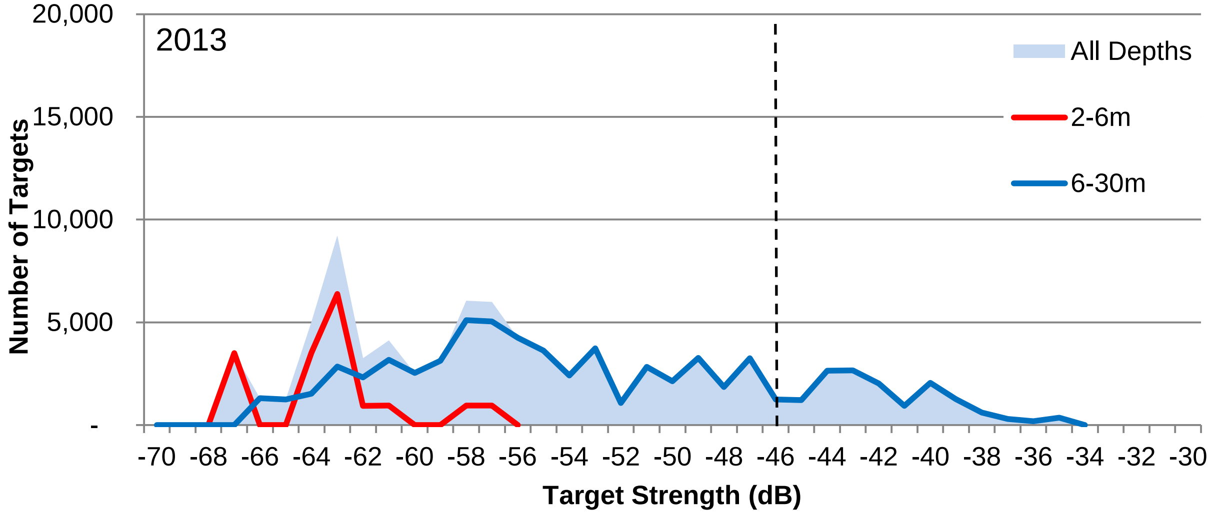
Appendix D Target size distributions from hydroacoustic surveys on Wahleach Reservoir, 2009-2015. Dashed line represent dB size threshold between the small and large-sized fish groups.

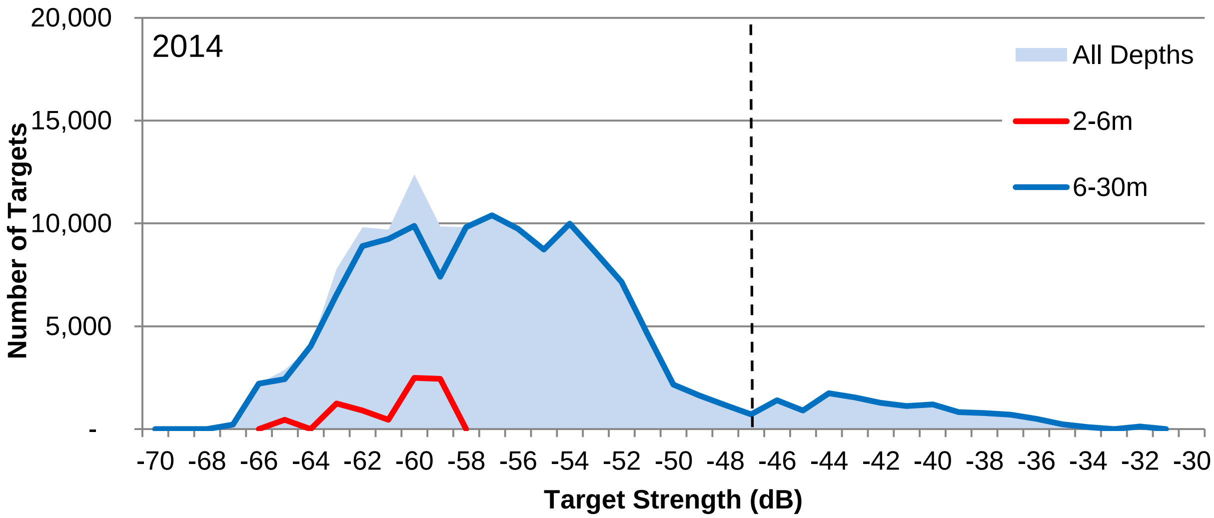


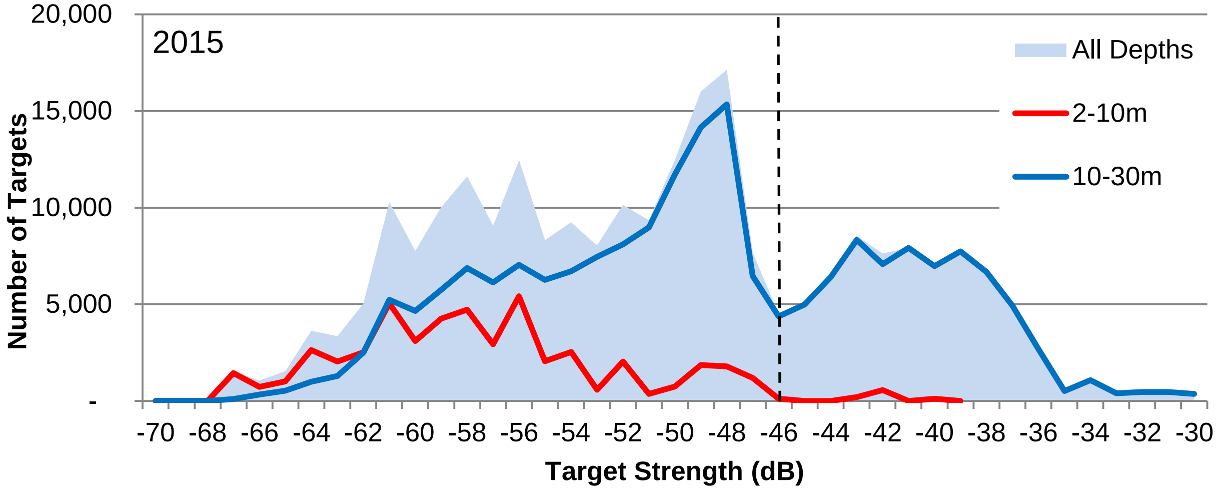





2012
All Depths
2-4m
4-30m
Number of Targets
40000
35000
30000
25000
20000
15000
10000
5000
0
-70 -68 -66 -64 -62 -60 -58 -56 -54 -52 -50 -48 -46 -44 -42 -40 -38 -36 -34 -32 -30
Target Strength (dB)


2013
All Depths
2-6m
6-30m
Number of Targets
20,000
15,000
10,000
5,000
-
-70 -68 -66 -64 -62 -60 -58 -56 -54 -52 -50 -48 -46 -44 -42 -40 -38 -36 -34 -32 -30
Target Strength (dB)


2014
All Depths
2-6m
6-30m
Number of Targets
20,000
15,000
10,000
5,000
-
-70 -68 -66 -64 -62 -60 -58 -56 -54 -52 -50 -48 -46 -44 -42 -40 -38 -36 -34 -32 -30
Target Strength (dB)


2015
All Depths
2-10m
10-30m
Number of Targets
20,000
15,000
10,000
5,000
-
-70
-68
-66
-64
-62
-60
-58
-56
-54
-52
-50
-48
-46
-44
-42
-40
-38
-36
-34
-32
-30
Target Strength (dB)

Appendix E Wahleach Reservoir acoustic survey transect densities (fish·ha^{-1}) by 2 meter depth intervals for all fish and large fish during 2009 (a, b), 2010 (c, d), 2011 (e, f), 2012 (g, h), 2013 (i, j), 2014 (k, l). Depth intervals 0 = from 0 to 2 m.

a) 2009 small-sized fish

Depth						**Transect**					
(m)	1	2	3	4	5	6	7	8	9	10	11
0	-	-	-	-	-	-	-	-	-	-	-
2	0	71	0	58	0	0	0	48	55	56	0
4	0	70	17	65	17	45	23	91	27	27	144
6	211	98	65	123	37	12	15	61	80	168	102
8	73	71	77	49	118	65	84	62	140	109	146
10		256	189	205	105	87	91	111	67	318	444
12		165	227	190	178	115	113	133	219	423	108
14		116	172	64	147	105	100	153	120		
16			209	73	179	88	119	114			
18			129	63	170	72	104	114			
20			99	78	152	162	203	232			
22			23	53	146	122	185	96			
24						133					
26						53					
28											
Total	283	847	1207	1023	1249	1060	1035	1214	708	1101	943

b) 2009 for large fish

Depth						**Transect**					
(m)	1	2	3	4	5	6	7	8	9	10	11
0	-	-	-	-	-	-	-	-	-	-	-
2	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
6	23	0	29	4	4	0	0	0	0	0	14
8	33	18	0	0	0	0	0	0	0	0	0
10		20	0	0	0	3	0	3	0	0	0
12		0	21	38	24	48	16	42	51	76	31
14		25	31	41	108	59	69	71	38		
16			48	23	94	73	53	45			
18			1	12	27	41	12	9			
20			0	0	0	1	0	17			
22			0	0	0	0	0	0			
24						0					
26						0					
28											
Total	56	62	129	119	257	225	149	187	89	76	44

c) 2010 small-sized fish

Depth	Transect										
(m)	1	2	3	4	5	6	7	8	9	10	11
0	-	-	-	-	-	-	-	-	-	-	-
2	0	0	0	0	0	0	0	0	0	0	0
4	81	59	63	67	57	87	0	39	97	0	81
6	175	176	182	108	19	120	67	67	114	115	175
8	201	184	316	290	133	182	252	106	195	151	201
10	258	437	235	170	325	201	134	141	83	259	258
12	42	166	80	144	79	93	82	68	115	99	42
14		15	39	58	100	76	151	109	79	9	
16			28	32	47	61	95	67			
18			15	62	16	56	169	110			
20			28	30	30	76	174	188			
22			17	117	53	117	182	96			
24						112	161				
26						51	27				
28											
Total	757	1037	1003	1078	858	1233	1492	992	682	633	757

d) 2010 for large fish

Depth	Transect										
(m)	1	2	3	4	5	6	7	8	9	10	11
0	-	-	-	-	-	-	-	-	-	-	-
2	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
6	0	44	10	22	0	0	0	0	0	0	0
8	0	9	0	6	0	0	0	0	0	0	0
10	16	61	28		7	0	0	4	0	0	16
12	0	55	37	45	39	12	12	9	32	19	0
14		15	30	112	55	20	56	40	41	0	
16			9	19	2	26	21	27			
18			0	9	42	5	7	12			
20			7	0	2	0	0	0			
22			0	0	13	0	0	0			
24						0	0				
26						0	0				
28											
Total	16	184	121	213	160	63	96	91	73	19	16

e) 2011 small-sized fish

Depth (m)	Transect 1	2	3	4	5	6	7	8	9	10	11	Avg
0	-	-	-	-	-	-	-	-	-	-	-	-
2	797	146	119	230	0	82	0	0	63	72	97	**146**
4	130	95	193	37	63	80	21	40	62	23	31	**71**
6	33	93	529	246	104	127	102	38	50	57	0	**125**
8	43	42	128	172	78	67	36	28	47	49	39	**66**
10	0	0	28	13	58	49	27	8	12	40	24	**24**
12		80	5	5	19	21	3	35	18	40	0	**23**
14		0	0	0	7	5	19	14	0			**6**
16			0	0	10	11	11	10	0			**6**
18			0	0	0	0	0	0				**0**
20			0	0	9	0	0	0				**2**
22			0	13	0	0	0	0				**2**
24				0		2	0					**1**
26						0						**0**
28												
Total	1003	455	1002	717	348	442	219	173	253	281	192	

f) 2011 large-sized fish

Depth (m)	Transect 1	2	3	4	5	6	7	8	9	10	11	Avg
0	-	-	-	-	-	-	-	-	-	-	-	-
2	0	0	0	0	0	0	0	0	0	0	0	**0**
4	0	0	0	0	0	0	0	0	0	0	0	**0**
6	0	0	0	0	0	0	0	0	0	0	0	**0**
8	21	112	21	0	17	0	0	6	0	0	10	**17**
10	0	10	43	40	58	59	59	43	20	54	64	**41**
12		56	0	19	24	21	62	53	79	40	75	**43**
14		0	0	0	11	11	6	14	0			**5**
16			6	0	0	6	4	19	0			**5**
18			0	0	0	0	7	0				**1**
20			0	0	0	0	0	0				**0**
22			0	0	0	0	0	0				**0**
24				0		0	0					**0**
26						0						**0**
28												
Total	21	178	70	59	110	96	138	135	99	94	149	

g) 2012 small-sized fish

Depth (m)	Transect 1	2	3	4	5	6	7	8	9	10	11	Avg
0	-	-	-	-	-	-	-	-	-	-	-	-
2	500	568	293	334	54	80	167	487	164	192	229	**279**
4	163	232	30	135	132	97	45	79	67	52	93	**102**
6	45	86	16	90	58	96	73	11	24	14	87	**55**
8	61	14	68	45	52	45	38	34	31	19	96	**46**
10	47	30	13	15	62	37	57	15	11	30	49	**33**
12		15	29	40	10	12	23	37	4	0	33	**20**
14		29	27	46	8	11	12	12	21	17	0	**18**
16		0	37	27	13	5	19	16	0			**15**
18			28	4	26	14	30	25				**21**
20			39	51	15	7	11	43				**28**
22			53	15	29	19	11	32				**26**
24			31	11	17	3	39	50				**25**
26						9	8					**9**
28						3						**3**
Total	816	974	664	812	476	437	531	841	323	324	588	

h) 2012 large-sized fish

Depth (m)	Transect 1	2	3	4	5	6	7	8	9	10	11	Avg
0	-	-	-	-	-	-	-	-	-	-	-	-
2	0	0	0	0	0	0	56	0	0	0	0	**5**
4	0	77	0	0	22	32	45	20	0	26	0	**20**
6	0	0	16	0	0	9	36	21	110	14	17	**20**
8	0	0	0	11	30	28	45	55	63	29	60	**29**
10	0	10	0	0	0	16	10	24	6	30	68	**15**
12		0	0	0	0	21	26	0	38	12	17	**11**
14		0	11	9	0	0	3	18	7	12	0	**6**
16		0	0	0	0	4	0	0	0			**1**
18			0	0	0	0	0	0				**0**
20			0	0	0	0	0	0				**0**
22			0	0	0	0	0	0				**0**
24			0	0	0	0	0	0				**0**
26						0	0					**0**
28						0						**0**
Total	0	87	27	20	52	110	221	138	224	122	162	

g) 2013 small-sized fish

Depth (m)	Transect 1	2	3	4	5	6	7	8	9	10	11	Avg
0	-	-	-	-	-	-	-	-	-	-	-	
2	0	0	0	0	0	0	60	0	65	0	0	11
4	58	0	42	0	50	20	0	78	0	0	38	26
6	0	28	0	61	41	44	52	56	15	18	0	29
8	0	0	154	88	48	63	98	100	49	38	64	64
10		0	87	43	8	24	28	97	156	28	54	53
12		46	29	7	7	34	41	75	34	26	57	36
14		0	11	11	13	18	65	21	74			27
16			15	0	35	20	11	8				15
18			0	22	13	9	7	4				9
20			0	4	0	0	2	8				2
22			0	0	0	0	0	52				9
24						24	20					22
26						18						18
28												
Total	58	74	338	237	215	274	384	499	394	110	214	

h) 2013 large-sized fish

Depth (m)	Transect 1	2	3	4	5	6	7	8	9	10	11	Avg
0	-	-	-	-	-	-	-	-	-	-	-	**-**
2	0	0	0	0	0	0	0	0	0	0	0	**0**
4	0	0	0	0	0	0	0	0	0	0	0	**0**
6	0	28	0	20	0	0	13	0	0	0	0	**6**
8	0	0	42	13	0	14	8	27	29	0	16	**14**
10		0	10	35	8	39	34	19	28	37	0	**21**
12		23	14	13	7	8	17	25	11	0	0	**12**
14		0	0	11	0	3	6	8	0			**4**
16			0	0	0	10	3	8				**3**
18			0	9	0	0	0	4				**2**
20			0	0	17	0	0	0				**3**
22			0	0	0	0	0	0				**0**
24						0	0					**0**
26						0						**0**
28												
Total	**0**	**51**	**66**	**101**	**32**	**73**	**80**	**92**	**69**	**37**	**16**	

i) 2014 small-sized fish

Depth (m)	1	2	3	4	5	6	7	8	9	10	11	Avg
						Transect						
0	-	-	-	-	-	-	-	-	-	-	-	
2	0	0	0	44	0	0	0	69	0	37	52	18
4	0	0	19	0	0	0	0	0	0	30	21	6
6	82	0	0	28	7	30	26	30	16	17	11	23
8		30	19	71	51	39	57	78	73	50	23	49
10		34	72	197	171	234	137	93	166	99	60	126
12			63	104	113	288	294	263	405			219
14			32	123	106	108	155	228	59			116
16			56	59	31	75	96	69				64
18			18	71	41	30	65	115				57
20			8	31	43	21	54	108				44
22			10	9		36	109	188				71
24						61	99					80
26						42						42
28												
Total	82	63	297	737	562	966	1092	1244	719	233	167	

j) 2014 large-sized fish

Depth (m)	1	2	3	4	5	6	7	8	9	10	11	Avg
						Transect						
0	-	-	-	-	-	-	-	-	-	-	-	**-**
2	0	0	0	0	0	0	0	0	0	0	0	**0**
4	0	0	0	0	0	0	0	0	0	0	0	**0**
6	0	0	0	0	0	0	0	0	8	0	0	**1**
8		0	6	6	0	0	12	0	0	0	0	**2**
10		34	0	0	7	5	0	0	4	0	0	**5**
12			13	0	20	32	19	51	6			**20**
14			13	3	9	29	45	18	44			**23**
16			0	8	2	18	37	29				**16**
18			7	0	13	13	18	19				**12**
20			4	0	0	6	5	4				**3**
22			0	0		1	0	0				**0**
24						0	0					**0**
26						0						**0**
28												
Total	0	34	44	16	52	104	135	121	62	0	0	

k) 2015 small-sized fish

Depth (m)	1	2	3	4	5	6	7	8	9	10	11	Avg
						Transect						
0	-	-	-	-	-	-	-	-	-	-	-	
2	66	0	43	0	0	0	0	0	37	71	147	33
4	0	0	0	0	35	20	46	70	59	29	0	23
6	15	91	0	8	62	11	48	37	0	0	64	31
8	23	151	91	145	83	97	68	33	51	27	7	71
10		341	343	246	154	136	112	221	134	174	143	200
12		118	151	126	78	124	137	159	202	103	22	122
14		39	81	86	49	151	166	101	90			95
16			86	85	68	134	156	124				109
18			71	66	41	148	113	80				87
20			41	11	14	125	68	57				53
22			50	41	66	106	20	33				53
24						17	66					42
26						85						85
28												
Total	104	739	957	813	650	1155	1000	915	573	404	383	

l) 2015 large-sized fish

Depth (m)	1	2	3	4	5	6	7	8	9	10	11	Avg
						Transect						
0	-	-	-	-	-	-	-	-	-	-	-	
2	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	17	0	0	0	0	0	0	0	0	2
6	0	0	0	0	6	0	0	0	0	0	0	1
8	0	6	0	0	0	0	8	0	0	0	0	1
10		224	28	27	0	0	0	0	15	8	0	30
12		92	107	30	31	18	25	57	58	42	0	46
14		22	65	45	63	159	184	115	142			99
16			54	77	40	236	270	157				139
18			3	44	45	147	137	107				80
20			20	11	17	53	39	14				26
22			0	7	0	20	21	0				8
24						0	7					3
26						3						3
28												
Total	0	344	294	241	201	636	690	449	215	50	0	

Appendix F Love's (1977) empirical relation of fish length to acoustic target strength.

$$\text{Aspect Dorsal:} TS = 19.1 \log_{10} (L) – 0.9 \log_{10} (F^1) – 62$$

Where TS=target strength in decibels (dB), L=length in cm, and F=frequency in KHz=120 KHz

Target Strength (dB)	**Fish Length Range (mm)**		**Target Strength (dB)**	**Fish Length Range (mm)**	
	Min	**Max**		**Min**	**Max**
-26	961	_	-46	86	96
-27	852	960	-47	76	85
-28	755	851	-48	68	75
-29	669	754	-49	60	67
-30	593	668	-50	53	59
-31	526	592	-51	47	52
-32	466	525	-52	42	46
-33	413	465	-53	37	41
-34	366	412	-54	33	36
-35	325	365	-55	29	32
-36	288	324	-56	26	28
-37	255	287	-57	23	25
-38	226	254	-58	20	22
-39	201	225	-59	18	19
-40	178	200	-60	16	17
-41	158	177	-61	14	15
-42	140	157	-62	13	13
-43	124	139	-63	11	12
-44	110	123	-64	10	10
-45	97	109	-65	9	9

Appendix G Wahleach Reservoir habitat areas used for hydroacoustic data analysis.

Table was developed from data supplied by Shuksan Fisheries Consulting Ltd.

Elevation (m)	Depth (m)	Area (ha)	Elevation (m)	Depth (m)	Area (ha)
640	0	397	625	15	159
639	1	383	624	16	145
638	2	368	623	17	131
637	3	351	622	18	117
636	4	334	621	19	93
635	5	314	620	20	69
634	6	295	619	21	48
633	7	280	618	22	26
632	8	264	617	23	19
631	9	249	616	24	12
630	10	234	615	25	8
629	11	217	614	26	4
628	12	201	613	27	3
627	13	187	612	28	1
626	14	174			

Wahleach Reservoir depth interval areas and volumes based on data supplied by BC Hydro. Depth 0 m is for a surface elevation of 640 m.

Depth Interval (m)	Midpoint Depth (m)	Area (m^2)	Area (ha)	Volume (m^3)
0-2	1	3,974,726	397	7,949,452
2-4	3	3,676,827	368	7,353,655
4-6	5	3,335,652	334	6,671,303
6-8	7	2,951,199	295	5,902,398
8-10	9	2,642,585	264	5,285,170
10-12	11	2,338,086	234	4,676,173
12-14	13	2,009,801	201	4,019,602
14-16	15	1,735,498	174	3,470,995
16-18	17	1,451,880	145	2.903,761
18-20	19	1,167,201	117	2,334,401
20-22	21	686,361	69	1,372,722
22-24	23	264,841	26	529,681
24-26	25	123,223	12	246,446
26-28	27	41,074	4	82,149

Appendix H Detailed Biomass Methods, Wahleach Reservoir, 2009-2015.

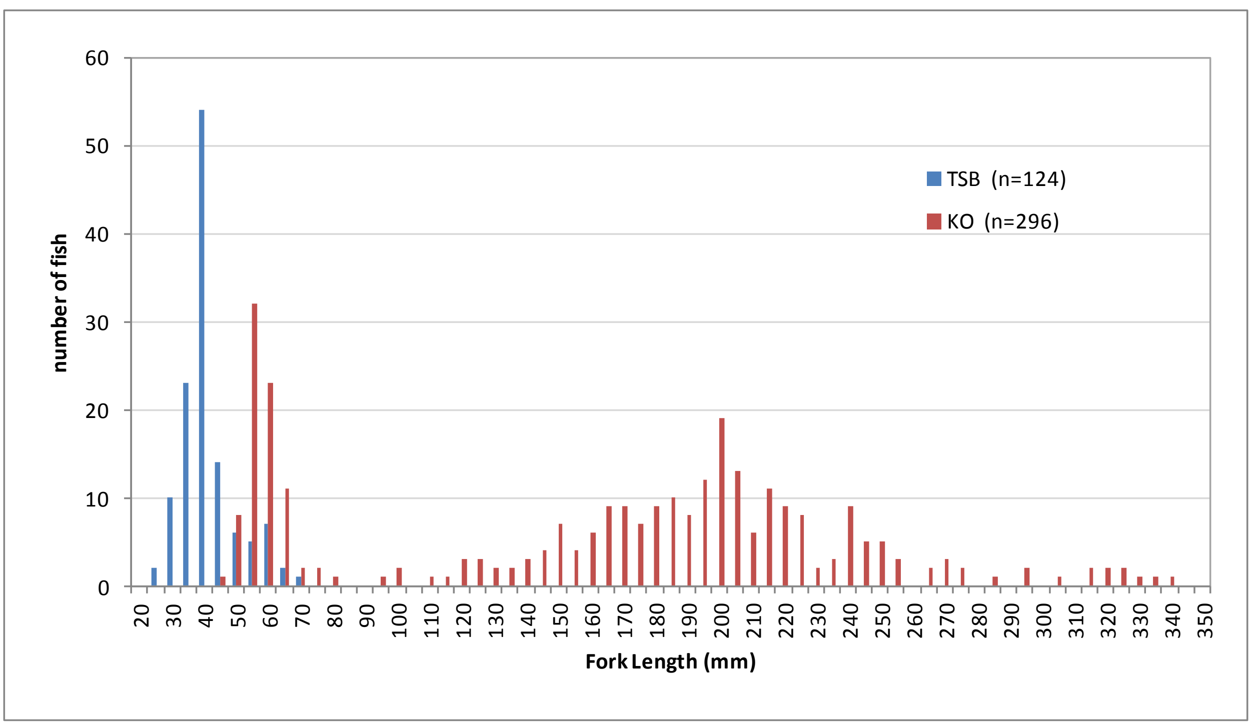
Approximate acoustic size (dB) of visible features (i.e. 7 reference points) from seven years of acoustic survey data on Wahleach Reservoir. Note the rounded average used for regression do not include the years highlighted in yellow as they were non-standard in terms of early survey timing and cooler water temperature.

	small fry peak	KO fry peak	cut-off	1-3 peak1	1-3 peak2	inflection	largest fish
2009	-58	-52	-44	-39	-36	-34	-30
2010	-56	-51	-45	-39	-37	-35	-31
2011	-59	-50	-46	-38	-35	-34	-33
2012	-57	-56	-51	-44	-42	-38	-34
2013	-63	-57	-46	-43	-40	-36	-35
2014	-60	-54	-47	-44	-40	-35	-32
2015	-57	-49	-47	-44	-40	-36	-30
average	-58.0	-51.2	-45.8	41.2	38.0	35.0	-32.1
rounded	**-58**	**51**	**-46**	**-41**	**-38**	**-35**	**-32**

Blue font indicates second(ary) peak

yellow highlights were non-typical results (cold year and early sampling) so not included in average

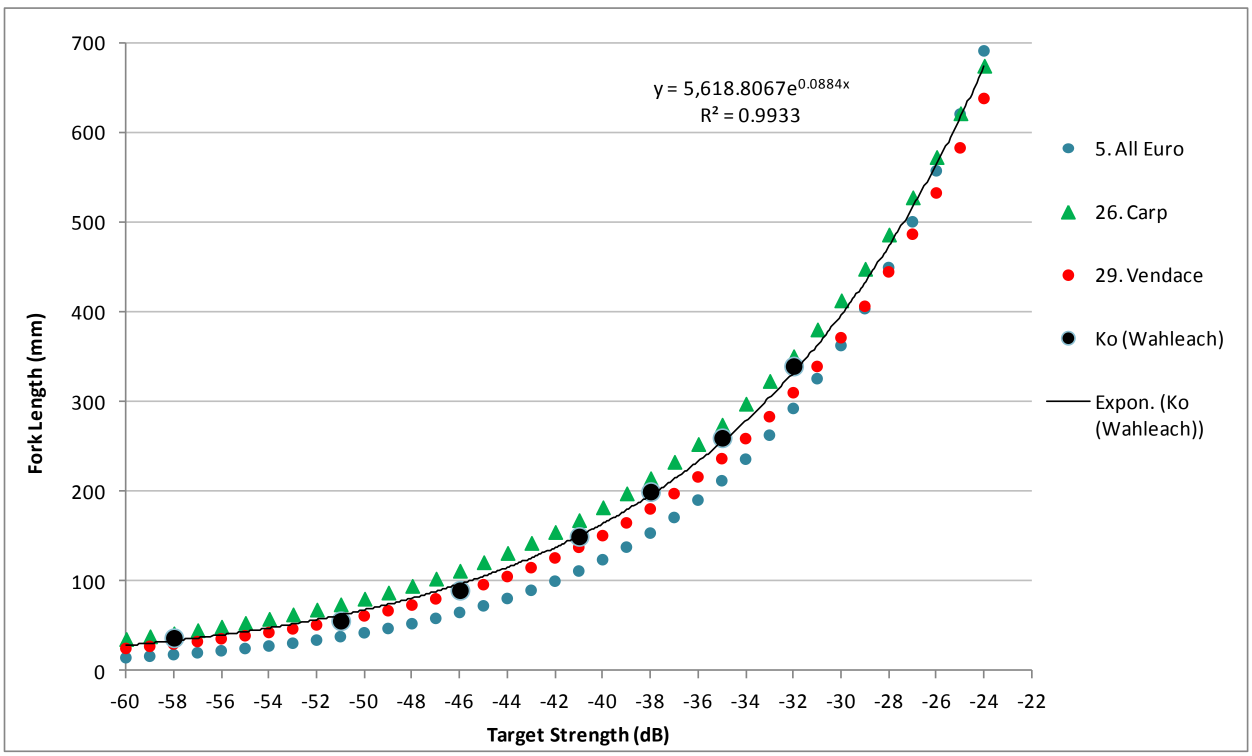
Cumulative length frequency distributions of kokanee and stickleback used to help estimate seven visible reference points. Due to resolution at the lower end, we decided to use the mean length for the first mode of TSB (i.e young of the year) and also the mean length of KO fry for reference points 1 and 2 respectively.



Visible reference points and corresponding length in mm from fish capture data.

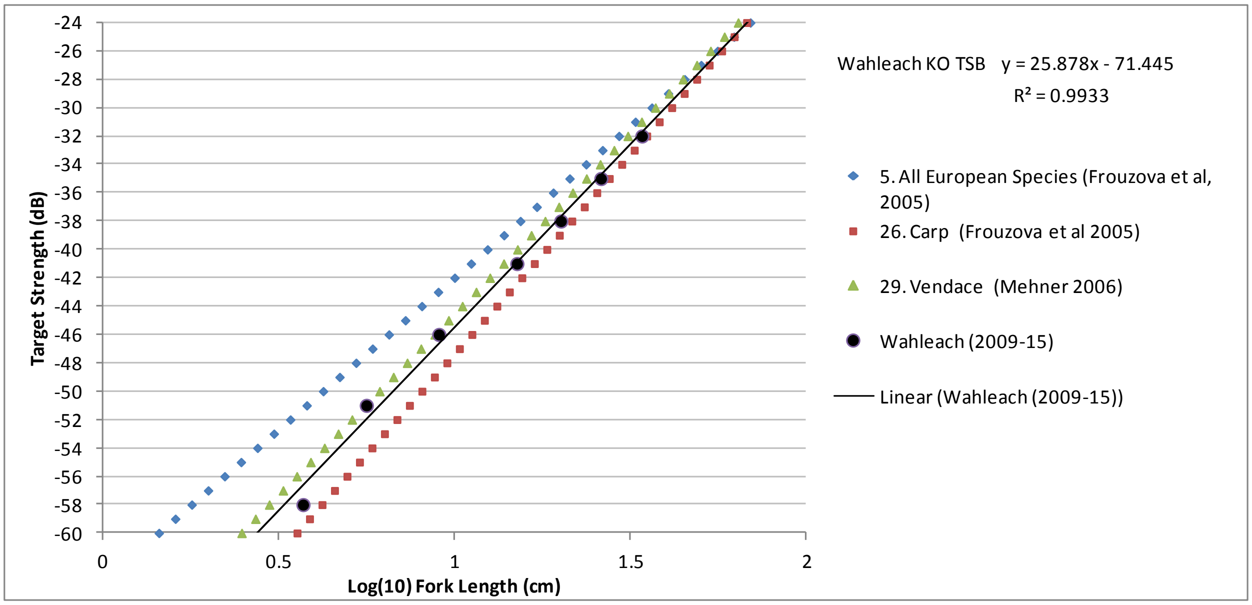
Reference	Description	FL (mm)	Description / comments
1	TSB fry peak	40	mm for stickleback (used mean length for young of the year TSB of 37mm)
2	KO fry peak	55	mm for Kokanee (used mean length of all kokanee fry of 56mm)
3	cut-off	90	mm (visible space between fry and non-fry
4	first peak	150	mm for age 1+ KO
5	main peak	200	mm for KO age 1-3+ (mostly age 2+ but also larger mode of age 1+)
6	inflection	260	mm indicating upper end for KO Could also be 280mm
7	large fish	340	mm - largest kokanee captured (CT)

Comparison of TS:FL relationship for Wahleach Reservoir fish from data in Appendix H with three most similar relations from the literature for vertical aspect studies using 120kHz equipment. Note: the large black points denote Wahleach data and the trendline and equation shown was developed from these points.



Log linear equivalent to above relation showing regression coefficients

A= 25.878 and B= -71.445. Note that these are the values that can be used in Sonar5 to estimate biomass directly from acoustic data for Wahleach Reservoir for future surveys.



Appendix I Detailed biomass estimates from acoustic surveys on Wahleach Reservoir, 2009-2015.

a) All species combined

Year	Threshold	Abundance all ages		Cut-off	Abundance by size		Biomass[3]
	(dB)	dB pop	MLE	(dB)	Fry[1]	Non-fry[2]	(kg)
2009	-65	234,280	234,000	-44	206,458	27,542	3,152
2010	-65	249,942	219,300	-45	199,387	19,913	1,526
2011	-65	155,524	171,600	-46	144,286	27,314	2,220
2012	-66	228,954	238,400	-50	200,700	37,700	1,226
2013	-66	85,911	79,907	-46	66,619	13,288	590
2014	-66	145,959	143,789	-47	130,767	13,022	675
2015	-66	246,775	233,515	-46	164,918	68,597	4,264
Average	-	192,478	188,644	-	159,019	29,625	1,950

1. Fry refers to kokanee fry and to all stickleback (TSB are kokanee fry sized and smaller)
2. Non-fry refers to all fish that are larger than fry and are not young of the year (eg kokanee age 1-3+)
3. Sonar5 estimate of Total biomass (kg) for all fish

b) Kokanee

Year	Threshold	Abundance all ages		Cut-off	Abundance by size		Biomass[3]
	(dB)	dB pop	MLE	(dB)	KO Fry[1]	Age > 1[2]	(kg)
2009	-65	146,325	146,890	-44	121,575	24,849	2,349
2010	-65	97,581	93,893	-45	75,378	18,515	1,220
2011	-65	90,535	90,972	-46	66,097	23,988	1,775
2012	-66	127,022	128,733	-50	94,335	33,861	983
2013	-66	72,214	67,275	-46	53,965	12,794	506
2014	-66	137,944	135,534	-47	122,546	12,855	620
2015	-66	198,084	184,852	-46	118,150	63,601	3,093
Average	-	124,244	121,164	-	93,149	27,209	1,507

1. KO fry population also contains small number of stickleback which cohabitate in the cooler water
2. Age 1-3 fish in cool water appeared to be mostly kokanee but may contain small numbers of CT and RB
3. Kokanee biomass (kg) excludes large fish beyond the upper "inflection point" indicating upper end of KO distribution