Wahleach Project Water Use Plan

Wahleach Reservoir Fertilization Program

Implementation Year 9-10

Reference: WAHWORKS-2

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Study Period: 2013 - 2014

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

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WAHLEACH RESERVOIR NUTRIENT RESTORATION PROJECT, 2013-2014

by

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

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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 and rainbow trout 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 2013 and 2014; this report is intended as a data summary with general comparisons made to baseline years (1993-1994).

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 June to September (ended once reservoir had turned over).

Both 2013 and 2014 had greater inflow relative to the long term with freshet peaking mid-May to mid-June. Peak outflows from Wahleach Reservoir generally following freshet and corresponded with the maximum reservoir surface elevation. In 2013, drawdown was 17.6 m ranging from 642.0 m to 624.0 m, which was 4.0 m below the minimum operating level of 628 m. Perrin and Stables (2000) suggested drawdowns below 627 m can negatively affect Wahleach Reservoir's rainbow trout population and counteract restoration activities. Initially, based on the presence of fry in 2013 minnow traps and age 1+ fish in gillnets during 2014, recruitment failure in the rainbow trout population does not appear to have occurred in 2013. The potential effects on fish populations from the large drawdown observed in both 2011 (Hebert et al. 2013) and 2013 will be further examined in the upcoming review report. In 2014, reservoir elevation was relatively stable year-round ranging from 633.5 m to 639.7 m with a drawdown of 6.2 m.

Generally, the warmest months were June through September during the nutrient addition period. Compared to the 1984-2014 average of 6.4 ± 6.1°C, the mean annual temperature in 2013 was marginally warmer (6.5 ± 6.22°C), while 2014 was 1.6°C warmer (8.0 ± 6.7°C). In terms of precipitation, the driest months were generally July and August, while the wettest months were in November and March-April. Precipitation levels were drier in 2013 and wetter in 2014 when compared to the long-term average.

Water temperature in 2013 for both stations combined ranged between 7.2°C and 21.5°C; temperature in 2014 was between 6.6°C and 20.3°C. Thermocline depth was generally between 4-8 m. Both basins showed orthograde oxygen profiles indicative of

oligotrophic conditions. Seasonal average secchi depth values for both stations were 4.0 ± 1.4 m in 2013 and 5.8 ± 1.1 m in 2014.

Total phosphorus (TP) concentrations were indicative of ultra-oligotrophic productivity nearing oligotrophic conditions. Several soluble reactive phosphorus (SRP) samples were below detection limits of 1 μg/L in 2013 and 2014 despite weekly phosphorus additions. Low SRP values suggest rapid uptake and assimilation of useable phosphorus by phytoplankton. Epilimnetic total nitrogen (TN) concentrations in 2013 and 2014 were greater than in baseline years. During both eras, summer nitrate and nitrite (NO_3+NO_2-N) concentrations dropped below 20 µg/L – which is considered limiting for phytoplankton; this drop was more pronounced during the nutrient restoration era suggesting strong biological utilization of nitrate. Nitrate is an important form of dissolved nitrogen that supports algal growth (Wetzel 2001). As well, seasonal average molar TN:TP ratios were nearly two-fold greater in 2013 and 2014 than in baseline years.

The phytoplankton community in the two study years were distinctly different from each other. In 2013, the community was dominated by chrysophyte and cryptophytes of moderate densities but owing to their mean size the biovolume was nearly 2 fold higher than biovolumes measured in the baseline year and in 2014. In 2014, the community was dominated by high densities of cyanophytes but owing to their relative small size the biovolume measured in 2014 was approximately 2 fold lower than the biovolumes measured in the baseline year and in 2013. Mean annual phytoplankton density in 2013 was 7,575 ± 4,679 cells/mL for both stations combined; biovolume was 1.30 ± 1.15 mm^3/L. In 2014, mean annual phytoplankton densities was 15,374 ± 13,780 cells/mL; biovolume was 0.56 ± 0.32 mm^3/L. Chlorophytes, dinophytes and diatom densities and biovolumes were low in both study years.

Zooplankton densities in 2013 and 2014 were 7-fold higher than those measured in the baseline years. Mean annual zooplankton density for 2013 was 7.50 ± 3.89 individuals/L and in 2014 was 6.54 ± 4.27 individuals/L compared baseline densities of 1.05 ± 0.81 individual/L. Prior to nutrient restoration the large cladoceran *Daphnia rosea*, considered critical for the restoration of Kokanee salmon, was absent from the zooplankton community. *Daphnia rosea* now account for nearly 80% of the total zooplankton biomass in Wahleach Reservoir. The mean *Daphnia* densities in 2013-2014 were 3.22 individuals/L but extremely high seasonal peaks of 8.95 individuals/L and 10.35 individuals/L were observed in 2013 and 2014 respectively. These high densities of Daphnia represent a significant increase in food availability for planktivores relative to baseline years.

During the 2013 nearshore gillnetting program, 81 fish were caught; Rainbow Trout and Cutthroat Trout (63 individuals) made up the majority of the catch followed by Kokanee

(15 individuals). In 2014, 114 fish were caught with most being Rainbow Trout (88 individuals); only 6 Kokanee were caught during 2014. Catch-per-unit-effort (CPUE) was 0.36 ± 0.09 fish-per-net-hour in 2013 and 0.47 ± 0.29 fish-per-net-hour in 2014. Threespine Stickleback catch in minnow traps was 0.12 ± 0.25 fish-per-trap-hour in 2013 and 0.15 ± 0.15 fish-per-trap-hour in 2014. Estimates of fish abundance in Wahleach Reservoir based on hydroacoustic data were 67,300 fish in 2013 and 135,500 fish in 2014; of which 53,700 (2013) and 123,300 (2014) represented kokanee fry and Threespine Stickleback from depths 6-30 m, and 14,500 (2013) and 12,500 (2014) represented age 1+ and older Kokanee, Rainbow Trout and Cutthroat Trout from depth 6-30 m.

Mean length-at-age data show 1+ and 2+ Kokanee caught in the reservoir during 2013-2014 were significantly larger than in 1993-94. No 3+ Kokanee were caught during 1993-94 baseline studies. Furthermore, slopes of Kokanee length-weight regressions for 2013 and 2014 were greater than baseline years, which is indicative of Kokanee in better condition during nutrient restoration. The increased body size and condition of Kokanee observed during 2013 and 2014 are evidence of increased forage potential from nutrient additions as illustrated by zooplankton results, and thus increased growth potential for Kokanee.

Furthermore, Kokanee spawner escapements during 2013 and 2014 were 14,862 fish (442 Boulder Creek; 11,389 Flat Creek; and 3,032 Jones Creek) and 8,424 fish (100 Boulder Creek; 7,609 Flat Creek; and 716 Jones Creek) respectively. Escapement results over the past decade have shown a dominant run every four years on Wahleach; the last peak run was in 2010 and as such, lower Kokanee spawner numbers in 2011-2013 were expected with the peak occurring in 2014. However, it appears that many of the Kokanee expected to spawn in 2014 did so in 2013, as evidenced by the high percentage (40%) of 2+ spawners in 2013 (typically spawners in Wahleach are age 3+). The mean age of Kokanee spawners in 2013 was 2.6 ± 0.5 years and in 2014 was 3.1 ± 0.5 years with 73% as age 3+ and 19% as age 4+. Length frequency distributions of kokanee spawners showed distinction as well; the majority of Kokanee in 2013 were 231-240 mm in size, while in 2014 Kokanee were primarily 261-270 mm with high numbers of fish in the 271-280 mm and 281-290 mm size classes as well.

Looking at rainbow trout metrics, the population appears to be in stable condition with rainbow trout caught in 2013 and 2014 in better condition for a given length or age than during baseline years. Sterile Cutthroat Trout, first introduced to Wahleach Reservoir as part of this project, also appear stable as demonstrated by results of biometric data.

Overall, monitoring data from 2013 and 2014 have shown positive results in terms of growth and abundance of a self-sustaining population of Kokanee – supporting the bottom-up effects of nutrient additions. Our results to date including Cutthroat Trout diet studies (Perrin *et al*. 2006), low catches of stickleback in the annual minnow trapping program, and the recovered Kokanee population suggest the biomanipulation portion of the project, which has been achieved through top-down predatory control of Threespine Stickleback by Cutthroat Trout has been successful. The Wahleach Reservoir Nutrient Restoration Project is based on known links between nutrient availability and the response in productivity. The plankton response clearly indicates the lower trophic levels have responded positively which supports restoration of planktivorous populations. Further refinement of the data over a longer time series will be presented in an upcoming review report to enhance our understanding of the ecological dynamics in Wahleach Reservoir.

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1. Introduction

The Wahleach Reservoir Nutrient Restoration Project draws on over forty years of lake and stream fertilization efforts in British Columbia (e.g. Stockner 1981, Stockner and MacIsaac 1996, Wilson *et al*. 2002, Stockner and Ashley 2003). Since the late 1960s, several federal and provincial nutrient addition experiments have resulted in a growing body of literature on large lake and reservoir restoration science (see review in Wilson *et al*. 2003; Schindler *et al*. 2007a; Schindler *et al*. 2007b). The Wahleach Reservoir Nutrient Restoration Project will further add to this knowledge base and enhance our understanding of ecosystem dynamics in a managed system.

Wahleach Reservoir was created in 1953 with the construction of a hydroelectric dam at the original lake's outlet stream. By 1993, when the first phase of restoration was initiated, the fishery on Wahleach had collapsed; rainbow trout (*Oncorhynchus mykiss*) were stunted (<20 cm) and in poor condition, while kokanee (*Oncorhynchus nerka*) were below detection limits and thus considered extirpated. In 2005, BC Hydro developed a Water Use Plan (WUP) to better balance water use and recreational interests in the Wahleach watershed. Amongst other things, the WUP included commitments to the nutrient restoration project and reservoir operating constraints.

The collapse of fish populations in Wahleach Reservoir coincided with multiple stressors; foremost was the increased age of the reservoir and subsequent decrease in nutrient availability and, in turn, decreased phytoplankton and zooplankton productivity – typical of ageing reservoirs (Ney 1996, Schallenberg 1993). This was further exacerbated by the illegal introduction of Threespine Stickleback (*Gasterosteus aculeatus*), a competitor fish species (Scott and Crossman 1973); and substantial spring drawdowns that exposed the littoral zone.

Recognizing the value of restoring fish stocks in Wahleach Reservoir, the Province and BC Hydro embarked on a multi-year restoration project. The restoration of Wahleach Reservoir combined bottom-up treatment via nutrient additions with top-down biomanipulation of the food web achieved through fish stocking. This was the first nutrient restoration project in BC coupled with a biomanipulation experiment.

The goal of nutrient addition was to restore nutrient availability and optimize 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); the stimulation of the lower trophic levels play a key role in increasing fish populations.

The goal of biomanipulation was to manipulate the food web in a top-down manner and enhance the effects of nutrient restoration specifically for Kokanee. In some systems, competition between Kokanee and other fish species, such as Threespine Stickleback, 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* spp., thus freeing up food resources for Kokanee. 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 over multiple seasons and years in Wahleach Reservoir did not include juvenile Kokanee (Perrin *et al*. 2006).

Overall, the objective of the Wahleach Nutrient Restoration Project is to restore historical populations of Kokanee and Rainbow Trout in the reservoir. The project consists of two phases: baseline studies completed in 1993 and 1994, and treatment (i.e. nutrient restoration and fish stocking) from 1995 to present day. Annual monitoring is completed to adaptively manage the program, as well as to assess limnological conditions and fish population status. This report presents data from 2013 and 2014; it is intended as a summary with general comparisons to baseline years. In 2015, a comprehensive review report will be written covering all years with a focus on the most recent five years relative to baseline conditions.

2. Methods

2.1. Study Site

Wahleach Reservoir is located at 49°13'N, 121°36'W, approximately 25 km southwest of Hope, British Columbia. It is situated in the Cascade Mountains at 642 m above sea level. At full pool, Wahleach Reservoir has a surface area of 489 ha, and can hold 66×10^{6} m^{3} of water at a maximum depth of 29 m. The reservoir is dimictic – having two seasons of complete mixing due to turnover in spring and fall, and two seasons of stratification in summer and winter. Ice cover on Wahleach Reservoir usually 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) and one in the south at LS2 (EMS ID#E219074) (Figure 1). Nearshore gillnetting and minnow trap sites are shown on Figure 1 with exact coordinates for 2013 and 2014 in Table 1 and Table 2, respectively.

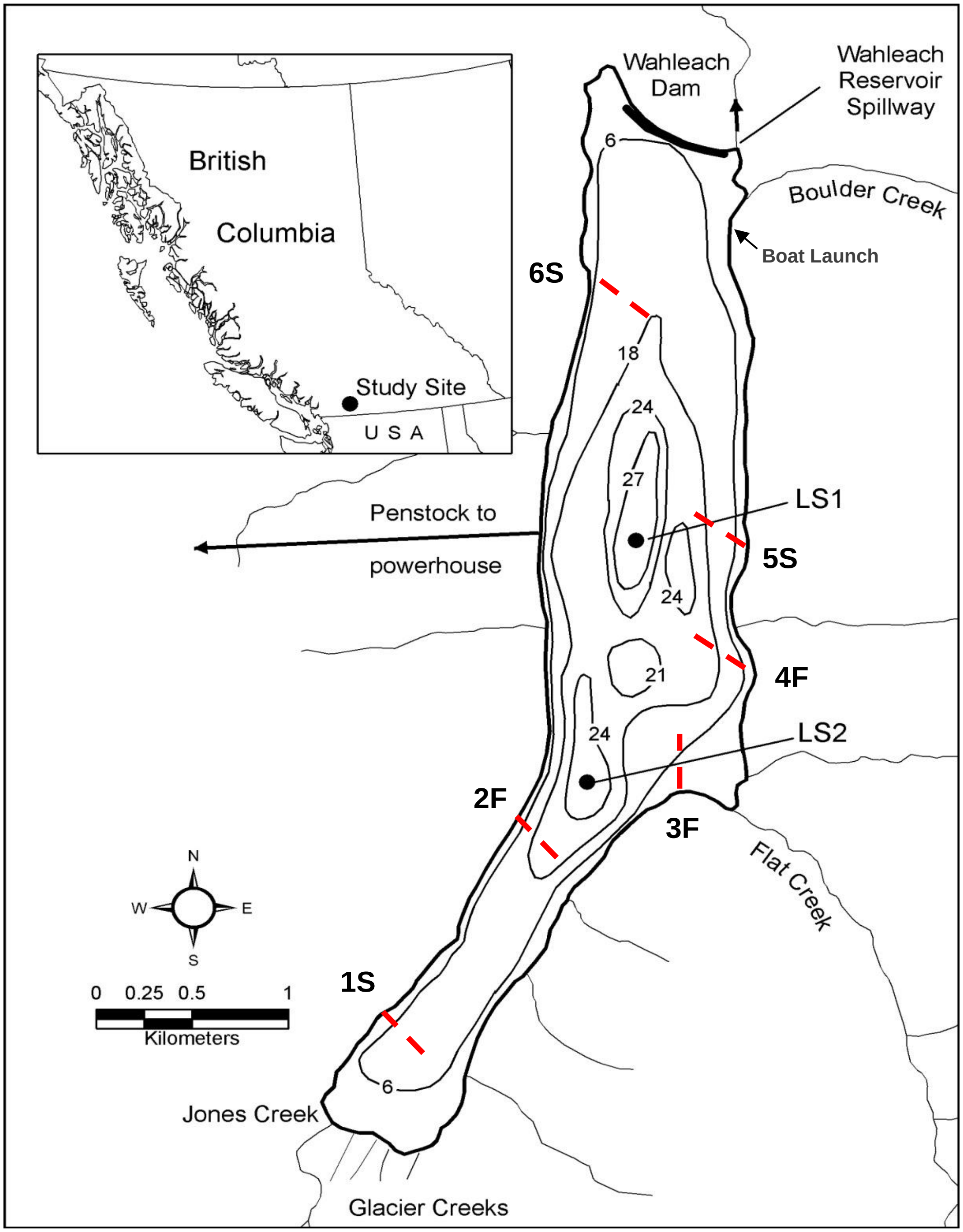


Figure 1 Map of Wahleach Reservoir showing Kokanee spawner index streams (Boulder Creek, Flat Creek, Jones Creek), limnology sampling sites (LS1 and LS2), and approximate locations of near shore gillnets (red dashed lines; S=sinking net, F=floating net). Bathymetric contour depths (m) represent the reservoir at full pool.

Table 1 Wahleach Reservoir nearshore gillnet locations, 2013-2014

Year	Net	Location Coordinates
2013	1S	49°12.471 N, 121°38.005 W
	2F	49°13.208 N, 121°37.181 W
	3F	49°13.054 N, 121°36.689 W
	4F	49°13.350 N, 121°36.281 W
	5S	49°14.222 N, 121°36.237 W
	6S	49°14.807 N, 121°36.868 W
2014	1S	49°12.463 N, 121°38.002 W
	2F	49°13.208 N, 121°37.184 W
	3F	49°13.058 N, 121°36.679 W
	4F	49°13.392 N, 121°36.257 W
	5S	49°14.222 N, 121°36.868 W
	6S	49°14.807 N, 121°36.868 W

Table 2 Wahleach Reservoir minnow trap locations, 2013-2014

Year	Trap #	Location
2013	1M	49°12.224 N, 121°38.007 W
	2M	49°12.203 N, 121°37.934 W
	3M	49°12.190 N, 121°37.906 W
	4M	49°12.169 N, 121°37.858 W
	5M	49°13.372 N, 121°37.143 W
	6M	49°13.372 N, 121°37.143 W
	7M	49°13.762 N, 121°37.142 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
2014	1M	49°12.199 N, 121°38.031 W
	2M	49°12.211 N, 121°38.016 W
	3M	49°13.372 N, 121°37.143 W
	4M	49°13.373 N, 121°37.146 W
	5M	49°13.762 N, 121°37.142 W
	6M	49°13.762 N, 121°37.142 W
	7M	49°14.823 N, 121°36.850 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 June 3 to September 24, 2013 and June 4 to September 23, 2014; nutrient additions are scheduled to end after a 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 ratio 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 phosphorus loading rates for Wahleach Reservoir are at least 200 mg·P/m^2 to improve the production of *Daphnia* sp. as based on recommendations by Perrin *et al*. (2006). Nitrogen is added concurrently to keep epilimnetic concentrations above 20 µg/L (the concentration considered limiting to phytoplankton growth [Wetzel 2001]) and maintain a high N:P ratio. During 2013, the planned N:P ratio was modified mid-season in an effort to boost low nitrogen levels; this schedule was maintained in 2014 (Figure 2). Overall in 2013, 2.64 tonnes of ammonium polyphosphate and 14.49 tonnes of urea-ammonium nitrate were added to the reservoir (Table 3). Weekly nitrogen and phosphorus loads were consistent with planned rates until week 6, after which nutrient loads were generally reduced or eliminated in order to reduce or prevent algal blooms. Nutrient additions were not conducted after week 17, as the reservoir had turned over. The actual annual phosphorus loading rate was 96 mg·P/m^2, which was about one half of planned loading (188 mg·P/m^2). For nitrogen, the planned annual loading rate was 1763 mg·N/m^2, while the actual annual rate was 1080 mg·N/m^2 (Figure 3). Actual molar N:P ratios of fertilizer additions ranged from 1.5 on week 1 to 26.4 on week 11 (Figure 3). The annual average molar N:P ratio was 15.3.

During 2014, 3.70 tonnes of ammonium polyphosphate and 16.59 tonnes of urea-ammonium nitrate were added to Wahleach Reservoir (Table 3). Actual loading rates for phosphorus and nitrogen were consistent with planned rates until week 9, after which nutrient loads were generally reduced or eliminated in an effort to prevent algal blooms (Figure 3). Nutrient additions were not conducted after week 17, as the reservoir had turned over. Overall, the actual annual phosphorus loading rate was 134 mg·P/m^2 compared to the planned loading rate of 185 mg·P/m^2; while the actual annual nitrogen loading rate was 1254 mg·N/m^2 compared to planned loading rate of 1934 mg·N/m^2 (Table 3). Actual molar N:P ratios of nutrient additions ranged from 1.5 at the beginning of the season to a maximum of 33.4 on week 14 (Figure 2); the annual average molar N:P ratio was 19.4 (Table 3). Ratios of N:P reported during earlier years of the project ranged from 13.0 to 25.6 without any undesirable effects (Perrin *et al*. 2006).

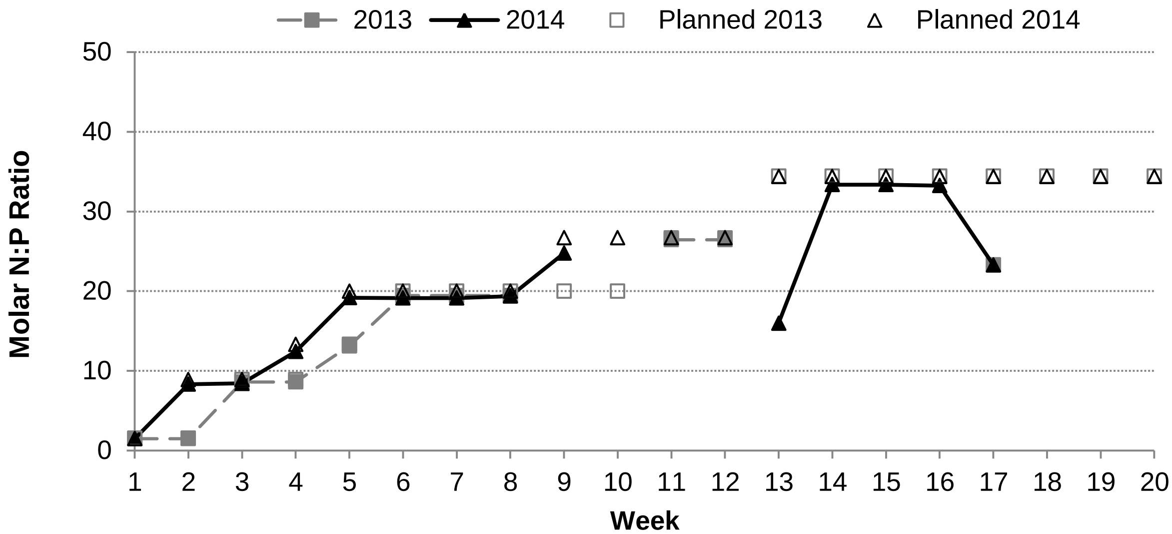


Figure 2 Seasonal molar N:P ratios of fertilizer additions for Wahleach Reservoir, 2013-2014.

Table 3 Annual nutrient additions to Wahleach Reservoir, 1995-2014

Year	Fertilizer Additions		Nutrient Additions				
	10-34-0	28-0-0	Phosphorus		Nitrogen		N:P
	t	t	kg	mg P m^2	kg	mg N m^2	molar ratio
1995	2.50	14.0	383	93	4170	1017	24.1
1996	2.80	15.7	429	105	4676	1140	24.1
1997	3.51	20.3	538	131	6035	1472	25.6
1998	4.07	23.1	624	152	6875	1677	24.9
1999	4.54	19.6	696	170	5942	1449	18.3
2000	-	-	-	225	-	1229	13.0
2001	-	-	-	-	-	-	-
2002	-	-	-	-	-	-	-
2003	5.39	10.68	826	202	3529	861	9.4
2004	5.01	13.50	768	187	4281	1044	12.3
2005	4.73	13.20	725	177	4169	1017	13.7
2006	5.50	17.00	843	206	5310	1295	13.9
2007	6.26	22.79	960	234	7007	1709	16.1
2008	5.64	21.23	865	211	6508	1587	16.6
2009	3.29	14.24	504	123	4316	1053	18.9
2010	0.66	11.22	101	25	3208	782	70.1
2011	0.00	15.78	0	0	4418	1078	-
2012	3.37	12.42	517	126	3815	930	16.3
2013	2.64	14.49	392	96	4321	1080	24.4
2014	3.70	16.59	549	134	5019	1254	20.2

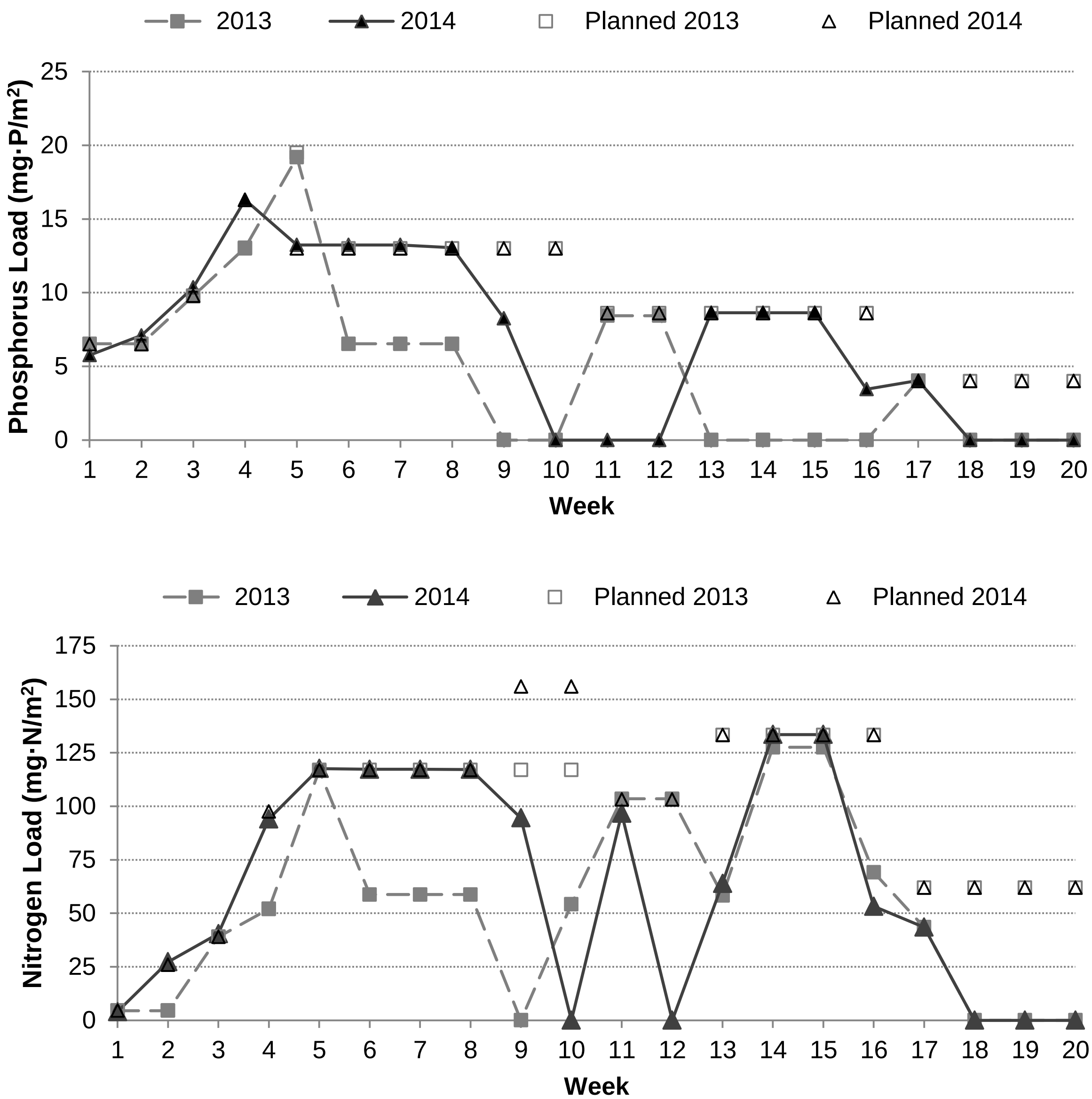


Figure 3 Seasonal phosphorus and nitrogen loading rates for Wahleach Reservoir, 2013-2014.

2.3. Hydrometrics and Reservoir Operations

Data were provided by BC Hydro. Average daily inflow, discharge, and day end reservoir surface elevations are reported.

2.4. Climate

Daily temperature and precipitation data were provided by BC Hydro. Maximum and minimum daily temperatures were averaged and then reported as monthly means. Daily precipitation was reported as monthly means.

2.5. Physical and Chemical Samples

Limnology sampling was conducted monthly from May 30 to October 16, 2013 and May 26 to October 21, 2014. Vertical profiles of dissolved oxygen (mg/L) 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 Van Dorn 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 that same day (<12 h). Lab analyses were completed by Maxxam Analytics in Burnaby, BC. TP and TDP samples were digested and analysed according to Menzel and Corwin (1965). SRP was analysed using the molybdenum blue method (Murphy and Riley 1962). TDP included orthophosphate, polyphosphates and organic phosphates (Strumm and Morgan 1981); SRP included the orthophosphate ion and acid-labile P compounds (Harwood *et al*. 1969), and may overestimate biologically available P (Rigler 1968; Bothwell 1989). TN was analysed using methods outlined in APHA (1995). 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 and analyzed by *in vitro* fluorometry (Yentsch and Menzel 1963). Values were corrected for phaeopigment concentrations, which may equal or exceed functional pigment. 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 enumerations 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 (20-200 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 250-300 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 are listed in Appendix A. Annual means ± the standard deviation, as well as monthly means ± the standard deviation are reported.

2.7. Zooplankton

Zooplankton enumerations 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* spp. were not identified to species for density counts. Appendix B contains a list of zooplankton species observed during each year. Values reported are annual means ± standard deviation and monthly means ± standard deviation for the major zooplankton groups. Values from stations LS1 and LS2 were combined for calculating monthly means.

2.8. Fish

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 Cutthroat Trout.

Table 4 Wahleach Reservoir fish stocking records, 1997-2014

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

Nearshore Gillnetting and Minnow Trapping

Standardized annual gillnetting sessions were completed on October 22-23, 2013 and October 21-22, 2014. In 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"). In 2014, the standard nets were modified to include a panel of 32 mm (1.25") mesh to address net fishing bias against 1+ sized Kokanee. In both years, six stations consisting of three floating nets set at the surface and three sinking nets set on the bottom 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. Typically, six minnow traps baited with salmon roe are set each year; however, additional traps were deployed in 2013 and 2014 in an effort to increase sample sizes. A total of eleven traps were set in 2013 and seven traps were set in 2014. All minnow traps were deployed in littoral habitat in approximately 2-3 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, 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 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 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), length frequency, age frequency, length-at-age, and length-weight relationships. CPUE for minnow trapping was calculated as individuals per hour of trap soak time.

Kokanee Spawner Surveys

Kokanee spawner escapement in three index streams - Boulder Creek, Flat Creek, and Jones Creek - was estimated using standardize 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 2-3 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.

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 6-15 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, for example. 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 *i*th survey day inclusive; the survey ranges from the first survey day to the last (*n*th) 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 length (mm), weight (g), sex, maturity, clips/marks and notes. Otoliths were taken from all individuals for ageing.

Hydroacoustics

Hydroacoustic surveys were conducted on August 8, 2013 and August 18, 2014. Surveys began approximately one hour after sunset during the new moon. Data were collected along eleven standardized transects (Figure 4) 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 the boat at a depth of 1.0 m. Transects were navigated with the aid of a Lowrance LCX27-C GPS, and a 10 million-cp light 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 $fish \cdot ha^{-1}$ by 2 m depth strata.

Software provided densities by 47 size groups in 1 decibel (dB) increments from -70 to -24 dB. A threshold of -66 dB was applied to remove noise and capture the majority of fish targets. Detailed data collection and analysis parameters are found in Appendix C.

Fork lengths of gillnet and trawl caught fish were converted to an acoustic size equivalent using Love (1977) empirical dorsal aspect relation (Appendix D); these were compared to acoustic targets in the same depth range and the resulting distributions were used to verify appropriate decibel ranges for separating out fish populations. Decibel thresholds used to differentiate smaller fry-sized fish from larger adult-sized fish were -46 dB for 2013 and -47 dB for 2014. 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 is challenging. In raw data form, the small size group (-66 to -46 dB in 2013; -66 to -47 dB in 2014) 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 below the thermocline at 6-30 m depth were mainly Kokanee, as supported by results of pelagic gillnetting and directed trawling. While we acknowledge that partitioned data still represent a somewhat mixed species composition, for simplicity, we refer to estimates as Kokanee populations, specifically Kokanee fry (i.e. age-0), adult Kokanee (i.e. age ≥1), and all Kokanee (i.e. fry plus adults; all fish targets 6-30 m). As well, we generally refer to the small size fish group above 6 m depth as Threespine Stickleback.

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 E). At the time of the hydroacoustics surveys in 2013 and 2014, reservoir surface elevations were 639.7 m and 639.3 m, respectively. The average start and end depth of the acoustic transects was 5.2 m in 2013, and 6.0 m in 2014; this equates to approximately 76 ha of shallow water habitat (19% of reservoir) not surveyed in 2013, and 102 ha (26% of reservoir) not surveyed in 2014.

We estimated Kokanee 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, 2014), producing estimates for all Kokanee, as well as adult Kokanee only. Fry population estimates were calculated as the difference between all Kokanee and adult Kokanee estimates. Threespine Stickleback populations were derived by taking the corresponding proportion of the trawl catch below 6 m, applying that percentage to the 6-30 m population estimate and then adding that value to the small fish population estimate above 6 m depth.

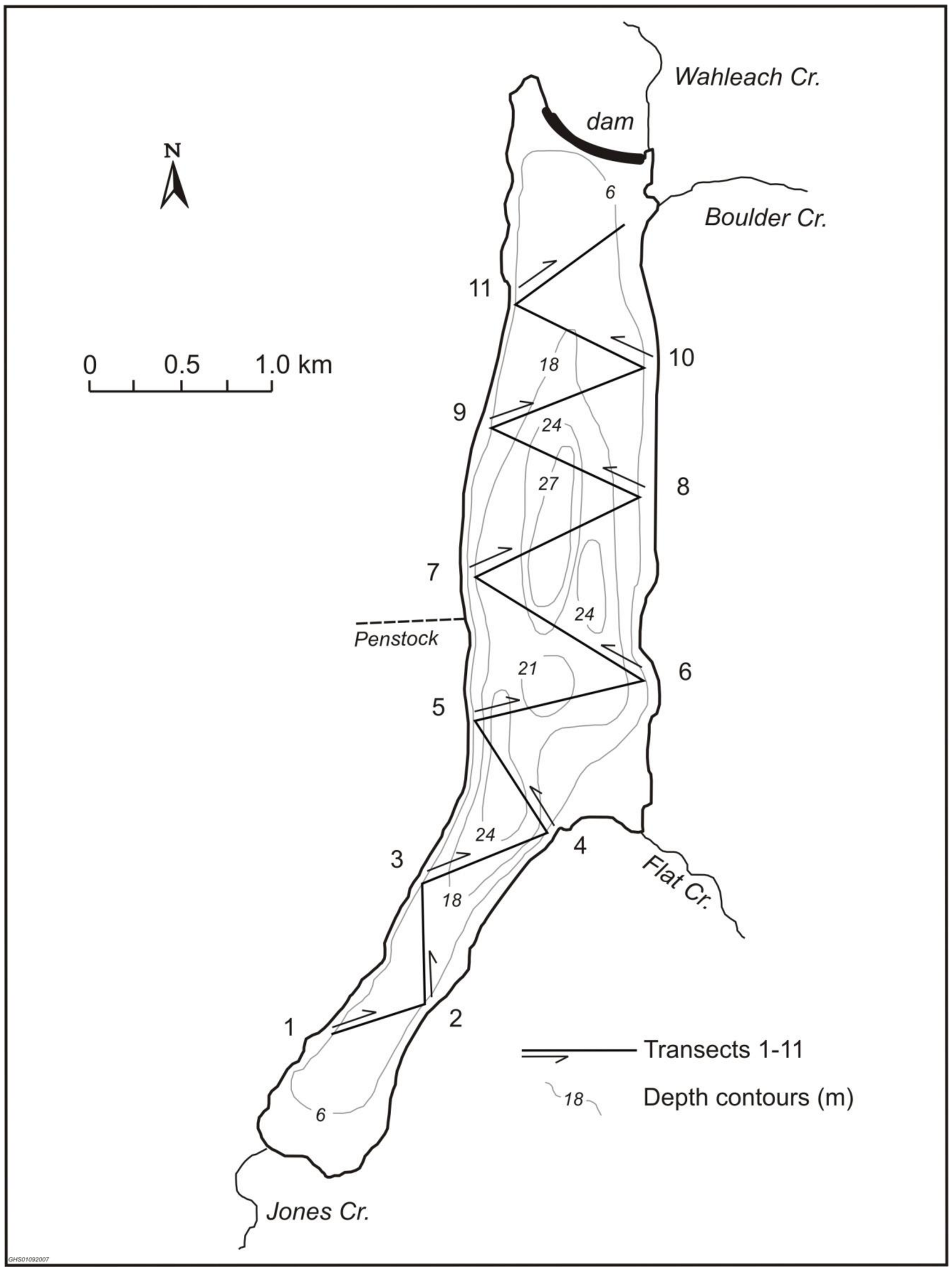


Figure 4 Map of Wahleach Reservoir showing standardized hydroacoustic transect locations

Trawl sampling (2013 and 2014) and pelagic gillnetting (2013) were completed to validate fish species composition and assist with interpretation of hydroacoustic data; as such, results of these sampling programs are reported under the Hydroacoustics sections.

Trawling

Trawl sampling was conducted during the new moon period at least one hour after sunset on August 9, 2013 and August 19, 2014 (i.e. nights following hydroacoustic surveys). Trawls were directed at the highest fish target densities, as determined from an initial analysis of the acoustic data. In 2013, two trawls of 50 and 55 minutes each were conducted. In 2014, three trawls with durations of 33-40 minutes each were conducted. 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 hydroacoustic transects 3-9. Additional trawl information is located in Appendix F.

In 2013, a 7.5 m long beam-trawl net with a 2×2 m opening was used. The net was towed by a single tow line attached to bridles from the top and bottom bars; two 6.8 kg lead weights were attached to each end of the bottom bar. Net specifications and deployment methods are described in MacLellan and Hume (2010).

The 2014 trawl set-up followed the system described by Gjernes (1979), in which a 12 m long beam-trawl net with an opening of 2.5×2.5 m was used. 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. Two 6.8 kg lead balls were attached to the ends of the bottom bar. The deployment set-up included a 20×38 cm boat bumper float attached to the top bar by a float bridle (3 m, black, 1 cm diameter rope) to assist with keeping the bar horizontal and the net open. In addition, 8 m sweep lines (black, 1 cm diameter static rope) were used between the single main tow line and the upper and lower net bridles. Upper and lower net bridles were constructed of 3.2 mm stainless steel cable and were 3.6 meters total length.

In both years, the net was towed at a target speed of 0.8-1.0 $m \cdot s^{-1}$. 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 on ice in labelled packages and sampled the following day for species, length (mm) and weight (g).

Pelagic Gillnetting

Pelagic gillnetting was conducted in conjunction with the hydroacoustic survey in 2013. Data from this program were not compared to past pelagic gillnetting data or fall nearshore gillnetting data. In 2013, nets were set at two sites; site 1 was located near transects 7-8, and site 2 was near transects 9-10 (Figure 4). At each site, a series of four nets (the same as those described in Section 2.8 *Nearshore Gillnetting and Minnow Trapping*) were set at depths of 5 m and 10 m; at site 2, a small mesh gillnet was used in place of one of the standard nets at 5 m. The small mesh gillnet consisted of six panels 15.2 m long by 2.4 m deep with mesh sizes of 25mm, 19 mm, 13 mm, 19 mm, 19 mm, and 13 mm. Nets were set overnight on August 9, 2013 and retrieved the following morning. Fish sampling methods were as described in Section 2.8 *Nearshore Gillnetting and Minnow Trapping*.

3. Results

3.1. Hydrometrics and Reservoir Operations

Both 2013 and 2014 were marginally greater inflow years when compared to the long-term (1984-2014) average of 6.2 ± 3.3 $m^{3} \cdot s^{-1}$; mean annual inflow was 6.3 ± 3.8 $m^{3} \cdot s^{-1}$ in 2013 and 7.3 ± 3.2 $m^{3} \cdot s^{-1}$ in 2014. In 2013, daily inflow ranged from 0-33.1 $m^{3} \cdot s^{-1}$ the maximum rates occurred in mid-May and late June, coinciding with freshet (Figure 5). In 2014, daily inflow ranged from 0.8-43.1 $m^{3} \cdot s^{-1}$ with the maximum occurring in late November and early December during winter storm events (Figure 5). When comparing long term (1984-2014) monthly means, June had the highest inflow at 11.0 ± 3.3 $m^{3} \cdot s^{-1}$ followed by May at 9.8 ± 3.3 $m^{3} \cdot s^{-1}$. Both May and June 2013 and 2014 were higher than long term means; in 2013, May had the highest mean inflow at 13.4 ± 3.8 $m^{3} \cdot s^{-1}$ followed closely by June at 13.0 ± 3.8 $m^{3} \cdot s^{-1}$; in 2014, May again had the highest inflow rate at 12.6 ± 3.2 $m^{3} \cdot s^{-1}$, followed by June at 11.3 ± 3.2 $m^{3} \cdot s^{-1}$.

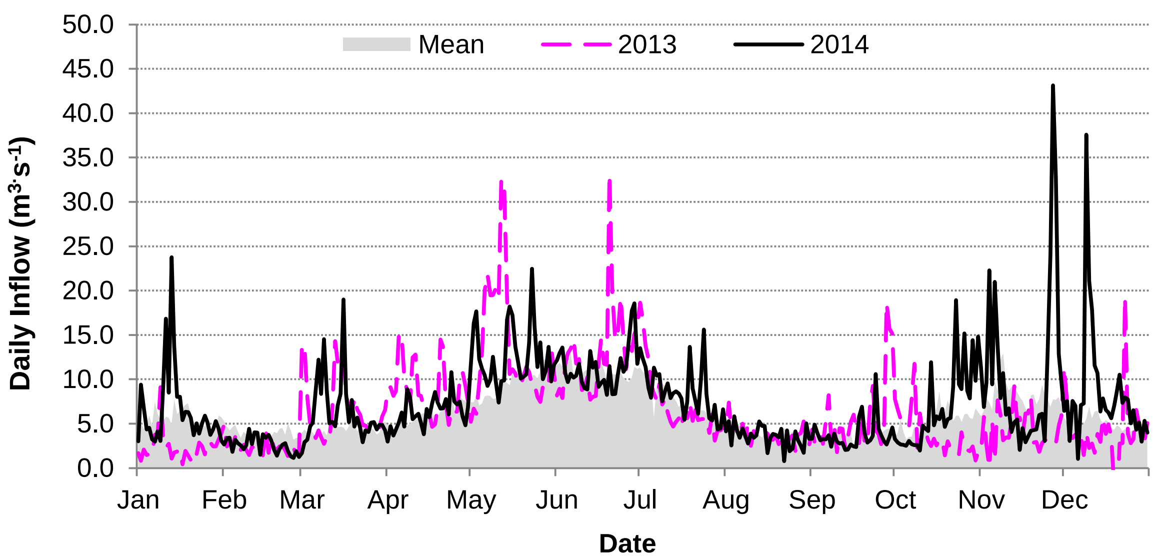


Figure 5 Daily inflow ($m^{3} \cdot s^{-1}$) into Wahleach Reservoir, 2013-2014. Shaded area represents mean inflow from 1984-2014.

Peak outflows from Wahleach Reservoir generally correspond with the timing of freshet and the maximum reservoir elevation for that year. The maximum daily outflow in 2013 was 27.2 $m^3 \cdot s^{-1}$ on June 2, while in 2014 the maximum outflow was 12.7 $m^3 \cdot s^{-1}$ recorded February 4 (Figure 6). In 2013, daily outflow dropped to zero around the end of March where it remained until early June (Figure 6). Contributing to this extended period with no outflow were likely the below average inflows January through March (Figure 5) and corresponding low reservoir surface elevations (Figure 7). Daily outflows in 2014 were generally typical of the long-term pattern. Comparing annual outflows, 2013 (5.8 ± 3.7 $m^3 \cdot s^{-1}$) was marginally below the long term mean of 6.2 ± 3.4 $m^3 \cdot s^{-1}$, the while 2014 (7.4 ± 1.9 $m^3 \cdot s^{-1}$) was greater than the long term mean.

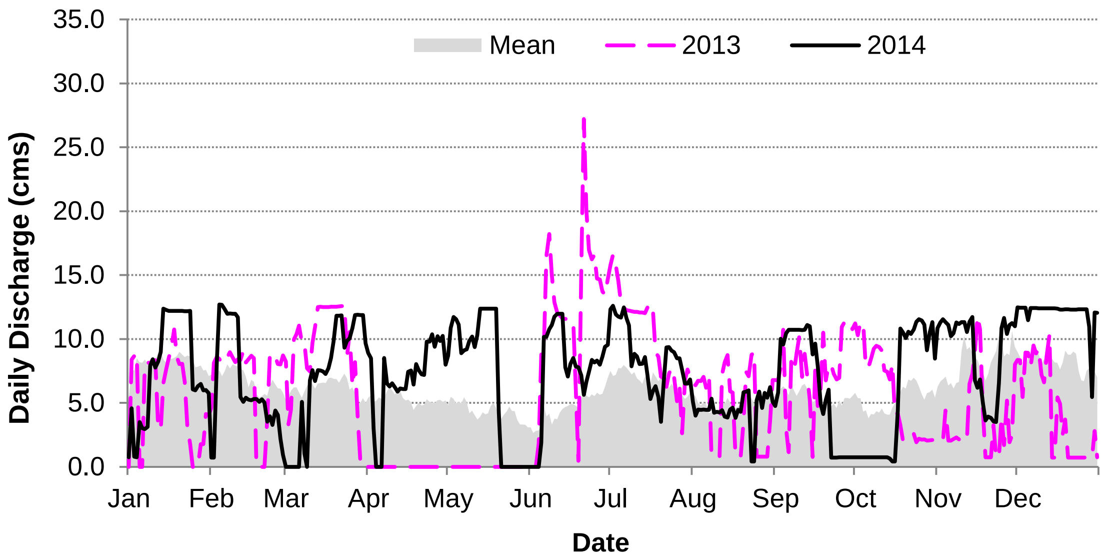


Figure 6 Daily outflow ($m^3 \cdot s^{-1}$) from Wahleach Reservoir, 2013-2014. Shaded area represents the mean daily discharge from 1984-2014.

In 2013, the mean reservoir surface elevation was 635.8 ± 4.6 m, while in 2014 it was 637.1 ± 1.9 m. Both years were similar to the long term mean of 636.1 ± 3.6 m. Drawdown in 2013 was extremely severe at 17.6 m with reservoir surface elevations ranging from 624.0 m to 642.0 m (Figure 7). In late March, reservoir elevations dropped 3.6 m below the 628 m minimum operating level and below the minimum elevation recommended by Perrin and Stables (2000) to protect rainbow trout spawning habitat. In 2014, drawdown was 6.2 m with reservoir elevations that ranged from 633.5 m to 639.7 m remaining above the minimum operating level (Figure 7). 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. In 2013 and 2014, the mean reservoir elevation during the nutrient addition period (June-August, inclusive) was 640.7 ± 1.0 m and 639.1 ± 0.5 m, respectively.

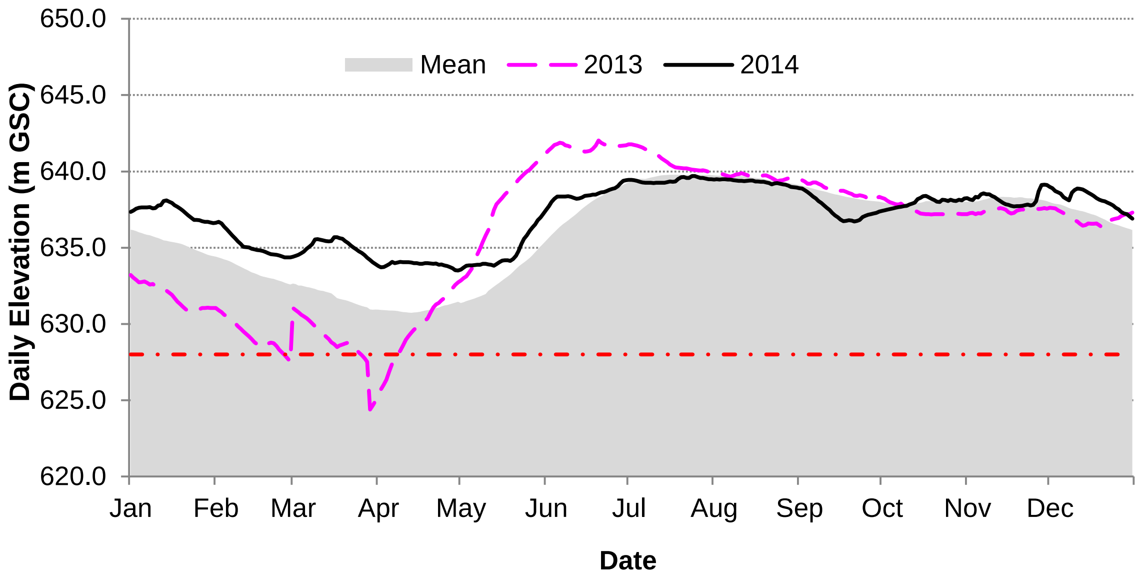


Figure 7 Daily reservoir surface elevation (m, GSC) for Wahleach Reservoir, 2013-2014. Shaded area represents mean elevation from 1984-2014. Dash-dot line at 628 m represents the minimum reservoir operating level.

3.2. Climate

On average for 2013 and 2014, the warmest months occurred from June through September during the nutrient addition period (Figure 8). The mean air temperature during nutrient additions was 11.98 ± 3.90°C in 2013 and 14.53 ± 3.75°C in 2014. For both years the maximum monthly mean temperature was August at 16.11 ± 1.72°C in 2013 and 18.00 ± 2.90°C in 2014. The coldest months were typically December through February; during which time air temperatures regularly drop below freezing (0°C). In 2013, the minimum daily temperature recorded was -8.8°C on January 18; the maximum daily temperature was 20.7°C on September 9. In 2014, the minimum daily temperature was -9.6°C on November 29, while the maximum was 24.9°C on August 5. Compared to the long term average (6.36 ± 6.06°C), the mean annual temperature in 2013 (6.48 ± 6.15°C) and 2014 (7.98 ± 6.68°C) were warmer. Specifically, air temperatures recorded from August through December 2013 were warmer when compared to the long term means; and all monthly mean temperatures recorded in 2014, except February, were warmer than the long term means (Figure 8).

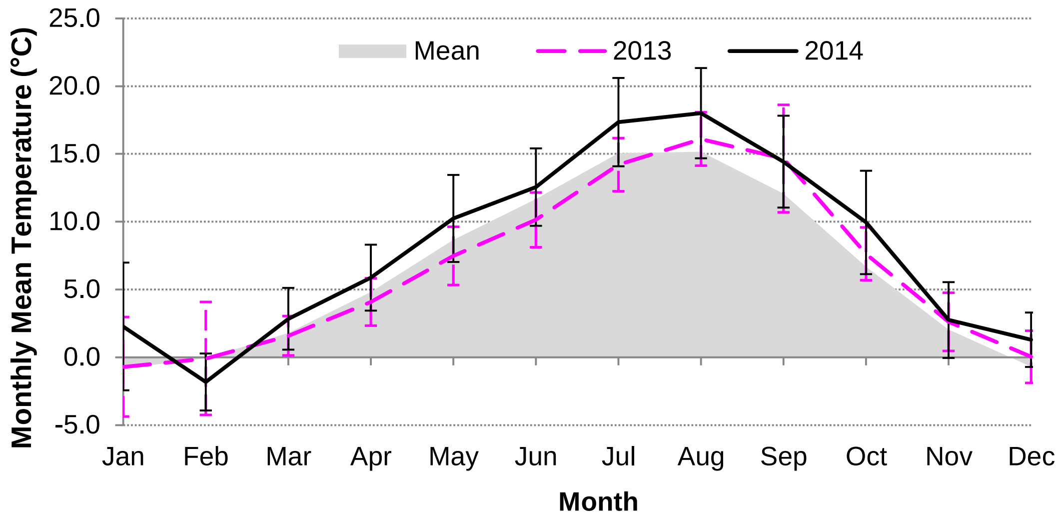


Figure 8 Mean monthly air temperature (ºC) ± SD measured at Wahleach Reservoir, 2013-2014. Shaded area represents mean air temperature from 1984-2014.

In terms of precipitation, the driest month in 2013 was July with a monthly mean of 0.25 ± 0.89 mm (Figure 9). The driest month in 2014 was August, with a monthly mean of 1.90 ± 4.19 mm (Figure 9). Both 2013 and 2014 had monthly averages that were lower than the minimum long-term monthly average of 3.0 ± 4.1 mm. The wettest months on average were April 2013 (12.98 ± 18.99) and March 2014 (15.65 ± 17.50 mm; Figure 9). When compared daily average and total annual precipitation, 2013 was drier (daily mean 6.9 ± 12.2 mm, total annual 2520.7 mm) and 2014 was wetter (daily mean 8.3 ± 13.2 mm, total annual 3032.3 mm) than the long-term (7.1 ± 3.5 mm an d 2612.5 mm). The maximum amount of precipitation recorded in one day was 81.4 mm on April 20, 2013 and 63.4 mm on November 25, 2014.

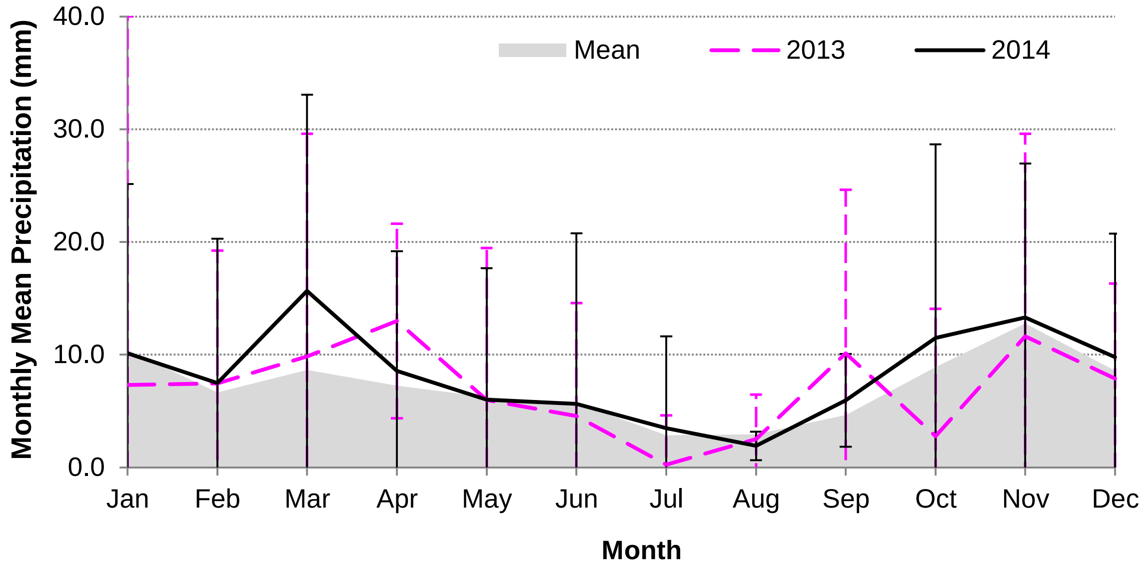


Figure 9 Mean monthly precipitation (mm) ± SD measured at Wahleach Reservoir, 2013-2014. Shaded area represents mean precipitation from 1984-2014.

3.3. Physical and Chemical Data

Wahleach Reservoir experiences a seasonal pattern of thermal stratification typical of temperate systems (Wetzel 2001). Thermocline depth was generally between 4-8 m (Figure 10 and Figure 11). The thermocline begins to develop in June with strong thermal stratification in July and August, and then a weakening of the stratification by September. The reservoir is isothermal in May and October.

Water temperature in 2013 for both stations ranged between 7.2°C and 21.5°C; temperature in 2014 was between 6.6°C and 20.3°C (Figure 10 and Figure 11). For both years, the maximum temperature recorded was at the surface (0 m) during August. Dissolved oxygen concentrations for both stations ranged between 4.47-11.37 mg/L in 2013 and 5.29-12.23 mg/L in 2014. Both basins showed orthograde oxygen profiles indicative of oligotrophic conditions (Figure 10 and Figure 11).

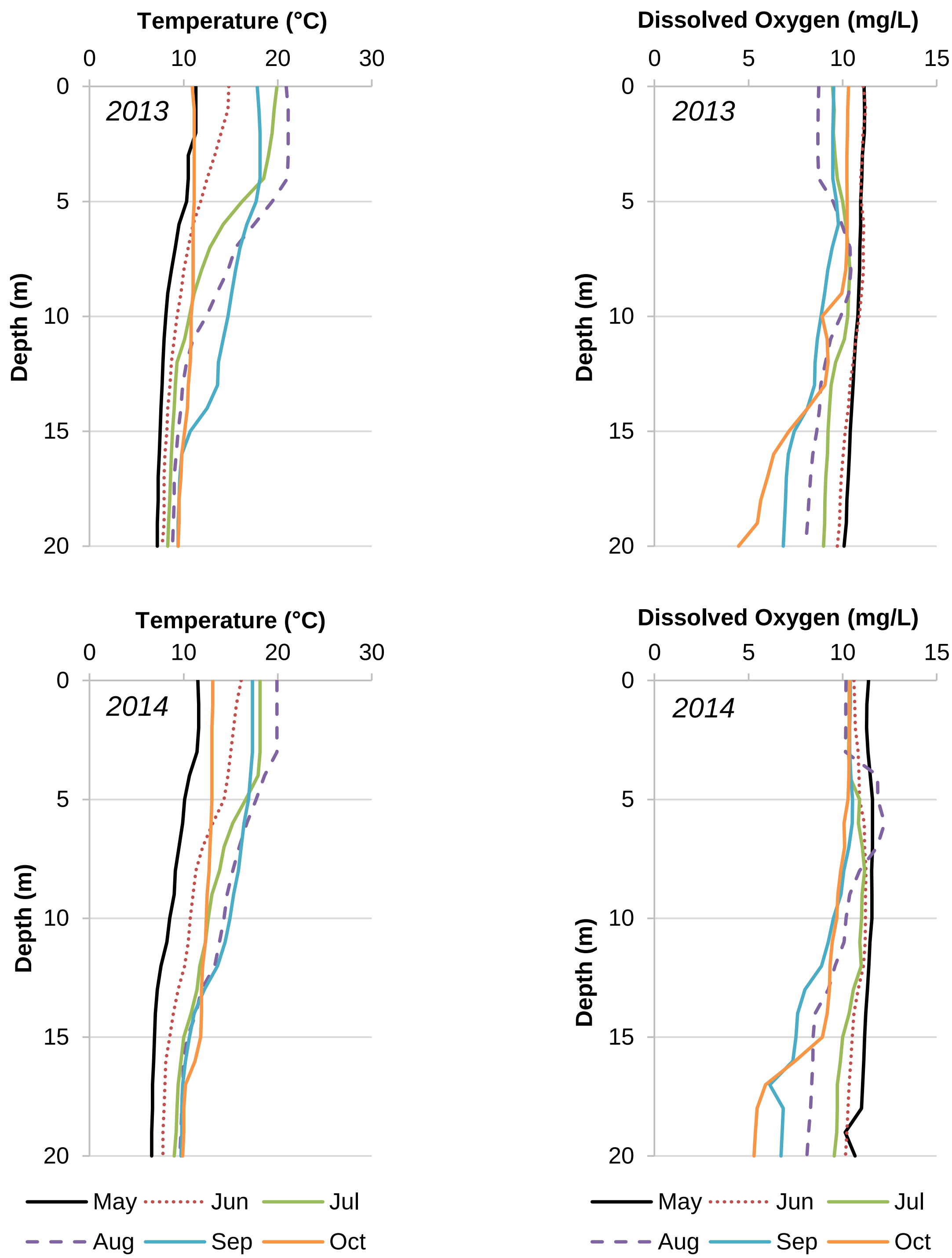


Figure 10 Temperature (°C) and dissolved oxygen (mg/L) profiles for LS1 in the north basin of Wahleach Reservoir, 2013 (top) and 2014 (bottom).

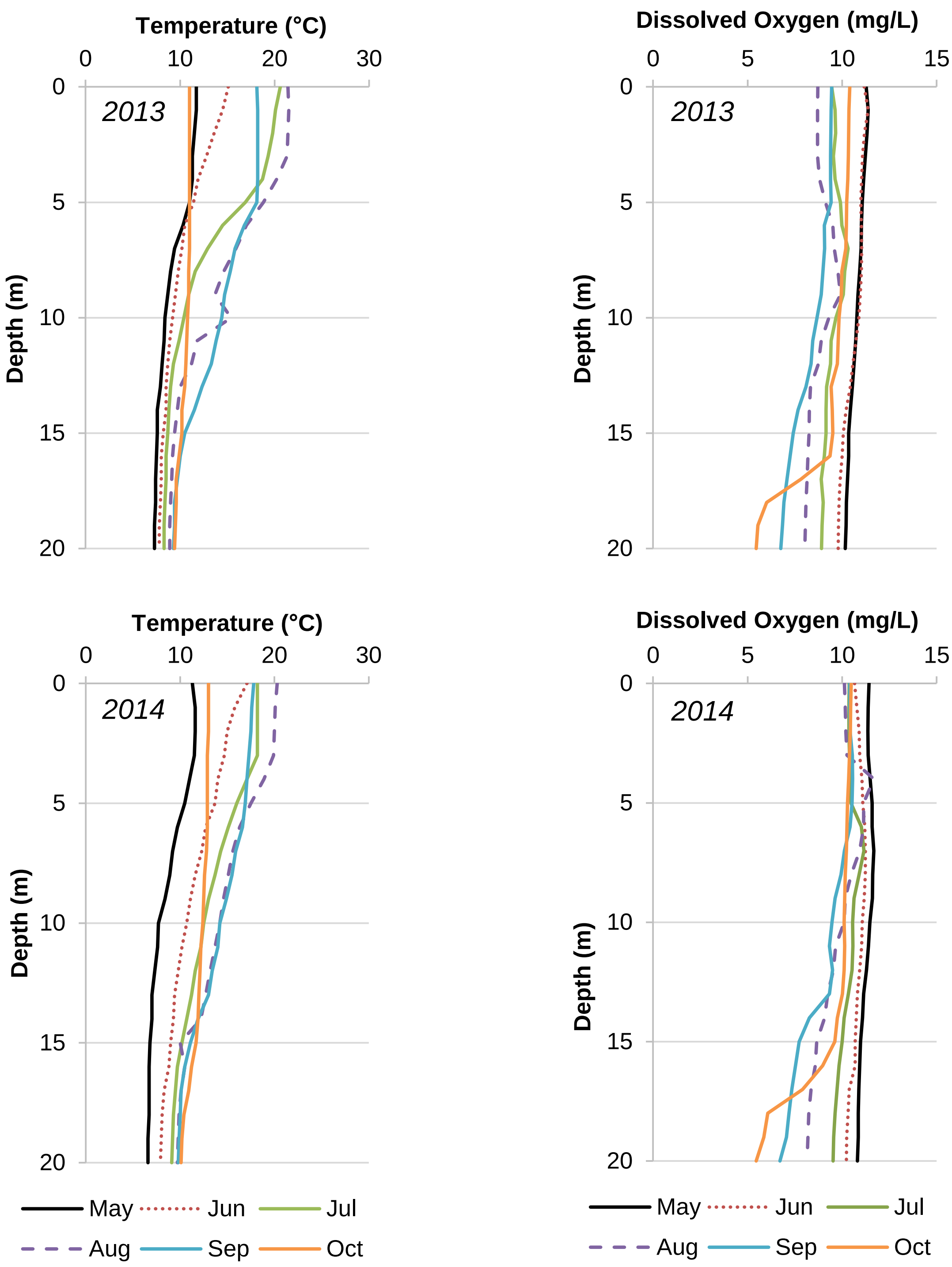


Figure 11 Temperature (°C) and dissolved oxygen (mg/L) profiles for LS2 in the south basin of Wahleach Reservoir, 2013 (top) and 2014 (bottom).

In 2013, the seasonal average Secchi depth for both stations was 4.0 ± 1.4 m (Figure 12). The maximum Secchi depth recorded in 2013 was 6.0 m in August at LS2 (SB), while the minimum Secchi depth recorded was 2.0 m in July at LS1 (NB) (Figure 12). In 2014, the seasonal average Secchi depth for both stations was 5.8 ± 1.1 m (Figure 12). The maximum Secchi depth recorded in 2014 was 7.8 m in June at LS1 (NB), while the minimum depth was 4.3 m in May at LS2 (SB) (Figure 12).

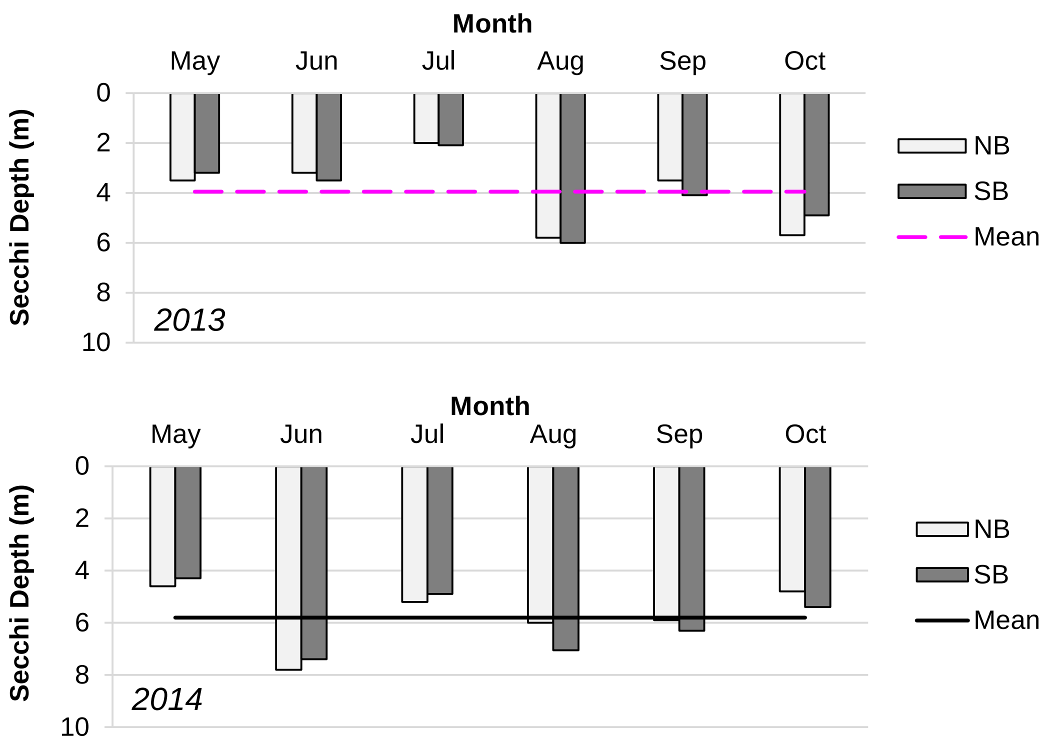


Figure 12 Monthly Secchi depth measurements (m) from LS1 in the north basin (NB) and LS2 south basin (SB) at Wahleach Reservoir, 2013-2014. Lines represent mean seasonal Secchi depth for corresponding years.

In studying the relationship between total phosphorus (TP) and lake productivity, Vollenweider (1968) found TP concentrations below 5 μg/L were indicative of ultra-oligotrophic productivity, while TP concentrations between 5-10 μg/L were indicative of oligotrophic productivity. Prior to nutrient restoration, seasonal mean epilimnetic TP was 4.3 ± 2.0 µg/L, and ranged from 2.9-12.0 µg/L indicative of ultra-oligotrophic productivity nearing oligotrophic productivity (Figure 13). In 2013, the seasonal mean TP was 5.5 ± 3.2 µg/L, and ranged from <2 to 12.1 µg/L (Figure 13). In 2014, seasonal mean TP was 3.6 ± 1.0 µg/L with values ranging from <2 to 5.6 µg/L which on average were lower than the values measured prior to nutrient restoration (Figure 13). Overall, TP values ranged between concentrations indicative of ultra-oligotrophic and oligotrophic productivity.

Seasonal mean soluble reactive phosphorous (SRP) levels during baseline years was 1.1 ± 0.3 µg/L with a range of 1-2 µg/L (Figure 13). Seasonal mean SRP in 2013 was 1.2 ± 1.3 µg/L and ranged from <1 to 4.6 µg/L (Figure 13). In 2014, seasonal mean SRP was 1.2 ± 0.9 µg/L, and ranged from <1 to 3.3 µg/L (Figure 13). Several soluble reactive phosphorus (SRP) samples were below detection limits of 1 µg/L for both years, despite weekly phosphorus additions suggesting rapid uptake and assimilation of useable phosphorus by phytoplankton.

Epilimnetic total nitrogen (TN) concentrations in 2013 and 2014 were greater than baseline years (112 ± 48 µg/L, range 9-22 µg/L) (Figure 14). In 2013, epilimnetic TN ranged between 102-495 µg/L with a seasonal mean of 201 ± 118 µg/L (Figure 14) and in 2014, epilimnetic TN were between 89-188 µg/L with a seasonal mean of 147 ± 33 µg/L (Figure 14).

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 µg/L) in both eras, the drop is more pronounced during nutrient restoration years (Figure 14) suggesting strong biological utilization of NO_3+NO_2 during these years. In 2013 and 2014 during nutrient restoration, seasonal mean NO_3+NO_2 concentrations were lower than baseline (57 ± 38 µg/L) at 17 ± 31 µg/L and 38 ± 37 µg/L, respectively.

Seasonal average epilimnetic molar TN:TP ratios were nearly two-fold greater in 2013 and 2014 than in baseline years. Prior to nutrient restoration, the molar TN:TP was 56 ± 23 with a range of 12-109; while in 2013, molar TN:TP was 83 ± 38 with a range of 55-159 and in 2014 molar TN:TP was 96 ± 26 with a range of 66-138 (Figure 15). Samples above 50 indicate a state of P limitation, while samples below 20 indicate a state of N limitation (Guildford and Hecky 2000).

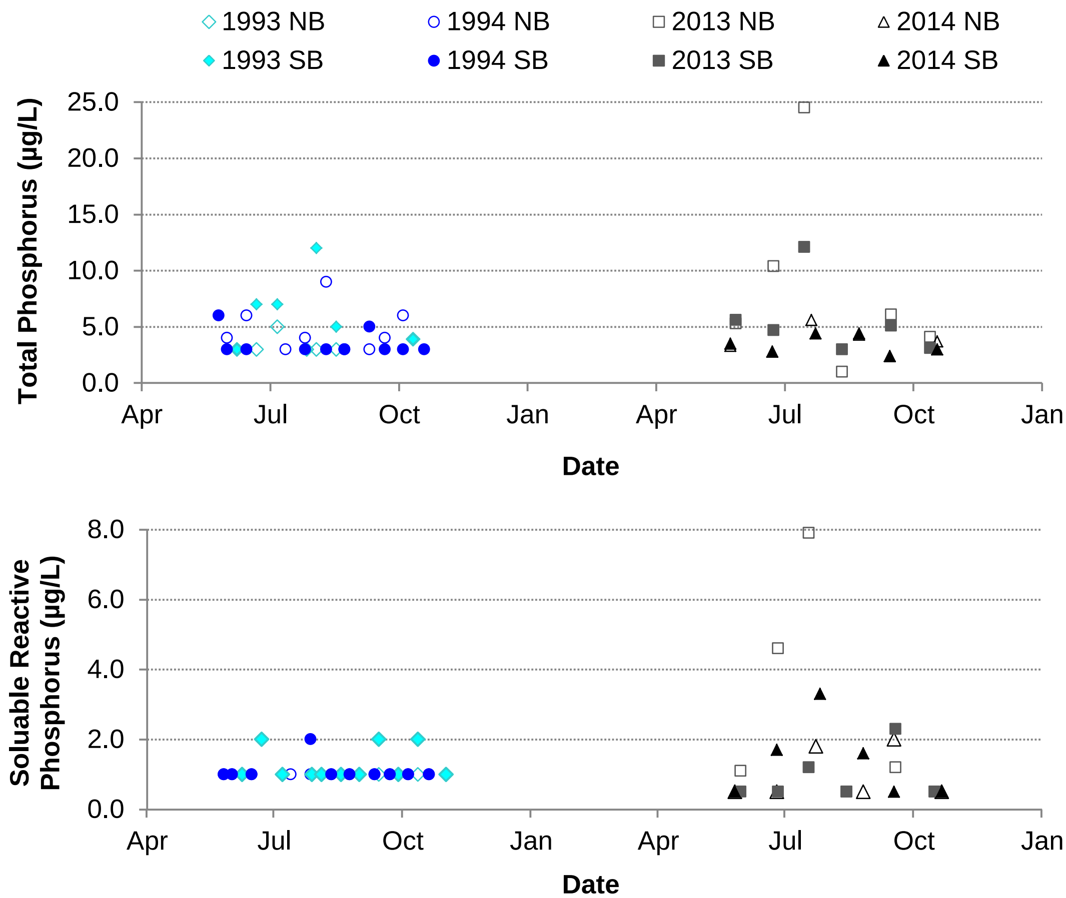


Figure 13 Epilimnetic total phosphorus and soluble reactive phosphorus concentrations at LS1 in the north basin (NB) and at LS2 in the south basin (SB) of Wahleach Reservoir for baseline years (1993-1994) and during nutrient restoration in 2013-2014. Values from 1993-1994 are for surface (0 m) samples; values from 2013-2014 are for 1 m samples.

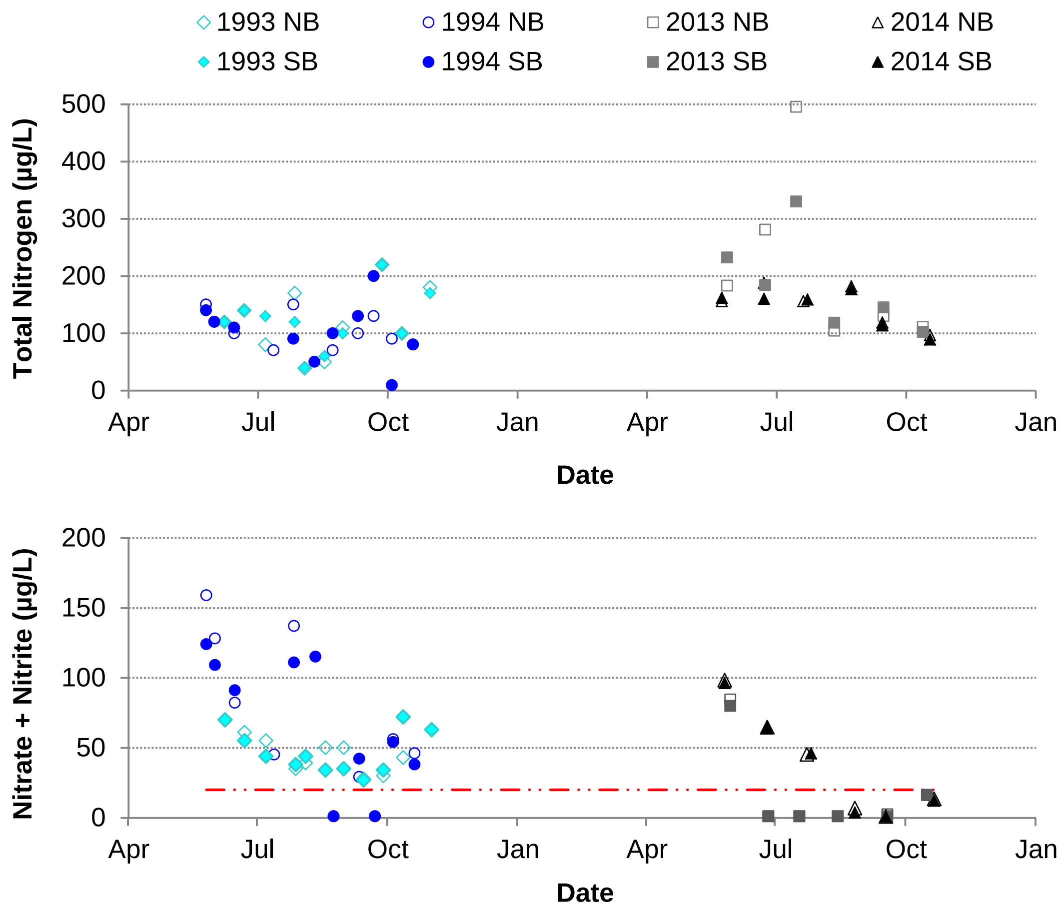


Figure 14 Epilimnetic total nitrogen and nitrate + nitrite concentrations at LS1 in the north basin (NB) and at LS2 in the south basin (SB) of Wahleach Reservoir for baseline years (1993-1994) and during nutrient restoration in 2013-2014. Red dashed line at 20 µg/L indicates the concentration considered limiting to phytoplankton growth. Values from 1993-1994 are for surface (0 m) samples; values from 2013-2014 are for 1 m samples.

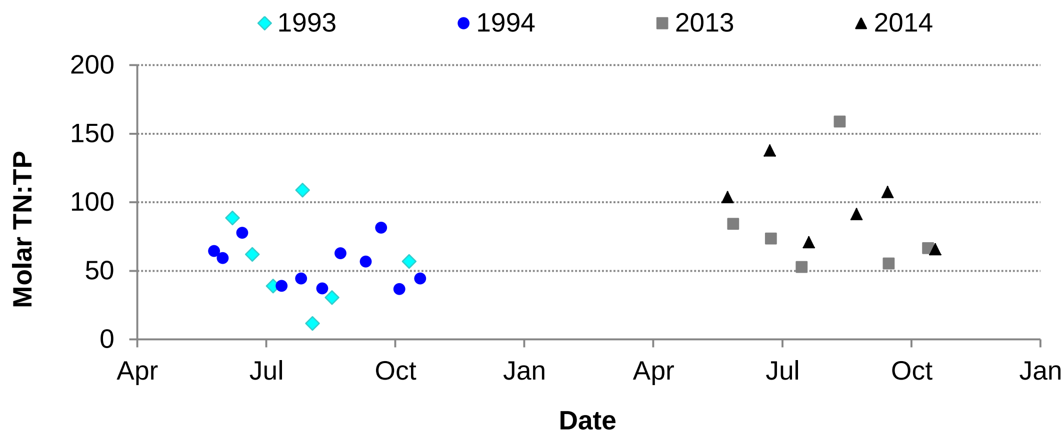


Figure 15 Molar epilimnetic total nitrogen (TN) to total phosphorus (TP) ratios for Wahleach Reservoir in baseline years (1993-1994), and during nutrient restoration in 2011-2012. Values from 1993-1994 are for 0 m surface samples; values from 2013-2014 are for 1 m samples.

3.4. Phytoplankton

Approximately the same number of phytoplankton species was observed in the two study years. In 2013 and 2014, a total of 59 and 51 phytoplankton species were identified in Wahleach Reservoir (Appendix A). No consistent trend was observed when comparing phytoplankton densities and biovolume in baseline years and treatment years (Figure 16). Mean phytoplankton densities in 2013 of 7,575 ± 4,679 cells/mL (mean of 2 stations) were similar to densities of 8,527 ± 2,370 cells/mL measured in the 1994, whereas in 2014 the densities of 15,374 ± 13,780 cells/mL were ~1.8 fold higher than those measured in the pre-treatment year (Figure 16). The opposite trend was observed for mean annual biovolume where biovolume was higher in 2013 relative to the pre-treatment year and in 2012 as lower relative to the pre-treatment year. In 2013 a biovolume concentration of 1.30 ± 1.15 mm^3/L was ~ 1.7 fold higher than 0.77 ± 0.25 mm^3/L measured in 1994 and in 2014 biovolume of 0.56 ± 0.32 mm^3/L was approximately 2 fold lower (Figure 16).

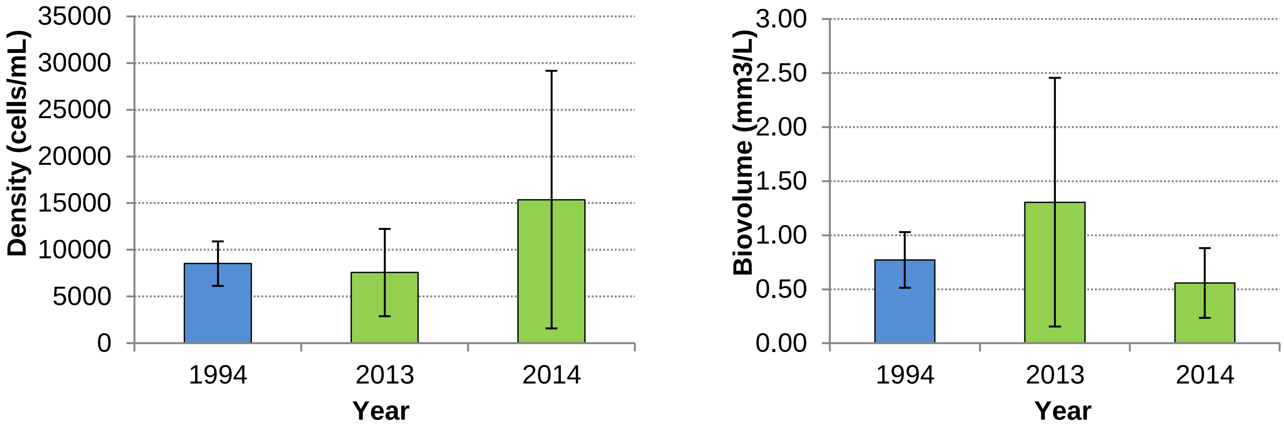


Figure 16 Seasonal mean abundance (±SD) and biovolume (±SD) of the phytoplankton community at LS1 in the north basin (NB) and LS2 in the south basin (SB) of Wahleach Lake Reservoir, 2013-2014.

The species composition of the phytoplankton community was also different between the two study years. Overall in 2013 chrysophytes and cryptophytes (*Chryso-* & *Cryptophyceae*) were the predominant phytoplankton class in Wahleach Reservoir accounting for 59.5% phytoplankton densities and 52.7% of the biovolume. The dominant species included *Ochromonas, Chrysochromulina*, *Dinobryon* and small microflagellates, which are in the edible size range for zooplankton. The phytoplankton community was distinctly different in 2014 where rather than a prevalence of chryso- & cryptophytes, cyanobacteria dominated the abundances accounting for 86.5% of the phytoplankton density but due to the small size of the species present cyanobacteria accounted for only 37% of the biovolume (Figure 17) while chrysophyte and cryptophyte accounted for 35% of biovolume (Figure 17). In both study years dinoflagellates were a minor component of the phytoplankton community accounting for less than 1% of cell densities and less than 5% of biovolume. Similarly while a diverse species assemblage was observed, chlorophytes densities and biovolumes were low in both study years. Generally, diatoms and dinophytes (*Dinophyceae*) made a greater contribution to the phytoplankton community during baseline years (Figure 17).

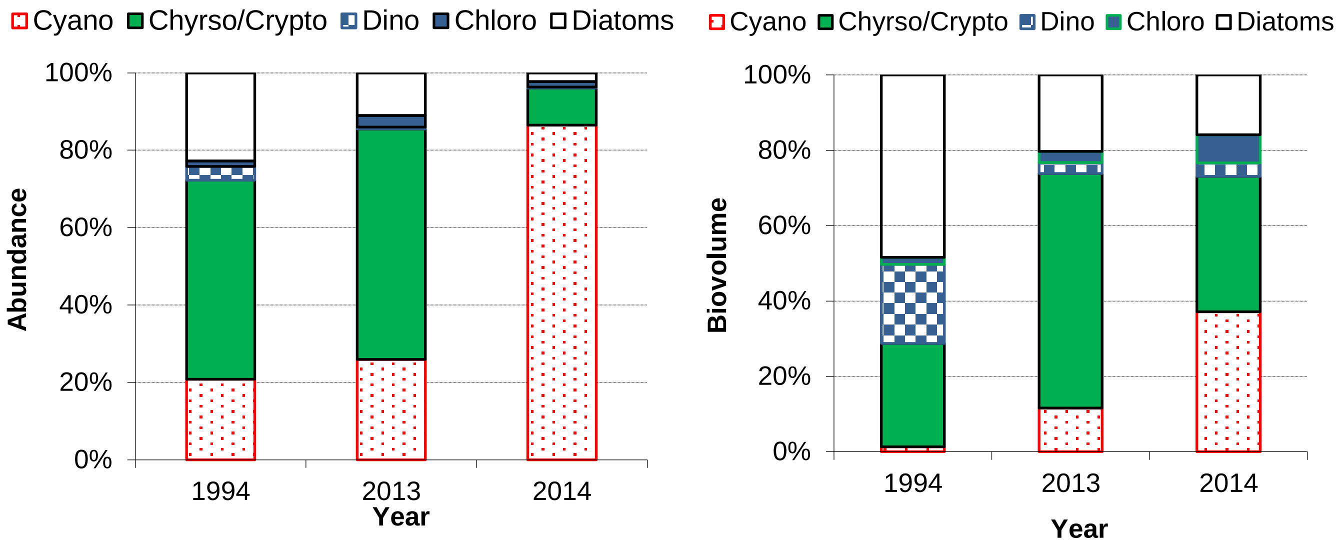


Figure 17 Relative contribution of major phytoplankton classes (Bacillariophyceae [diatoms], Dinophyceae, Chlorophyceae, Cyanophyceae, Chryso- & Cryptophyceae) to seasonal mean density (cells/L) and biovolume (mm^3/L) in Wahleach Reservoir for baseline years and during fertilization in 2013-2014.

The seasonal succession of the major phytoplankton classes was also different in each of 2013 and 2014. In terms of seasonal trends, chrysophytes and cryptophytes were prominent early in the season of both study years accounting for the majority of the phytoplankton densities in late spring and early summer. A large bloom of *Ochromonus* sp. was observed in July 2013 which accounted for a large 5 fold increase in biovolume (Figure 18). It is not uncommon to observe large blooms of chrysophytes and cryptophytes in Wahleach Reservoir. In June 2011, chryso- & cryptophytes densities peaked at 34,896 cells/mL which was approximately 10-times greater than the cell densities observed in the previous sampling month (3801 cells/mL). Starting in August 2013 and continuing into September, cyanophyte abundances increased but never attained the densities observed for the chryso- & cryptophytes. A mixed assemblage of cyanobacteria species was observed, consisting of *Synechococcus*, *Synnechocystic* but by far the most common species were *Microcystis* sp. In 2014, cyanobacteria densities largely consisting of *Merismopedia* sp were prominent from July through to October (Figure 18). *Merismopedia* sp is generally associated with the littoral zone of aquatic ecosystems and its prevalence in the pelagic zone suggests this littoral species is drifting off the littoral zone into the pelagic habitat of the reservoir. This close coupling of the two habitats highlights the close coupling between habitats due to the reservoirs relatively small size. *Merismopedia* sp may produce toxic microcystins but the densities observed in Wahleach Reservoir are not concerning (J. Stockner, pers. comm). Generally diatoms were a minor component of the phytoplankton community until

August and September where a small increase was observed. Dinoflagellates and chlorophytes showed little seasonality in both study years, maintaining low densities throughout the sampling season (Figure 18).

Seasonal patterns in biovolume generally followed abundance with the exception of cyanophytes, which accounted for very little biovolume even during their peak abundance (Figure 18). 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 class, and it ultimately reflects a combination of factors that increase and decrease the abundance and biomass of the community such as flushing, sinking and variable zooplankton grazing.

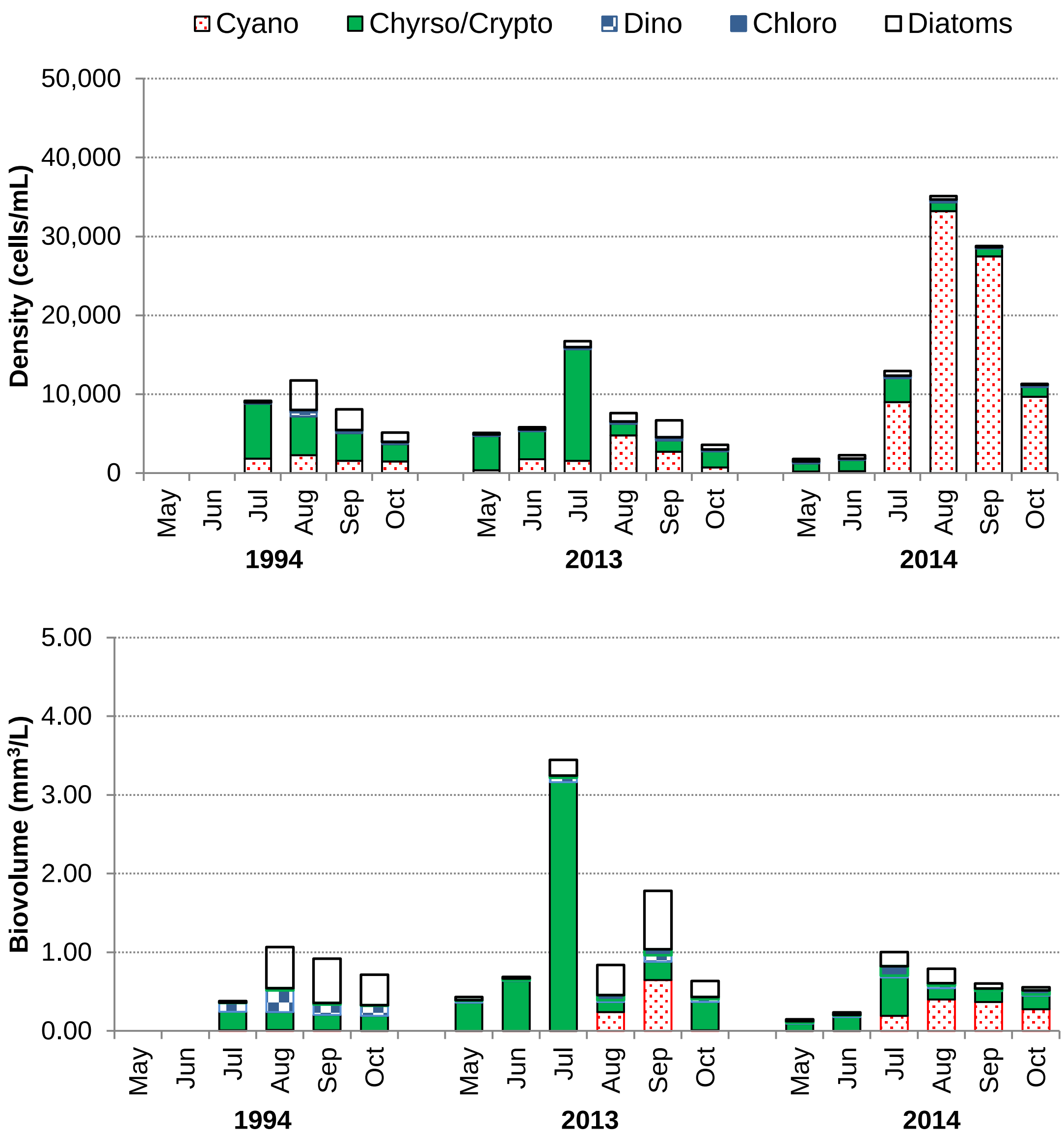


Figure 18 Abundance and biovolume of the major phytoplankton classes (*Cyanophyceae, Chryso-* & *Cryptophyceae, Dinophyceae, Chlorophyceae Bacillariophyceae* [diatoms]) in Wahleach Reservoir over the sampling season (May-October) during baseline years (1994) and during nutrient restoration in 2013-2014; values are averages of samples taken at LS1 (north basin) and LS2 (south basin).

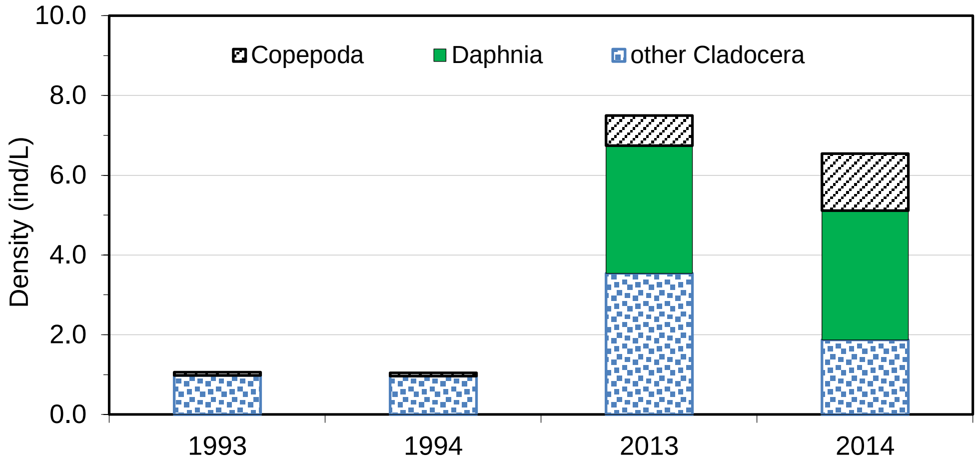
3.5. Zooplankton

Zooplankton species identified in Wahleach Reservoir during the 2013 and 2014 sampling seasons are shown in Appendix B. One cyclopoid copepod species, *Diacyclops bicuspidatus thomasi* was identified in the samples from the Wahleach Reservoir and six species of Cladocera were present in samples 2013-2014 (Appendix

B). *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. In 2013 & 2014 *Chydorus sphaericus* was present, albeit at low densities, in most samples from late June to October. *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 it is not surprising to find low densities of these two species in the pelagic habitat.

Zooplankton densities in 2013-2014 were significantly higher than those measured in 1993-1994 where densities increased from 1.05 ± 0.81 individuals/L in the pre-treatment era to 7.02 ±4.02 individuals/L in 2013 and 2014 (Figure 18). Zooplankton densities were slightly higher in 2013 at 7.50 ± 3.89 individuals/L than in 2014 at 6.54 ± 4.27 individuals/L which was largely due to a drop in cladocerans other than *Daphnia*. The density of *Daphnia* sp, the zooplankton species largely favoured by Kokanee remained static over the two year study period at 3.20 ± 3.44 individuals/L in 2013 and 3.24 ± 3.76 individuals/L in 2014. It is important to note that *Daphnia sp* were absent from the zooplankton community in 1993 and 1994 and now account for a large relative contribution to the zooplankton community (Figure 19). It is also important to note the strong seasonal cycle throughout the growing season as reflected by the high standard deviations for each zooplankton group.

Biomass data of the major zooplankton groups were not recorded during baseline studies. Mean annual zooplankton biomass for Wahleach Reservoir in 2013 was 100.36 ± 69.28 µg/L in 2013 and 91.08 ± 90.28 µg/L in 2014 (Figure 19). In 2013 and 2014 the vast majority of the mean annual biomass was accounted for by *Daphnia* sp and by other Cladocera (Figure 19). During these two study years, copepods were a minor component of the zooplankton community. In 2013, mean annual biomass of *Daphnia* sp. was 74.38 ± 73.35 µg/L, other cladocerans were 24.51 ± 38.54 µg/L, and copepods were 1.49 ± 1.51 µg/L. In summary, in 2013 74.1% of the total biomass was account for by *Daphnia* while cladocerans other than *Daphnia* account for 24.4% and finally copepods accounting for just 1.5% of the total zooplankton biomass. As was also seen in the zooplankton density data, the mean annual biomass was slightly lower in 2014 where mean annual biomass of *Daphnia* was 78.08 ± 93.63 µg/L, cladocerans other than *Daphnia* were 11.32 ± 16.74 µg/L, and copepods were 1.68 ± 1.25 µg/L. The community composition in 2014 was composed of 85.7% Daphnia sp, 12.4% cladocerans other than *Daphnia* and as seen in 2013, just 1.6% was accounted for by copepods. Overall, the zooplankton community in Wahleach Reservoir in 2013 and 2014 represent a significant increase in food availability for planktivores relative to baseline years.



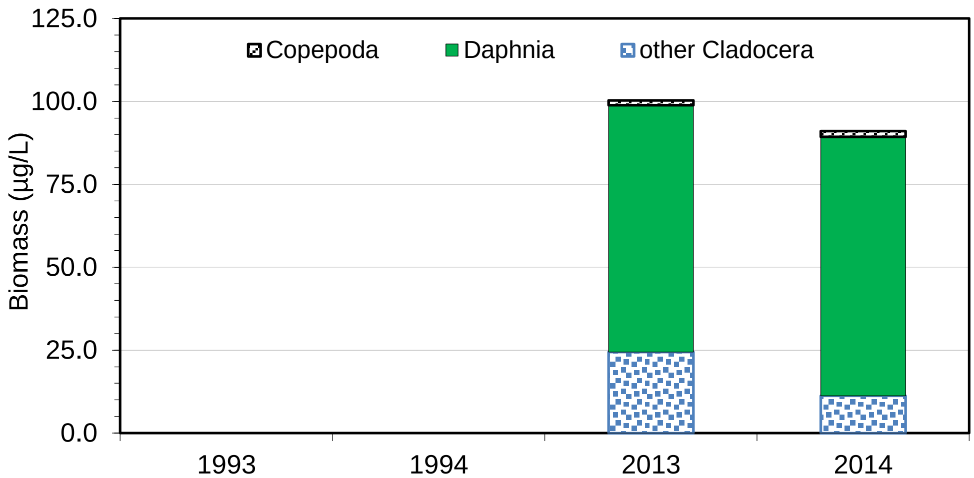


Figure 19 Mean annual zooplankton density and biomass of the major zooplankton groups (Copepoda, *Daphnia* spp. and other Cladocera) in Wahleach Reservoir, 2013 and 2014.

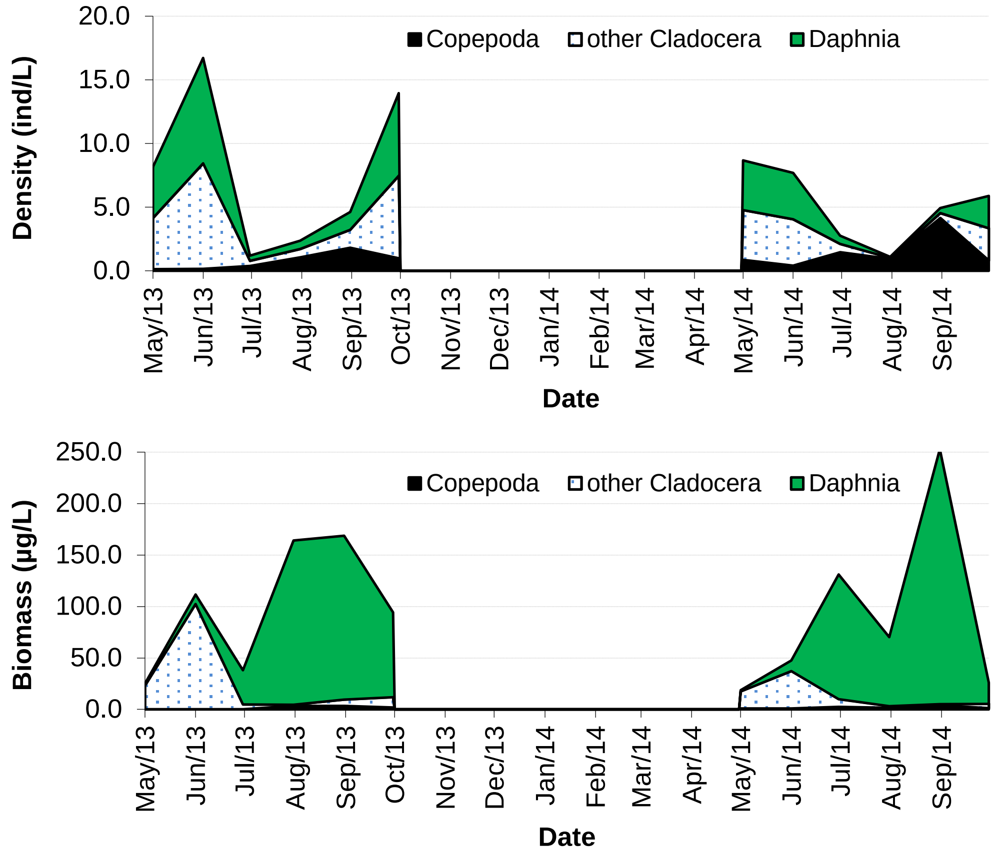


Figure 20 Monthly mean density (individuals/L) and biomass (µg/L) of major zooplankton groups (Copepoda, *Daphnia* spp. and other Cladocera) in Wahleach Reservoir over the sampling season (May-October), 2013- 2014.

At the beginning of both sampling seasons in May, moderate densities of zooplankton were found, averaging 4.26 ± 0.60 individuals/L in 2013 and 4.85 ± 1.5 individuals/L in 2014 (Figure 20). In 2013, mean densities increased as the season progressed reaching peak densities in August of 10.66 ± 5.18 individuals/L and 10.95 ± 1.9 individuals/L in October. The seasonal low in 2013 was observed in July where just 2.17 ± 0.24 individuals/L were measured. In 2014, mean densities followed a similar pattern but the seasonal low occurred in August, one month later than in 2013 and the seasonal peak occurred in September which was also one month later than it was observed in 2013. Peak densities in August averaged 14.89 ± 0.07 individuals/L, which were approximately 30% higher than peak densities in 2013. Unlike the high densities observed in the late fall in 2013, the densities measured were in the late fall in 2014 were similar to the densities observed at the start of the growing season (Figure 20).

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 averaging

25.2 ± 9.0 µg/L in 2013 and 18.7 ± 6.27 µg/L in 2014 (Figure 20). Biomass peaked in September in both study years at 168.8 ± 3.44 µg/L in 2013 and nearly 44% higher in 2014 at 252.9 ± 2.9 µg/L in 2013 (Figure 20).

As seen in other temperate systems, there is some notable seasonal succession in the zooplankton dataset. At the beginning of both sampling seasons, the zooplankton community in May and June was dominated by cladocerans other than *Daphnia*, primarily *Holopedium gibberum*, with low numbers of *Daphnia sp* and *Bosmia longirostris*. Starting in July in 2013 and June in 2014, the cladoceran community composition shifted from primarily *Holopedim gibberum* to primarily *Daphnia sp* which persisted until a late fall bloom of *Bosmia longirostris* appeared. *Daphnia* densities peaked in 2013 at 8.95 ± 4.4 individuals/L in August and in 2014 they peaked a month later in September at 10.35 ± 0.58 individuals/L while *Bosnia sp* peaked at 6.63 ± 0.92 individuals/L in late October 2013 and 2.83 ± 0.17 individuals/L in October 2014 (Figure 20). Copepods, primarily *Diacyclops bicuspidatus thomasi*, were present throughout the sampling season in both study years, though the densities were low in both years. *Diacyclops bicuspidatus thomasi*,densities peaked in September of both study years reaching 1.82 ± 0.42 in 2013 and doubling to 4.14 ± 0.69 individuals/L in 2014.

3.6. Fish

Nearshore Gillnetting and Minnow Trapping

During the 2013 nearshore gillnetting program, a total of 81 fish were caught; rainbow trout and cutthroat trout made up the majority of the catch followed by Kokanee (Table 5). Mean CPUE in 2013 was 0.36 ± 0.09 individuals per 100 m^2 net per hour. In 2014, a total of 114 fish were caught in nearshore gillnets; Rainbow Trout were the predominate species caught at 88 individuals (Table 5). Kokanee catch in 2014 was lower than in previous years (e.g. Hebert et al. 2013) with only 6 individuals caught (Table 5). Mean CPUE in 2014 was higher than in 2013 at 0.47 ± 0.29 individuals per 100 m^2 net per hour, though Kokanee CPUE was lower at 0.02 ± 0.03 individuals per 100 m^2 net per hour when compare to 2013 (0.07 ± 0.07 individuals per 100 m^2 net per hour) (Table 5).

Threespine stickleback catch (24 individuals) during minnow trapping improved with increased effort in 2013 (Table 6); catch in 2014 was also up compared to previous years (Hebert et al. 2013) with 17 individuals caught (Table 6). Mean Threespine Stickleback CPUE was 0.12 ± 0.25 fish per trap hour for 2013 and 0.15 ± 0.15 fish per trap hour for 2014 Table 6).

Table 5 Summary of fall nearshore gillnetting catch and catch-per-unit-effort (CPUE) for Wahleach Reservoir, 2013-2014. Species include Kokanee (KO), Cutthroat Trout (CT) and Rainbow Trout (RB)

	Catch					**CPUE** (individuals per 100 m^2 net per hour)			
Year	**Station**	**KO**	**CT**	**RB**	**Total**	**KO**	**CT**	**RB**	**Total**
2013	1S	1	12	0	13	0.03	0.31	0.00	0.34
	2F	5	7	4	16	0.13	0.18	0.10	0.40
	3F	6	1	4	11	0.17	0.03	0.11	0.32
	4F	0	4	9	13	0.00	0.11	0.25	0.37
	5S	2	2	4	8	0.06	0.06	0.11	0.22
	6S	1	5	11	20*	0.03	0.13	0.28	0.50
	Total	15	31	32	81	0.07	0.14	0.14	0.36
	Mean	-	-	-	-	0.07	0.14	0.14	0.36
	SD	-	-	-	-	0.07	0.10	0.10	0.09
2014	1S	0	6	4	10	0.00	0.13	0.09	0.22
	2F	3	0	21	24	0.06	0.00	0.45	0.52
	3F	0	3	23	26	0.00	0.11	0.85	0.96
	4F	0	0	26	26	0.00	0.00	0.54	0.54
	5S	1	4	2	7	0.02	0.08	0.04	0.14
	6S	2	7	12	21	0.04	0.14	0.25	0.43
	Total	6	20	88	114	0.02	0.08	0.33	0.43
	Mean	-	-	-	-	0.02	0.08	0.37	0.47
	SD	-	-	-	-	0.03	0.06	0.31	0.29

* 3 fish caught were unidentified or hybrids, so total value is greater than sum of species catch

Table 6 Summary of minnow trap catch and catch-per-unit-effort (CPUE) for Wahleach Reservoir, 2013-2014

	Catch					CPUE (individuals per trap per hour)			
Year	**Station**	**TSB**	**RB**	**Hybrid (RB/CT)**	**Total**	**TSB**	**RB**	**Hybrid (RB/CT)**	**Total**
2013	1M	1	0	0	1	0.06	0.00	0.00	0.06
	2M	0	0	0	0	0.00	0.00	0.00	0.00
	3M	0	0	0	0	0.00	0.00	0.00	0.00
	4M	1	0	0	1	0.06	0.00	0.00	0.06
	5M	0	1	0	1	0.00	0.06	0.00	0.06
	6M	1	2	0	3	0.06	0.11	0.00	0.17
	7M	0	0	0	0	0.00	0.00	0.00	0.00
	8M	14	0	0	14	0.78	0.00	0.00	0.78
	9M	7	0	0	7	0.39	0.00	0.00	0.39
	10M	0	1	1	2	0.00	0.06	0.06	0.11
	11M	0	0	0	0	0.00	0.00	0.00	0.00
	Total	24	4	1	29	0.12	0.02	0.01	0.15
	Mean	-	-	-	-	0.12	0.02	0.01	0.15
	SD	-	-	-	-	0.25	0.04	0.02	0.24
2014	1M	0	0	0	0	0.00	0.00	0.00	0.00
	2M	2	0	0	2	0.11	0.00	0.00	0.11
	3M	17	0	0	17	0.95	0.00	0.00	0.95
	4M	0	0	0	0	0.00	0.00	0.00	0.00
	5M	0	0	0	0	0.00	0.00	0.00	0.00
	6M	0	0	0	0	0.00	0.00	0.00	0.00
	7M	0	0	0	0	0.00	0.00	0.00	0.00
	Total	19	0	0	19	0.15	0.00	0.00	0.15
	Mean	-	-	-	-	0.15	0.00	0.00	0.15
	SD	-	-	-	-	0.36	0.00	0.00	0.36

Kokanee

In 2013 and 2014, the mean length of Kokanee caught in gillnets was 216 ± 32 mm and 207 ± 47 mm, respectively. Mean weight of Kokanee in 2013 was 128.2 ± 62.3 g and in 2014 was 116.6 ± 74.5 g. Both mean length and mean weight of Kokanee in 2013 and 2014 were higher than in baseline years despite age 2+ Kokanee catch in 2013 and 2014 being less than half of what it was during baseline (Table 7, Figure 21). As expected, no 3+ or 4+ Kokanee were captured during the 2013 and 2014 nearshore gillnetting programs (Figure 21); 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. Length frequency distributions for Kokanee show no individuals over 220 mm were caught during baseline years, while in 2013 and 2014 over 20% of the Kokanee caught were in the 221-290 mm size range (Figure 22). Furthermore, Kokanee of the same age caught during nutrient restoration years were larger than those caught prior. Mean length-at-age data show 1+ and 2+ Kokanee caught in 1993-94 were significantly smaller than during 2013-2014 (Figure 23). Condition factors of Kokanee in 2013 (1.19 ± 0.06) and 2014

(1.15 ± 0.06) were greater than in baseline years (0.97 ± 0.10) (Table 7). And, the slopes of the Kokanee length-weight regressions for 2013 and 2014 are greater than prior to nutrient restoration (Table 8,Table 7, Figure 24); both of which suggest Kokanee growth conditions were better during 2013 and 2014 than in baseline years.

Table 7 Summary of Kokanee biometric data, including length, weight, condition factor (CF) and age, for Wahleach Reservoir in baseline years (1993-1994) and during nutrient restoration in 2013 and 2014

	Year	Mean	SD	Max	Min	n
Length	1993-94	170	23	217	115	107
(mm)	2013	216	32	286	173	14
	2014	207	47	262	152	6
Weight	1993-94	50.2	17.5	86.3	15.5	107
(g)	2013	128.2	62.3	275.0	56.0	14
	2014	116.6	74.5	208.5	40.5	6
CF	1993-94	0.97	0.10	1.14	0.56	107
	2013	1.19	0.06	1.30	1.08	14
	2014	1.15	0.06	1.23	1.04	6
Age	1993-94	1.8	0.4	2	1	107
	2013	1.4	0.5	2.0	1.0	14
	2014	1.3	0.5	2	1	6

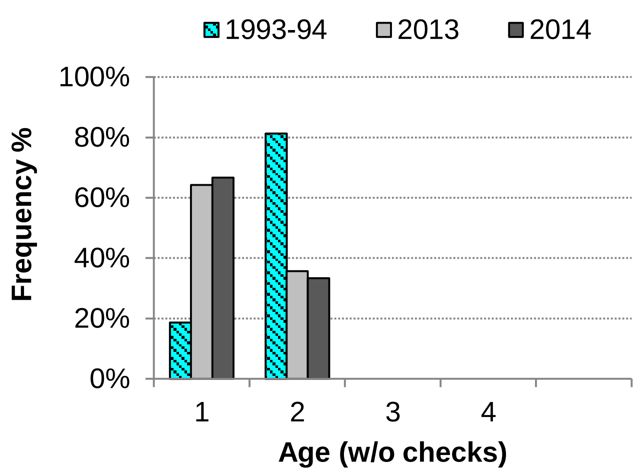


Figure 21 Age frequency distribution of Kokanee caught in gillnets during baseline years (1993-1994) and nutrient restoration in 2013-2014, Wahleach Reservoir.

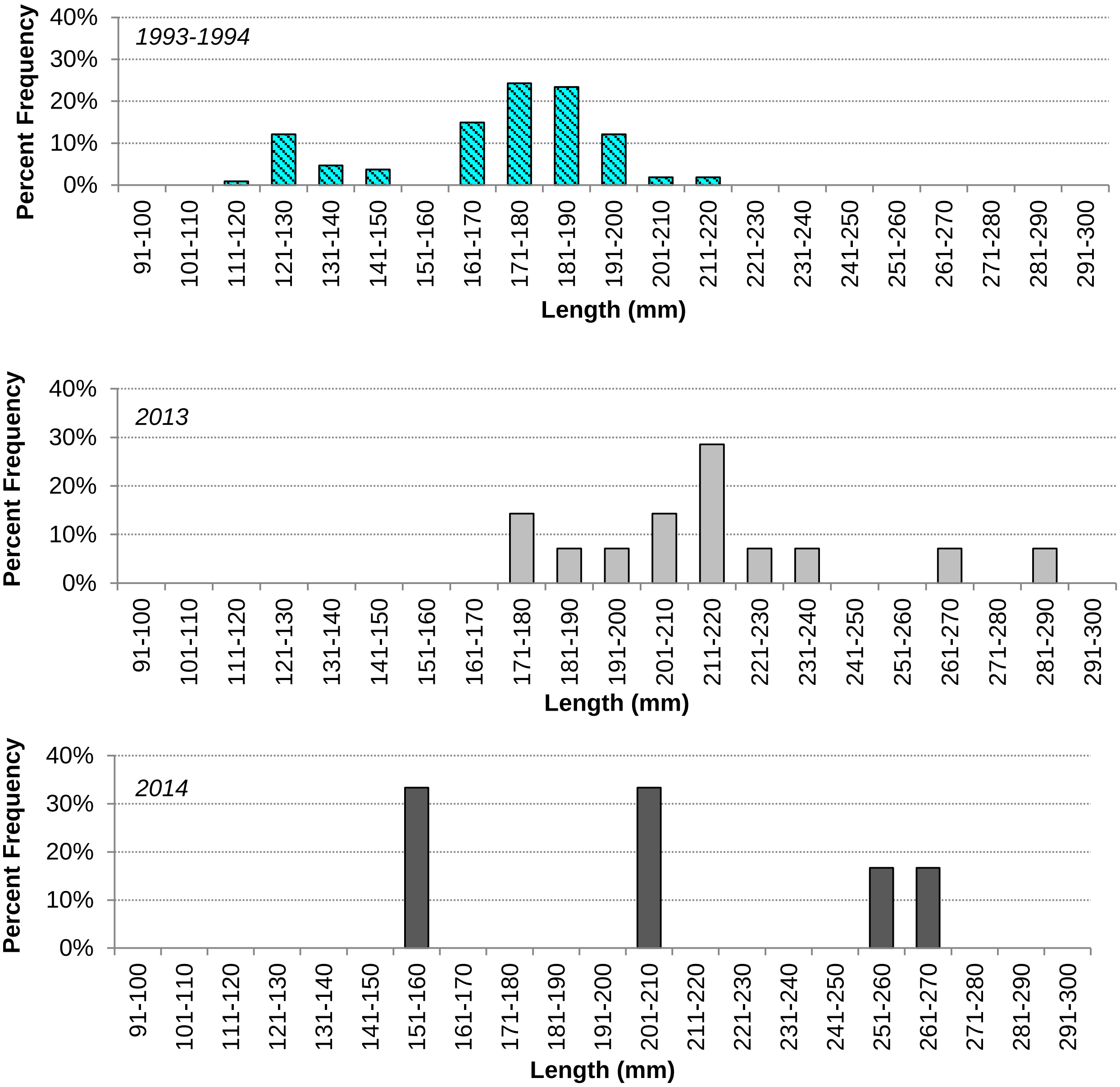


Figure 22 Length frequency distribution of Kokanee caught in gillnets during baseline years (1993-94) and during nutrient restoration in 2013 and 2014, Wahleach Reservoir.

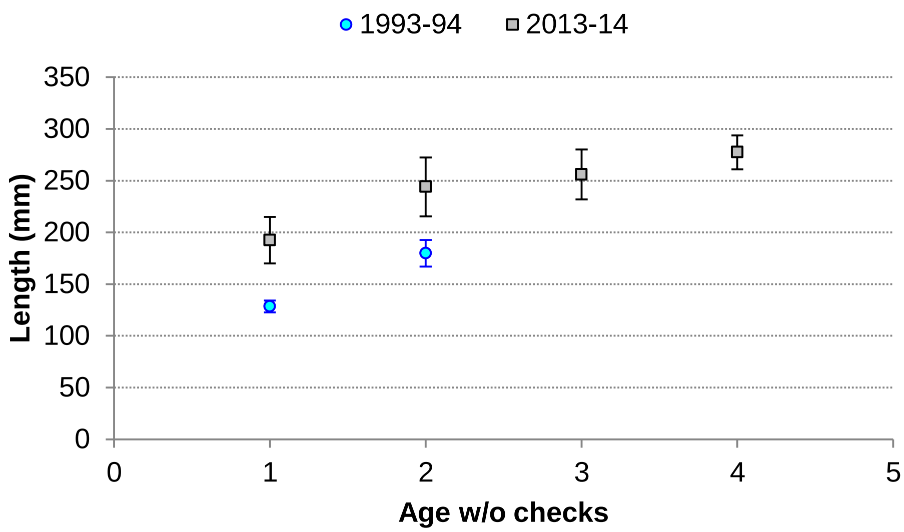


Figure 23 Mean length-at-age (± SD) for Wahleach Reservoir Kokanee in baseline years (1993-1994) and during nutrient restoration in 2013-2014; baseline data represents Kokanee sampled during gillnetting; 2013 and 2014 data includes Kokanee sampled during gillnetting (ages 1+ to 2+) and spawner surveys (ages 2+ to 4+).

Table 8 Summary of variables for Kokanee length weight relationships ($W = a \cdot L^b$; $\log W = b \cdot \log L + \log a$) in baseline years (1993-94) and during nutrient restoration in 2013 and 2014, Wahleach Reservoir

Year	a	b	R^2
1993-94	0.0130	2.8946	0.9377
2013	0.0073	3.1569	0.9880
2014	0.0079	3.1216	0.9953

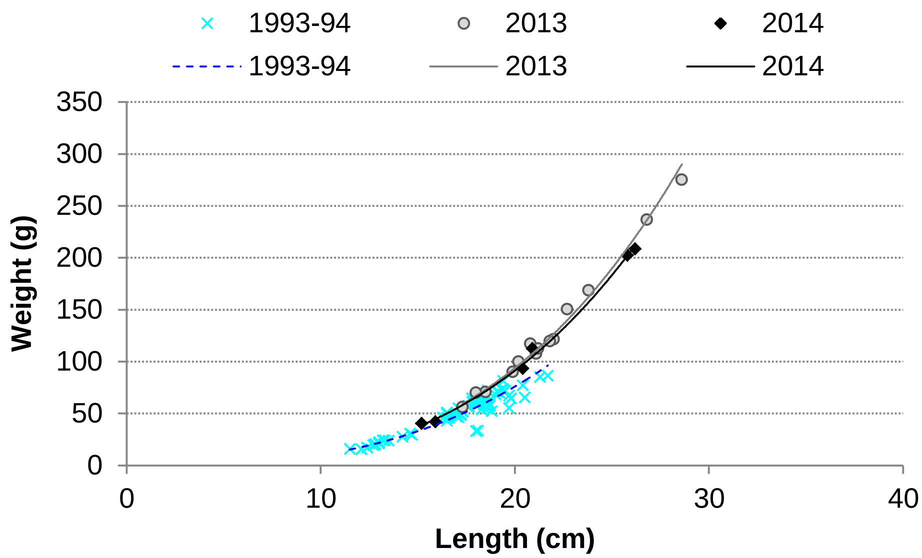


Figure 24 Length weight plot and relationship ($W = a \cdot L^b$) of Kokanee caught in gillnets in baseline years (1993-1994) and during nutrient restoration in 2013 and 2014, Wahleach Reservoir

<u>Rainbow Trout</u>

Rainbow Trout caught in 2013 and 2014 were generally larger than in baseline years (i.e. greater mean length and mean weight; Table 9). The patterns observed in mean lengths and weights were largely explained by differences in age classes of captured fish; there was a greater percentage of age 3+ to age 5+ caught in 2013 and 2014 than in baseline years (Figure 25). Rainbow trout caught during 2013 and 2014 were relatively evenly distributed amongst size and age classes with a higher percentage of older and larger fish relative to baseline (Figure 25, Figure 26). Mean length-at-age data show age 1+ to 3+ rainbow trout were larger during 2013-2014 than in baseline years (Figure 27). As well, the slopes of rainbow trout length-weight regressions for the nutrient restoration era were greater than baseline suggesting rainbow trout of any given length were also heavier (Table 10, Figure 28); this was supported by condition factor calculations (Table 9).

Table 9 Summary of rainbow trout biometric data, including length, weight, condition factor (CF) and age, for Wahleach Reservoir in baseline years (1993-1994) and during nutrient restoration in 2013 and 2014

	Year	Mean	SD	Max	Min	n
Length	1993-94	186	45	329	109	374
(mm)	2013	205	73	318	78	35
	2014	230	64	335	110	84
Weight	1993-94	71.5	52.0	316.2	13.9	374
(g)	2013	124.6	96.0	356.0	4.9	36
	2014	156.8	95.7	377.5	15.5	84
CF	1993-94	0.99	0.33	5.24	0.52	374
	2013	1.05	0.07	1.25	0.91	35
	2014	1.12	0.35	3.89	0.84	88
Age	1993-94	2.0	0.6	4	1	372
	2013	2.2	1.7	5	0	35
	2014	2.4	1.0	5	1	86

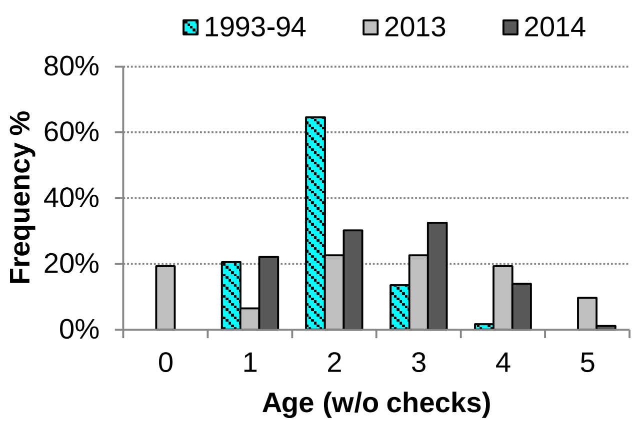


Figure 25 Age frequency distribution of rainbow trout caught in gillnets during baseline years (1993-1994) and nutrient restoration in 2013-2014, Wahleach Reservoir.

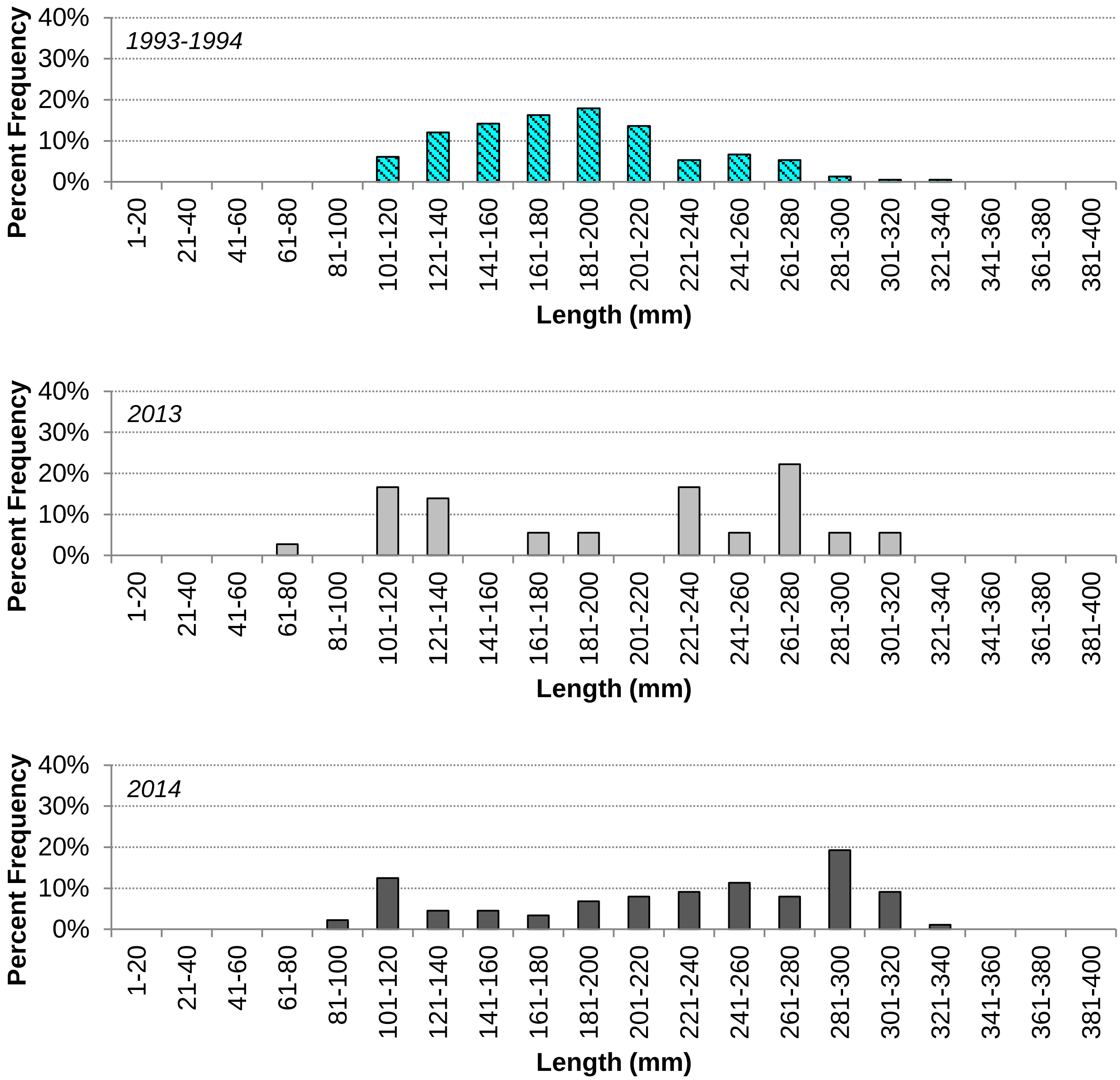


Figure 26 Length frequency distribution of rainbow trout caught in gillnets in baseline years (1993-1994) and during nutrient restoration in 2013 and 2014, Wahleach Reservoir.

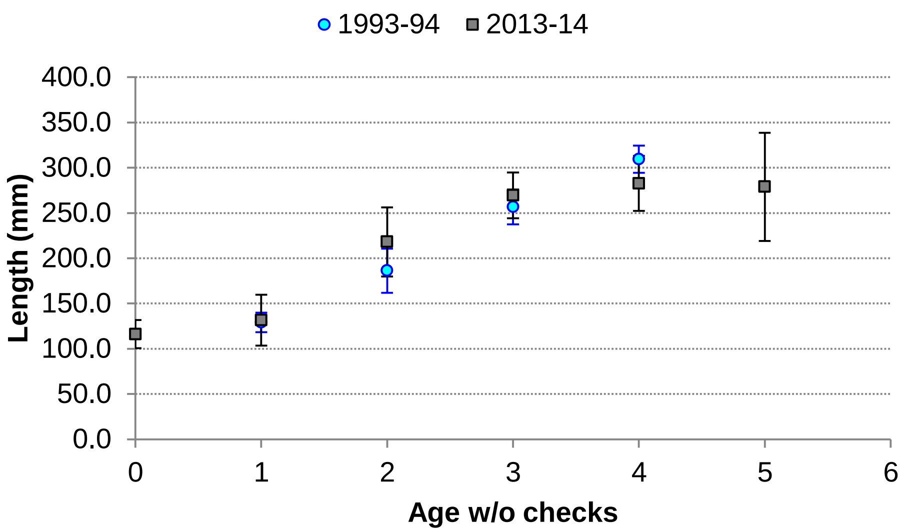


Figure 27 Mean length-at-age (±SD) for Wahleach Reservoir rainbow trout in baseline years (1993-1994) and during nutrient restoration in 2013-2014.

Table 10 Summary of variables for rainbow trout length weight relationships ($W = a \cdot L^b$; $\log W = b \cdot \log L + \log a$) in baseline years (1993-94) and during nutrient restoration in 2013 and 2014, Wahleach Reservoir

Year	a	b	R^2
1993-94	0.0247	2.6765	0.9286
2013	0.0121	2.9634	0.9691
2014	0.0188	2.8237	0.9691

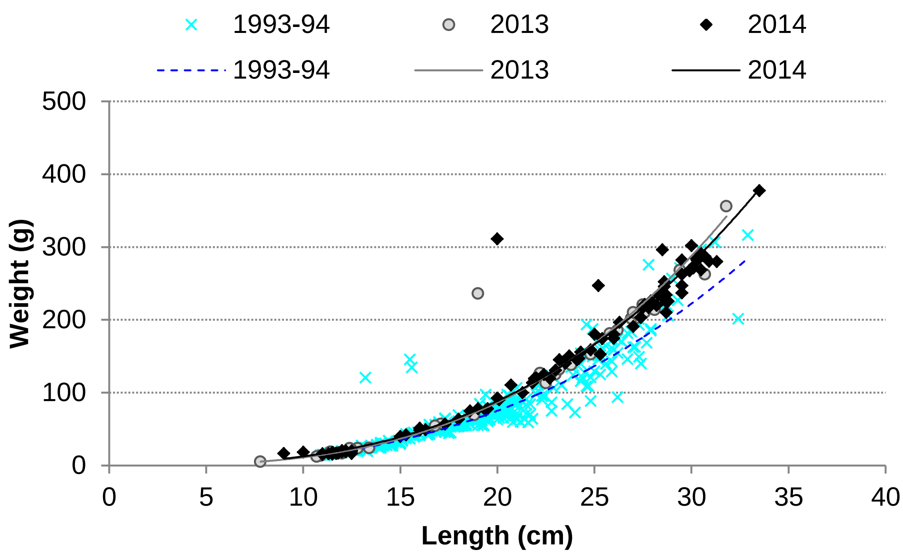


Figure 28 Length weight plot and relationship (W = a · L^{b}) of rainbow trout caught in gillnets during baseline years (1993-1994) and during nutrient restoration years in 2013 and 2014, Wahleach Reservoir.

In addition to Rainbow Trout caught in nearshore nets, four juvenile (age 0+) Rainbow Trout were caught during minnow trapping in 2013 (Table 11); no juvenile salmonids were caught during minnow trapping in 2014.

Table 11 Summary of juvenile (age 0+) Rainbow Trout lengths, weights, and condition factors (CF) for Wahleach Reservoir during nutrient restoration in 2013

	Year	Mean	SD	Max	Min	n
Length (mm)	2013	107	20	121	78	4
Weight (g)	2013	12.9	5.9	18.2	4.9	4
CF	2013	0.99	0.04	1.03	0.94	4

<u>Cutthroat Trout</u>

Sterile Cutthroat Trout were introduced to Wahleach Reservoir as part of the nutrient restoration project, thus no comparisons were made to baseline years. Cutthroat trout caught in 2014 had larger mean lengths and weights compared to 2013 with a greater representation of older individuals (Table 12, Figure 29). Length frequency distributions of Cutthroat Trout in 2013 and 2014 each had a single mode with the majority of individuals in the 261-280 mm and 321-340 mm size ranges, respectively; although neither distribution had ideal coverage of all sizes. Similarly, condition factors and the slope of length-weight regressions in 2014 were greater in than in 2013 (Table 12, Table 13, Figure 31).

Table 12 Summary of Cutthroat Trout biometric data, including length, weight, condition factor (CF) and age, for Wahleach Reservoir during nutrient restoration in 2013 and 2014. Cutthroat Trout were not present in Wahleach Reservoir prior to nutrient restoration

	Year	Mean	SD	Max	Min	n
Length	2013	301	85	539	200	31
(mm)	2014	332	65	511	258	20
Weight	2013	302.5	283.5	1250.0	76.0	31
(g)	2014	398.3	248.2	1200.0	169.5	20
CF	2013	0.97	0.33	2.44	0.40	31
	2014	1.02	0.29	2.20	0.79	20
Age	2013	1.8	0.5	2	1	4
	2014	2.8	0.9	5	2	19

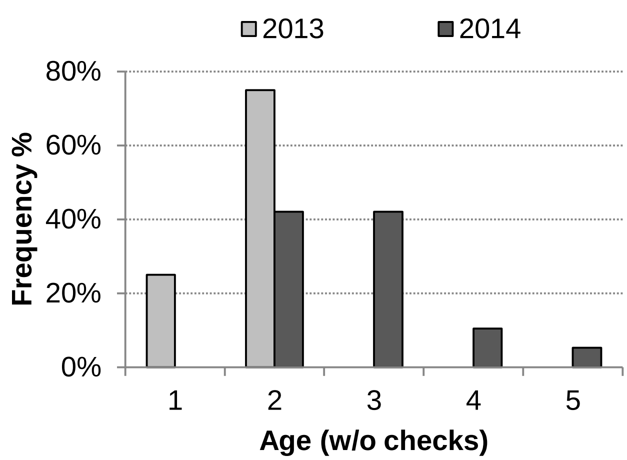


Figure 29 Age frequency distribution of Cutthroat Trout caught in gillnets during nutrient restoration in 2013-2014, Wahleach Reservoir.

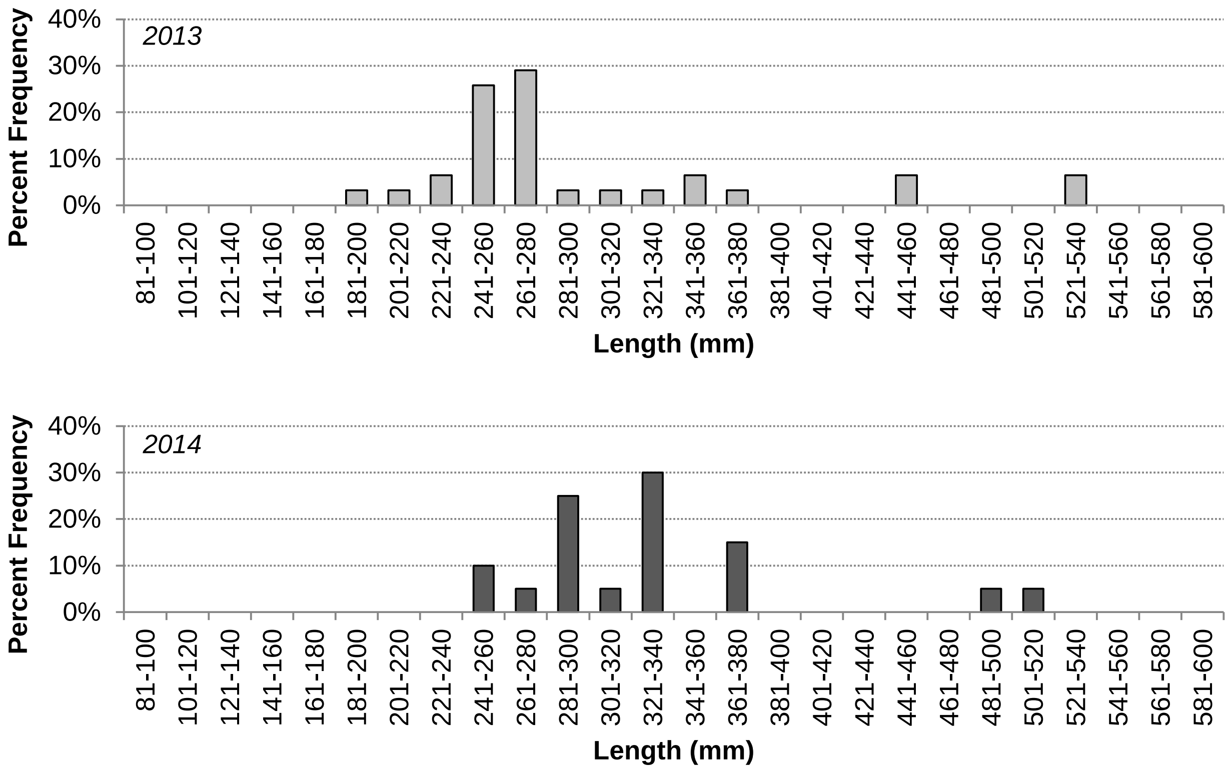


Figure 30 Length frequency distribution of Cutthroat Trout caught in during 2013 and 2014 gillnetting program in Wahleach Reservoir.

Table 13 Summary of variables for cutthroat trout length weight relationships ($W = a \cdot L^b$; $\log W = b \cdot \log L + \log a$) during nutrient restoration in 2013 and 2014, Wahleach Reservoir. Cutthroat trout were not present in Wahleach Reservoir prior to nutrient restoration.

Year	a	b	R^2
2013	0.0455	2.5306	0.8508
2014	0.0421	2.5875	0.8459

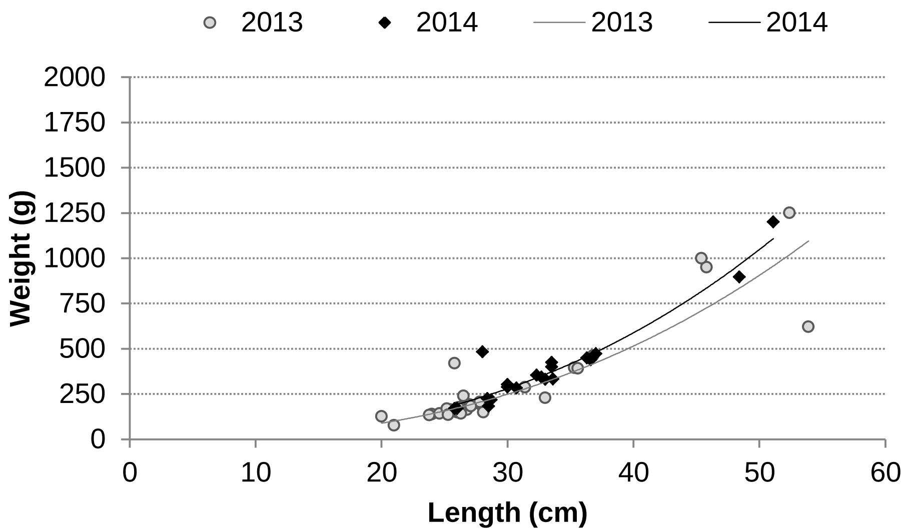


Figure 31 Length weight plot and relationship ($W = a \cdot L^b$) of cutthroat trout caught in gillnets during nutrient restoration years in 2013 and 2014, Wahleach Reservoir.

<u>Threespine Stickleback</u>

When comparing amongst baseline years and during nutrient restoration in 2013-2014, Threespine Stickleback mean length, weight and condition factor were all greater prior to nutrient additions (Table 14). Numerous Threespine Stickleback samples in 2013 and 2014 had large tapeworms in their gut, so actual fish weights would be overestimated in Table 14. Furthermore, Threespine Stickleback catch has dramatically decreased since the beginning of the study (Table 6, also sample size in Table 14).

Table 14 Summary of threespine stickleback length and weight data for Wahleach Reservoir in baseline years (1993-1994) and during nutrient restoration in 2013 and 2014

	Year	Mean	SD	Max	Min	n
Length	1993-94	52	7	62	31	251
(mm)	2013	37	4	44	22	24
	2014	42	5	53	35	19
Weight	1993-94	1.6	0.5	2.8	0.4	251
(g)	2013	0.5	0.2	0.8	0.1	24
	2014	0.7	0.3	1.7	0.4	19

Kokanee Spawner Surveys

Timing of the 2013 and 2014 Kokanee runs was similar; Kokanee were observed in index streams by the second week of September with peak numbers in late September and most of the spawning completed by early October (Figure 32). In 2013, the low count on September 21 was the result of turbid stream conditions and was not considered representative of an actual decrease in spawner numbers (Figure 32).

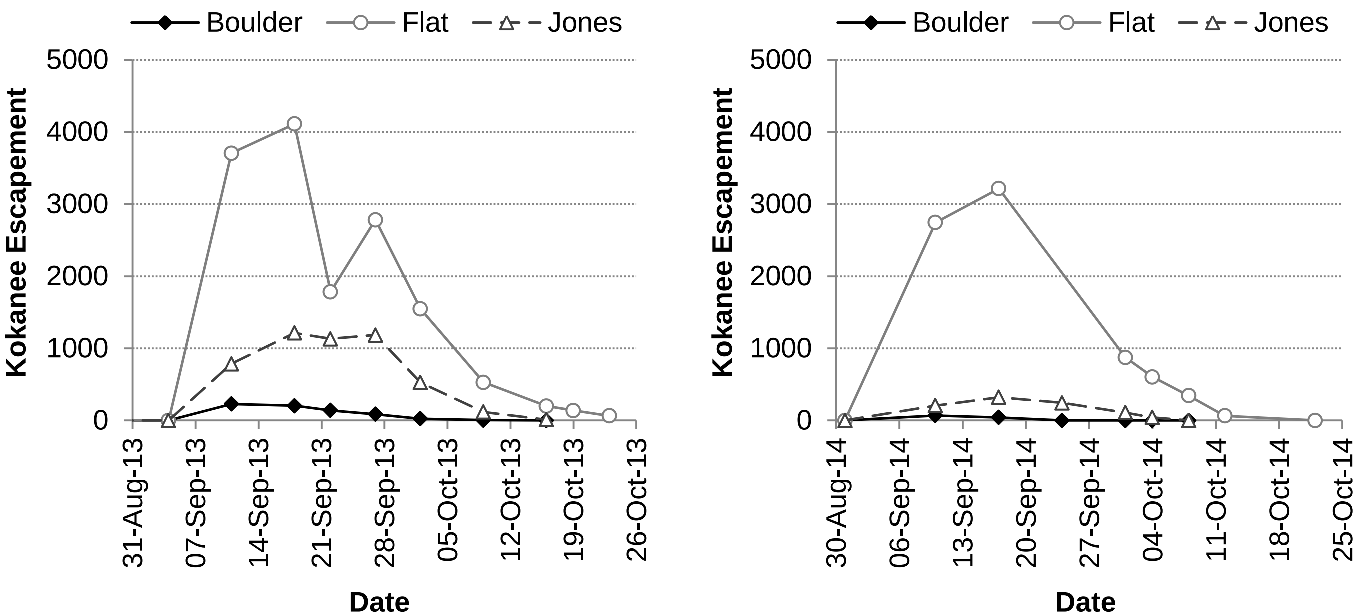


Figure 32 Kokanee spawner counts from each index stream (Boulder Creek, Flat Creek, and Jones Creek) during the 2013 and 2014 spawning seasons in Wahleach Reservoir.

Kokanee escapement was 14,862 fish in 2013 (442 Boulder; 11,389 Flat; 3,032 Jones) and 8,424 fish in 2014 (100 Boulder; 7,609 Flat; 716 Jones) (Figure 33). In both years, Flat Creek had the most spawners, followed by Jones Creek, and then Boulder Creek; a pattern observed for the past several years. Escapement results over the past decade showed a dominant Kokanee run every four years; the last peak run was in 2010 and so the next peak would have been expected in 2014. As Figure 33 shows, the peak came in 2013, one year earlier than expected; age 2+ fish made up approximately 40% of the run in 2013 (Figure 34) which is greater than typically seen in Wahleach Reservoir (e.g. Hebert et al. 2013) and likely resulted in the shift of the peak run.

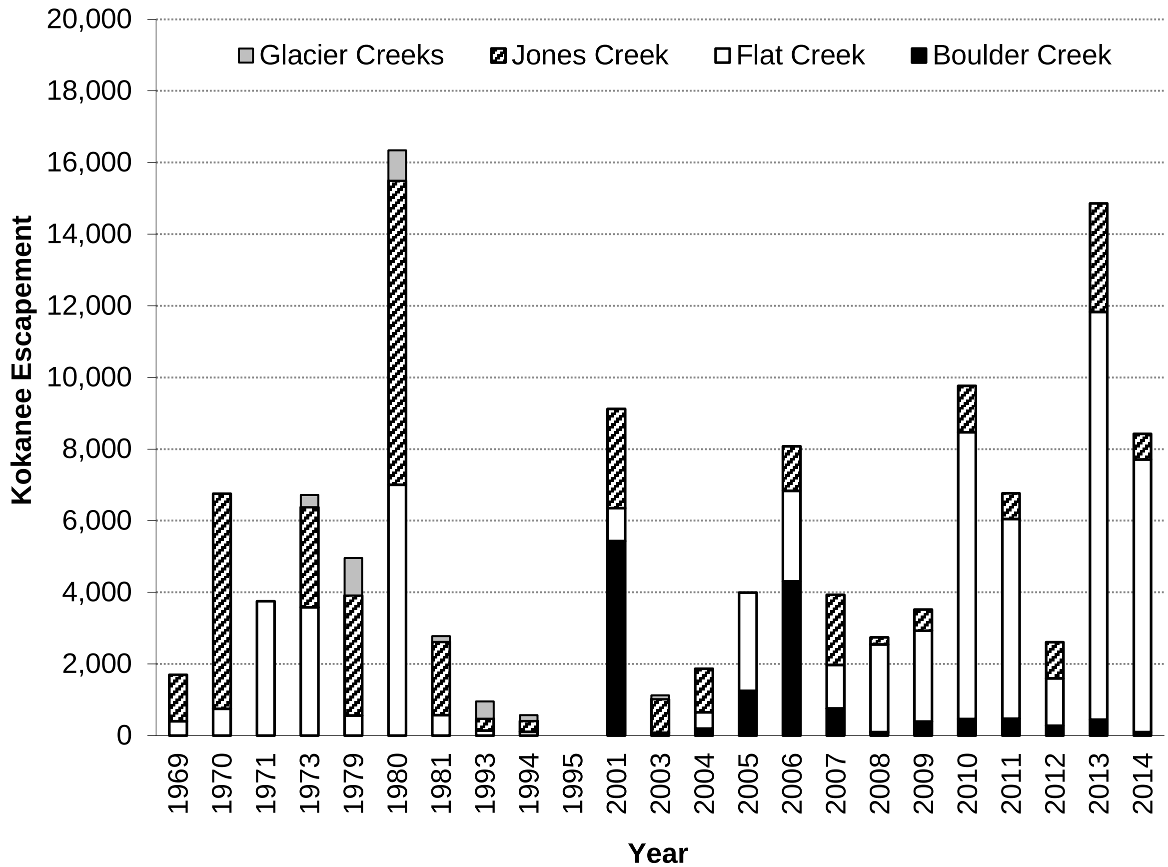


Figure 33 Annual Kokanee escapement estimates in Wahleach Reservoir.

Kokanee samples were of generally classified as spawning or spent, as so weights were not considered representative and condition factors were not reported. Mean fork length of Kokanee spawners was 241 ± 24 mm in 2013 and 273 ± 16 mm in 2014 (Table 15). The majority of spawners in both years were age 3+ (Figure 34). In 2013, age 4+ spawners were rare, while in 2014 approximately 20% of spawners were age 4+ (Figure 34). Length frequency distributions were distinct; the 2013 distribution showed two modes with the dominant size class being 231-240 mm (Figure 35), reflective of the split between age 2+ and age 3+ spawners. In 2014, the dominant size class was 261-270 mm followed closely by 271-280 mm and 281-290 mm (Figure 35).

Table 15 Summary of Kokanee biometric data – including post-orbital hypural length (POHL), fork length (FL), weight and age – during the 2013 and 2014 spawning seasons in Wahleach Reservoir. Data are for all three index streams combined: Boulder Creek, Flat Creek, and Jones Creek. All 2013 FL data are calculated values based on a 2008-2014 regression equation ($y = 1.4876x - 49.869$, $R^2 = 0.969$) for years when both POHL and FL were measured

	Year	Mean	SD	Max	Min	n
POHL	2013	195	16	280	174	77
(mm)	2014	216	13	246	181	64
FL	2013	241	24	367	209	77
(mm)	2014	273	16	310	236	64
Weight	2013	149.6	35.7	218.0	83.0	77
(g)	2014	258.4	50.2	401.0	159.0	64
Age	2013	2.6	0.5	4	2	77
	2014	3.1	0.5	4	2	59

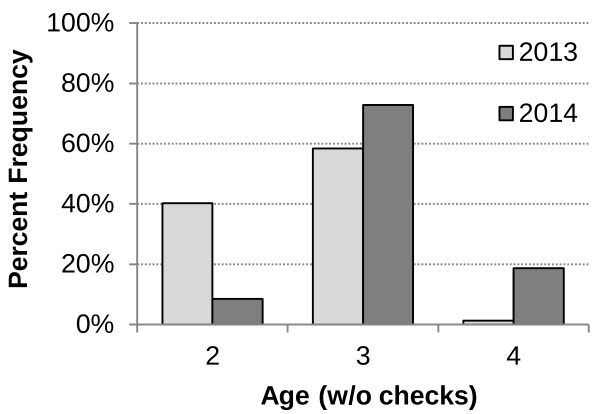


Figure 34 Age frequency distribution of Kokanee spawners caught in index streams (Boulder Creek, Flat Creek and Joes Creek) of Wahleach Reservoir during 2013-2014.

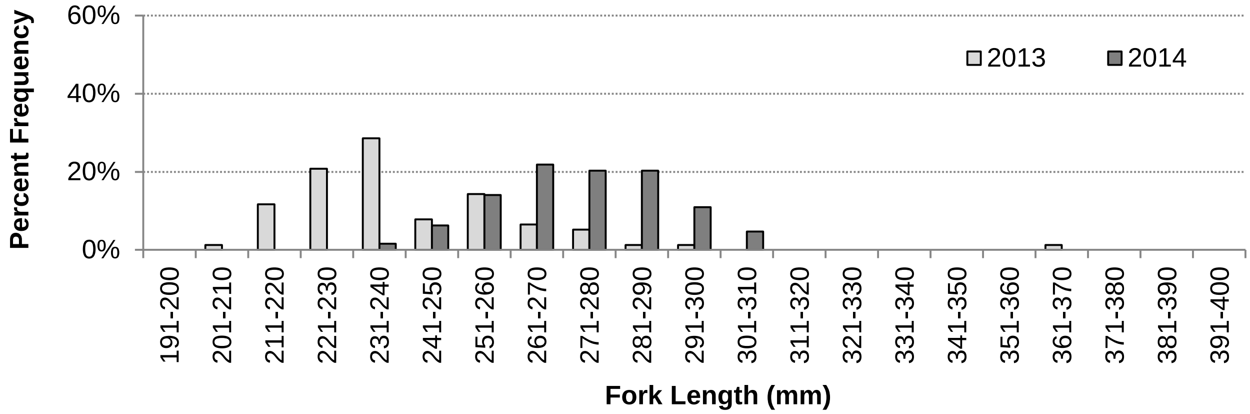


Figure 35 Length frequency distribution of Kokanee spawners for 2013 and 2014, Wahleach Reservoir. Values for 2014 represent measured fork lengths; values for 2013 are calculated fork lengths based on a 2008-2014 regression equation (y = 1.4876x - 49.869, R^2 = 0.969) for years when both POHL and FL were measured.

Hydroacoustics

Acoustic Target Size Distribution

The acoustic target size distribution was split at 6 m depth to more accurately represent the Kokanee population (Figure 36). Targets above 6 m were in the small fish decibel size range and were expected to represent Threespine Stickleback based on their smaller size and presence in warmer epilimnetic water (Figure 36). Supporting trawl and gillnet data validate the exclusion of fish targets above 6 meters to refine the Kokanee population estimate.

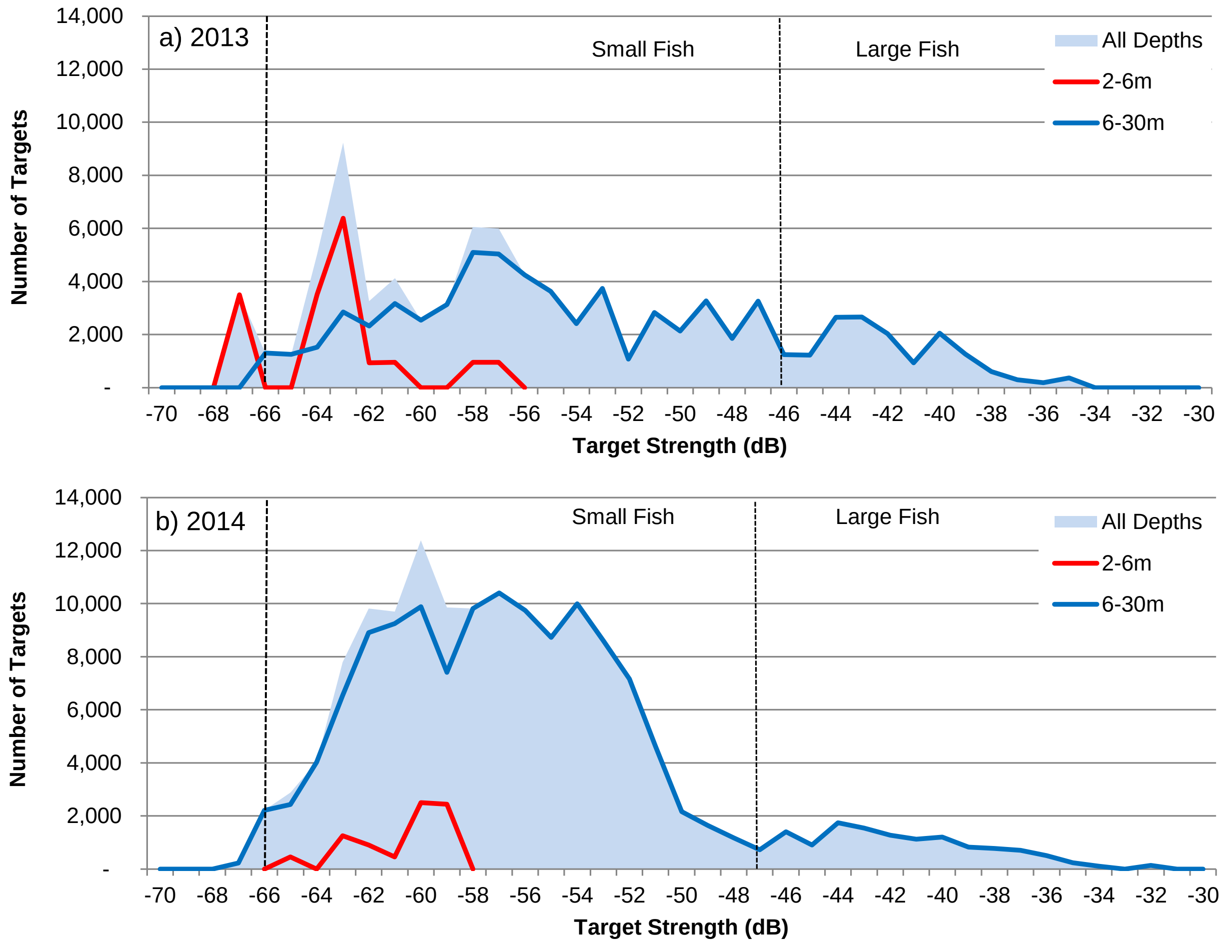


Figure 36 Wahleach Reservoir acoustic fish target distributions for (a) August 8, 2013 and (b) August 18, 2014. The number of targets represents acoustic density data expanded by area to produce a population by acoustic decibel bin. The dotted lines indicate the decibel threshold used to separate noise from small fish sized targets, and small fish sized targets from large fish sized targets.

<u>Density and Distribution</u>

Detailed density data are located in Appendix G and Appendix H.

Kokanee fry densities in 2013 ranged from 74-420 fish·ha^{-1} (Figure 37a) and averaged 216 ± 125 fish·ha^{-1} (± SD). The highest densities of Kokanee fry were found in the deepest part of the reservoir between transects 3 and 9. Threespine Stickleback in water less than 6 meters were relatively evenly distributed across the reservoir in low densities, averaging 37 ± 28 fish·ha^{-1} (Figure 37a).

Kokanee fry densities in 2014 were greater and more variable than in 2013, ranging from 63-1173 fish·ha^{-1} (Figure 37b) and averaging 535 ± 423 fish·ha^{-1}. Similar to 2013, the highest densities of Kokanee fry in 2014 were found in the deepest part of the reservoir between transects 3 and 9. Threespine Stickleback in water above 6 meters were found along transects 4, 8, 10 and 11 in low densities, averaging 18 ± 27 fish·ha^{-1}.

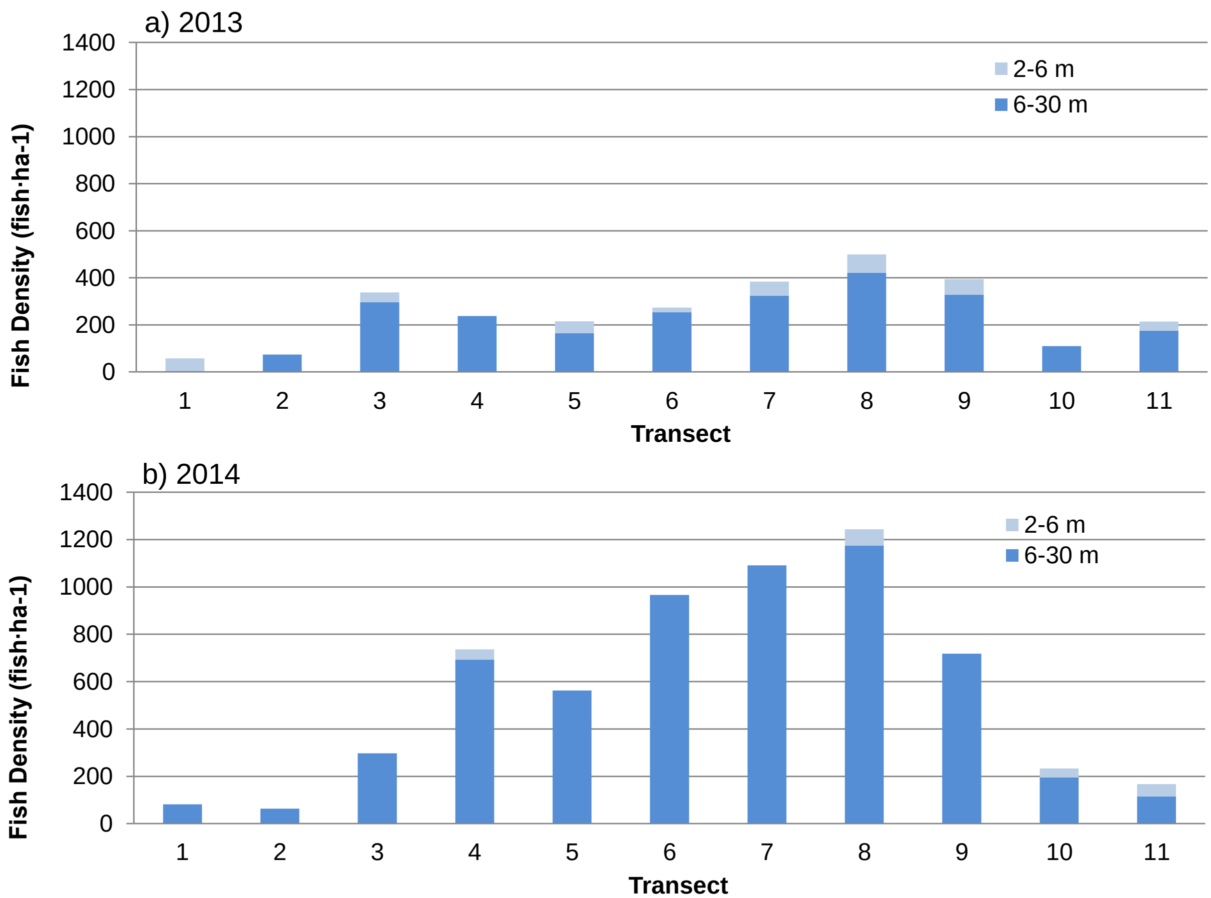


Figure 37 Wahleach Reservoir density distribution by transect for small fish targets (<-46 dB 2013; <-47 dB 2014) during August 8, 2013 (a) and August 18, 2014 (b); targets 2-6 m were considered to generally represent threespine stickleback, while targets 6-30 m were generally considered as Kokanee fry

No targets greater than -46/-47 dB were detected above 6 meters in 2013 or 2014, and so targets densities shown in Figure 38 represent adult Kokanee (age ≥1) from 6-30 m only. In 2013, the average density of adult Kokanee along transects 2-11 was 56 ± 32 fish·ha^{-1}. In 2014, adult Kokanee were found at the greatest densities in the center of the reservoir; the maximum density of adult Kokanee was 135 fish·ha^{-1} with an average of 52 ± 49 fish·ha^{-1} (± SD) across all transects (Figure 38b).

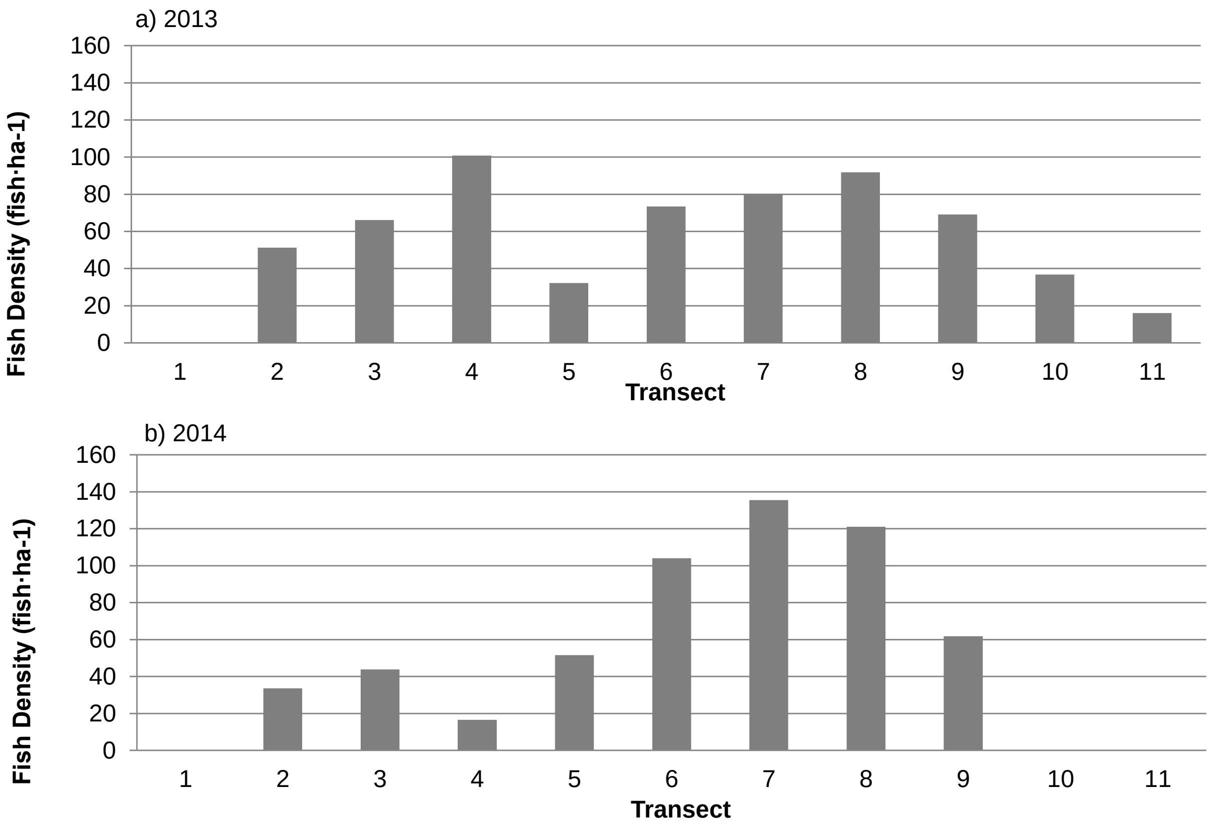


Figure 38 Wahleach Reservoir acoustic density distribution by transect for adult Kokanee (age ≥1) at depths 6-30 m for (a) August 8, 2013 (targets >-46 dB) and (b) August 18, 2014 (targets >-47 dB)

Dissolved oxygen levels in 2013 and 2014 were greater than 8 $mg{\cdot}L^{-1}$ at depths of 0-20 m (Figure 39). Temperatures of ≤15°C, the optimal temperature for Kokanee (Ford et al. 1995), occurred at 8 m and below during 2013 and 2014 (Figure 39). Maximum Kokanee densities for both fry and adults occurred at depths where water temperatures were within the optimal range for growth.

In 2013, Kokanee fry densities reached a maximum of 63 $fish{\cdot}ha^{-1}$ in the 8-10 m stratum (Figure 39a). The vertical density profile was bimodal with the secondary peak occurring deeper than the maximum, a pattern common in Wahleach for fry in recent years (Harris *et al.* 2011, Hebert et al. 2013). In 2013, the secondary peak of 22 $fish{\cdot}ha^{-1}$ occurred in the 24-26 m stratum (Figure 39a). Adult Kokanee were distributed from 6-24 m in depth with the greatest density occurring at the 10-12 m stratum with 21 $fish{\cdot}ha^{-1}$ (Figure 39a).

In 2014, Kokanee fry densities peaked at 219 $fish{\cdot}ha^{-1}$ in the 12-14 m stratum; the adjacent strata (10-12 m and 14-16 m) also had high densities with >100 $fish{\cdot}ha^{-1}$ (Figure 39b). Like 2013, a secondary peak (80 $fish{\cdot}ha^{-1}$) occurred at the 24-26 m stratum

(Figure 39b). It is worth noting that these deeper strata do not contribute substantially to overall population estimates, due to their limited habitat areas. Adult Kokanee distribution in 2014 had a single mode spanning depths of 6-24 m with the greatest density (23 fish·ha^{-1}) at the 14-16 m stratum (Figure 39b).

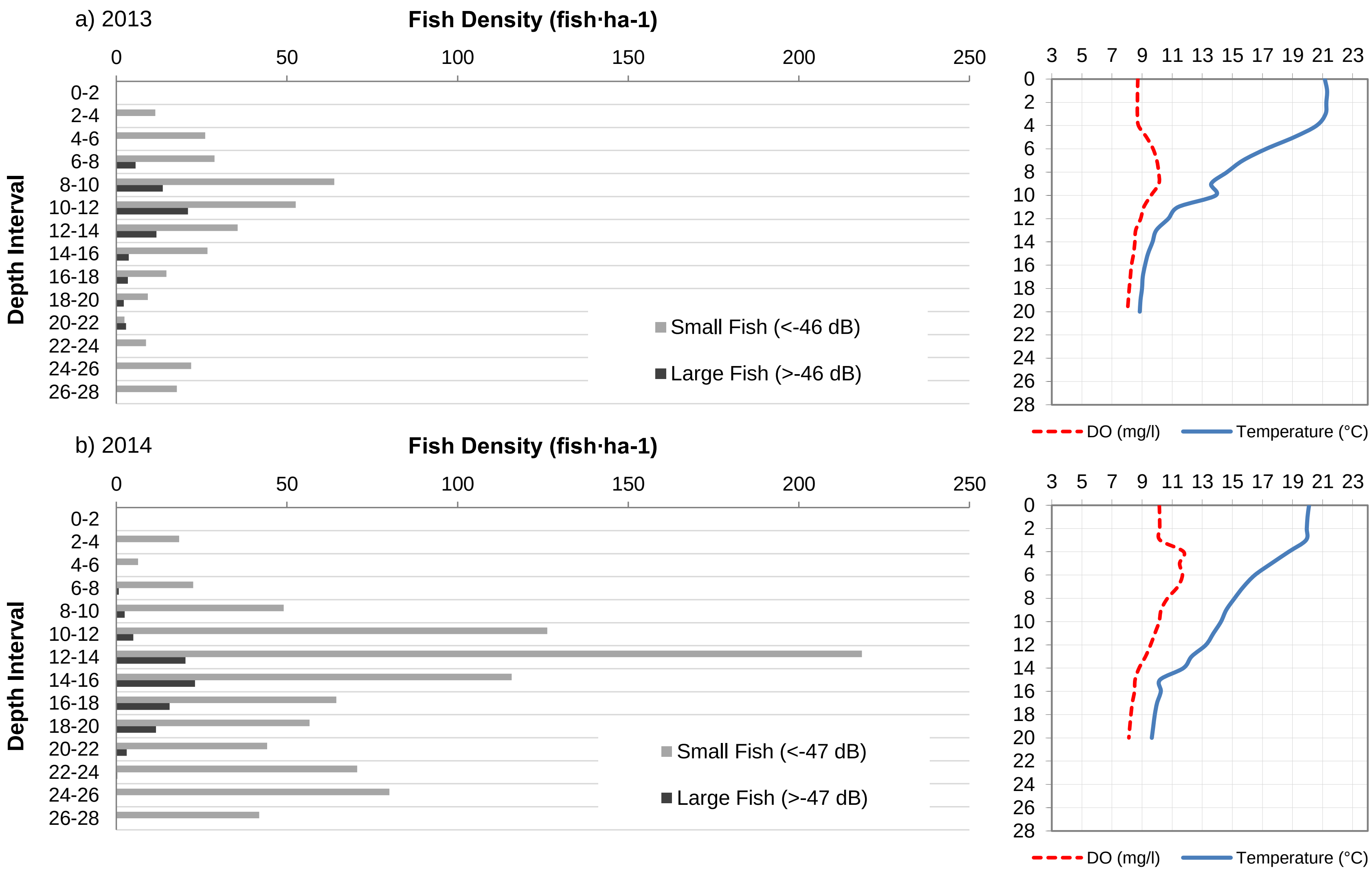


Figure 39 Wahleach Reservoir average fish density distributions by depth from August 8, 2013 and August 18, 2014 hydroacoustic surveys relative to temperature and dissolved oxygen profiles taken August 14, 2013 and August 26, 2014.

Trawling

In 2013, two trawls were conducted through the deepest central portion of Wahleach Reservoir targeting depths of 5.5-7.5 m and 8.5-10.5 m, where acoustic data indicated the highest densities of small fish. Catch was limited; only one Kokanee fry (50 mm. 1.1 g) was captured in the first trawl and no fish were caught during the second trawl. After trawling was completed, one Threespine Stickleback (24 mm) was found in the boat and assumed to have fallen through the trawl mesh unnoticed during retrieval of the net.

In 2014, three trawls were complete capturing a total of 41 (86%) Kokanee fry and 5 (14%) Threespine Stickleback. Figure 40 illustrates trawl catch by species for each depth. We assumed Kokanee fry and all age classes of Threespine Stickleback were equally vulnerable to the trawl gear.

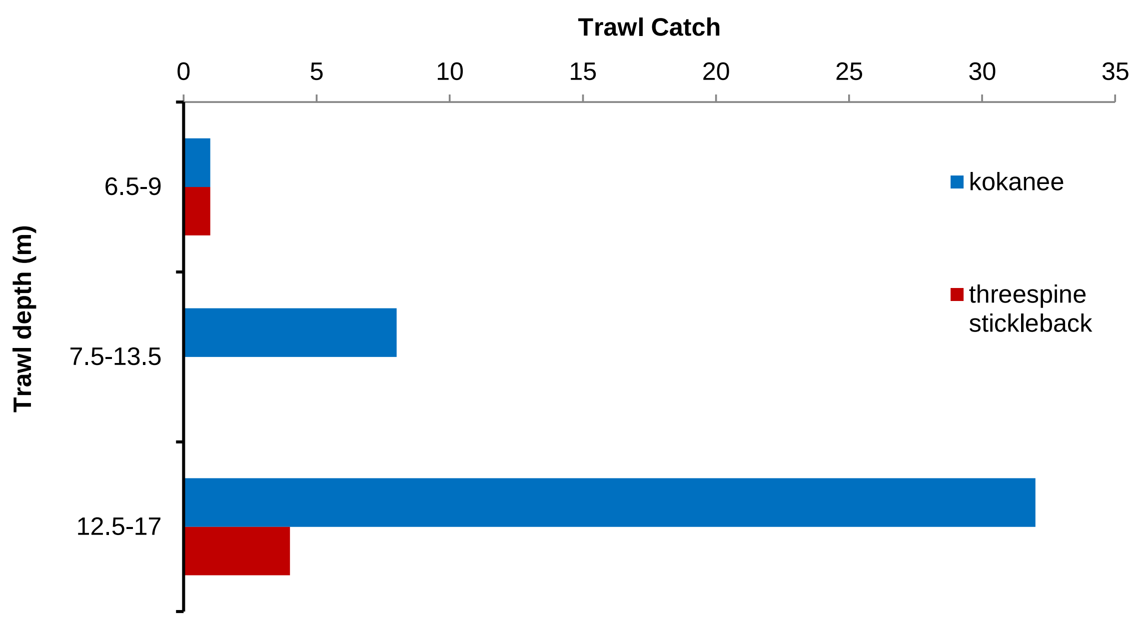


Figure 40 Catch by species for each of 3 trawls at Wahleach Reservoir the night of August 19, 2014.

The mean length and weight (± SD) of Threespine Stickleback captured during 2014 trawl sampling was 45 ± 11 mm and 1.1 ± 0.6 g, respectively. Kokanee fry had a mean length of 53 ± 5 mm and mean weight of 1.6 ± 0.4 g. The length frequency distribution of trawl caught fish shows a slight overlap in size between Kokanee fry and Threespine Stickleback in the 46-55 mm size range, though Kokanee fry represented all fish greater than 55 mm (Figure 41). Complete trawl catch and effort data are provided in Appendix F.

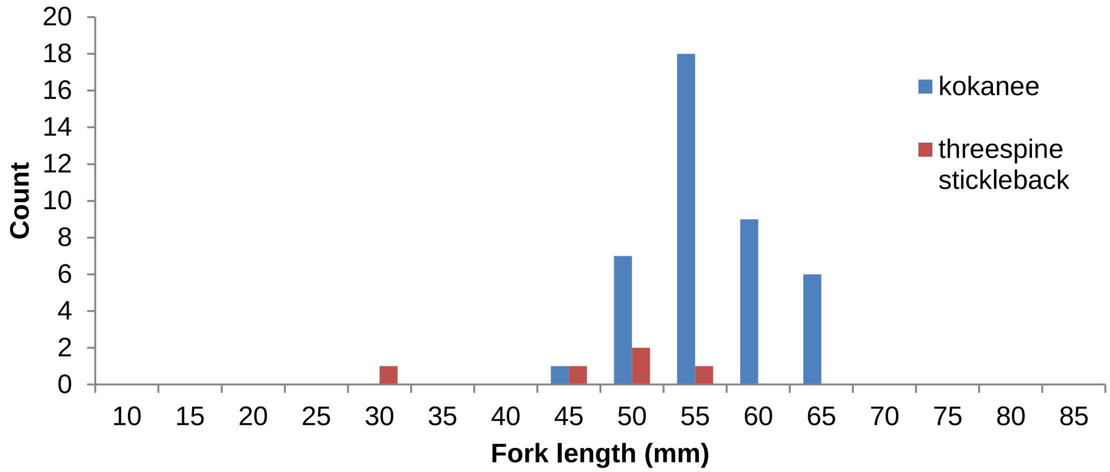


Figure 41 Length frequency of fish captured during three trawls at Wahleach Reservoir August 19, 2014.

<u>Pelagic Gillnetting</u>

A total of 104 fish were caught during pelagic gillnetting, of which there were 94 (90%) Kokanee, 6 (6%) Cutthroat Trout, 3 (3%) Rainbow Trout, and 1 (1%) Threespine Stickleback. Kokanee had a mean length of 217 ± 28 mm (± SD; range 50-243 mm) and mean weight of 125.3 ± 33.7 (± SD; range 1.1-179.0 g). Cutthroat Trout captured were significantly larger than Kokanee (Figure 42) with a mean length of 401 ± 90 mm (± SD; range 271-500) and mean weight of 512.1 ± 235.5 g (± SD; range 176.0-722.5 g). Rainbow Trout on the other hand overlapped with what would be considered a "KJokanee size target" (Figure 42); the mean length and weight of rainbow trout captured during pelagic netting were 196 ± 27 mm (± SD; range 180-227 mm) and 85.7 ± 31.7 g (± SD; range 58.5-120.5 g). The single Threespine Stickleback captured had a length of 55 mm and weight of 1.5 g; similar to those captured in trawl sampling.

Complete pelagic gillnetting catch and effort data are provided in Appendix I

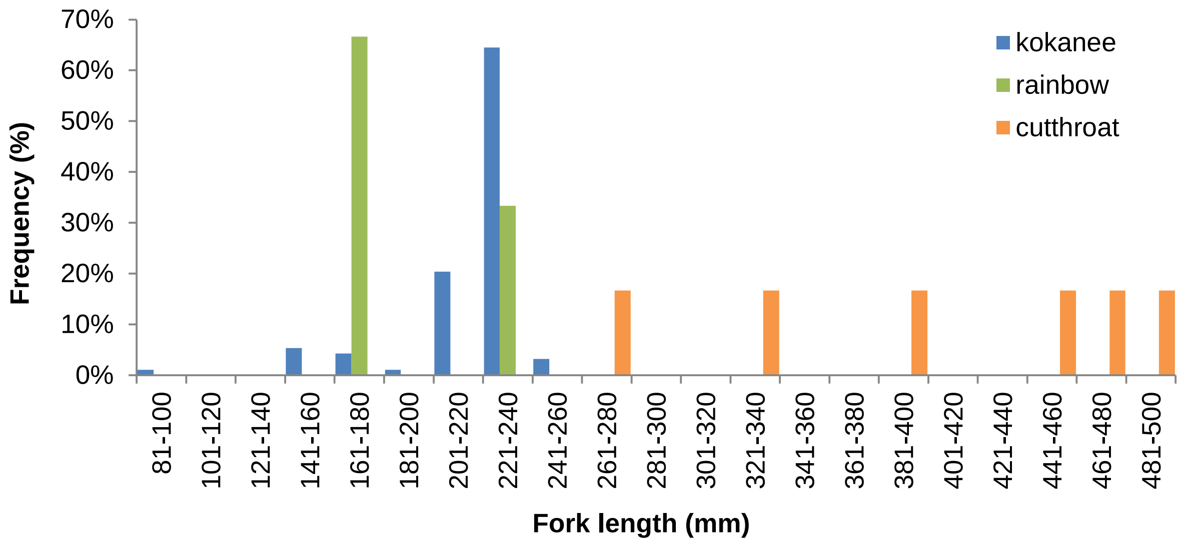


Figure 42 Length frequency of fish captured during pelagic gillnetting on Wahleach Reservoir, August 9, 2013.

Population Estimates

The population estimate for all Kokanee (i.e. targets below 6 m depth) within Wahleach Reservoir was 67,300 individuals in 2013 (with 95% confidence limits of 53,600-80,800) and 135,500 individuals in 2014 (with 95% confidence limits of 113,100-158,200) (Table 16). Kokanee fry made up the majority of the population estimated at 53,700 in 2013 and 123,300 in 2014 (Table 16). Adult Kokanee (age ≥1) were estimated at 14,500 individuals in 2013 and 12,500 individuals in 2014 (Table 16). Total population estimates representing all species at all depths are also included in Table 16 for reference.

Table 16 Wahleach Reservoir fish population estimates based on hydroacoustic surveys on August 8, 2013 and August 18, 2014.

Year	Depth Range	Total Population[1]	95% CI	Small Fish[2]	95% CI	Large Fish[3]	95% CI
2013	2-30 m	79,900	64,100-95,700	66,400	52,000-80,700	14,500	10,600-18,300
	6-30 m	67,300	53,600-80,800	53,700	42,000-65,400	14,500	10,600-18,300
2014	2-30 m	143,800	120-400-167,100	131,500	108,600-154,100	12,500	8,900-16,200
	6-30 m	135,500	113,100-158,200	123,300	101,100-145,600	12,500	8,900-16,200

[1]All acoustic targets >-66 dB

[2]Acoustic target size range of -66 dB to -47 dB in 2013 and -66 dB to -48 dB in 2014

[3]All acoustic targets >-46 dB in 2013 and >-47 dB in 2014

In 2013, although the fish distribution met criteria for trawling, catch was very limited and did not provide enough data to be used for species partitioning. Low small fish density was likely the main factor for the low catch; though net malfunction was not ruled out. In 2014, acoustic data showed favorable small fish densities with the majority of targets above 16 m in the water column, as a result trawl catch improved greatly (n=46) of which 86% were Kokanee. Using the 2014 trawl catch data to look at species composition, we can approximate the Threespine Stickleback population. If we assume that all small fish targets above 6 m were Threespine Stickleback and that the proportion of Kokanee captured in the trawl was representative (i.e. 86% of the small fish targets below 6 m were Kokanee), this produces a Threespine Stickleback population estimate of 20,200 for 2013 and 25,500 for 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. The purpose of this monitoring report is to provide a summary of conditions relevant to the Wahleach Reservoir Nutrient Restoration Project during 2013 and 2014.

There is an overwhelming amount of evidence supporting the relationship between the quantity of nitrogen and phosphorus entering a lake and the measured 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. 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. As in past years, in 2013 and 2014 Wahleach Reservoir was characterized by ultra-oligotrophic to oligotrophic conditions (Table 17).

Table 17 Trophic state classification of Wahleach Reservoir during nutrient restoration in 2011-2012 using criteria defined by Wetzel (2001) and Wetzel (1983)

Parameter		**Nutrient Restoration Year**		**Trophic Classification**			
		2013	**2014**	**Ultra-Oligotrophic**	**Oligotrophic**	**Mesotrophic**	**Eutrophic**
TP	Mean ± SD	5.5 ± 3.2	3.6 ± 1.0	-	8	27	84
(µg/L)	Range	<2-12.1	<2-5.6	<1-5	3-18	11-96	16-386
TN	Mean ± SD	201 ± 118	147 ± 33	-	661	753	1875
(µg/L)	Range	102-495	89-188	<1-250	307-1630	361-1387	393-6100
Secchi	Mean ± SD	4.0 ± 1.4	5.8 ± 1.1	-	9.9	4.2	2.5
(m)	Range	2.0-6.0	4.3-7.8	-	5.4-29.3	1.5-8.1	0.8-7.0

The goal of the nutrient restoration program is to stimulate primary productivity which in turn will stimulate zooplankton and fish production, particularly for Kokanee. When examining the response of the phytoplankton and zooplankton community it is important to keep in mind the dynamic nature of these two trophic levels. Our hope is to stimulate the production of desirable phytoplankton species which will efficiently fuel the production of desirable zooplankton species, particularly *Daphnia* - a large bodied zooplankter that a preferred forage species for Kokanee (Thompson 1999). Ideally, we would prefer that the desirable phytoplankton species are quickly ingested and assimilated by *Daphnia*, leaving little trace of enhancement at the phytoplankton trophic level. Our monthly sampling allows us to track a fast changing ecosystem to ensure the species we are stimulating will in turn lead to desired outcomes.

In 2013 the phytoplankton densities were similar to the baseline year whereas the biovolume and species composition were different. In 2013, biovolumes were 1.7 fold higher than the baseline year and were largely composed of highly edible chryso- and cryptophytes, species that are highly desirable by cladocerans. In 2014, phytoplankton densities were 1.8 fold higher than baseline densities but due to the small size of the predominant species, the biomass was 2 fold lower than baseline biovolumes. In 2014, a large cyanobacteria bloom was observed but the taxonomic examination of the species assemblage revealed *Merismopedia* sp. largely accounted for this dramatic increase. As discussed earlier, *Merismopedia* is a littoral dwelling species and was likely swept into the pelagic zone by some sort of physical dynamic such as wave action or reservoir elevation changes. This apparent habitat overlap highlights the close linkages between habitats in this relatively small reservoir. *Merismopedia* is considered both edible and inedible depending on the number of cells in the colony and therefore is still at times a forage species for zooplankton as are the chryso- and cryptophytes observed in 2014.

All major zooplankton groups have increased since the nutrient restoration project began. Densities have increased 7-fold but the most significant result observed during nutrient restoration years is the appearance of *Daphnia* –. A close examination of the dynamics of *Daphnia* shows that the absolute densities were similar over the two study years at ~3 individuals/L and biomass was extremely high at ~80 µg/L. Overall, zooplankton results represent a significant increase in food availability for Kokanee relative to baseline 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. Kokanee have not been stocked in the reservoir since 2004 thus, Kokanee populations since 2008 have been the result of natural recruitment. When compared to those more recent years (i.e. since 2008; Hebert *et al*. 2013, Harris *et al*. 2011), acoustic estimates of Kokanee abundance suggested a decline in population for 2013 and 2014. In 2013, the fry proportion (53,700) of the population estimate was one of the lowest on record for Wahleach Reservoir and tracks the low Kokanee spawner escapement of 2012 (2,606 fish); this event was expected as it occurred during the low period of the four-year peak cycle generally observed in Wahleach spawner numbers over time (Figure 33). Still, the adult (age ≥1) proportion (14,500) of the Kokanee population was also lower than in recent years. Interestingly, Kokanee spawner escapements in 2013 were one of the highest on record (14,862 fish) owing to the large proportion of age 2+ spawners. Naturally, the Kokanee fry population in 2014 rebounded substantially to 123,300. The adult Kokanee population declined again, however, to 12,500 fish. Acknowledging the considerable uncertainty in Wahleach Reservoir's acoustic estimates, Kokanee population numbers for 2013 and 2014 were still within the normal range of variability; as well, with the large cohort coming from the 2013 spawn year, we would not expect to see continual declines in adult Kokanee abundance.

Furthermore, gillnetting and spawner data from 2013 and 2014 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 2013 and 2014 showed 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. Rainbow Trout caught in 2013 and 2014 were also in better condition than during baseline years. And although length-at-age trends have remained stable, length-weight relationships show Rainbow Trout were heavier for a given length during the nutrient addition period.

An unusually large drawdown was recorded during in 2013; as well, for just over one week, reservoir levels dropped below 627 m to a low of 624.4 m, nearly 4 m below the minimum operating level of 628 m. Perrin and Stables (2000) suggested that drawdowns below 627 m can negatively affect Wahleach Reservoir's rainbow trout population and counteract restoration activities. In 1996, Wahleach Reservoir's surface elevation also dropped below 627 m and 628 m for a period of 32 and 40 days, respectively; during which time, the minimum elevation recorded was 624.6 m. This drawdown event coincided with the absence of a Rainbow Trout cohort for that year (Perrin and Stables 2000). It is noted the time period of the large drawdown in 1996 occurred later in the season from mid-March to the end of April than what was observed in 2013, as well the time period when reservoir levels were below 672 m was much greater in 1996 than in 2013. Initially, based on the presence of fry in 2013 minnow traps and age 1+ fish in gillnets during 2014, recruitment failure in the rainbow trout population does not appear to have occurred in 2013. The potential effects on fish populations from the large draw down observed in 2013 will be further examined in the upcoming review report.

Results of the assessments for Cutthroat in 2013 and 2014 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). 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. As well, the condition of Threespine Stickleback caught in recent years has been lower than in years prior to Cutthroat Trout stocking. It should be noted that minnow trapping data represent nearshore/littoral stickleback populations; data does not account for pelagic populations. Pelagic species specific abundance estimation remains a challenge for Wahleach Reservoir. In previous years, Threespine Stickleback populations have shown substantial increases and decreases in numbers, which would not be explained by the project data (Perrin *et al*. 2006).

Various approaches have been taken in an attempt to determine species specific abundances from acoustic data in Wahleach, particularly for Kokanee fry and threespine stickleback. Trawl sampling aimed at resolving fish species composition in Wahleach Reservoir has been attempted in the past with limited success (Harris *et al*. 2011, Hebert *et al.* 2013); this was due to the shallow nature and variable bathymetry of the small reservoir, as well as inconsistencies in the distribution of targets in the water column. In order for trawling to be safe and effectively capture a represent sample, the target distribution needs to consist of a distinct concentrated layer well off the bottom. Thus, surveys in recent years were conducted in August when favorable conditions were expected – i.e. a strong thermocline and warm surface temperatures to separate Kokanee fry and Threespine Stickleback according to habitat preferences. Although trawl catch in 2013 was low likely due to the low densities of small fish targets, 2014 trawl sampling produced enough fish to approximate the composition of Kokanee fry and Threespine Stickleback in the reservoir; using this approach, estimated Threespine Stickleback populations were 20,200 in 2013 and 25,500 in 2014 indicating numbers have remained low and stable – a result consistent with gillnetting and minnow trapping data. With more years of successful trawl results, we will continue to refine methods for monitoring threespine stickleback populations; at some point, the entire hydroacoustic time series can be re-evaluated using standard criteria and allow for long term trend analysis.

Overall, monitoring data from 2013 and 2014 have shown positive results in terms of growth and abundance of Kokanee when compared to baseline levels – results that support the bottom-up effects of nutrient additions. Monitoring results also support the top-down effects of predatory control on Threespine Stickleback. The Wahleach Reservoir Nutrient Restoration Project approach is based on known links between nutrient availability and productivity; the outcome of which has been to restore Wahleach Reservoir and add to the body of scientific literature.

5. Recommendations

- Continue seasonal nutrient additions while ensuring planned nitrogen loads are delivered during late summer when values tend to drop to limiting concentrations (i.e. <20 µg/L).

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

- Complete an additional limnology trip between June and July to allow for closer tracking of nitrogen concentrations. When phytoplankton are healthy they double at least once a day and therefore sampling once every 30 days during a dynamic period of the year is inadequate.

- Complete analysis of chlorophyll *a* samples.

- Complete analysis of phytoplankton edibility, which will further refine a measure of success for the program. This will be included in upcoming review report.

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

- Continue annual Kokanee spawner surveys on index streams.

- Complete analysis of stream temperature data and accumulated thermal units to estimate fry emergence and compare with reservoir conditions at that time.

- Continue with hydroacoustic and trawl program in August to ensure consistency of the time-series dataset and when thermal stratification is strongest.

- Complete pelagic gillnetting using small mesh gillnets set at depth to determine species assemblage of secondary peak evident in hydroacoustic data within the small fish group. Gillnetting or trapping would be preferred methods since trawl sampling this close to the bottom is not safe.

- Complete a review of the hydroacoustic program to date to determine its efficacy in smaller mixed species systems.

- Continue with stocking of marked, sterile Cutthroat Trout based on information gathered from the gillnetting program.

- Review Cutthroat diet data and investigate options for diet analysis study to further validate most recent results of the biomanipulation component of the project.

- Continue to abstain from Kokanee and Rainbow Trout stocking.

- Complete analysis of creel data collected in 2013 and 2014; this will be included in upcoming review report.

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Appendix A List of phytoplankton species found in Wahleach Reservoir, 2013-2014

Class	**Species**	2013 **NB**	2013 **SB**	2014 **NB**	2014 **SB**
Bacillariophyceae (diatoms)	*Achnanthidium spp.*	+	+	+	+
Bacillariophyceae (diatoms)	*Asterionella formosa*	+	+	+	+
Bacillariophyceae (diatoms)	*Cyclotella comta*	+		+	+
Bacillariophyceae (diatoms)	*Cyclotella glomerata*	+	+	+	+
Bacillariophyceae (diatoms)	*Cyclotella stelligera*		+	+	+
Bacillariophyceae (diatoms)	*Fragilaria capucina*		+	+	+
Bacillariophyceae (diatoms)	*Fragilaria construens*	+			
Bacillariophyceae (diatoms)	*Navicula sp.*	+		+	+
Bacillariophyceae (diatoms)	*Rhizosolenia sp.*	+	+	+	+
Bacillariophyceae (diatoms)	*Synedra acus var angustissima*		+		
Bacillariophyceae (diatoms)	*Synedra nana*		+		
Bacillariophyceae (diatoms)	*Synedra ulna*		+		
Bacillariophyceae (diatoms)	*Tabellaria fenestrata*	+	+	+	+
Chlorophyceae	*Ankistrodesmus sp.*	+	+	+	+
Chlorophyceae	*Botryococcus sp.*	+	+	+	
Chlorophyceae	*Carteria sp.*			+	+
Chlorophyceae	*Chlorella sp.*	+	+	+	+
Chlorophyceae	*Clamydocapsa sp.*		+		
Chlorophyceae	*Coelastrum sp.*	+	+	+	+
Chlorophyceae	*Cosmarium sp.*		+		+
Chlorophyceae	*Crucigenia sp.*	+	+	+	+
Chlorophyceae	*Elakatothrix sp.*	+	+		
Chlorophyceae	*Gleotila sp.*	+			
Chlorophyceae	*Golenkinia sp.*		+		
Chlorophyceae	*Gyromitus sp.*	+	+	+	+
Chlorophyceae	*Monomastic sp.*	+	+	+	+
Chlorophyceae	*Nephroselmis sp.*	+	+	+	+
Chlorophyceae	*Oocystis sp.*	+	+	+	+
Chlorophyceae	*Phacus sp.*			+	+
Chlorophyceae	*Planctosphaeria sp.*		+		+
Chlorophyceae	*Pyramimonas sp.*	+			
Chlorophyceae	*Scenedesmus sp.*	+			
Chlorophyceae	*Scourfieldia sp.*	+	+	+	+
Chlorophyceae	*Sphaerocystis sp.*	+	+		
Chlorophyceae	*Spondylosium sp.*		+		
Chlorophyceae	*Staurastrum sp.*		+	+	+
Chlorophyceae	*Tetraedron sp.*	+	+		
Chryso- & Cryptophyceae (flagellates)	*Bitrichia sp.*			+	+
Chryso- & Cryptophyceae	*Chromulina sp.*	+	+	+	+
Chryso- & Cryptophyceae	*Chroomonas acuta*	+	+	+	+
Chryso- & Cryptophyceae	*Chryptomonas spp.*	+	+		+
Chryso- & Cryptophyceae	*Chrysochromulina sp.*	+	+	+	+
Chryso- & Cryptophyceae	*Chrysococcus sp.*	+	+	+	+
Chryso- & Cryptophyceae	*Chrysoikos sp.*			+	+

Class	**Species**	2013 **NB**	2013 **SB**	2014 **NB**	2014 **SB**
Chryso- & Cryptophyceae	*Dinobryon 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*	+	+	+	+
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)*	+	+	+	+
Cyanophyceae	*Synechococcus sp. (coccoid)*	+	+	+	+
Cyanophyceae	*Synechocystis sp.*	+	+	+	+
Dinophyceae (dinoflagellates)	*Ceratium hirundinella*		+		
Dinophyceae	*Gymnodinium sp. (large).*	+	+	+	+
Dinophyceae	*Gymnodinium sp. (small)*	+	+	+	+
Dinophyceae	*Peridinium spp.*	+	+	+	+

Appendix B List of zooplankton species identified in Wahleach Reservoir, 2013-2014

Species	2013	2014
Cladocera		
Bosmina longirostris	+	+
Chydorus sphaericus	+	+
Daphnia rosea	+	+
Holopedium gibberum	+	+
Leptodora kindtii	+	+
Scapholeberis mucronata	r	r
Copepoda		
D. bicuspidatus thomasi	+	+

r = rare species

Appendix C Hydroacoustic equipment specifications and data analysis parameters used for Wahleach Reservoir surveys, 2013-2014

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	2013 analysis threshold	-66 to -26 dB
		2014 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 Love's (1977) empirical relation of fish length to acoustic target strength

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 E Wahleach Reservoir habitat areas used for hydroacoustic data analysis

Areas in 2013 begin at 368 ha for the 2 m depth stratum, based on a survey pool elevation of 639.7 m. In 2014, areas begin at 351 ha for the 2 m stratum, based on a survey pool elevation of 639.3 m.

Table was developed from data supplied by Shuksan Fisheries Consulting Ltd. Shaded areas are midpoints of 2 m depth strata areas used for expansion of acoustic densities in 2013 and 2014.

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 F Trawl catch (a) and effort (b) for Wahleach Reservoir, August 9, 2013 and August 19, 2014

a)

Date	Trawl #	Species	Fork Length (mm)	Weight (g)
9-Aug-13	1	KO	50	1.1
9-Aug-13	2	TSB*	24	
19-Aug-14	1	KO	51	1.30
19-Aug-14	1	KO	51	1.30
19-Aug-14	1	KO	51	1.20
19-Aug-14	1	KO	61	2.15
19-Aug-14	1	KO	51	1.43
19-Aug-14	1	KO	46	0.99
19-Aug-14	1	KO	52	1.46
19-Aug-14	1	KO	51	1.30
19-Aug-14	2	KO	51	1.24
19-Aug-14	2	TSB	26	0.19
19-Aug-14	3	KO	43	1.81
19-Aug-14	3	KO	61	2.23
19-Aug-14	3	KO	52	1.3
19-Aug-14	3	KO	54	1.51
19-Aug-14	3	KO	58	2.05
19-Aug-14	3	KO	51	1.36
19-Aug-14	3	KO	51	1.32
19-Aug-14	3	KO	62	2.5
19-Aug-14	3	KO	56	1.87
19-Aug-14	3	KO	48	1.09
19-Aug-14	3	KO	51	1.31
19-Aug-14	3	KO	50	1.25
19-Aug-14	3	KO	64	2.53
19-Aug-14	3	KO	61	2.22
19-Aug-14	3	KO	51	1.27
19-Aug-14	3	KO	56	1.49
19-Aug-14	3	KO	51	1.23
19-Aug-14	3	KO	49	1
19-Aug-14	3	KO	56	1.63
19-Aug-14	3	KO	56	1.75
19-Aug-14	3	KO	57	1.82
19-Aug-14	3	KO	55	1.65
19-Aug-14	3	KO	61	2.39
19-Aug-14	3	KO	48	1.07
19-Aug-14	3	KO	59	1.98
19-Aug-14	3	KO	56	1.78
19-Aug-14	3	KO	60	2.03
19-Aug-14	3	KO	55	1.53

Date	Trawl #	Species	Fork Length (mm)	Weight (g)
19-Aug-14	3	KO	52	1.42
19-Aug-14	3	KO	54	1.63
19-Aug-14	3	KO	50	1.34
19-Aug-14	3	KO	47	1.03
19-Aug-14	3	TSB	52	1.51
19-Aug-14	3	TSB	50	1.36
19-Aug-14	3	TSB	45	0.89
19-Aug-14	3	TSB	50	1.55

** Note: One TSB was found in boat after trawling completed in 2013, assumedly fell through the net mesh into the boat during retrieval, and have assigned to trawl 2 arbitrarily in this table*

b)

Date	Trawl #	Depth Fished (m)	Catch		Duration (min)
			TSB	KO	
August 9, 2013	1	5.5-7.5	0	0	55
	2	8.5-10.5	0	0	50
August 19, 2014	1*	7.5-13.5	0	8	33
	2	6.5-9	1	1	40
	3**	12.5-17	4	32	40

* Two layers fished: 7.5-10 m for 16 minutes and 11-13.5 m for 17 minutes.
**Two layers fished: 14.5-17 m for 7 minutes and 12.5-15 m for 33 minutes.

Appendix G Wahleach Reservoir acoustic survey transect densities (fish·ha^{-1}) by 2 meter depth intervals for all fish and large fish during 2013 (a, b) and 2014 (c, d)

a) 2013 All Fish (> -66 dB)

Depth (m)	**1**	**2**	**3**	**4**	**5**	**Transect 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	56	0	82	41	44	65	56	15	18	0	**34**
8	0	0	196	101	48	77	106	127	79	38	80	**77**
10		0	97	78	16	64	61	116	184	64	54	**74**
12		69	43	20	14	42	58	100	45	26	57	**47**
14		0	11	22	13	21	71	29	74			**30**
16			15	0	35	29	13	15				**18**
18			0	31	13	9	7	8				**11**
20			0	4	17	0	2	8				**5**
22			0	0	0	0	0	52				**9**
24						24	20					**22**
26						18						**18**
28												
Total	**58**	**125**	**404**	**338**	**247**	**347**	**464**	**591**	**463**	**146**	**230**	

b) 2013 Large Fish (> -46 dB)

Depth (m)	**1**	**2**	**3**	**4**	**5**	**Transect 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**	

Depth intervals 0 = from 0.0 to 2.0m

c) 2014 All Fish (> -66 dB)

Depth						Transect						Avg
(m)	1	2	3	4	5	6	7	8	9	10	11	
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	24	17	11	**23**
8		30	26	76	51	39	69	78	73	50	23	**51**
10		67	72	197	178	240	137	93	170	99	60	**131**
12			76	104	133	320	313	314	411			**239**
14			46	126	115	137	200	246	103			**139**
16			56	67	33	93	133	99				**80**
18			24	71	54	43	83	134				**68**
20			12	31	43	27	59	112				**47**
22			10	9		37	109	188				**71**
24						61	99					**80**
26						42						**42**
28												
Total	**82**	**97**	**341**	**753**	**614**	**1070**	**1227**	**1365**	**780**	**233**	**167**	

d) 2014 Large Fish (> -47 dB)

Depth						Transect						Avg
(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	**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**	

Depth intervals 0 = from 0.0 to 2.0m

Appendix H Population statistics for Wahleach Reservoir hydroacoustic surveys on August 8, 2013 and August 18, 2014, based on Monte Carlo simulations

a) 2013 All Fish (-66 to -26 dB)

Depth (m)	n	Average Density (fish·ha^{-1})	SD	SE	Area (ha)	Population (# fish)
2	11	11.4	25.4	7.7	368	4048
4	11	26.1	28.5	8.6	334	8684
6	11	34.4	29.1	8.8	295	10030
8	11	77.5	57.0	17.2	264	20328
10	10	73.5	51.7	16.3	234	17316
12	10	47.3	25.6	8.1	201	9447
14	8	30.3	27.7	9.8	174	5220
16	6	18.0	12.6	5.1	145	2610
18	6	11.4	10.6	4.3	117	1287
20	6	5.3	6.6	2.7	69	345
22	6	8.7	21.3	8.7	26	234
24	2	21.9	2.4	1.7	12	264
26	1	17.7			4	72

b) 2014 All Fish (-66 to -26 dB)

Depth (m)	n	Average Density (fish·ha^{-1})	SD	SE	Area (ha)	Population (# fish)
2	11	18.4	26.6	8.0	351	6318
4	11	6.3	11.2	3.4	314	1884
6	11	23.2	22.5	6.8	280	6440
8	10	51.5	21.6	6.8	249	12699
10	10	131.3	62.4	19.7	217	28427
12	7	238.8	131.1	49.6	187	44693
14	7	138.9	65.7	24.8	159	22101
16	6	80.0	35.5	14.5	131	10480
18	6	68.3	38.2	15.6	93	6324
20	6	47.2	35.5	14.5	48	2256
22	5	70.8	77.4	34.6	19	1349
24	2	80.0	26.3	18.6	8	640
26	1	41.9			3	126

c) 2013 Large Fish (> -46 dB)

Depth (m)	n	Average Density (fish·ha^{-1})	SD	SE	Area (ha)	Population (# fish)
6	11	5.6	10.2	3.1	295	1770
8	11	13.6	14.2	4.3	264	3696
10	10	21.0	15.5	4.9	234	4914
12	10	11.8	8.5	2.7	201	2412
14	8	3.6	4.5	1.6	174	696
16	6	3.4	4.3	1.8	145	493
18	6	2.2	3.7	1.5	117	234
20	6	2.9	7.0	2.9	69	207

d) 2014 Large Fish (> -47 dB)

Depth (m)	n	Average Density (fish·ha^{-1})	SD	SE	Area (ha)	Population (# fish)
6	11	0.7	2.4	0.7	280	280
8	10	2.4	4.3	1.3	249	498
10	10	5.0	10.4	3.3	217	1085
12	7	20.2	17.0	6.4	187	3740
14	7	23.0	16.6	6.3	159	3657
16	6	15.6	15.1	6.2	131	2043.6
18	6	11.6	7.2	3.0	93	1116
20	6	3.0	2.4	1.0	48	144

Appendix I Pelagic gillnetting catch (a) and effort (b) for Wahleach Reservoir, August 10, 2013

a)

Date	Site	Depth (m)	Fish #	Spp	Length (mm)	L Mtd	Weight (g)	Sex	Maturity	Spawn Year	Clip	Age Str	Age	CF
10-Aug-13	Set 1	5	100	CT	500	FL								
10-Aug-13	Set 1	5	101	KO	229	FL	139	M	M	Y	NC	SC		1.16
10-Aug-13	Set 1	5	102	KO	232	FL	143.5	M	M	Y	NC	SC		1.15
10-Aug-13	Set 1	5	103	KO	226	FL	145	M	M	Y	NC	SC		1.26
10-Aug-13	Set 1	5	104	KO	230	FL	146.5	M	M	Y	NC	SC		1.20
10-Aug-13	Set 1	5	105	KO	224	FL	133.5	F	M	Y	NC	SC		1.19
10-Aug-13	Set 1	5	106	KO	198	FL	93	F	IM	N	NC	SC		1.20
10-Aug-13	Set 1	5	108	KO	206	FL	101	F	M	Y	NC	SC		1.16
10-Aug-13	Set 1	5	109	KO	149	FL	34.5	U	IM	N	NC	SC		1.04
10-Aug-13	Set 1	5	110	KO	224	FL	126.5	F	M	Y	NC	SC		1.13
10-Aug-13	Set 1	5	113	KO	216	FL	122.5	F	M	Y	NC	SC		1.22
10-Aug-13	Set 1	5	107	RB	227	FL	120.5	F	IM	N	NC	SC		1.03
10-Aug-13	Set 1	5	111	RB	180	FL	78	F	IM	N	NC			1.34
10-Aug-13	Set 1	5	112	RB	180	FL	58.5	F	IM	N	NC			1.00
10-Aug-13	Set 1	10	55	CT	271	FL	176	U	IM	N	AD	OT		0.88
10-Aug-13	Set 1	10	117	CT	444	FL	722.5	M	IM	N	RP	OT		0.83
10-Aug-13	Set 1	10	42	KO	226	FL	150	F	M	Y	NC	SC	2+	1.30
10-Aug-13	Set 1	10	43	KO	225	FL	138	M	M	Y	NC	SC	2+	1.21
10-Aug-13	Set 1	10	44	KO	218	FL	126.5	M	M	Y	NC	SC		1.22
10-Aug-13	Set 1	10	45	KO	238	FL	175	M	M	Y	NC	SC		1.30
10-Aug-13	Set 1	10	46	KO	230	FL	153	M	M	Y	NC	SC		1.26
10-Aug-13	Set 1	10	47	KO	234	FL	157	F	M	Y	NC	SC		1.23
10-Aug-13	Set 1	10	48	KO	213	FL	112.5	M	M	Y	NC	SC		1.16
10-Aug-13	Set 1	10	49	KO	162	FL	47	F	IM	N	NC	SC		1.11
10-Aug-13	Set 1	10	50	KO	225	FL	137	M	M	Y	NC	SC		1.20
10-Aug-13	Set 1	10	51	KO	230	FL	136.5	M	M	Y	NC	SC		1.12

Date	Site	Depth (m)	Fish #	Spp	Length (mm)	L Mtd	Weight (g)	Sex	Maturity	Spawn Year	Clip	Age Str	Age	CF
10-Aug-13	Set 1	10	52	KO	219	FL	125.5	F	M	Y	NC	SC		1.19
10-Aug-13	Set 1	10	53	KO	231	FL	152	F	M	Y	NC	SC		1.23
10-Aug-13	Set 1	10	54	KO	235	FL	156.5	M	M	Y	NC	SC		1.21
10-Aug-13	Set 1	10	56	KO	221	FL	126.5	M	M	Y	NC			1.17
10-Aug-13	Set 1	10	57	KO	235	FL	146.5	M	IM	N	NC			1.13
10-Aug-13	Set 1	10	58	KO	238	FL	165.5	M	M	Y	NC			1.23
10-Aug-13	Set 1	10	59	KO	229	FL	132	F	M	Y	NC			1.10
10-Aug-13	Set 1	10	60	KO	226	FL	130.5	F	M	Y	NC			1.13
10-Aug-13	Set 1	10	61	KO	225	FL	146.5	F	M	Y	NC			1.29
10-Aug-13	Set 1	10	62	KO	215	FL	112	M	M	Y	NC			1.13
10-Aug-13	Set 1	10	63	KO	232	FL	128	F	M	Y	NC			1.03
10-Aug-13	Set 1	10	64	KO	224	FL	129.5	F	M	Y	NC			1.15
10-Aug-13	Set 1	10	65	KO	228	FL	141.5	F	M	Y	NC			1.19
10-Aug-13	Set 1	10	66	KO	220	FL	121	F	M	Y	NC			1.14
10-Aug-13	Set 1	10	67	KO	224	FL	144	M	M	Y	NC			1.28
10-Aug-13	Set 1	10	68	KO	222	FL	136.5	M	M	Y	NC			1.25
10-Aug-13	Set 1	10	69	KO	204	FL	100.5	U	IM	N	NC			1.18
10-Aug-13	Set 1	10	114	KO	230	FL	147.5	M	M	Y	NC	SC		1.21
10-Aug-13	Set 1	10	115	KO	232	FL	143	M	M	Y	NC	SC		1.15
10-Aug-13	Set 1	10	116	KO	150	FL	37.5	F	IM	N	NC	SC		1.11
10-Aug-13	Set 1	10	118	KO	225	FL	140.5	F	M	Y	NC	SC		1.23
10-Aug-13	Set 1	10	119	KO	220	FL	127.5	F	M	Y	NC	SC		1.20
10-Aug-13	Set 1	10	120	KO	243	FL	179	M	M	Y	NC	SC		1.25
10-Aug-13	Set 1	10	121	KO	234	FL	150.5	M	M	Y	NC	SC		1.17
10-Aug-13	Set 1	10	122	KO	224	FL	130	F	M	Y	NC	SC		1.16
10-Aug-13	Set 1	10	123	KO	166	FL	53	F	IM	N	NC	SC		1.16
10-Aug-13	Set 1	10	124	KO	235	FL	151	F	M	Y	NC	SC		1.16
10-Aug-13	Set 1	10	125	KO	229	FL	137.5	F	MT	Y	NC	SC		1.14
10-Aug-13	Set 1	10	126	KO	234	FL	157	M	MT	Y	NC	SC		1.23
10-Aug-13	Set 1	10	127	KO	226	FL	132	F	MT	Y	NC	SC		1.14

Date	Site	Depth (m)	Fish #	Spp	Length (mm)	L Mtd	Weight (g)	Sex	Maturity	Spawn Year	Clip	Age Str	Age	CF
10-Aug-13	Set 1	10	128	KO	220	FL	118.5	F	MT	Y	NC	SC		1.11
10-Aug-13	Set 1	10	129	KO	221	FL	128.5	M	MT	Y	NC	SC		1.19
10-Aug-13	Set 1	10	130	KO	162	FL	46	F	IM	N	NC	SC		1.08
10-Aug-13	Set 1	10	131	KO	208	FL	109.5	F	MT	N	NC	SC		1.22
10-Aug-13	Set 1	10	132	KO	218	FL	134.5	M	MT	Y	NC	SC		1.30
10-Aug-13	Set 1	10	133	KO	156	FL	46.5	M	IM	N	NC	SC		1.22
10-Aug-13	Set 1	10	134	KO	226	FL	124.5	F	MT	Y	NC	SC		1.08
10-Aug-13	Set 2	5	38	KO	214	FL	117.5	M	M	Y	NC	SC	2+	1.20
10-Aug-13	Set 2	5	39	KO	213	FL	121	M	M	Y	NC	SC	3+	1.25
10-Aug-13	Set 2	5	40	KO	227	FL	126	M	M	Y	NC	SC	3+	1.08
10-Aug-13	Set 2	5	41	TSB	55	TL	1.5							
10-Aug-13	Set 2	10	22	CT	475	FL	704	F	M	N	NC	SC		0.66
10-Aug-13	Set 2	10	36	CT	390	FL	592	U	IM	N	Y	SC		1.00
10-Aug-13	Set 2	10	37	CT	323	FL	366	U	IM	N	NC	SC		1.09
10-Aug-13	Set 2	10	1	KO	50	FL	1.1	U	IM	N	NC			0.88
10-Aug-13	Set 2	10	2	KO	216	FL	127.5	M	M	Y	NC	SC	2+	1.27
10-Aug-13	Set 2	10	3	KO	225	FL	120	F	M	Y	NC	SC	2+	1.05
10-Aug-13	Set 2	10	4	KO	228	FL	147	M	M	Y	NC	SC	2+	1.24
10-Aug-13	Set 2	10	5	KO	236	FL	148.5	M	M	Y	NC	SC	2+	1.13
10-Aug-13	Set 2	10	6	KO	204	FL	109	U	IM	N	NC	SC	2+	1.28
10-Aug-13	Set 2	10	7	KO	228	FL	138.5	F	M	Y	NC	SC	2+	1.17
10-Aug-13	Set 2	10	8	KO	228	FL	144.5	M	M	Y	NC	SC	2+	1.22
10-Aug-13	Set 2	10	9	KO	235	FL	156	M	M	Y	NC	SC	2+	1.20
10-Aug-13	Set 2	10	10	KO	237	FL	147	F	M	Y	NC	SC	2+	1.10
10-Aug-13	Set 2	10	11	KO	222	FL	129.5	M	M	Y	NC	SC	2+	1.18
10-Aug-13	Set 2	10	12	KO	235	FL	162.5	M	M	Y	NC	SC	2+	1.25
10-Aug-13	Set 2	10	13	KO		FL	135	M	M	Y	NC	SC	2+	
10-Aug-13	Set 2	10	14	KO	228	FL	145	M	M	Y	NC	SC	3+	1.22
10-Aug-13	Set 2	10	15	KO	224	FL	132.5	M	M	Y	NC	SC	2+	1.18
10-Aug-13	Set 2	10	16	KO	233	FL	141.5	F	M	Y	NC	SC	2+	1.12

Date	Site	Depth (m)	Fish #	Spp	Length (mm)	L Mtd	Weight (g)	Sex	Maturity	Spawn Year	Clip	Age Str	Age	CF
10-Aug-13	Set 2	10	17	KO	222	FL	125	F	M	Y	NC	SC	2+	1.14
10-Aug-13	Set 2	10	18	KO	225	FL	141.5	F	M	Y	NC	SC	2+	1.24
10-Aug-13	Set 2	10	19	KO	218	FL	120	F	M	Y	NC	SC	2+	1.16
10-Aug-13	Set 2	10	20	KO	242	FL	158	F	M	Y	NC	SC	2+	1.11
10-Aug-13	Set 2	10	21	KO	230	FL	128.5	F	M	Y	NC	SC		1.06
10-Aug-13	Set 2	10	23	KO	228	FL	134.5	M	M	Y	NC	SC	2+	1.13
10-Aug-13	Set 2	10	24	KO	222	FL	139	F	M	Y	NC	SC	2+	1.27
10-Aug-13	Set 2	10	25	KO	222	FL	137.5	F	M	Y	NC	SC	2+	1.26
10-Aug-13	Set 2	10	26	KO	241	FL	150	M	M	Y	NC	SC	3+	1.07
10-Aug-13	Set 2	10	27	KO	212	FL	112	M	M	Y	NC	SC	2+	1.18
10-Aug-13	Set 2	10	28	KO	222	FL	140	M	M	Y	NC	SC	2+	1.28
10-Aug-13	Set 2	10	29	KO	222	FL	125	F	M	Y	NC	SC	2+	1.14
10-Aug-13	Set 2	10	30	KO	225	FL	141.5	M	M	Y	NC	SC	2+	1.24
10-Aug-13	Set 2	10	31	KO	208	FL	104	F	M	N	NC	SC	2+	1.16
10-Aug-13	Set 2	10	32	KO	226	FL	135.5	F	M	Y	NC	SC	2+	1.17
10-Aug-13	Set 2	10	33	KO	161	FL	47.5	F	IM	N	NC	SC	1+	1.14
10-Aug-13	Set 2	10	34	KO	159	FL	42.5	U	IM	N	NC	SC	1+	1.06
10-Aug-13	Set 2	10	35	KO	150	FL	40.5	F	IM	N	NC	SC	1+	1.20

b)

Set Date	Pull Date	Set Time	Pull Time	Site	Gear (Number)	Net Type	Mesh	Depths (m)	Net Area (m^2)	Total Hours	Total Catch	CPUE (fish per 100 m^2 net per hour)	Notes
9-Aug-13	10-Aug-13	20:52	09:30	1	GN (4)	SK	ST(4)	5, 5, 10, 10	876	12.63	63	0.57	Site near TR 7-8
9-Aug-13	10-Aug-13	21:30	10:15	2	GN (4)	SK	ST(3), IN (1)	5, 5, 10, 10	876	12.75	42	0.37	Site near TR 9-10; WOD net at 5 m