Wahleach Project Water Use Plan

Wahleach Reservoir Fertilization Program

Implementation Year 7-8

Reference: WAHWORKS-2

WAHLEACH RESERVOIR NUTRIENT RESTORATION PROJECT REPORT, 2011-2012 - Fisheries Project Report No. RD 145

Study Period: 2011 - 2012

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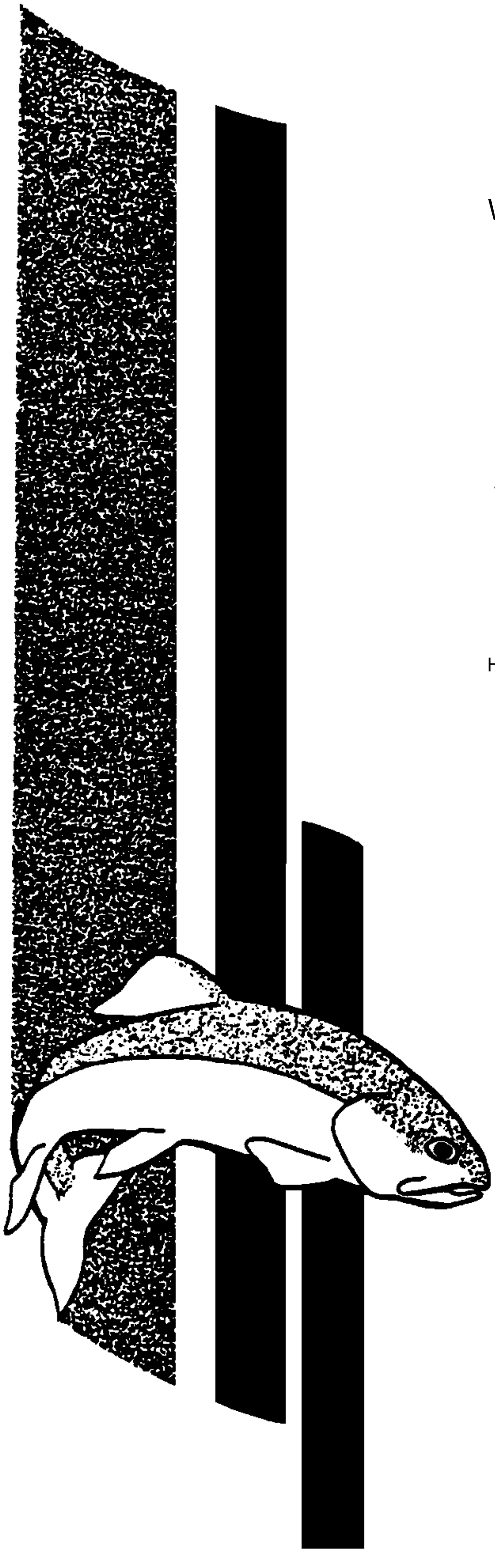

WAHLEACH RESERVOIR NUTRIENT RESTORATION PROJECT, 2011-2012

by

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

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Field assistance was provided by Robert W. Land, Lynn Avis, and Petra Wykpis. Climate and hydrometric data were provided by Jennifer Saklofsky of BC Hydro. Taxonomic identification and enumeration of phytoplankton samples were conducted by Dr. John Stockner, Eco-Logic Ltd. Identification and enumeration of zooplankton samples were conducted by Lidija Vidmanic, Ecolab Ltd. Kokanee spawner enumerations were completed by students of the British Columbia Institute of Technology, Fish and Wildlife Program: Andrew Schellenberg, Desirae McMurray, and Don Petrocco (2011), and Caroline Walter, Daniel Dixon and Ioana Popa (2012). Tyler Weir and David Johner with the Ministry of Forests, Lands and Natural Resource Operations (Victoria) conducted hydroacoustic surveys and data analyses. The Freshwater Fisheries Society of British Columbia, Charlotte Lawson in particular, was responsible for fish stocking, including triploiding, rearing and marking.

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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 2011 and 2012; this report is intended as a data summary with general comparisons made to baseline pre-fertilization 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 October. Unlike previous years, nutrient additions for 2011 included nitrogen only (i.e. urea-ammonium nitrate).

Overall, 2011 and 2012 were high inflow years with freshet peaking later in the season relative to the long term average. In 2011, the late timing of freshet delayed the start of nutrient additions until early July. Peak outflows from Wahleach Reservoir generally corresponded with the timing of freshet and the maximum reservoir surface elevation. In 2011, drawdown was 17.7 m with a maximum reservoir elevation of 642.0 m and a minimum of 624.3 m; this was 3.7 m below the minimum operating level of 628 m. Perrin and Stables (2000) suggested draw downs below 627 m can negatively affect Wahleach Reservoir's rainbow trout population and counteract restoration activities. Initially, based on the presence of age 1+ fish captured during the 2012 nearshore gillnetting program, recruitment failure in the rainbow trout population does not appear to have occurred in 2011. The potential effects on fish populations from the large drawdown observed in 2011 will be further examined in the upcoming review report. In 2012, reservoir elevation ranged from 629.1 m to 642.0 m with a drawdown of 12.9 m.

Generally, the warmest months were June through September during the fertilization period. Compared to the 1984-2012 average (6.4 ± 5.9°C), the mean annual temperature in 2011 was marginally cooler (6.1 ± 6.3°C), while 2012 was 0.5°C warmer (6.9 ± 6.8°C). Notably, air temperatures in April through July 2011 were lower than usual; in particular, July 2011 was 2.1°C cooler than the long term monthly mean. In terms of precipitation, the driest months were generally July and August, while the wettest months were January and March. September 2012 was also usually dry. Precipitation levels overall in both years were wetter than the long-term average; in fact, 2011 was one of the wettest years on record (second in terms of mean daily precipitation, third for total annual precipitation).

Water temperature in 2011 for both stations combined ranged between 9.3°C and 22.8°C; temperature in 2012 was between 6.4°C and 17.3°C. Thermocline depth was generally between 3-7 m. Both basins showed orthograde oxygen profiles indicative of oligotrophic conditions, though this pattern was weaker in 2011. Seasonal average secchi depth values for both stations were 4.30 ± 1.61 m in 2011 and 4.89 ± 1.38 m in 2012

Total phosphorus (TP) concentrations were indicative of oligotrophic productivity. Several soluble reactive phosphorus (SRP) samples were below detection limits of 1 μg/L in 2011; this was also true for 2012 despite weekly phosphorus additions. Low SRP values suggest rapid uptake and assimilation of useable phosphorus by phytoplankton.

Epilimnetic total nitrogen (TN) concentrations in 2011 and 2012 were greater than in baseline years. During both baseline and fertilization 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 fertilization era, however, suggesting a 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 almost two-fold greater in 2011 and 2012 than in baseline years.

Mean annual phytoplankton abundance was about 50% greater during fertilization than in baseline years; biovolume was about two times greater than baseline. Mean annual phytoplankton abundance in 2011 was 13129 ± 6288 cells/mL for both stations combined; biovolume was 2.04 ± 1.49 mm^3/L. In 2012, mean annual phytoplankton abundance was12352 ± 10901 cells/mL; biovolume was 1.57 ± 1.22 mm^3/L. Wahleach Reservoir typically experiences a diatom bloom during late summer and early fall; while true during baseline years and 2012, diatom abundance in 2011 was low throughout the entire season. Overall, chrysophytes and cryptophytes were the dominant phytoplankton class. In May 2011, the north basin sample had an unusually high abundance of chrysophytes and cryptophytes (34896 cells/mL); abundance was nearly 10-times greater than the south basin sample (3801 cells/mL) for that month.

Prior to fertilization, zooplankton abundance was approximately 1 ind/L and biomass was negligible at <1 μg/L. All major zooplankton groups have increased since the nutrient restoration project began; the appearance of *Daphnia* spp. has accounted for the dramatic increase in biomass observed during the fertilization era. Mean annual zooplankton density for 2011 was 19.03 ± 11.59 ind/L – the highest on record. Densities were driven by cladocerans other than *Daphnia*, primarily *Bosmina longirostris*. *Daphnia* numbers peaked in late summer and early fall (August/September). In 2011, mean annual

Daphnia abundance was 1.94 ± 2.10 ind/L. Zooplankton abundance in 2012 was relatively low compared to recent years; mean annual zooplankton density was 4.36 ± 2.44 ind/L; yet, *Daphnia* abundance remained stable with a mean annual density of 2.02 ± 2.85 ind/L. Zooplankton biomass was significantly greater in 2011 and 2012 than in baseline years with 82.75 ± 53.37 µg/L and 67.71 ± 57.11 µg/L, respectively. Zooplankton results represent a significant increase in food availability for planktivores relative to baseline years.

During the 2011 nearshore gillnetting program, 145 fish were caught; rainbow trout made up 85% of the catch and kokanee accounted for 9% of the total catch. In 2012, 87 fish were caught with a relatively even distribution amongst kokanee, rainbow trout and cutthroat trout. Catch-per-unit-effort (CPUE) was 1.29 ± 0.68 fish per net hour in 2011 and 0.82 ± 0.74 fish per net hour in 2012. Kokanee CPUE, however, was higher in 2012 (0.27 ± 0.41 fish per net hour) than 2011 (0.11 ± 0.13 fish per net hour). Threespine stickleback catch in minnow traps was low in 2011 and 2012. Maximum likelihood estimates of fish abundance in Wahleach Reservoir based on hydroacoustic data were 171,600 fish in 2011 and 238,400 fish in 2012; of which 148,000 (2011) and 205,400 (2012) represented kokanee fry and threespine stickleback, and 23,600 (2011) and 33,000 (2012) represented age 1+ and older kokanee, rainbow trout and cutthroat trout.

Mean length-at-age data show 1+ and 2+ kokanee caught in the reservoir during 2011 and 2012 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 2011 and 2012 were greater than baseline years, which is indicative of kokanee in better condition during fertilization. The increased body size and condition of kokanee observed during 2011 and 2012 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 2011 and 2012 were 6762 fish (474 Boulder Creek, 5578 Flat Creek, and 710 Jones Creek) and 2606 fish (277 Boulder Creek, 1323 Flat Creek, and 1006 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 through 2013 were expected. The mean age of kokanee spawners was 2.8 ± 0.6 years in 2011 and 2.9 ± 0.4 years in 2012. The mode spawning age for both years was 3+. Length frequency distributions of kokanee spawners had significant overlap in amongst age classes for both years; the majority of spawners were in the 201-220 mm size class.

Looking at rainbow trout metrics, mean length-at-age values between baseline and fertilization years were very similar. On the other hand, rainbow trout caught in 2011 and 2012 were in better condition than during baseline years; as well, the slopes of length-weight regressions for rainbow trout caught during the fertilization era were greater in 2011 and 2012 than in 1993-94. So although length-at-age remained stable in the rainbow trout population, individuals were putting on more weight during fertilization years.

Sterile cutthroat trout were first introduced to Wahleach Reservoir as part of this project. Results of the assessments in 2011 and 2012 were similar and indicate the condition of the cutthroat trout population, as demonstrated by biometric data is stable.

Overall, monitoring data from 2011 and 2012 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 recovery kokanee population also support the biomanipulation portion of the project, which has been achieved through top-down predatory control of threespine stickleback by cutthroat trout. The Wahleach Reservoir Nutrient Restoration Project is based on known links between nutrient availability and the response in productivity; restoring Wahleach Reservoir to its former potential and adding to the body of scientific literature. Further refinement of the data over a longer time series will be presented in the upcoming review report; this comprehensive analysis will increase 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 the restoration experiment was initiated, the fishery on Wahleach had collapsed, rainbow trout (*Oncorhynchus mykiss*) were stunted (<20 cm fish) and in poor condition, and kokanee (*Oncorhynchus nerka*) were below the limit of detection and 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 – a behaviour 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 draw downs 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 addition 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 additions can compensate for the loss in productivity resulting from dam construction and operation (Stockner and Shortreed 1985, Ashley *et al*. 1997). Nutrient addition can increase the production of edible phytoplankton and, in turn, increase 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); these trophic transfers play a key role in increasing fish populations.

The goal of biomanipulation was to influence 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 2011 and 2012; it is intended as a summary with general comparisons to the pre-fertilization baseline. 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#E219074) and one in the south at LS2 (EMS ID#E219070) (Figure 1). Nearshore gillnetting and minnow trap sites are shown on Figure 1 with exact coordinates for 2011 and 2012 in Table 1 and Table 2, respectively.

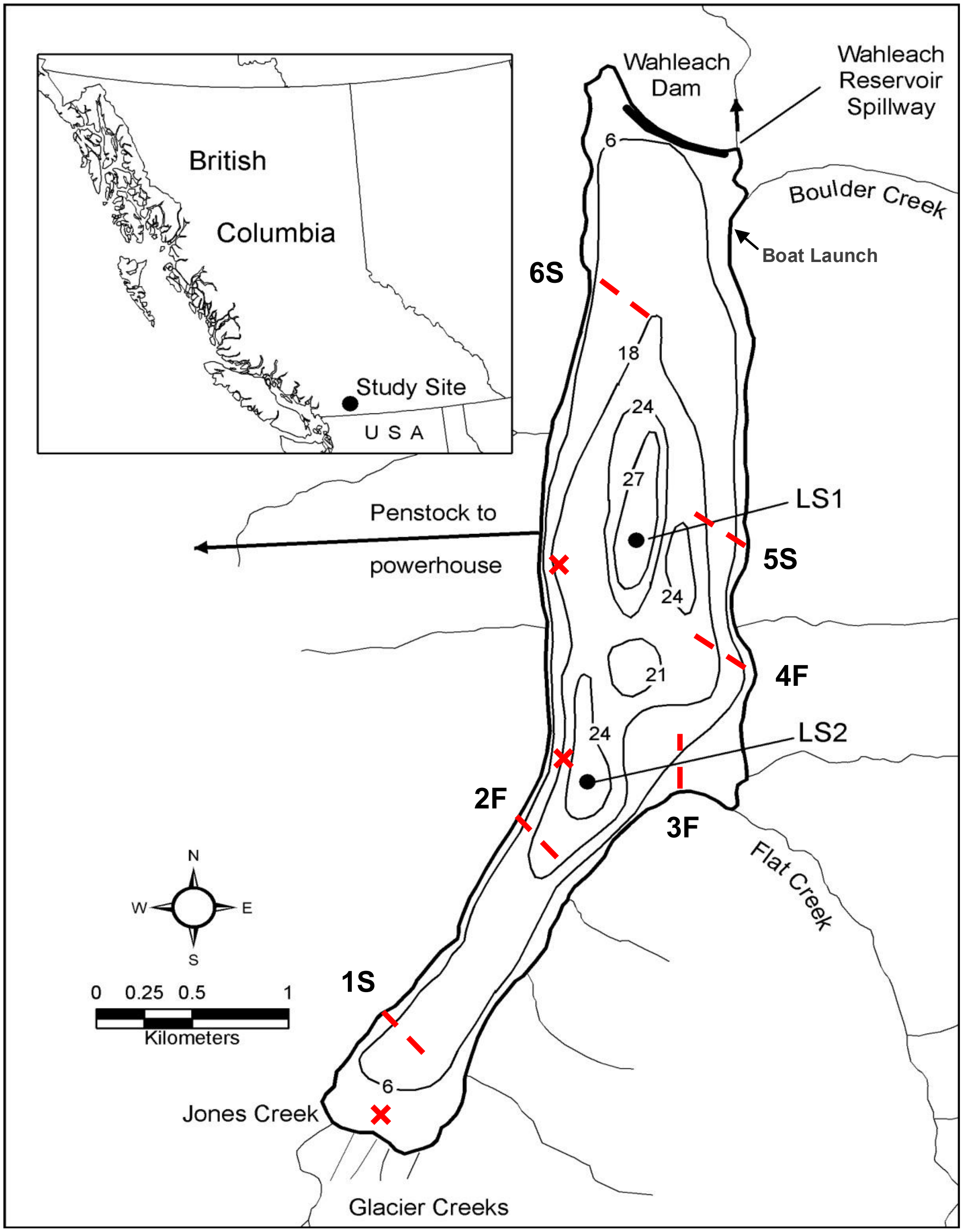


Figure 1 Map of Wahleach Reservoir showing limnology sampling sites (LS1 and LS2), approximate locations of near shore gillnets (dashed lines; S=sinking net, F=floating net) and minnow trap sites (x), as well as kokanee spawner survey index streams (Boulder Creek, Flat Creek, Jones Creek). Bathymetric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

Table 1 Wahleach Reservoir near shore gillnet locations, 2011-2012

Year	Net	Location
2011	1S	49°12.399 N, 121°38.020 W
	2F	49°13.164 N, 121°37.123 W
	3F	49°13.113 N, 121°36.681 W
	4F	49°13.568 N, 121°36.433 W
	5S	49°14.030 N, 121°36.310 W
	6S	49°14.687 N, 121°36.802 W
2012	1S	not available
	2F	49°13.088 N, 121°37.255 W
	3F	49°13.102 N, 121°36.734 W
	4F	49°13.350 N, 121°36.397 W
	5S	49°14.090 N, 121°36.351 W
	6S	49°14.673 N, 121°36.732 W

Table 2 Wahleach Reservoir minnow trap locations, 2011-2012

Year	Trap	Location
2011	G1	49°12.241 N, 121°37.962 W
	G2	49°12.210 N, 121°38.014 W
	G3	49°12.186 N, 121°37.914 W
	G4	49°12.156 N, 121°37.882 W
	G5	49°13.350 N, 121°37.136 W
	G6	49°13.371 N, 121°37.142 W
2012	G1	49°12.204 N, 121°38.030 W
	G2	49°12.192 N, 121°37.957 W
	G3	49°13.228 N, 121°37.177 W
	G4	49°13.290 N, 121°37.149 W
	G5	49°13.795 N, 121°37.150 W
	G6	49°13.960 N, 121°37.112 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 July 11 to October 4, 2011 and June 5 to October 10, 2012; fertilizer additions were ended once the reservoir had turned over. The ammonium polyphosphate and urea-ammonium nitrate were blended 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 annual monitoring results.

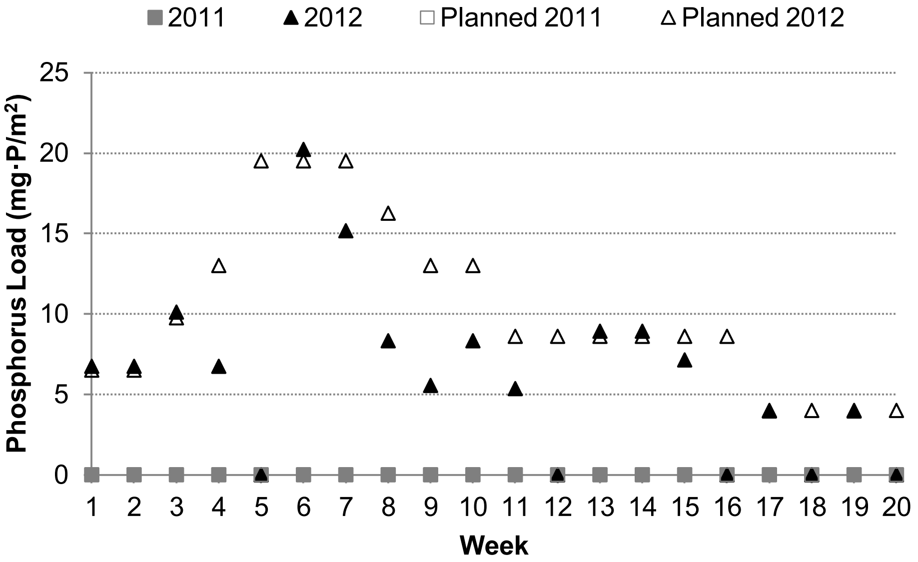
Unlike previous years, nutrient additions for 2011 included nitrogen only. Typically, planned phosphorus loading rates for Wahleach Reservoir are at least 200 mg·P/m^2 to improve the production of *Daphnia* sp. as based on recommendations by Perrin *et al*. (2006). Nitrogen is added concurrently to keep epilimnetic concentrations above 20 µg/L (the concentration considered limiting to phytoplankton growth [Wetzel 2001]) and maintain a high N:P ratio. In 2009 and 2010, Wahleach Reservoir experienced persistent blooms of inedible and potentially toxic blue-green algae (*Cyanophyceae*) that can be caused by low N:P ratios and act as a nutrient sink (Schindler 1977; Watson and Kalff 1981; Pick and Lean 1987; Stockner and Shortreed 1988, 1989). In this case, phosphorus remineralization from the littoral zone was suspected as an aggravating factor. The addition of nitrogen only was an experimental measure undertaken in an effort to eliminate these chronic blooms.

During 2011, 15.78 tonnes of urea-ammonium nitrate were added to the reservoir (Table 3). Weekly nitrogen additions were planned for early June, but due to a later than usual freshet (see Section 3.1 “Hydrometrics and Reservoir Operations”) fertilizer additions were delayed until early July. On week 7, nitrogen additions began at the planned loading rate of 101 mg·N/m^2 (Figure 2). Weekly nitrogen loads were consistent with planned rates, which were slowly ramped down beginning on week 15 with a final loading rate of 71 mg·N/m^2 (Figure 2). Nitrogen was not added in later weeks as the reservoir was no longer stratified. Overall, the planned annual nitrogen loading rate was 1627 mg·N/m^2, while the actual annual nitrogen loading rate was 1077 mg·N/m^2 (Figure 2). N:P ratios were not calculated, as no phosphorus was added to the reservoir in 2011.

During 2012, 3.37 tonnes of ammonium polyphosphate and 12.42 tonnes of urea-ammonium nitrate were added to Wahleach Reservoir (Table 3). Planned weekly phosphorus and nitrogen loading rates are compared with actual loading rates in Figure 2. Actual loading rates for phosphorus and nitrogen were consistent with planned rates until week 4, after which nutrient loads were generally reduced or eliminated in an effort to prevent algal blooms. Fertilization was not conducted on week 20, as the reservoir had turned over. Overall, the planned annual phosphorus loading rate was 204 mg·P/m^2 as recommended by Perrin *et al*. (2006); the planned annual nitrogen loading rate was 1770 mg·N/m^2. The actual annual loading rate for phosphorus was 126 mg·P/m^2 and for nitrogen was 930 mg·N/m^2 (Table 3). Molar N:P ratios of fertilizer additions ranged from 1.4 at the beginning of the season to a maximum of 39.1 on week 15 (Figure 3); the annual average molar N:P ratio was 16.7 ± 10.5 with a seasonal total of 16.3 (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).

Table 3 Annual nutrient additions to Wahleach Reservoir, 1995-2012

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



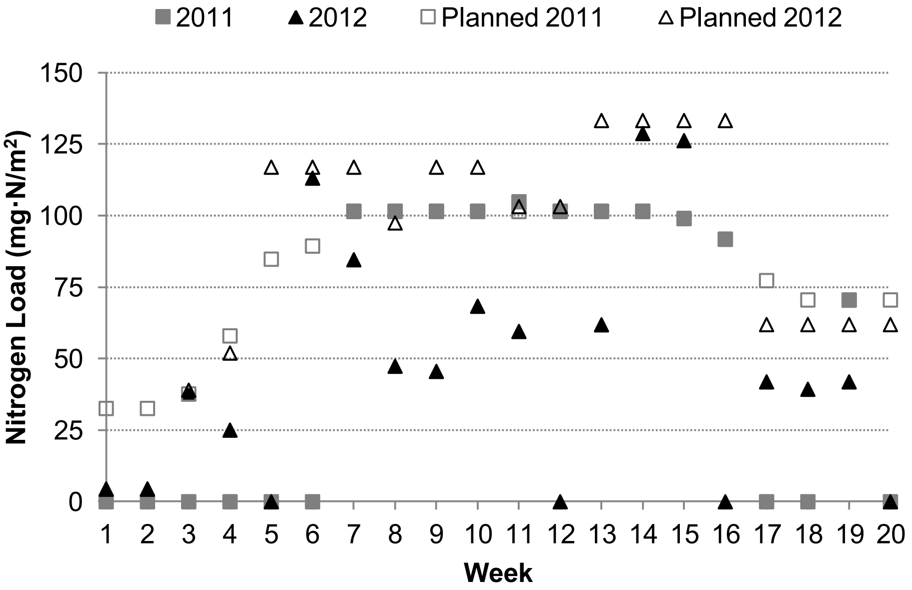


Figure 2 Seasonal phosphorus and nitrogen loading rates for Wahleach Reservoir, 2011-2012

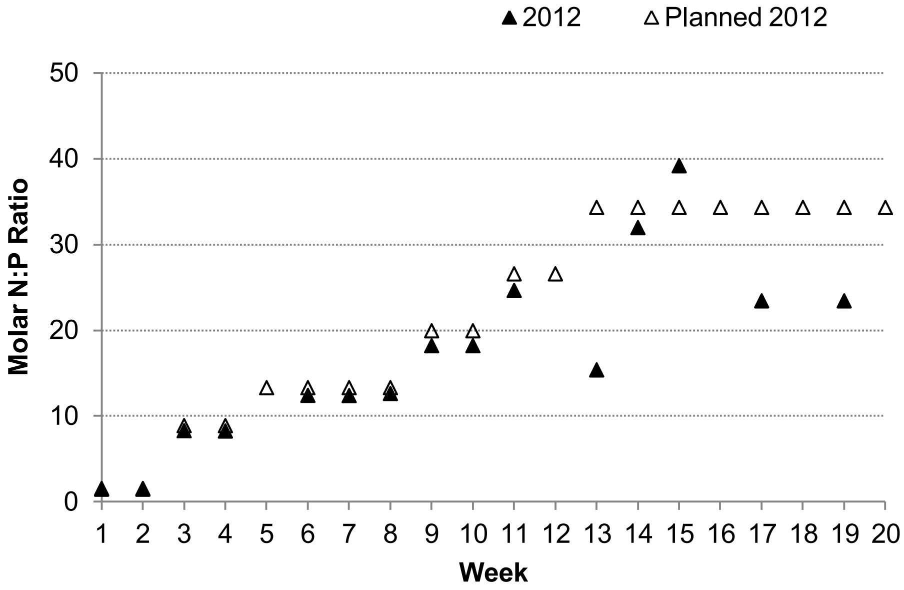


Figure 3 Seasonal molar N:P ratios of fertilizer additions for Wahleach Reservoir, 2012; ratios for 2011 were not calculated as no phosphorus was added that season.

2.3. Hydrometrics and Reservoir Operations

Data were provided by BC Hydro for 1984-2012. 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 for 1984-2012. Maximum and minimum daily temperatures were averaged and then reported as monthly means. Daily precipitation is reported as monthly means.

2.5. Physical and Chemical Samples

Limnology sampling was conducted monthly from May 31 to October 25, 2011 and May 30 to October 31, 2012. 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; a depth integrated sample was taken from the epilimnion using tygon tubing. Parameters 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 150-750 mL were filtered using parallel filtration onto 47-mm diameter 0.45 µm cellulose acetate filters using a vacuum pressure differential of <100 mm of Hg. Filters were wrapped in aluminum foil and stored at -20°C. Chlorophyll *a* data were not available at the time of writing.

2.6. Phytoplankton

Phytoplankton sampling was completed during monthly limnology field sessions (see Section 2.5 for dates). A depth integrated sample of the epilimnion was 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 involved a two-step process. First, several random fields (5-10) were examined 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. Species abundance (cells/mL) and biovolume (mm^3/L), as well as class abundance and biovolume for each station and month are shown in Appendix B. Annual means ± the standard deviation, as well as monthly means ± the standard deviation are reported.

2.7. Zooplankton

Zooplankton sampling was completed during monthly limnology field sessions (see Section 2.5 for dates). Two replicate zooplankton samples were 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 C 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 all fish stocking records for Wahleach Reservoir since 1997. Kokanee have not been stocked in Wahleach Reservoir since 2004. Likewise, rainbow trout have not been stocked since 2002. Stocking of sterile (3N) cutthroat trout continues as the biomanipulation portion of the project and to ensure top down pressure maintains control of the threespine stickleback population to the benefit of kokanee. 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, 1997-2012

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

Nearshore Gillnetting and Minnow Trapping

Standardized annual gillnetting sessions were completed on October 17-18, 2011 and October 23-24, 2012. 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"). Three individual floating nets were set at the surface and three individual sinking nets were set on the bottom. Gillnets were set perpendicular to the shoreline; one end of the net was tied to shore, while the other end was anchored with a lead weight and marked with a buoy. Nets were set near dusk, left overnight, and then retrieved the following morning. In addition, six minnow traps baited with salmon roe and/or moist cat food were set and retrieved at the same time. Minnow traps were set in littoral habitat in approximately 2-3 m deep 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 approximately 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), length frequency, age frequency, length-at-age, and length-weight relationships. Each gillnet set was considered a replicate for calculating mean CPUE (individuals per hour of net soak time) to be consistent with earlier years of the study (Perrin *et al*. 2006). CPUE of minnow trapping was calculated as individuals per hour of trap soak time.

In addition to the standard gillnetting program, an experimental small mesh gillnet was set in Wahleach Reservoir during 2011. Catch and CPUE was not reported; however, biological data from the fish captured were included in calculations of mean lengths, weights, ages etc. Thus, n values for the 2011 biological data are greater than the reported catch.

Kokanee Spawner Surveys

Kokanee spawner escapement in three index streams - Boulder Creek, Flat Creek, and Jones Creek - were estimated using standardized visual survey methods. Adult fish and carcasses were enumerated from the confluence with Wahleach Reservoir upstream for 600 m on Boulder Creek, 1000 m on Flat Creek and 400 m 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 are not included in standardized annual surveys. Spawner surveys were conducted weekly on each index stream from the last week of August to mid-October over a 6-8 week period, depending on observed trends in spawner numbers. During the survey, a 2-3 person crew walked each index stream in an upstream direction. Surveyors positioned themselves near the right and left banks to increase the overall field of view, and taking care to avoid spawning substrate and suspected redds. Each surveyor counted the number of spawners and carcasses in a defined reach, and then the average number was recorded before moving on.

Kokanee spawner counts provide an estimate of the number of mature kokanee in each index stream on that survey day. Total escapement estimates were made using a modified area-under-the-curve (AUC) model from Irvine *et al*. (1993) that uses kokanee spawner counts, stream residency time, and estimated observed efficiency. Stream residency time is 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%, consistent with previous years of the study. The AUC model involves two calculations – (1) the AUC estimate and (2) the escapement estimate:

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

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

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

In addition to escapement estimates, a random sample of kokanee spawners from each index stream was taken for sampling using RISC standard methods (RISC 2004); parameters included 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 26, 2011 and July 18, 2012; when surface water temperatures were 22.8 °C and 16.2 °C, respectively. Surveys began approximately 1 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 flashlight while in close proximity to shore. Acoustic data were monitored on a computer screen during collection and stored for later analysis.

Hydroacoustic data were analyzed using Sonar 5 post processing software (Balk and Lindem 2011). Estimates of fish size and abundance were reported as fish·ha^{-1} by 2 m depth strata. Program outputs provided density by 47 size groups of 1 decibel (dB) increments from -70 to -24 dB. Working lower thresholds of -61 dB (2011) and -66 dB (2012) were applied to remove bottom end noise and capture the majority of fish targets in Wahleach Reservoir. Population estimates were calculated by multiplying the average layer densities by the corresponding habitat strata area, and then summed to get the reservoir population. Maximum likelihood estimates and 95% confidence intervals were calculated by a Monte Carlo Simulation procedure using 30,000 iterations. Detailed data collection and analysis parameters are found in Appendix D.

Size cut-offs between kokanee fry (age 0+) and older individuals (age ≥1) were determined by examining the distribution of acoustic target strengths by 1 dB increments. Typically, an inflection point is evident between large numbers of fry and substantially lower numbers of age 1+ and older fish. Complicating interpretation for Wahleach Reservoir is the presence of threespine stickleback that mix with kokanee fry in pelagic habitats; as well as rainbow trout and cutthroat trout that are in the same range as age 1+ and older kokanee. While an inflection point separating small fish from the large fish component is still evident, species differentiation within each size group is challenging. Inflection points of -46 dB for 2011 and -50 dB for 2012 were used to separate kokanee fry and threespine stickleback (small fish) from age 1+ and older kokanee, rainbow trout and cutthroat trout (large fish). All age classes of kokanee were considered present in the pelagic survey area and represented by the acoustic target distribution, as spawning occurred after hydroacoustic surveys both survey years. Empirical fish lengths were converted to the equivalent acoustic target strength in decibels using Love’s (1977) dorsal aspect formula (Appendix E) for comparison to the acoustic distribution.

Habitat areas used to extrapolate 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 for a surface area of 410 ha (Appendix F). At the time of the hydroacoustics surveys in 2011 and 2012, reservoir surface elevations were 639.7 m and 641.7 m, respectively. The average start and end depth of the acoustic transects was 6.0 m in 2011, and 6.3 m in 2012. Subtracting the habitat area for depths less than 6 m from the total surface area equates to approximately 96 ha of shallow water habitat, or 25% of the reservoir, that was not surveyed in 2011. In 2012, reservoir elevation was 1.7 m above the 640 m full pool benchmark used to determine habitat areas; thus, calculating the un-surveyed area was not possible. It is expected that the un-surveyed habitat area in 2012 was similar to 2011.

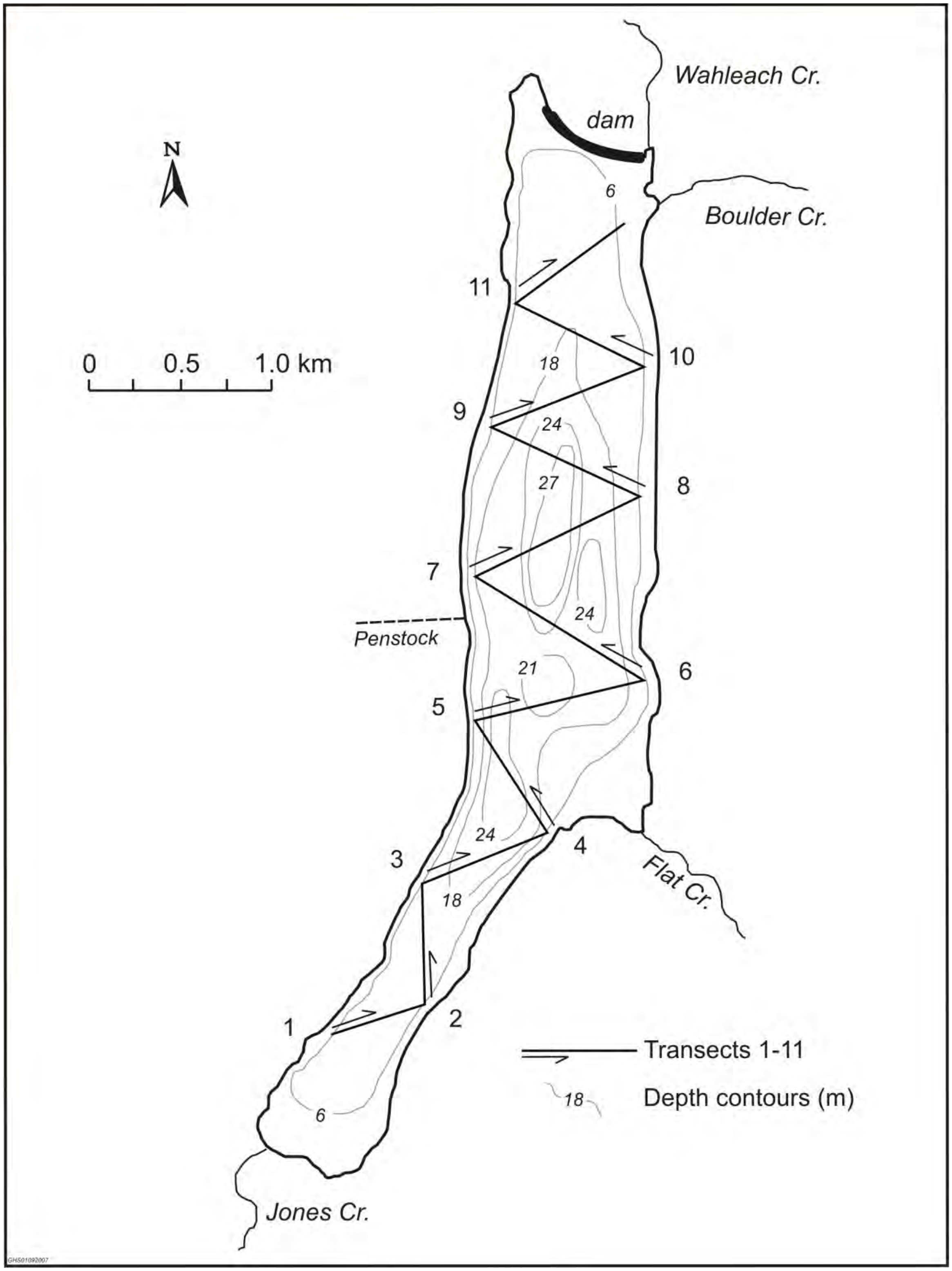


Figure 4 Map of Wahleach Reservoir showing standardized hydroacoustic transect locations

Trawl sampling (2011) and pelagic gillnetting (2012) were conducted along with hydroacoustic surveys in an attempt to validate fish species composition and assist with interpretation of acoustic data; results of these sampling programs are reported under the “Hydroacoustics” section.

Trawling

Trawl sampling with the goal of determining species specific population estimates from hydroacoustic data has been attempted on Wahleach Reservoir with limited success (Harris *et al*. 2011). In 2011, another trawl survey attempt was made, because initial hydroacoustic data showed favourable target depths and density distributions. Unfortunately, the trawl survey could not be completed concurrently with the hydroacoustic survey; trawling was conducted on September 20, 2011, the next available opportunity in proximity to a new moon. A secondary hydroacoustic survey to establish trawl depths was conducted over the deepest portion of the reservoir immediately prior to trawling. Trawls were directed at the densest layer of fish targets. One of the challenges during previous years was the inability to obtain real time net depth data; therefore, a Notus trawl sensor was used to collect real time net depth information.

A 5.4 m long beam-trawl net with a 2×2 m opening, and a graduated stretched mesh size of 4.1 cm at the mouth to 0.3 cm at the cod end was towed at 0.6-0.8 $m \cdot s^{-1}$ for 40 minutes per haul. A total of 4 hauls were successfully completed. Captured fish were kept on ice in labelled packages and sampled the following day for length (mm) and weight (g).

Pelagic Gillnetting

Pelagic gillnetting was conducted in conjunction with the hydroacoustic survey in 2012. The main objective was to determine species composition at depth thereby assisting with acoustic data interpretation. CPUE and biological data from the pelagic netting in 2012 were not compared to past pelagic gillnetting data or fall nearshore gillnetting data due to the non-standard timing.

Pelagic gillnetting followed the methods employed in 2008 and 2009 (Squires and Stables 2009, Harris *et al*. 2011). A series of three standard RISC nets at depths of 0, 5, and 10 m were set in a gang at the limnology sampling station, LS1 (Figure 1). Each net consisted of six panels (15.2 m long by 2.4 m deep) with 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"); this is a modification of the standard RISC net mesh size order. In addition, one small mesh gillnet consisting 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 was set a 4 m. Nets were left overnight on July 18, 2012 and retrieved the following morning.

3. Results

3.1. Hydrometrics and Reservoir Operations

Both 2011 and 2012 were high inflow years when compared to the long-term (1984-2012) average of 6.2 ± 2.5 $m^{3\cdot}s^{-1}$; mean annual inflow was 7.3 ± 6.1 $m^{3\cdot}s^{-1}$ in 2011 and 7.2 ± 5.9 $m^{3\cdot}s^{-1}$. In 2011, daily inflow rates ranged from 0-50.6 m^3/s (Figure 5). The maximum inflow rate occurred in January with high inflows also observed in late November, and during freshet with a peak in early July. In 2012, daily inflow rates ranged from 0.6-42.0 $m^{3\cdot}s^{-1}$ with the maximum occurring in mid-June during freshet (Figure 5). Long-term average data show freshet in late May to early June (Figure 5). Typically fertilization starts in early June following the peak of freshet; in 2011 and 2012, however, freshet occurred later in the season – so much so in 2011 that the beginning of fertilization was delayed until early July.

When comparing monthly inflows, June had the highest monthly mean inflow rate for all years; in 2011 it was 15.6 ± 4.2 $m^{3\cdot}s^{-1}$ and in 2012 it was 15.7 ± 7.5 $m^{3\cdot}s^{-1}$. The mean inflow rate for July was also high at 13.7 ± 2.6 $m^{3\cdot}s^{-1}$ in 2011, and 14.9 ± 5.0 $m^{3\cdot}s^{-1}$ in 2012. These rates were greater than the long-term monthly means, which were 10.9 ± 1.0 $m^{3\cdot}s^{-1}$ for June and 7.6 ± 1.8 $m^{3\cdot}s^{-1}$ for July.

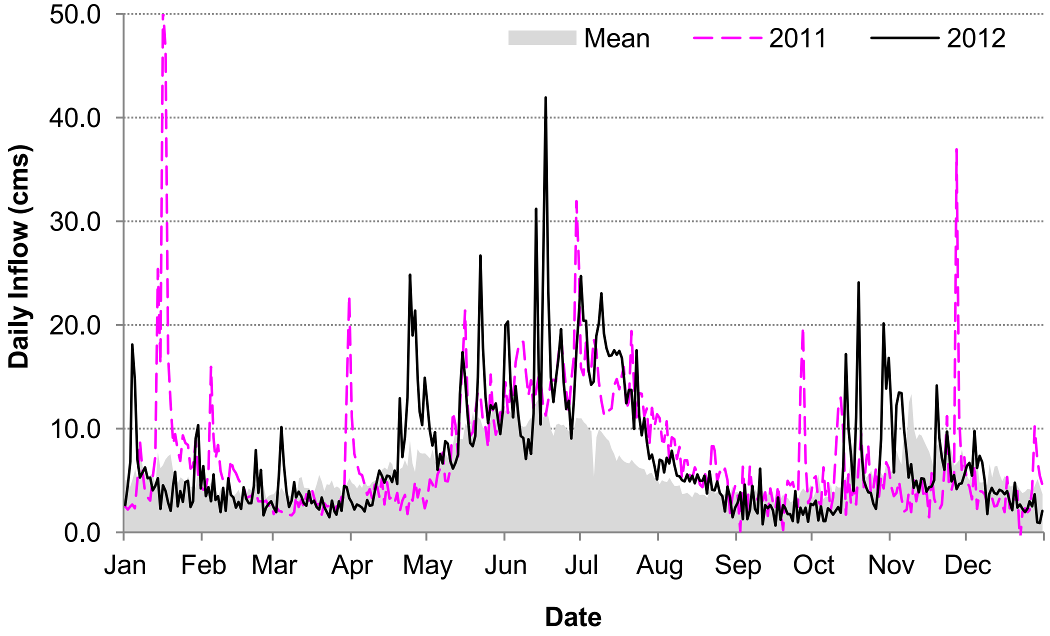


Figure 5 Daily inflow (m^3/s) into Wahleach Reservoir, 2011-2012. Shaded area represents mean inflow from 1984-2012.

Peak outflows from Wahleach Reservoir generally correspond with the timing of freshet and the maximum reservoir elevation for that year. In 2011, the maximum daily outflow rate was 28.0 $m^{3\cdot}s^{-1}$; in 2012, it was 23.0 $m^{3\cdot}s^{-1}$ (Figure 6). These rates were recorded in late June to early July in both years (Figure 6). Mean annual outflows were 6.9 ± 6.0 $m^{3\cdot}s^{-1}$ in 2011 and 7.3 ± 5.0 $m^{3\cdot}s^{-1}$ in 2012; both of which are greater than the long-term average of 6.0 ± 1.5 $m^{3\cdot}s^{-1}$.

In January through February of 2011, discharge from Wahleach was consistently high relative to the average; discharge then rapidly dropped to zero in late February where it remained until early June (Figure 6). This pattern corresponds with the timing of high inflows observed in late January, and low reservoir surface elevations which drop below the minimum operating level in mid to late February (Figure 5, Figure 7).

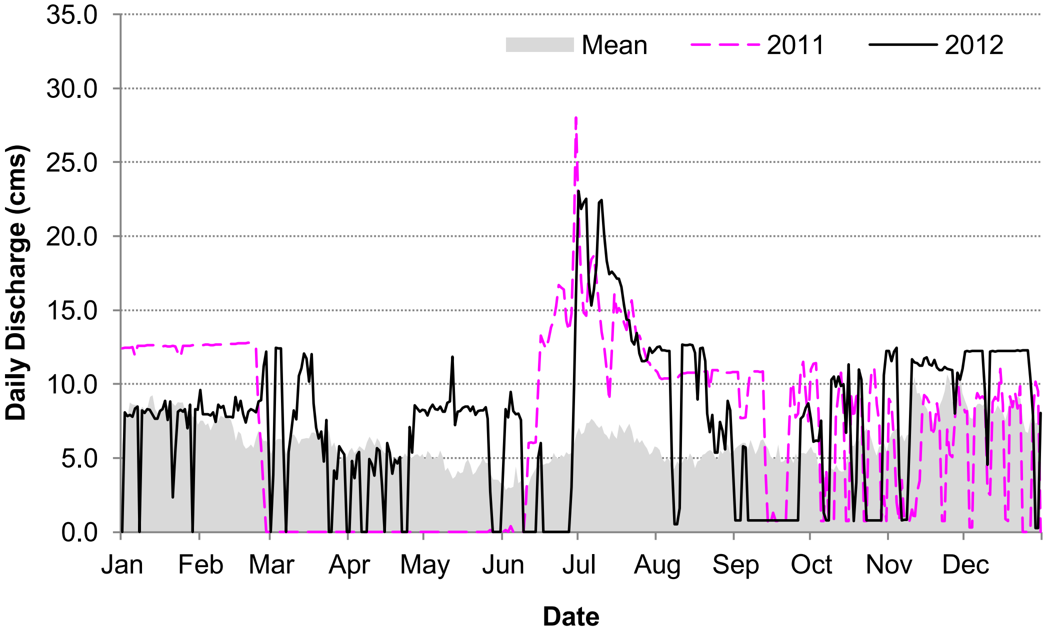


Figure 6 Daily outflow (m^3/s) from Wahleach Reservoir, 2011-2012. Shaded area represents the mean daily discharge from 1984-2012.

In 2011, the mean annual reservoir surface elevation was 635.2 ± 5.2 m. In 2012, the mean annual reservoir surface elevation was 636.1 ± 3.8 m. Both years were similar to the long term average of 636.1 ± 3.0 m. Reservoir elevations in late February to March of 2011 dropped 3.7 m below the 628 m minimum operating level; this was also below the 627 m minimum reservoir surface elevation as recommended by Perrin and Stables (2000) to protect rainbow trout spawning habitat. Drawdown in 2011 was 17.7 m with the reservoir surface elevations ranging between 624.3 m and 642.0 m. In 2012, reservoir elevation ranged from 629.1 m to 642.0 m with a drawdown of 12.9 m; surface elevations in 2012 remained above the minimum operating level (Figure 7). Drawdown in both years was greater than the long-term mean of 9.1 m. The slow 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 through July which corresponds with the start of fertilization. In 2011 and 2012, the mean reservoir elevation during the fertilization period (June-September, inclusive) was 640.3 ± 1.6 m and 639.7 ± 1.5 m, respectively.

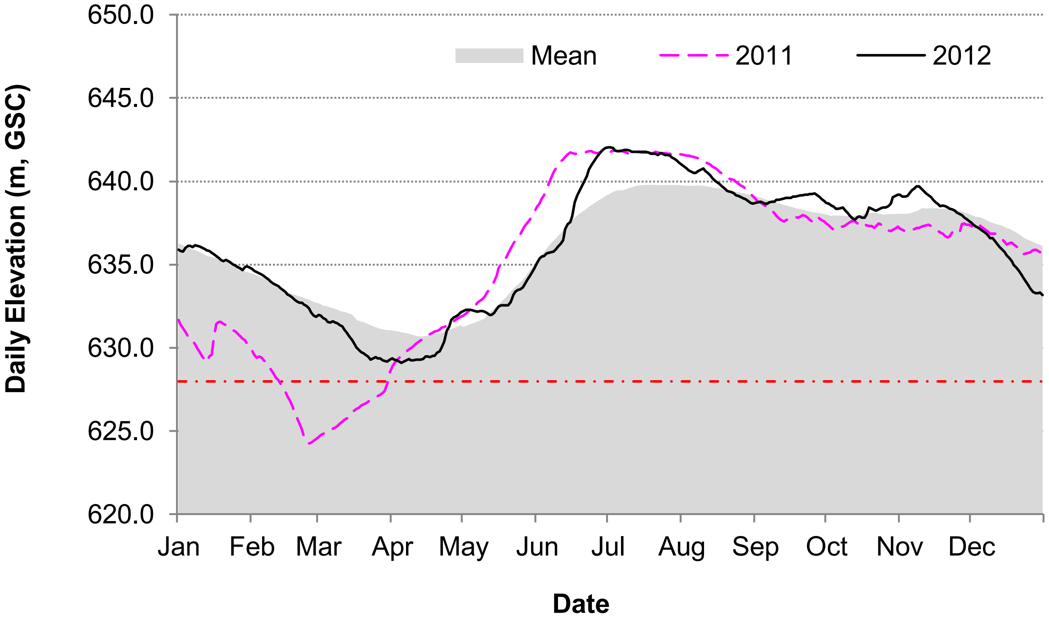


Figure 7 Daily reservoir surface elevation (m, GSC) for Wahleach Reservoir, 2011-2012. Shaded area represents mean elevation from 1984-2012. Dash-dot line at 628 m represents the minimum reservoir operating level.

3.2. Climate

On average, the warmest months were June through September during the fertilization period; this was true for 2011 and 2012 (Figure 8). The mean air temperature during fertilization was 13.4 ± 2.2°C in 2011 and 14.2 ± 3.0°C in 2012. For both years the maximum monthly mean temperature was for August at 15.4 ± 2.0°C in 2011 and 16.7 ± 3.3°C in 2012 (Figure 8). The coldest months were typically December through February; during which time air temperatures regularly drop below freezing (0°C). In 2011, the minimum daily temperature recorded was -12.4°C; the maximum daily temperature was 21.8°C. In 2012, the minimum daily temperature was -17.3°C, while the maximum was 23.6°C. Compared to the 1984-2012 average (6.4 ± 5.9°C), the mean annual temperature in 2011 was marginally cooler (6.1 ± 6.3°C), while 2012 was 0.5°C warmer (6.9 ± 6.8°C). Specifically, air temperatures in April through July 2011 were lower than usual; July 2011 in particular was 2.1°C cooler than the long term monthly mean.

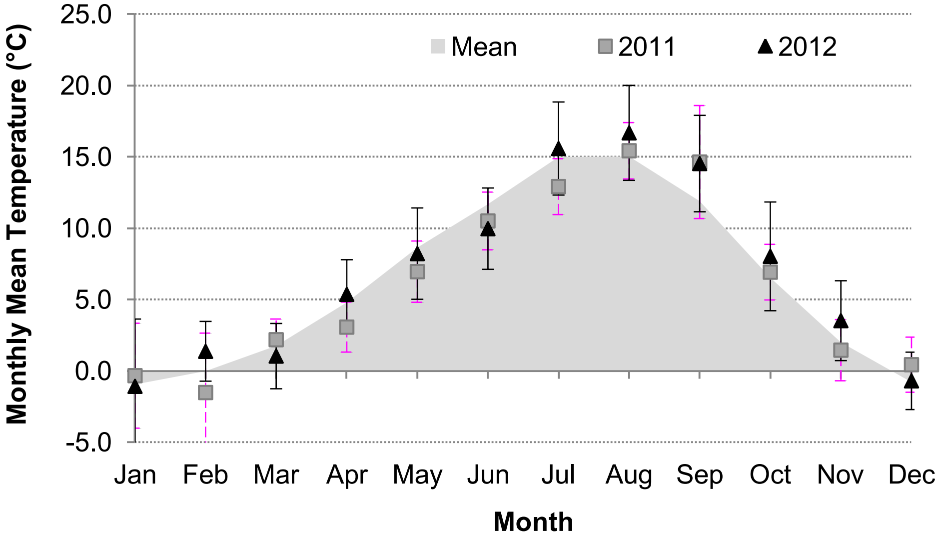


Figure 8 Mean monthly air temperature (ºC) ± SD measured at Wahleach Reservoir, 2011-2012. Shaded area represents mean air temperature from 1984-2012.

In terms of precipitation, the driest month was August with a monthly mean precipitation level of 1.2 ± 3.96 mm in 2011 and 0.3 ± 1.3 mm in 2012; both of which were lower than the long-term average (3.0 ± 4.1 mm; Figure 9). September 2012 was also unusually dry with a monthly mean precipitation of 1.1 ± 4.1 mm (Figure 9). The wettest months were January and March (Figure 9). In 2011, the maximum monthly mean precipitation level was for January at 19.8 ± 32.7 mm. In 2012, the maximum was for March at 13.8 ± 17.4 mm; January 2012 had the second highest amount of precipitation.

Compared to the long-term daily and total annual averages of 7.1 ± 3.6 mm and 2601.5 mm, both 2011 (daily mean 8.6 ± 15.6 mm, total annual 3123.7 mm) and 2012 (daily mean 7.8 ± 13.0 mm, total annual 2847.0 mm) were wetter. In fact, 2011 was one of the wettest years on record (second in terms of mean daily precipitation, third for total annual precipitation). The maximum amount of precipitation recorded in one day was 103.4 mm for 2011 and 65.5 mm for 2012.

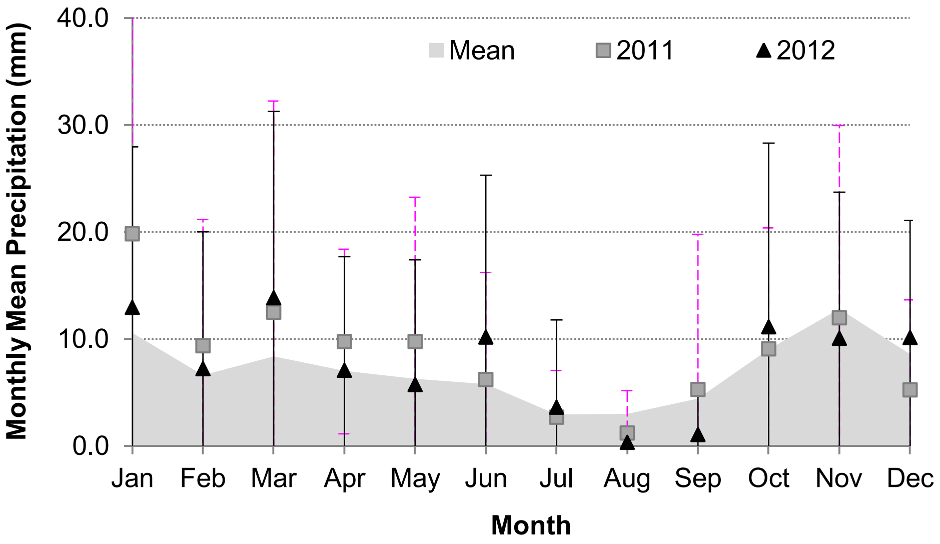


Figure 9 Mean monthly precipitation (mm) ± SD measured at Wahleach Reservoir, 2011-2012. Shaded area represents mean precipitation from 1984-2012.

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 3-7 m (Figure 10). 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 2011 for both stations combined ranged between 9.3°C and 22.8°C; temperature in 2012 was between 6.4°C and 17.3°C (Figure 10). For both years, the maximum temperature recorded was at the surface (0 m) during August. Dissolved oxygen concentrations for both stations combined ranged between 5.96-11.98 mg/L in 2011 and 7.13-12.91 mg/L in 2012. Both basins showed orthograde oxygen profiles indicative of oligotrophic conditions, though this pattern was weaker in 2011 (Figure 10).

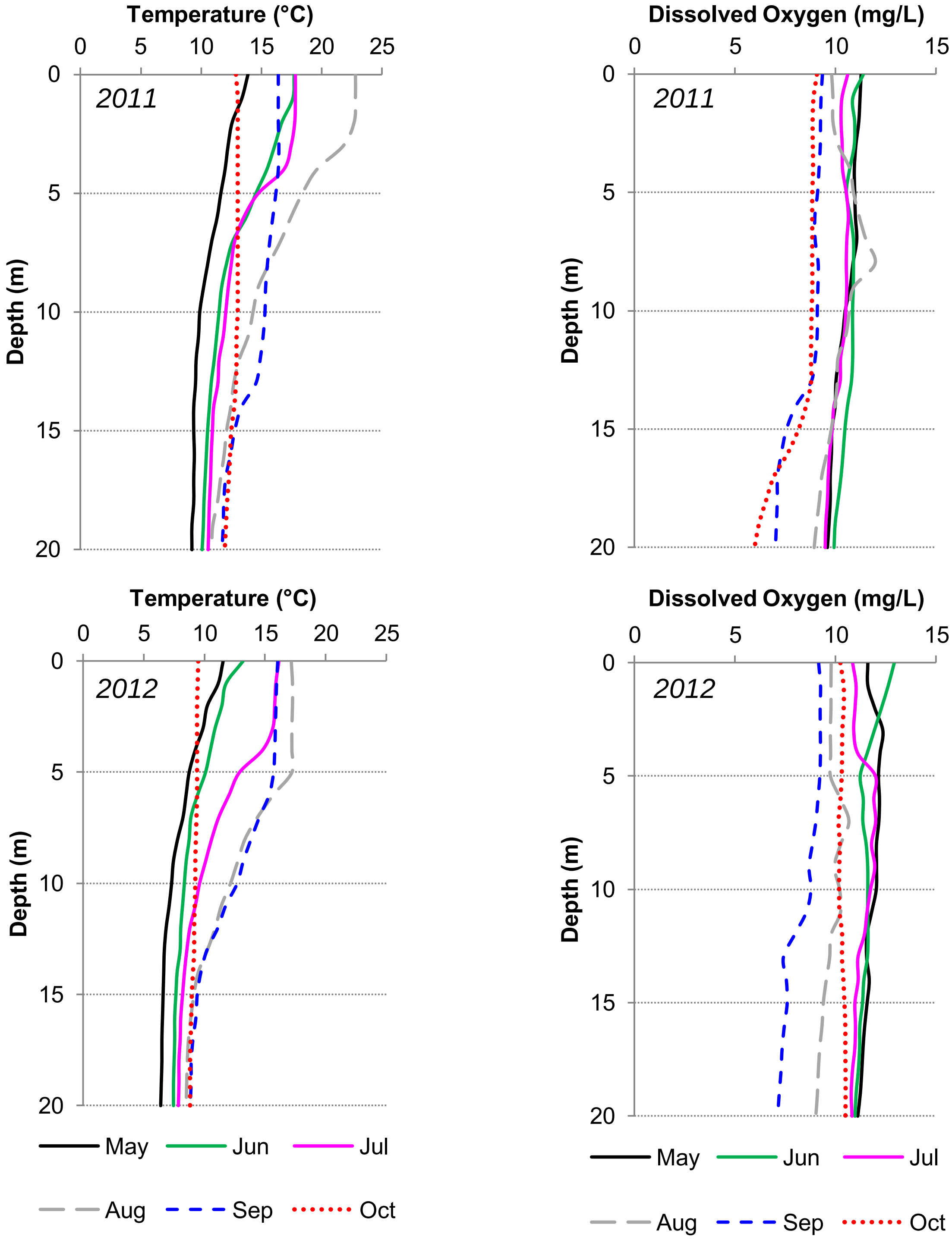


Figure 10 Temperature (°C) and dissolved oxygen (mg/L) profiles for Wahleach Reservoir, 2011 (top) and 2012 (bottom); values are averages of depth measurements taken at LS1 (north basin) and LS2 (south basin).

For 2011, the seasonal average Secchi depth at LS1 (north basin) was 4.07 ± 2.07 m and was 4.53 ± 1.12 at LS2 (south basin) (Figure 11); the combined seasonal average for both stations was 4.30 ± 1.61 m. The maximum Secchi depth recorded in 2011 was 6.60 m in October at LS1, while the minimum Secchi depth recorded was 1.75 m in May also at LS1 (Figure 11). The shallow depth recorded in May was due to suspended sediments from freshet run-off. In 2012, the seasonal average Secchi depth for LS1 was 4.83 ± 1.42 m and 4.95 ± 1.48 m for LS2 (Figure 11); the combined seasonal average for both stations was 4.89 ± 1.38 m. The maximum Secchi depth recorded in 2012 was 7.10 m in September at LS1, while the minimum depth was 3.10 m in July also at LS1 (Figure 11).

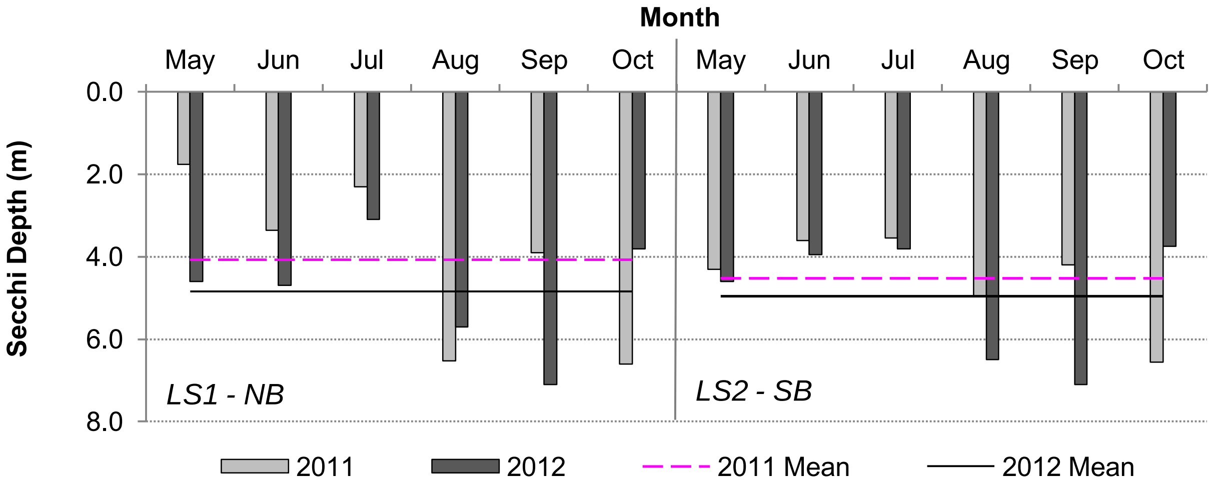


Figure 11 Monthly Secchi depth measurements (m) from LS1 in the north basin (NB) and LS2 south basin (SB) at Wahleach Reservoir, 2011-2012. Lines represent mean seasonal Secchi depth for corresponding years.

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 fertilization, seasonal mean epilimnetic TP was 4 ± 2 μg/L, and ranged from 3-12 μg/L indicative of ultra-oligotrophic productivity nearing oligotrophic productivity (Figure 12). In 2011, when no phosphorus was added to the reservoir, the seasonal mean TP was 4 ± 1 μg/L, and ranged from <2 to 5 μg/L (Figure 12). In 2012, seasonal mean TP was 5 ± 1 μg/L with values ranging from 3-7 μg/L (Figure 12). TP values in 2011 and 2012 were generally straddling between ultra-oligotrophic and oligotrophic productivity.

Seasonal mean soluble reactive phosphorous (SRP) levels during baseline years was 1 ± 0.3 µg/L with a range of 1-2 µg/L (Figure 12). Seasonal mean SRP in 2011 without any phosphorus added during fertilization was 1 ± 1 µg/L and ranged from <1-4 µg/L (Figure 12). In 2012, seasonal mean SRP was 1 ± 1 µg/L, and ranged from <1-2 µg/L (Figure 12). Several soluble reactive phosphorus (SRP) samples were below detection limits of 1 µg/L for both years, despite weekly phosphorus additions in 2012. Low SRP values suggest rapid uptake and assimilation of useable phosphorus by phytoplankton.

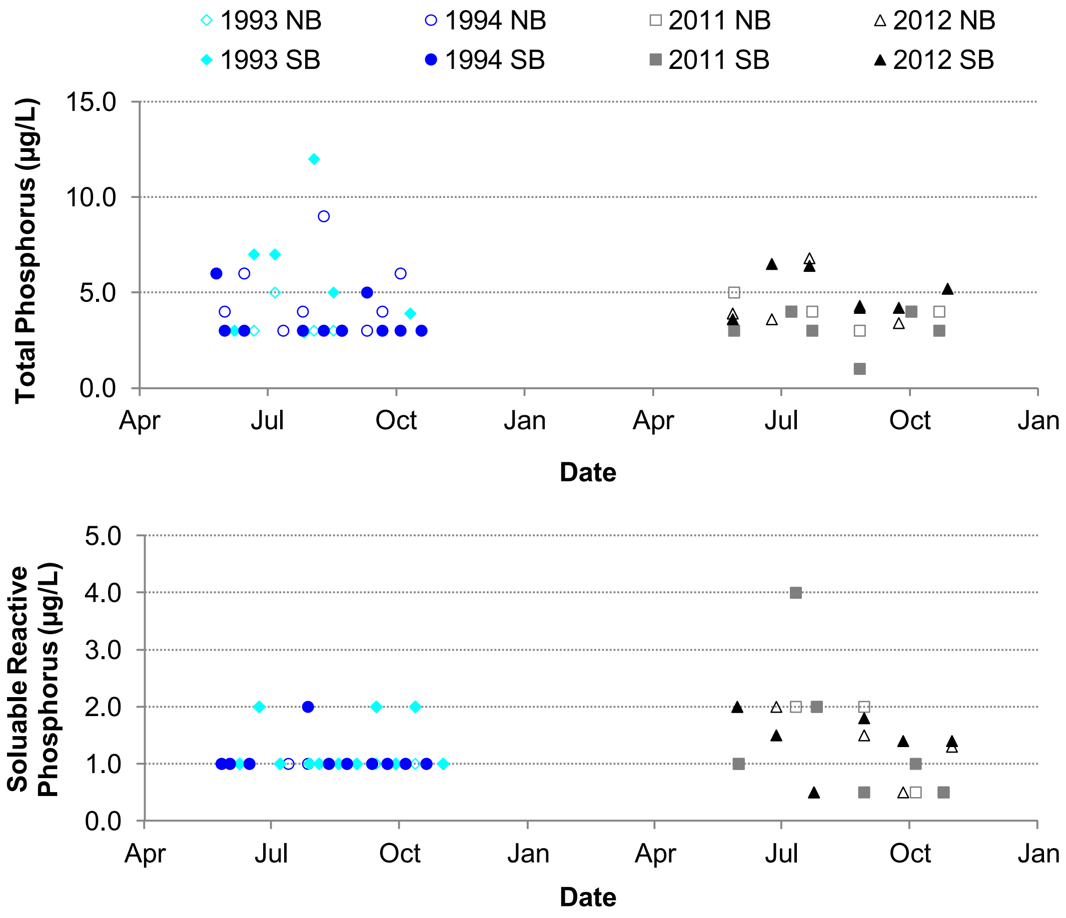


Figure 12 Epilimnetic total phosphorus and soluble reactive phosphorus concentrations at LS1 in the north basin (NB) and at LS2 in the south basin (SB) of Wahleach Reservoir for baseline years (1993-1994) and during fertilization in 2011-2012. Values from 1993-1994 are for surface (0 m) samples; values from 2011-2012 are for 1 m samples.

Epilimnetic total nitrogen (TN) concentrations in 2011 and 2012 were greater than in baseline years (112 ± 48 µg/L, range 9-22 µg/L) (Figure 13). In 2011, epilimnetic TN ranged between 80-390 µg/L with a seasonal mean of 177 ± 95 µg/L (Figure 13). In

2012, epilimnetic TN were between 135-273 µg/L with a seasonal mean of 207 ± 50 µg/L (Figure 13).

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 are typically observed in the spring; NO_3+NO_2 decrease through summer and then increase in early fall. This pattern was evident in baseline and fertilization years. 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 fertilization years (Figure 13) suggesting strong biological utilization of NO_3+NO_2 during these years. In 2011 and 2012 during fertilization, seasonal mean NO_3+NO_2 concentrations were lower than baseline (57 ± 38 µg/L) at 40 ± 32 µg/L and 46 ± 56 µg/L, respectively.

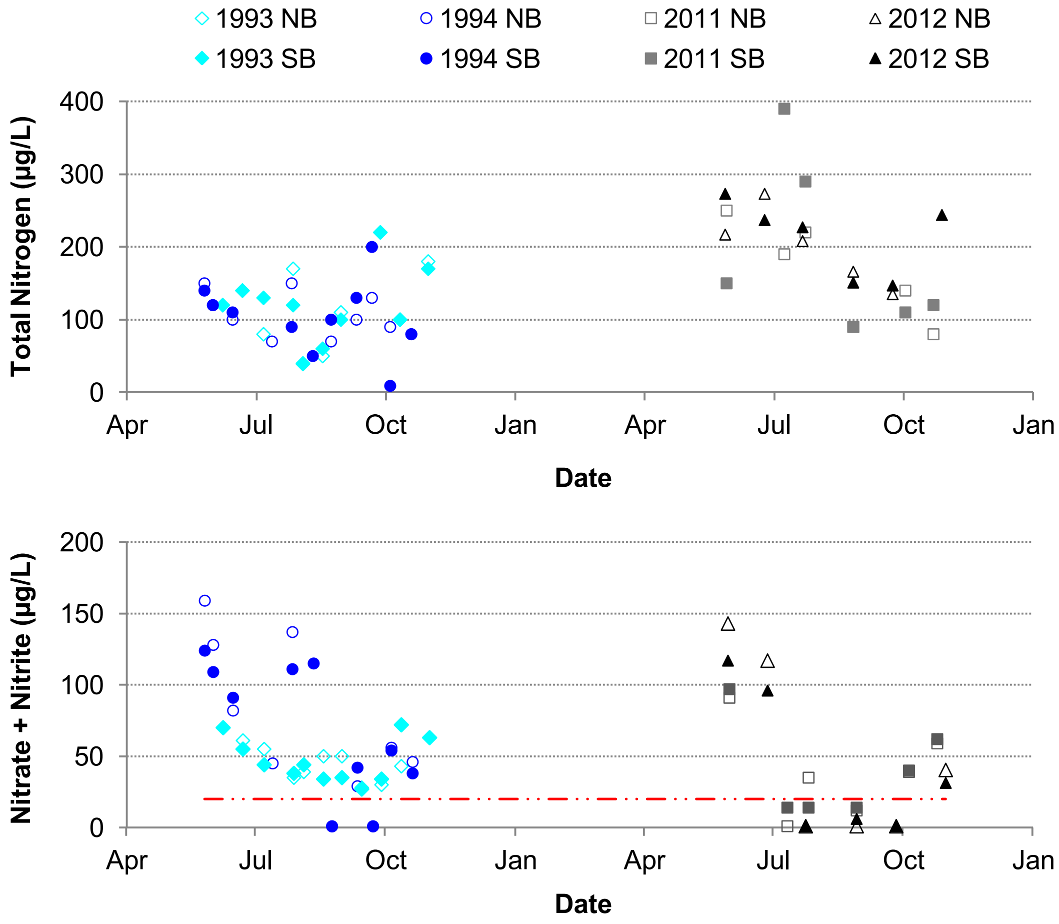


Figure 13 Epilimnetic total nitrogen and nitrate + nitrite concentrations at LS1 in the north basin (NB) and at LS2 in the south basin (SB) of Wahleach Reservoir for baseline years (1993-1994) and during fertilization in 2011-2012. Red dashed line at 20 µg/L indicates the concentration considered limiting to phytoplankton growth. Values from 1993-1994 are for surface (0 m) samples; values from 2011-2012 are for 1 m samples.

Seasonal average epilimnetic molar TN:TP ratios were almost two-fold greater in 2011 and 2012 than in baseline years. Prior to fertilization, the molar TN:TP was 56 ± 23 with a range of 12-109; while in 2011, molar TN:TP was 111 ± 43 with a range of 63-161 and in 2012 molar TN:TP was 100 ± 26 with a range of 73-145 (Figure 14).

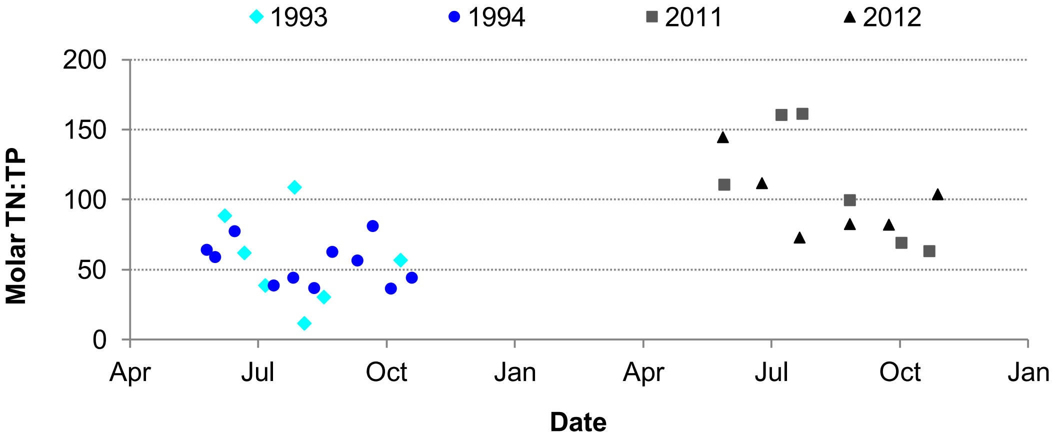


Figure 14 Molar epilimnetic total nitrogen (TN) to total phosphorus (TP) ratios for Wahleach Reservoir in baseline years (1993-1994), and during fertilization in 2011-2012. Values from 1993-1994 are for 0 m surface samples; values from 2011-2012 are for 1 m samples.

3.4. Phytoplankton

In 2011 and 2012, a total of 63 and 51 phytoplankton species were identified in Wahleach Reservoir (Appendix B). Mean annual phytoplankton abundance in 2011 was 13129 ± 6288 cells/mL for both stations combined; biovolume was 2.0487 ± 1.4958 mm^3/L (Figure 15). In 2012, the mean annual phytoplankton abundance was12352 ± 10901 cells/mL; mean annual biovolume was 1.5741 ± 1.2218 mm^3/L (Figure 15). Between the north and south basins, phytoplankton abundance and biovolume was generally lower in the south than the north. Compared to baseline years (8527 ± 2370 cells/mL; 0.7705 ± 0.2573 mm^3/L), phytoplankton abundance and biovolume were greater during fertilization (Figure 15). Separate data for stations LS1 and LS2 during baseline years was not available at the time of writing.

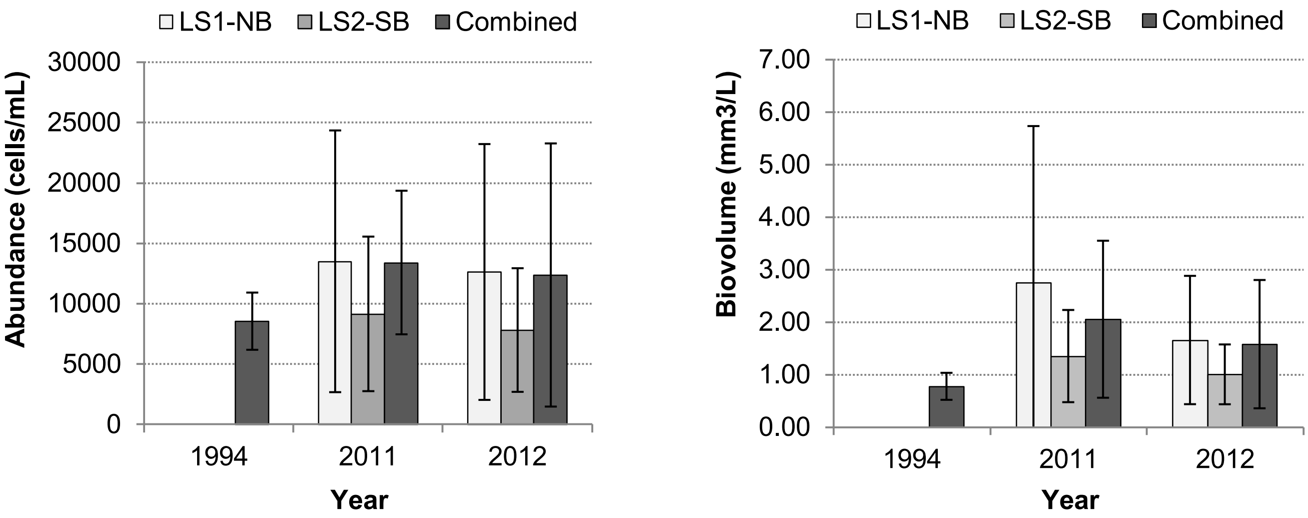


Figure 15 Seasonal mean abundance (±SD) and biovolume (±SD) of the phytoplankton community at LS1 in the north basin (NB) and LS2 in the south basin (SB) of Wahleach Lake Reservoir, 2011-2012.

Overall, chrysophytes and cryptophytes (*Chryso*- & *Cryptophyceae*) were the predominant phytoplankton class in Wahleach Reservoir; these include species such as *Ochromonas Chrysochromulina*, *Dinobryon*, *Chroomonas,* and small microflagellates that are in the edible size range for zooplankton. The phytoplankton community in 2011 was relatively unique with an exceptionally large proportion of chrysophytes and cryptophytes (85% abundance, 94% biovolume) and only minor contributions from all other classes (Figure 16). In 2012, chrysophyte and cryptophyte abundance was 46% while biovolume was 76% (Figure 16). Cyanophytes (*Cyanophyceae*) had the second greatest abundance in 2012 with a minimal effect on biovolume, as would be expected with cyanobacteria (Figure 16). Diatoms (*Bacillariophyceae*) made up the second greatest contribution to biovolume and were the third most abundant in 2012 (Figure 16). Generally, diatoms and dinophytes (*Dinophyceae*) made a greater contribution to the phytoplankton community during baseline years (Figure 16).

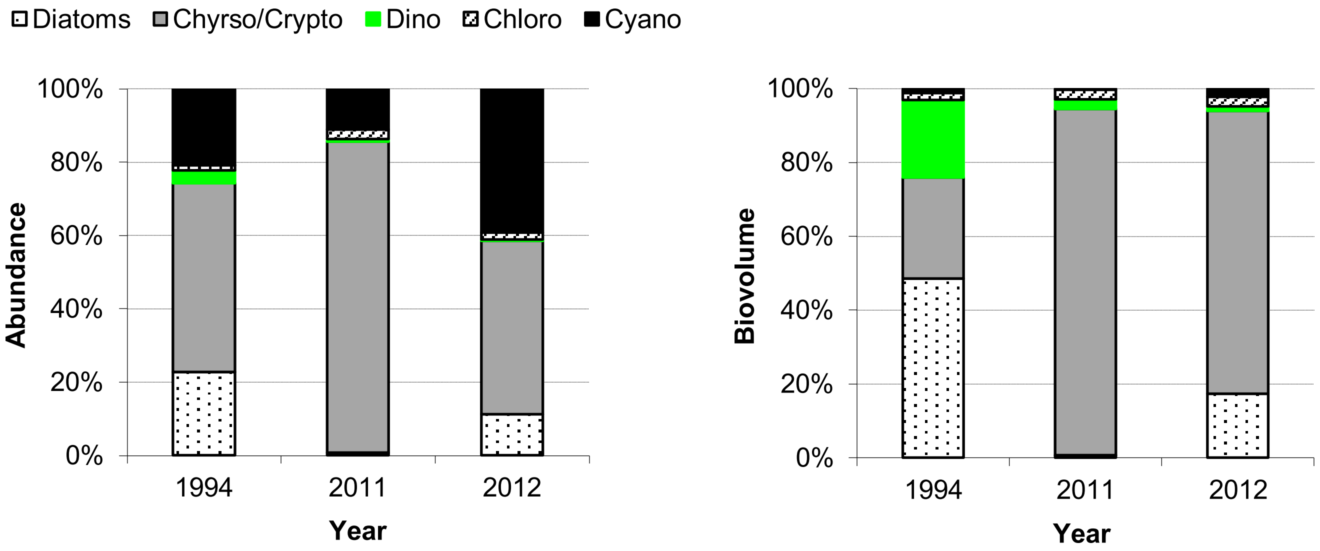


Figure 16 Relative contribution of major phytoplankton classes (*Bacillariophyceae* [diatoms], *Dinophyceae*, *Chlorophyceae*, *Cyanophyceae*, *Chryso*- & *Cryptophyceae*) to seasonal mean density (cells/L) and biomass (µg/L) in Wahleach Reservoir for baseline years and during fertilization in 2011- 2012.

In terms of seasonal trends amongst the major phytoplankton classes, chrysophytes and cryptophytes were prominent throughout the season making up the majority of the phytoplankton community in late spring and early summer. In May 2011, the north basin sample at LS1 had an unusually high abundance of chrysophytes and cryptophytes (34896 cells/mL); this was approximately 10-times greater than the May 2011 sample for LS2 (3801 cells/mL). Cyanophyte peak abundance occurred in June and July during 2011 and 2012, respectively; a secondary peak was observed in September and October for both years (Figure 17). Specifically, *Microcystis* sp. was quite common. Wahleach Reservoir generally experiences a diatom bloom in late summer and early fall; this was true for baseline years and during 2012; as mentioned previously diatoms were relatively rare in 2011 (Figure 17). Chlorophyte and dinophyte abundance were low throughout the season in all years (Figure 17).

Seasonal patterns in biovolume generally followed abundance with the exception of cyanophytes, which accounted for very little biovolume even during their peak abundance (Figure 17). 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.

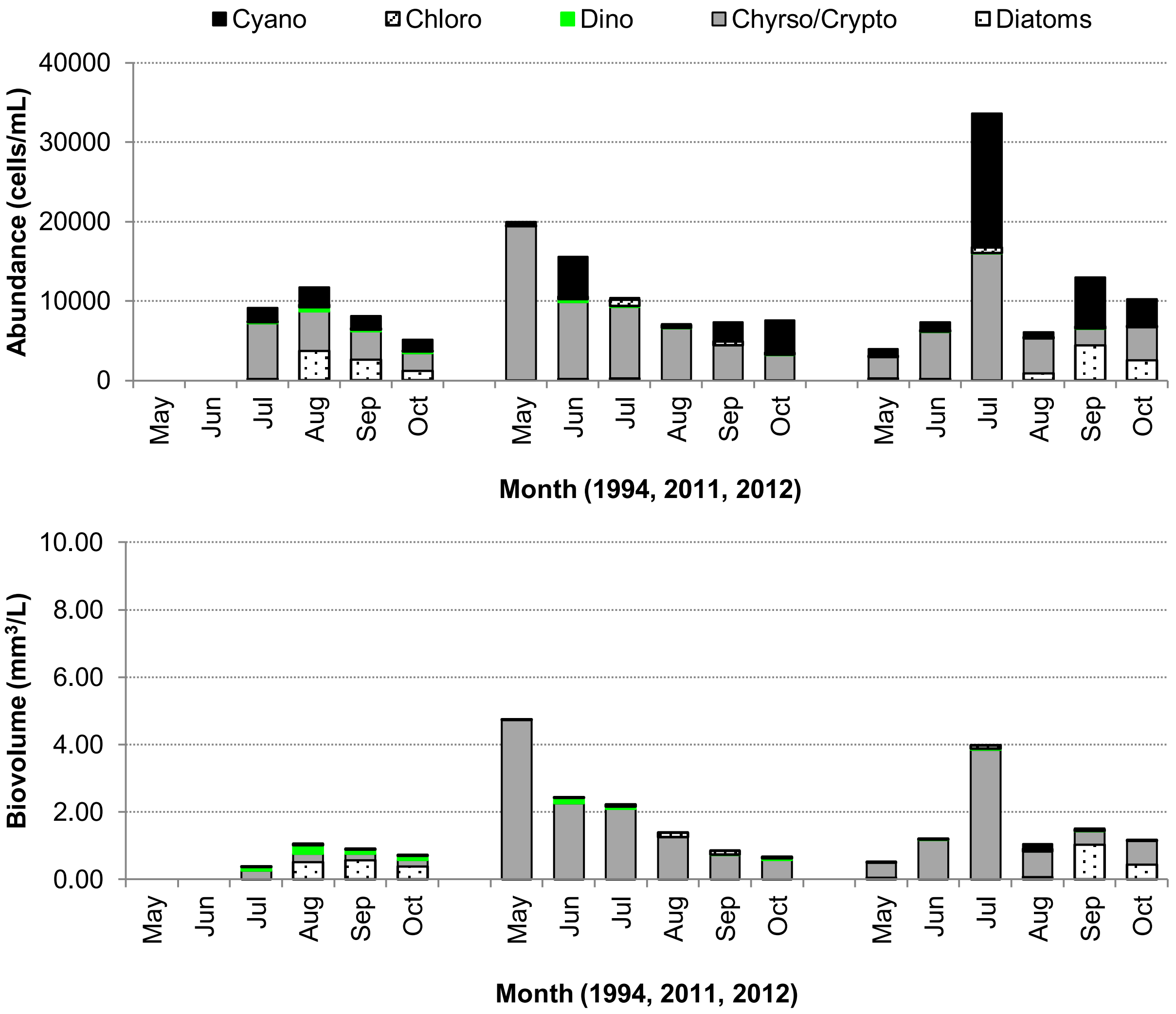


Figure 17 Abundance and biovolume of the major phytoplankton classes (*Bacillariophyceae* [diatoms], *Chryso-* & *Cryptophyceae*, *Dinophyceae*, *Chlorophyceae*, *Cyanophyceae*) in Wahleach Reservoir over the sampling season (May-October) during baseline years (1994) and during fertilization in 2011-2012; 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 2011 and 2012 sampling seasons are shown in Appendix C. Two copepod species were found in Wahleach Reservoir; *Cyclops vernalis* (Fischer) was present in all sampling years, while *Macrocyclops fuscus* (Jurine) was observed rarely. Nine species of *Cladocera* were identified in 2011 and 2012, of those *Daphnia rosea* (Sars), *Bosmina longirostris* (O.F.M.), *Holopedium gibberum* (Zaddach), and *Leptodora kindtii* (Focke) were common; other species were observed sporadically.

Prior to fertilization, overall zooplankton abundance was approximately 1 ind/L and biomass was negligible at <1 µg/L (Figure 18). *Daphnia*, a large cladoceran zooplankter, was first detected in Wahleach Reservoir in 1997 after two years of fertilization, but did not make up more than 1 ind/L until 2000 (Figure 18). Although all zooplankton groups have increased relative to baseline years, the appearance of *Daphnia* accounted for the dramatic increase in biomass. Overall, zooplankton density and biomass during fertilization years has reflected patterns in *Daphnia* density and biomass.

Mean annual zooplankton density for 2011 was 19.03 ± 11.59 ind/L (Figure 18), – the highest on record. Densities were driven by cladocerans other than *Daphnia*, particularly *Bosmina longirostris*. *Daphnia* abundance in 2011 was similar to recent fertilization years at 1.94 ± 2.10 ind/L; the mean annual abundance of other cladocerans was 16.67 ± 10.93 ind/L while mean annual copepod abundance was 0.43 ± 0.32 ind/L. Zooplankton abundance in 2012 was relatively low compared to recent years at 4.36 ± 2.44 ind/L; yet, *Daphnia* abundance remained stable at 2.02 ± 2.85 ind/L. Abundance of other cladoceran species in 2012 was 2.03 ± 2.68 ind/L, while copepods were 0.31 ± 0.28 ind/L.

Biomass data of the major zooplankton groups were not recorded during baseline studies. Regardless, it is a safe assumption based on abundance metrics that zooplankton biomass was significantly greater in 2011 and 2012 than in baseline years with 82.75 ± 53.37 µg/L and 67.71 ± 57.11 µg/L, respectively. Looking in more detail for 2011, *Daphnia* biomass was 27.03 ± 28.01 µg/L, other cladocerans biomass was 55.21 ± 45.76 µg/L; and copepod biomass was 0.50 ± 0.38 µg/L. In 2012, mean annual biomass of the major zooplankton groups were as follows: *Daphnia* was 46.86 ± 64.23 µg/L, other cladocerans were 20.35 ± 35.38 µg/L, and copepods were 0.49 ± 0.48 µg/L. Overall, zooplankton results represent a significant increase in food availability for planktivores relative to baseline years.

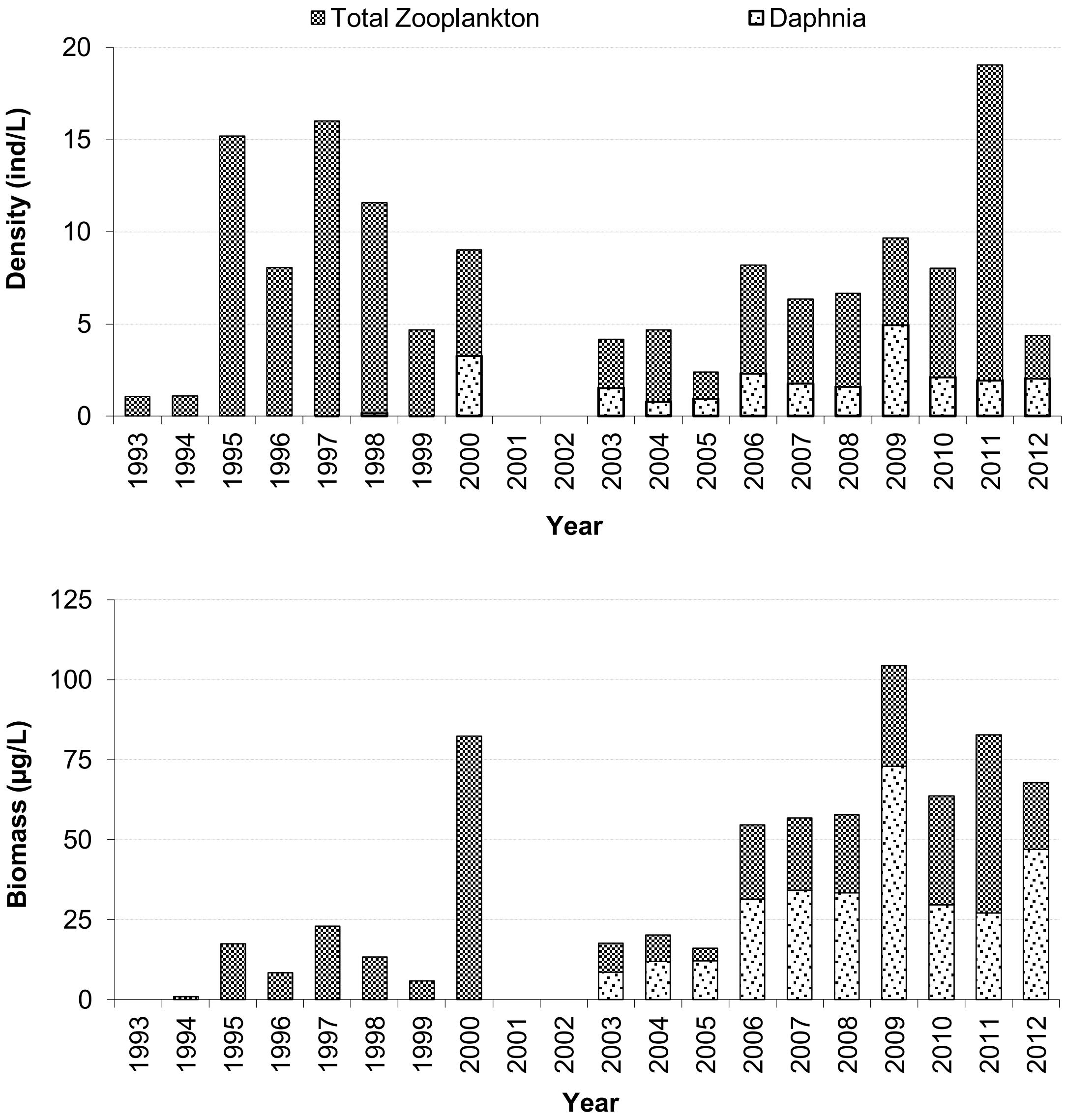


Figure 18 Seasonal mean density (ind/L) and biomass (µg/L) of *Daphnia* and total zooplankton in baseline years (1993-1994) and during fertilization in 1995-2012. *Daphnia* were detected in 1997-1999, but quantities were <1 ind/L which does not show up well in the figure. Zooplankton biomass data time series starts in 1995; *Daphnia* biomass data time series starts in 2003.

The most obvious difference in zooplankton community composition between baseline and fertilization years is the appearance of *Daphnia*. In 2011, *Daphnia* accounted for 10% of zooplankton abundance and 33% of biomass; other cladocerans represented a largest proportion of the zooplankton community at 88% of abundance and 67% of biomass (Figure 19). In 2012, *Daphnia* and other cladocerans were relatively equal in terms of abundance at 47% and 46%, respectively (Figure 19). As expected, *Daphnia* comprised a larger proportion of the biomass that year at 68%, while other cladocerans accounted for 30% (Figure 19). Copepods represented 2% of zooplankton abundance in 2011 and 7% in 2012, which is similar to pre-fertilization years (8% abundance in both 1993 and 1994) (Figure 19). Copepods made up 1% of zooplankton biomass in both 2011 and 2012 (Figure 19).

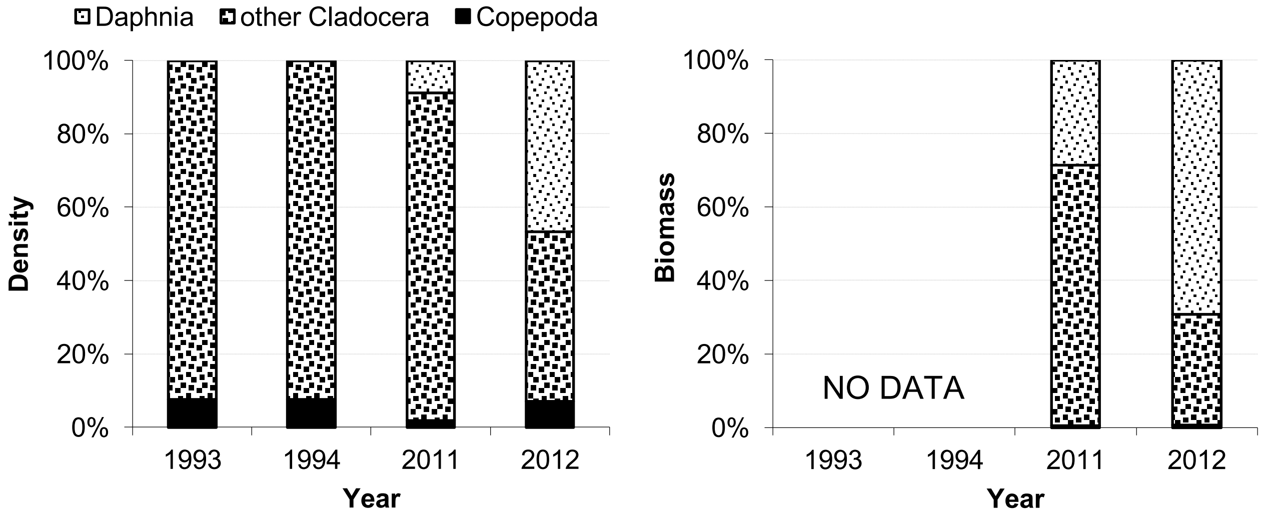


Figure 19 Relative contribution of major zooplankton groups (*Copepoda*, *Daphnia* spp., and other *Cladocera*) to seasonal mean density (ind/L) and biomass (µg/L) in Wahleach Reservoir for baseline years and during fertilization in 2011- 2012. No biomass data are available for 1993-1994.

Seasonally during fertilization, relatively high densities of other cladocerans were observed at beginning of season in late spring and early summer; other cladoceran densities then decrease while *Daphnia* densities increase and peak in late summer early fall. In 2011, peak zooplankton abundance (32.27 ± 10.77 ind/L) occurred in July (Figure 20). Densities were driven by other cladocerans, particularly *Bosmina longirostris*. Peak biomass (151.69 ± 42.38 µg/L) occurred in August corresponding with the timing of peak *Daphnia* density, though other cladoceran densities still remained high (Figure 20). *Daphnia* densities in 2011 ranged from 0.20 ± 0.02 to 5.82 ± 1.41 ind/L. *Daphnia* biomass in 2011 ranged from 1.84 ± 0.58 to 68.40 ± 17.84 µg/L. For the same year, densities of other cladocerans ranged from 4.00 ± 0.41 to 31.13 ± 10.45 ind/L; while biomass was 10.24 ± 6.21 to 119.44 ± 56.07 µg/L.

During 2012, there were two seasonal peaks in zooplankton abundance and biomass; one in July in which other cladoceran species were dominant (*Holopedium gibberum* prevailing numerically) and one in September in which *Daphnia* was dominant (Figure 20). Overall, the greatest zooplankton density and biomass in 2012 was 6.90 ± 2.10 ind/L, and 147.98 ± 27.41 µg/L corresponding with the *Daphnia* peak in September (Figure 20). *Daphnia* densities in 2012 ranged from 0 to 6.11 ± 2.10 ind/L while biomass ranged from 0 to 145.27 ± 26.73 µg/L. Other cladoceran densities ranged from 0.07 ± 0.00 to 6.34 ± 1.55 ind/L while biomass ranged from 0.64 ± 0.12 to 89.85 ± 30.36 µg/L.

As a small proportion of the zooplankton community overall, copepod density ranged from 0.03 ± 0.00 to 0.76 ± 0.29 ind/L in 2011 and 0.07 ± 0.01 to 0.70 ± 0.02 ind/L in 2012; the highest densities were found in August to October (Figure 20). Copepod biomass ranged between 0.03 ± 0.00 to 1.03 ± 0.33 µg/L in 2011 and 0.06 ± 0.01 to 1.15 ± 0.19 µg/L in 2012.

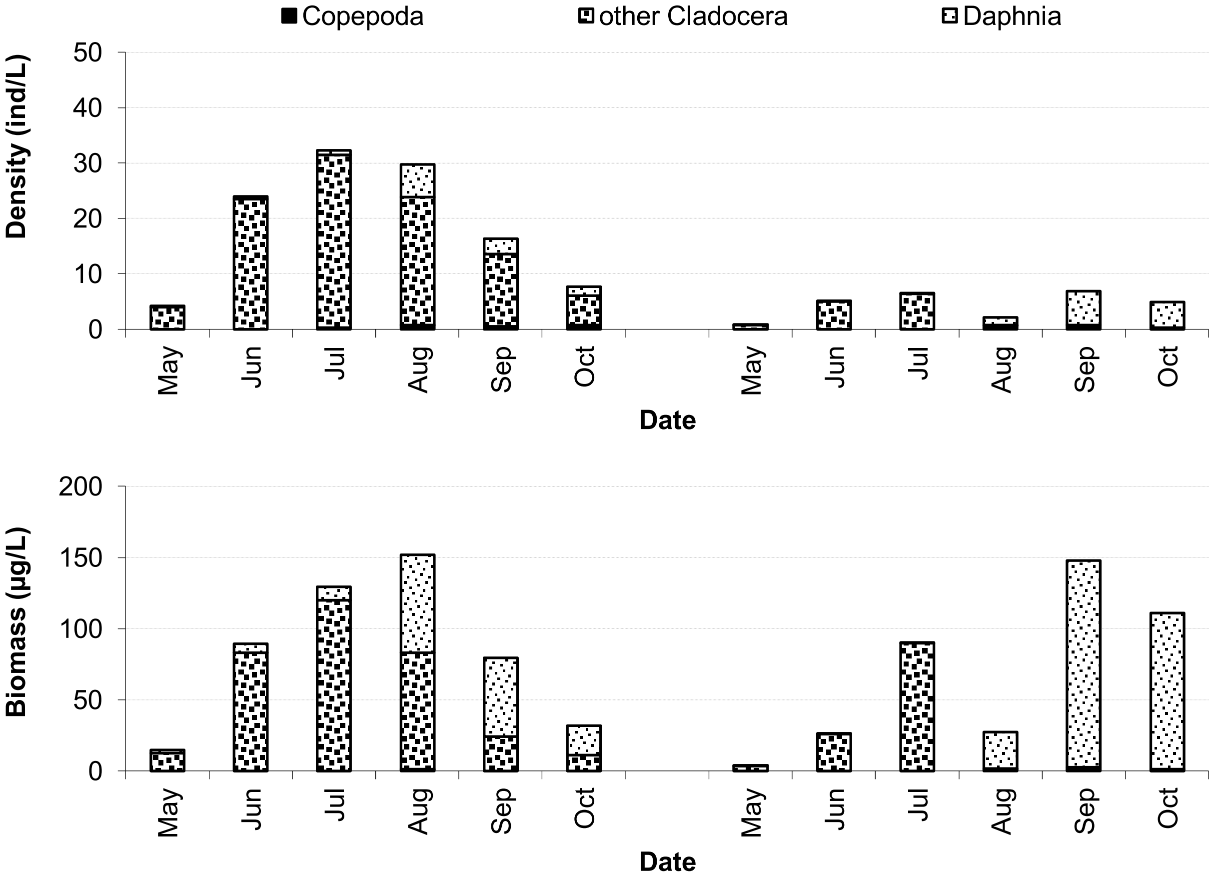


Figure 20 Monthly mean density (ind/L) and biomass (µg/L) of major zooplankton groups (*Copepoda*, *Daphnia* spp. and other *Cladocera*) in Wahleach Reservoir over the sampling season (May-October), 2011- 2012.

3.6. Fish

Nearshore Gillnetting and Minnow Trapping

During the 2011 nearshore gillnetting program, a total of 166 fish were caught. Rainbow trout made up 85% of the catch at 123 individuals. Kokanee were the second most abundant species caught (30) followed by cutthroat trout (13). In 2012, a total of 87 fish were caught in nearshore gillnets. Kokanee, cutthroat trout and rainbow trout catch were nearly equal with 29, 25 and 32 individuals caught, respectively. Table 5 contains summaries of the 2011 and 2012 nearshore gillnetting catch. Table 5 also contains summaries of the catch-per-unit-effort (CPUE) from the 2011 and 2012 nearshore gillnetting. The mean CPUE in 2011 was 1.29 ± 0.68 fish per net hour; a function of the high rainbow trout catch that year. In 2012, mean CPUE was lower at 0.82 ± 0.74 fish per net hour. Kokanee CPUE, however, was higher in 2012 (0.27 ± 0.41 fish per net hour) than 2011 (0.11 ± 0.13 fish per net hour). In both 2011 and 2012, station 3F located near the mouth of Flat Creek (Figure 1) had the highest CPUE.

Threespine stickleback catch in minnow traps was low in 2011 and 2012; only 1 individual caught in 2012 (Table 6). Mean threespine stickleback CPUE was 0.08 ± 0.13 fish per trap hour for 2011 and 0.01 ± 0.02 fish per trap hour for 2012 (Table 6).

Table 5 Summary of fall nearshore gillnetting catch and catch-per-unit-effort (CPUE) for Wahleach Reservoir, 2011-2012. Species include kokanee (KO), cutthroat trout (CT) and rainbow trout (RB).

	Catch					**CPUE** (individuals per net[†] h)			
Year	**Station**	**KO**	**CT**	**RB**	**Total**	**KO**	**CT**	**RB**	**Total**
2011	1S	1	4	7	12	0.04	0.18	0.31	0.53
	2F	8	0	34	42	0.36	0.00	1.52	1.87
	3F	1	0	38	39	0.05	0.00	2.08	2.13
	4F	2	0	18	20	0.12	0.00	1.06	1.18
	5S	1	4	3	8	0.06	0.25	0.18	0.49
	6S	0	1	23	24	0.00	0.07	1.50	1.56
	Total	**13**	**9**	**123**	**145**	**-**	**-**	**-**	**-**
	Mean	**-**	**-**	**-**	**-**	**0.11**	**0.08**	**1.11**	**1.29**
	SD	**-**	**-**	**-**	**-**	**0.13**	**0.11**	**0.74**	**0.68**
2012	1S	0	4	2	6	0.00	0.23	0.11	0.34
	2F	5	3	7	15	0.29	0.17	0.40	0.86
	3F	19	10	10	40	1.07	0.57	0.57	2.26
	4F	4	1	7	12	0.23	0.06	0.40	0.69
	5S	0	3	3	6	0.00	0.17	0.17	0.34
	6S	1	4	3	8	0.05	0.22	0.16	0.44
	Total	**29**	**25**	**32**	**87**	**-**	**-**	**-**	**-**
	Mean	**-**	**-**	**-**	**-**	**0.27**	**0.23**	**0.30**	**0.82**
	SD	**-**	**-**	**-**	**-**	**0.41**	**0.17**	**0.18**	**0.74**

[†] *net = 6 panel RISC size gillnet totaling* $218.88m^2$

Table 6 Summary of minnow trap catch and catch per unit effort (CPUE) for Wahleach Reservoir, 2011-2012. The only species caught was threespine stickleback (TSB).

	Year	G1	G2	G3	G4	G5	G6	Total	Mean	SD
TSB Catch	2011	0	0	0	4	6	0	**10**	**-**	**-**
	2012	0	0	0	0	1	0	**1**	**-**	**-**
CPUE	2011	0	0	0	0.20	0.28	0	**-**	**0.08**	**0.13**
(TSB per trap h)	2012	0	0	0	0	0.06	0	**-**	**0.01**	**0.02**

Kokanee

Summary statistics of kokanee biometric data from nearshore gillnetting programs during baseline studies and 2011-2012 fertilization years are shown in Table 7. In baseline years, the mean length of kokanee caught in gillnets was 170 ± 23 mm. In 2011, the mean length of kokanee caught in gillnets was lower at 153 ± 39 mm; in 2012, mean kokanee length was higher than baseline at 195 ± 17 mm. Similarly, the mean weight of kokanee caught during gillnetting programs followed the same pattern (Table 7). The differences amongst mean lengths and weights are explained by ageing data. The mode age of kokanee caught during gillnetting in 2011 was 1+, whereas in baseline years and in 2012 the majority of kokanee caught were 2+ (Figure 21). The lower mean length and weight values in 2011 are thus consistent with younger aged fish.

The length frequency distributions for kokanee in baseline years and in 2011 were bimodal, though the peaks of both modes were larger in 2011 relative to pre-fertilization data (Figure 22). In 2012, the length frequency distribution of kokanee had a single mode in the same range as the second mode in 2011 (Figure 22). When length frequency distributions are separated by age (data on file), the first mode evident in pre-fertilization and fertilization eras represented age 1+ kokanee while the second mode represented age 2+ kokanee. Kokanee of the same age caught during fertilization years were larger than those caught prior to fertilization. Mean length-at-age data also show 1+ and 2+ kokanee caught in 1993-94 were noticeably smaller than during 2011 and 2012 (Figure 23). No 3+ kokanee were caught during pre-fertilization baseline studies. Furthermore, the condition factor of kokanee in 2011 (1.06 ± 0.13) and 2012 (1.16 ± 0.07) were greater than in baseline years (0.97 ± 0.10). And, the slopes of the kokanee length-weight regressions for 2011 and 2012 are greater than prior to fertilization; both of which suggest kokanee were better condition during 2011 and 2012 than in baseline years (Table 7, Figure 24).

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 fertilization in 2011 and 2012

	Year	Mean	SD	Max	Min	n
Length	1993-94	170	23	217	115	107
(mm)	2011	153	39	217	66	30
	2012	195	17	261	163	28
Weight	1993-94	50.2	17.5	86.3	15.5	107
(g)	2011	46.4	28.8	113.5	2.0	30
	2012	88.5	26.9	205.0	46.0	28
CF	1993-94	0.97	0.10	1.14	0.56	107
	2011	1.06	0.13	1.36	0.70	30
	2012	1.16	0.07	1.24	1.01	28
Age	1993-94	1.8	0.4	2	1	107
	2011	1.2	0.5	3	1	25
	2012	1.6	0.6	3	1	29

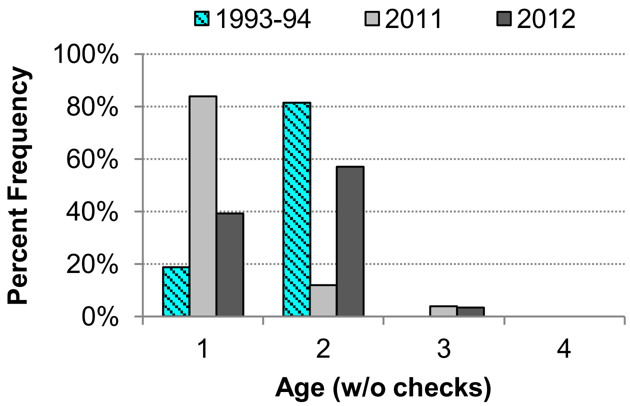


Figure 21 Age frequency distribution of kokanee caught in gillnets during baseline years (1993-1994) and fertilization in 2011-2012, Wahleach Reservoir

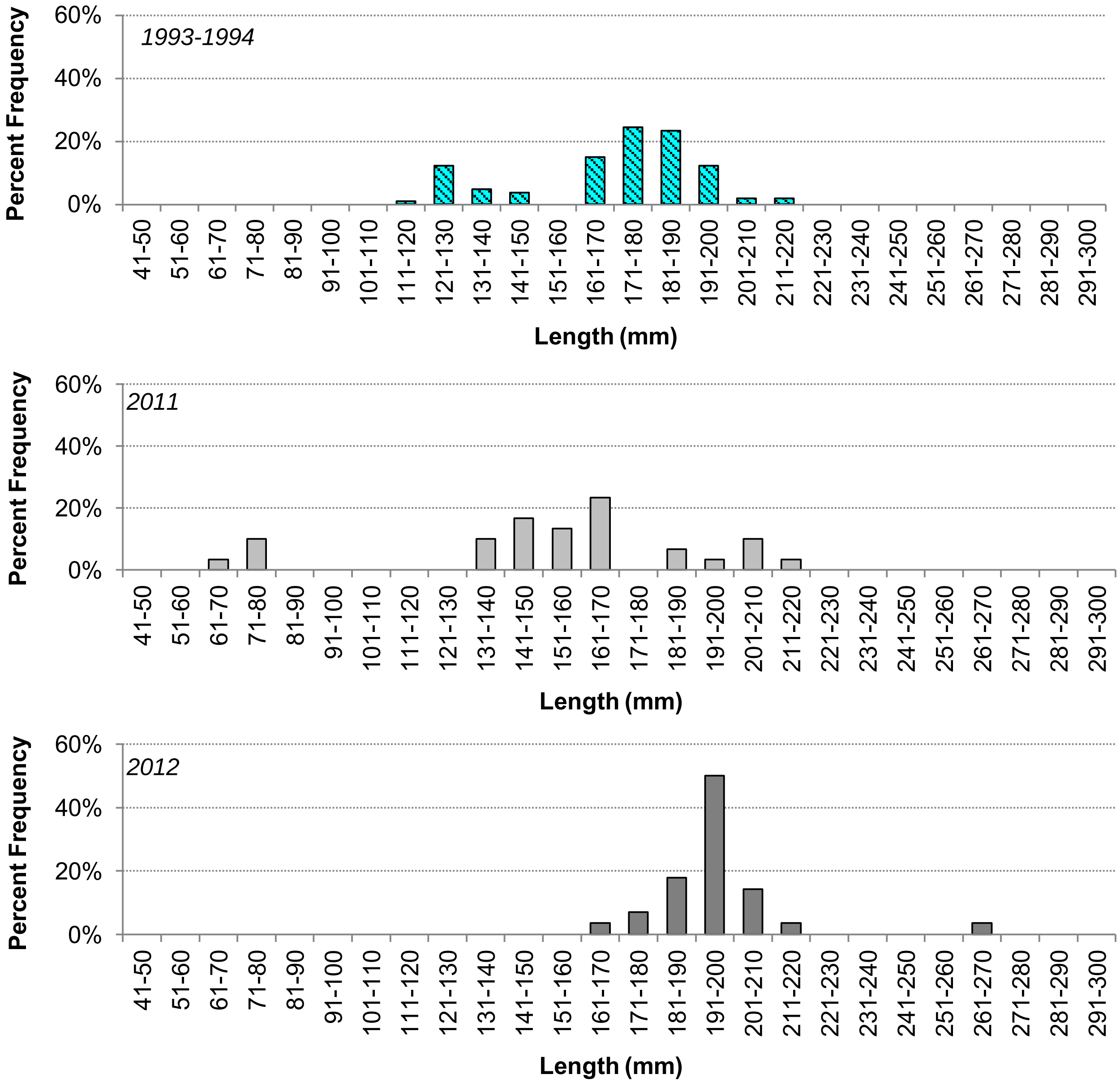


Figure 22 Length frequency distribution of kokanee caught in gillnets during baseline years (1993-94) and during fertilization in 2011 and 2012, Wahleach Reservoir

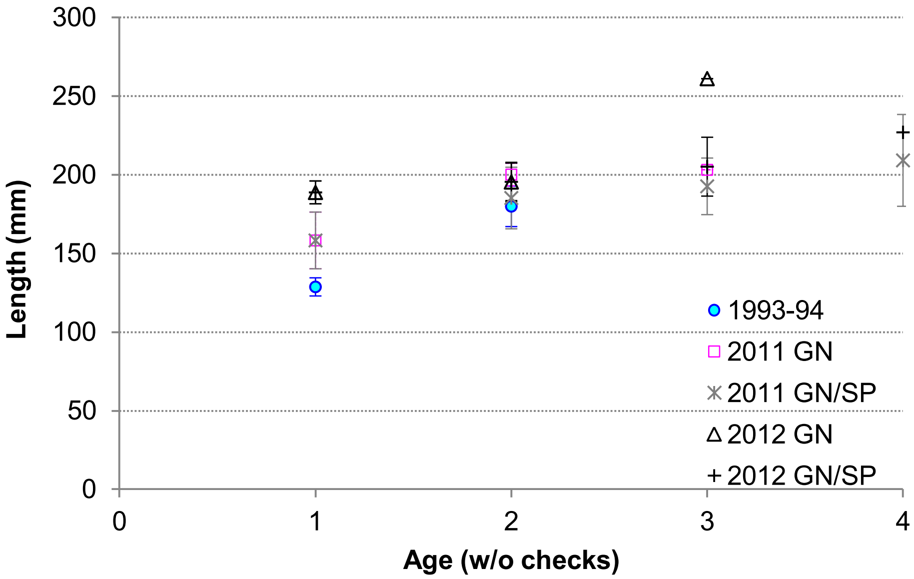


Figure 23 Mean length at age (±SD) for Wahleach Reservoir kokanee in baseline years (1993-1994) and during fertilization in 2011 and 2012; baseline data represents kokanee sampled during gillnetting; 2011 and 2012 data includes kokanee sampled during gillnetting (GN; October) and spawner surveys (SP; September-October)

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 fertilization in 2011 and 2012, Wahleach Reservoir

Year	a	b	R^2
1993-94	0.0130	2.8946	0.9377
2011	0.0046	3.3078	0.9922
2012	0.0087	3.0950	0.9496

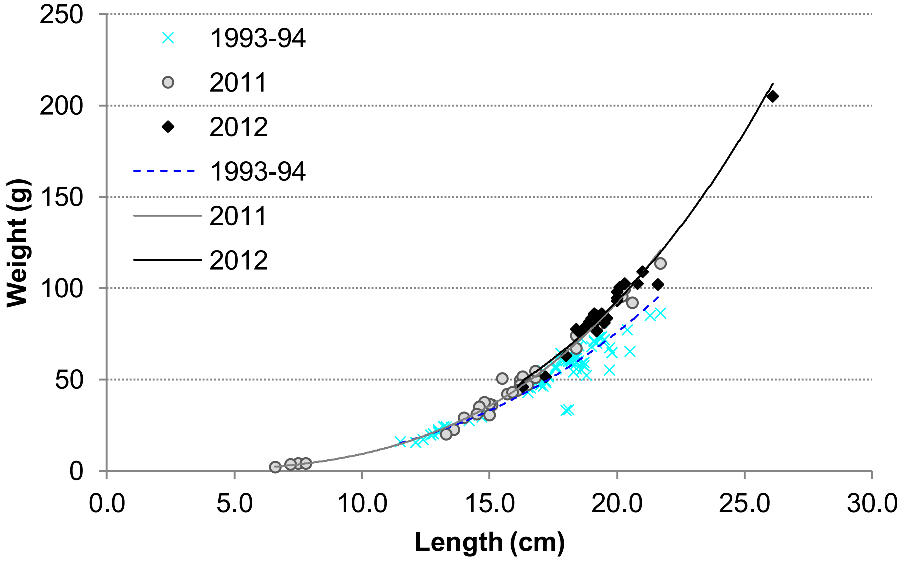


Figure 24 Length weight plot and relationship ($W = a \cdot L^b$) of kokanee caught in gillnets in baseline years (1993-1994) and during fertilization in 2011 and 2012, Wahleach Reservoir

Rainbow Trout

Summary statistics of biometric data for rainbow trout caught in gillnetting programs during baseline studies and in 2011 and 2012 are shown in Table 9. Rainbow trout caught in baseline years and in 2011 were similar, while rainbow trout caught in 2012 were generally larger (i.e. greater mean length and mean weight). The patterns observed in mean length and mean weight can be explained by differences in ageing data amongst the study years. The majority of rainbow trout caught in baseline years and in 2011 were 1+ or 2+, while rainbow trout caught in 2012 were primarily 3+ fish (Figure 25). Likewise, the length frequency distribution of rainbow trout during pre-fertilization years was heavily weighted towards smaller size classes (Figure 26). Rainbow trout caught during 2011 were more evenly distributed amongst size and age classes with a higher percentage of older and larger fish caught relative to baseline (Figure 25, Figure 26). In 2012, smaller size and age classes were underrepresented; the majority of rainbow trout caught were in mid-size classes and were age 3+ (Figure

25, Figure 26). Interestingly, although mean length-at-age between baseline and fertilization eras was very similar, the slopes of rainbow trout length-weight regressions for the fertilization era are greater than baseline (Figure 27, Figure 28). Condition factors of rainbow trout caught during the fertilization era are also greater than in baseline years (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 fertilization in 2011 and 2012

	Year	Mean	SD	Max	Min	n
Length (mm)	1993-94	186	45	329	109	374
	2011	187	63	366	106	114
	2012	221	56	343	113	30
Weight (g)	1993-94	71.5	52.0	316.2	13.9	374
	2011	84.4	74.1	356.0	13.0	113
	2012	133.0	85.0	422.0	17.0	30
CF	1993-94	0.99	0.33	5.24	0.52	374
	2011	1.05	0.10	1.49	0.79	113
	2012	1.06	0.09	1.33	0.92	30
Age	1993-94	2.0	0.6	4	1	372
	2011	2.1	1.0	4	1	99
	2012	3.1	1.0	5	1	31

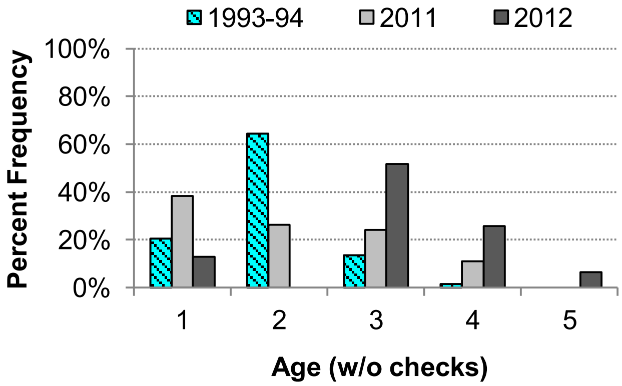


Figure 25 Age frequency distribution of rainbow trout caught in gillnets during baseline years (1993-1994) and fertilization in 2011-2012, Wahleach Reservoir

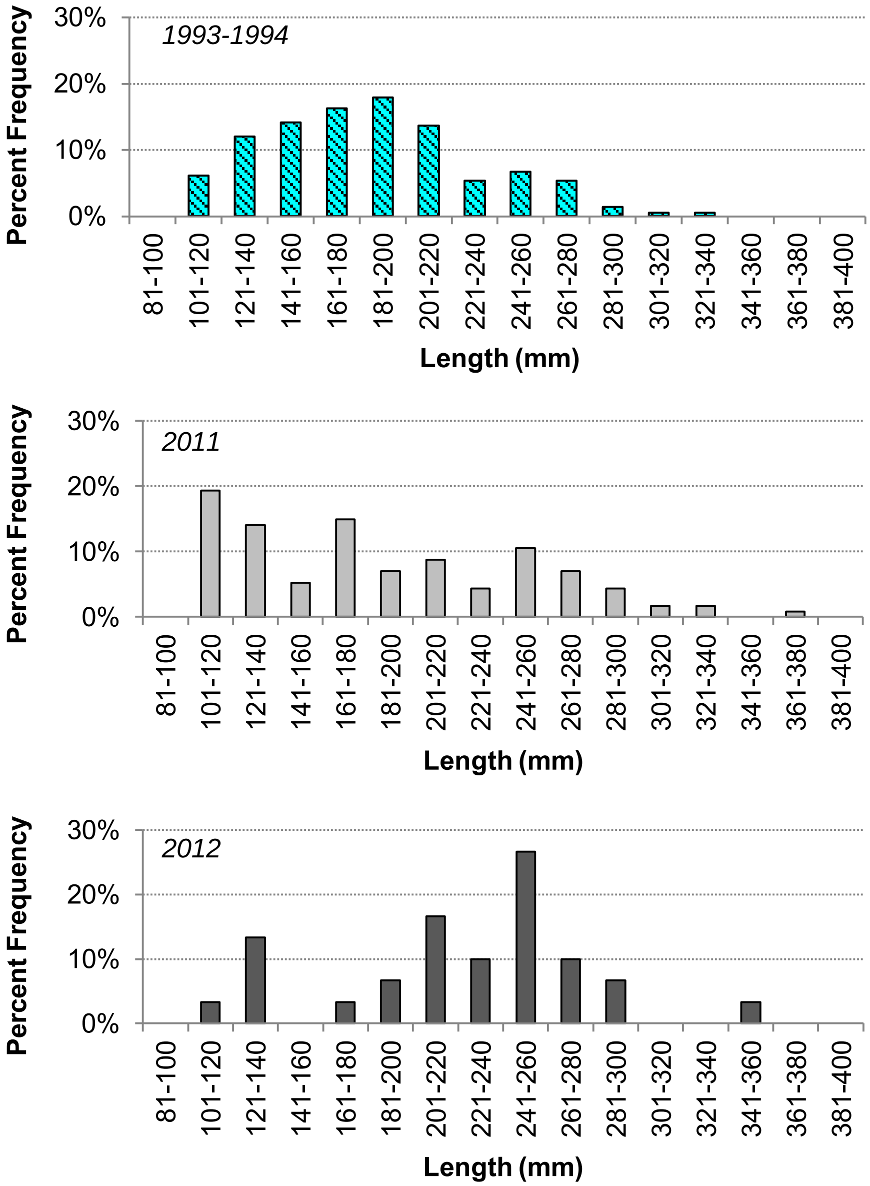


Figure 26 Length frequency distribution of rainbow trout caught in gillnets in baseline years (1993-1994) and during fertilization in 2011 and 2012, Wahleach Reservoir

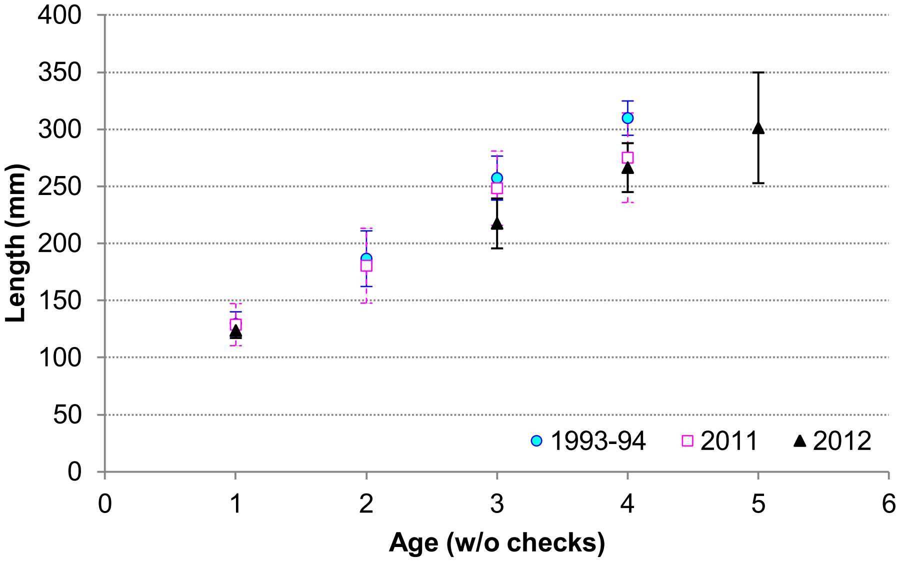


Figure 27 Mean length-at-age (±SD) for Wahleach Reservoir rainbow trout in baseline years (1993-1994) and during fertilization in 2011 and 2012

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 fertilization in 2011 and 2012, Wahleach Reservoir

Year	a	b	R^2
1993-94	0.0247	2.6765	0.9286
2011	0.0170	2.8293	0.9936
2012	0.0141	2.9061	0.9911

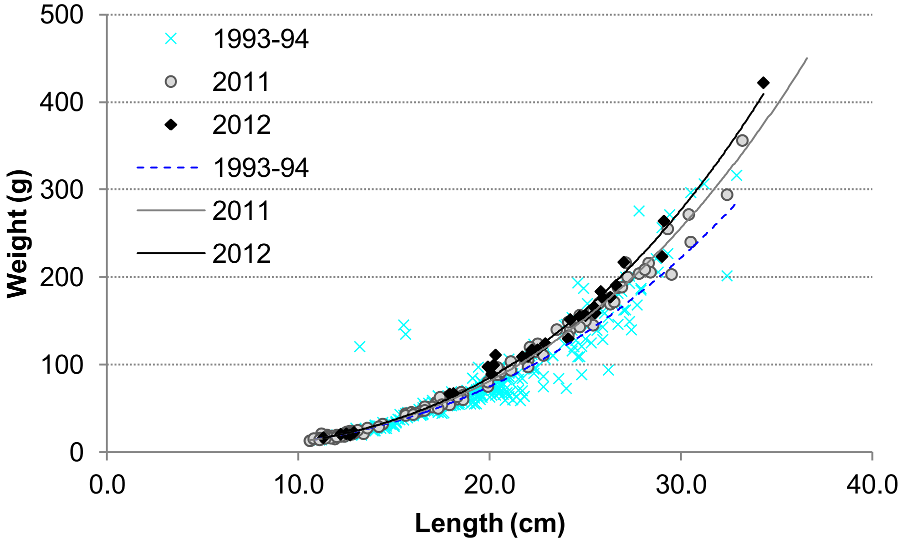


Figure 28 Length weight plot and relationship ($W = a \cdot L^b$) of rainbow trout caught in gillnets during baseline years (1993-1994) and during fertilization years in 2011 and 2012, Wahleach Reservoir

<u>Cutthroat Trout</u>

Sterile cutthroat trout were introduced to Wahleach Reservoir as part of the nutrient restoration project, thus no comparisons to baseline years. Cutthroat trout caught in 2011 had a greater mean length and weight relative to those caught in 2012, although the 2011 catch had a greater percentage of older fish (Table 11, Figure 29). It should be noted that ageing data for cutthroat trout may be somewhat unreliable; all individuals in Wahleach Reservoir were stocked fish which may affect the annuli patterns on scales and otoliths. The length frequency distribution of cutthroat trout in 2011 had a single mode with the greatest percentage of fish in the 361-380 mm size range. In 2012, the length frequency distribution is more spread out with the majority of fish in the 301-320 mm range and a secondary peak in the 501-520 mm size range. Although age and length frequency distributions are variable, condition factors and length-weight regressions between 2011 and 2012 were nearly identical, suggesting the cutthroat population was stable during those years (Table 11, Figure 31).

Table 11 Summary of cutthroat trout biometric data, including length, weight, condition factor (CF) and age, for Wahleach Reservoir during fertilization in 2011 and 2012. Cutthroat trout were not present in Wahleach Reservoir prior to fertilization.

	Year	Mean	SD	Max	Min	n
Length	2011	366	42	451	294	13
(mm)	2012	330	100	555	185	21
Weight	2011	489.9	176.6	855.5	238.0	12
(g)	2012	391.8	385.8	1587	60.5	20
CF	2011	0.96	0.04	1.03	0.93	12
	2012	0.96	0.09	1.22	0.79	20
Age	2011	2.7	1.4	4	1	6
	2012	2.7	0.6	4	2	16

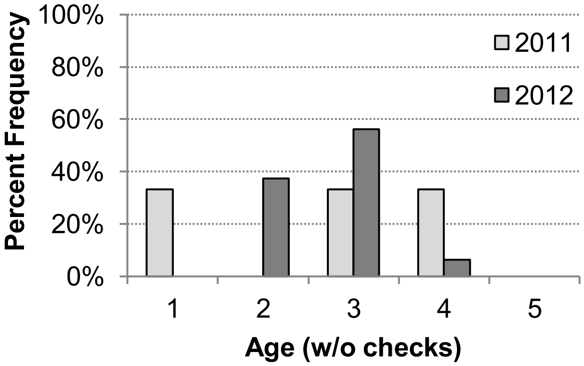


Figure 29 Age frequency distribution of cutthroat trout caught in gillnets during fertilization in 2011-2012, Wahleach Reservoir

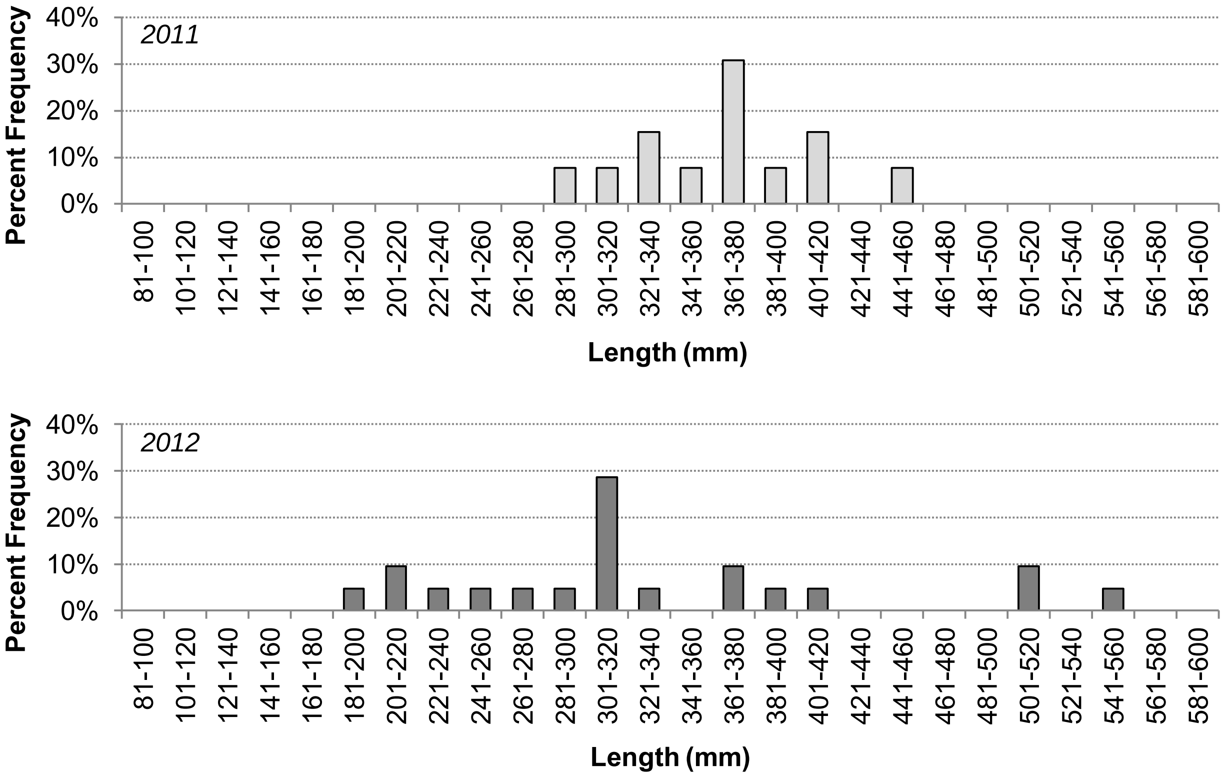


Figure 30 Length frequency distribution of cutthroat trout caught in during 2011 and 2012 gillnetting program in Wahleach Reservoir

Table 12 Summary of variables for cutthroat trout length weight relationships (W = a · L^b; log W = b · log L + log a) during fertilization in 2011 and 2012, Wahleach Reservoir. Cutthroat trout were not present in Wahleach Reservoir prior to fertilization.

Year	a	b	R^2
2011	0.0078	3.0566	0.9902
2012	0.0093	3.0063	0.9879

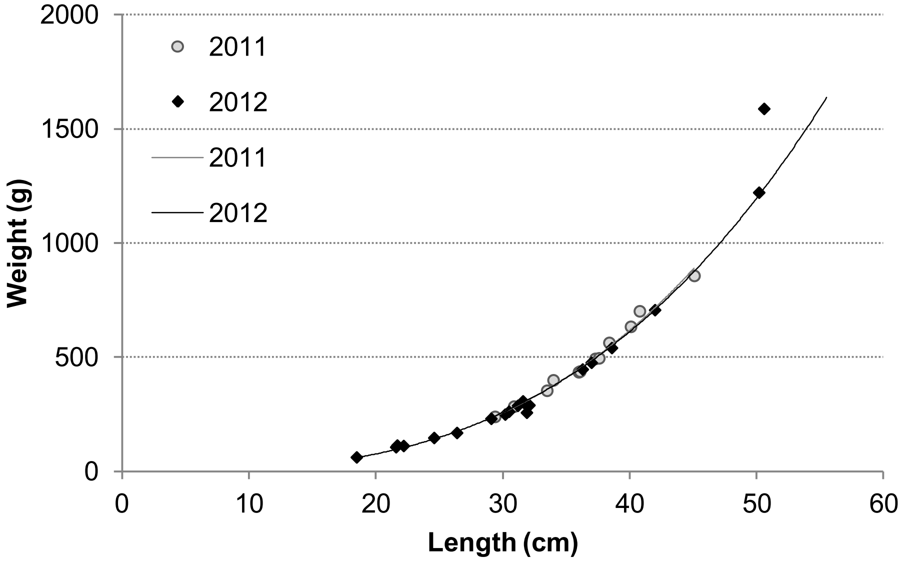


Figure 31 Length weight plot and relationship (W = a · L^b) of cutthroat trout caught in gillnets during fertilization years in 2011 and 2012, Wahleach Reservoir

Threespine Stickleback

Between pre-fertilization years and 2011, threespine stickleback mean length, mean weight and mean condition factor were all greater prior to fertilization than in 2011 (Table 13). In addition, the number of threespine stickleback caught has dramatically decreased since the beginning of the fertilization study (Table 6, also sample size in Table 13). In 2012, only one threespine stickleback was caught; when the fish was dissected a large tapeworm was found inside its gut, thus weight and condition factor comparisons were not made to previous years.

Table 13 Summary of threespine stickleback biometric data, including length, weight, and condition factor (CF), for Wahleach Reservoir in baseline years (1993-1994) and during fertilization in 2011 and 2012

	Year	Mean	SD	Max	Min	n
Length	1993-94	52	7	62	31	251
(mm)	2011	37	7	53	30	10
	2012	47	-	-	-	1
Weight	1993-94	1.6	0.5	2.8	0.4	251
(g)	2011	0.6	0.3	1.5	0.3	10
	2012	2.0	-	-	-	1
CF	1993-94	1.07	0.16	1.89	0.47	251
	2011	0.99	0.22	1.27	0.63	10
	2012	-	-	-	-	-

Kokanee Spawner Surveys

Figure 32 shows results of spawner surveys during the 2011 and 2012 seasons. Timing of the 2011 and 2012 kokanee run in Wahleach Reservoir 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 both years, the Boulder Creek run peaked first, while the Jones Creek run peaked later. The timing of peak spawner numbers in Flat Creek was variable (Figure 32).

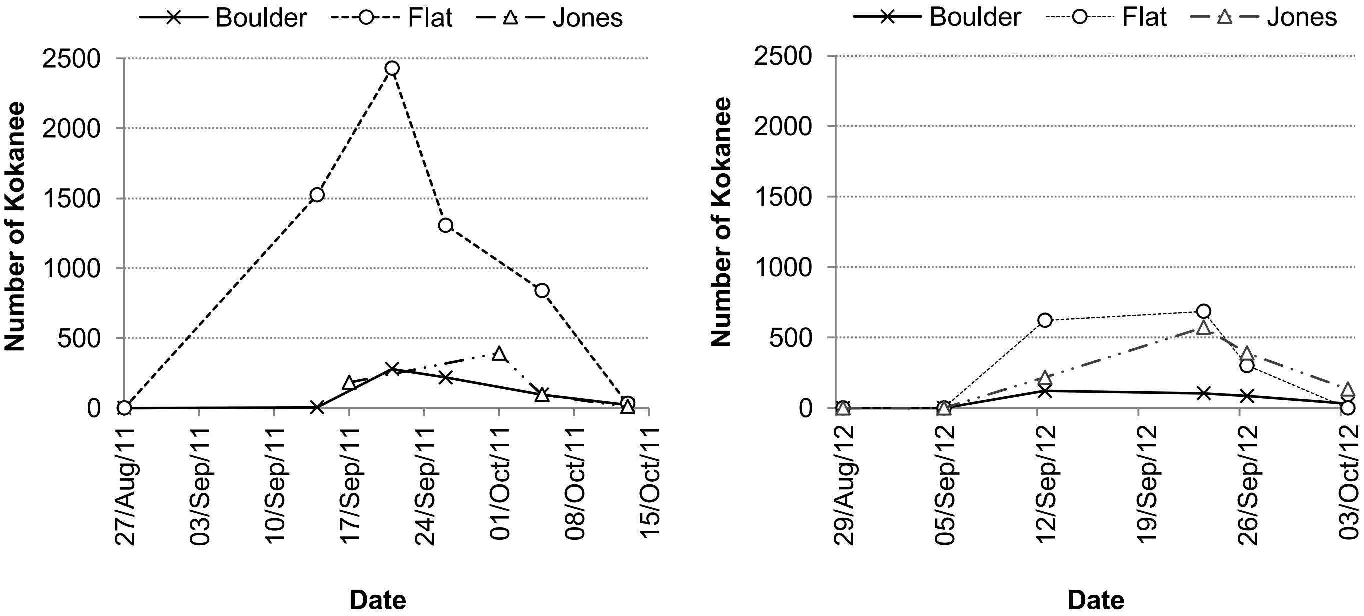


Figure 32 Kokanee spawner counts from each index stream (Boulder Creek, Flat Creek, and Jones Creek) during the 2011 and 2012 spawning seasons in Wahleach Reservoir

Kokanee escapement was 6,762 fish in 2011 (474 Boulder, 5,578 Flat, 710 Jones) and 2,606 fish in 2012 (277 Boulder, 1,323 Flat, 1,006 Jones) (Figure 33). Annual escapement numbers by index stream are shown in 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 show a dominant kokanee run every four years; the last peak run was in 2010 and as such, lower spawner numbers would be expected in 2011 through 2013 followed by another peak run in 2014.

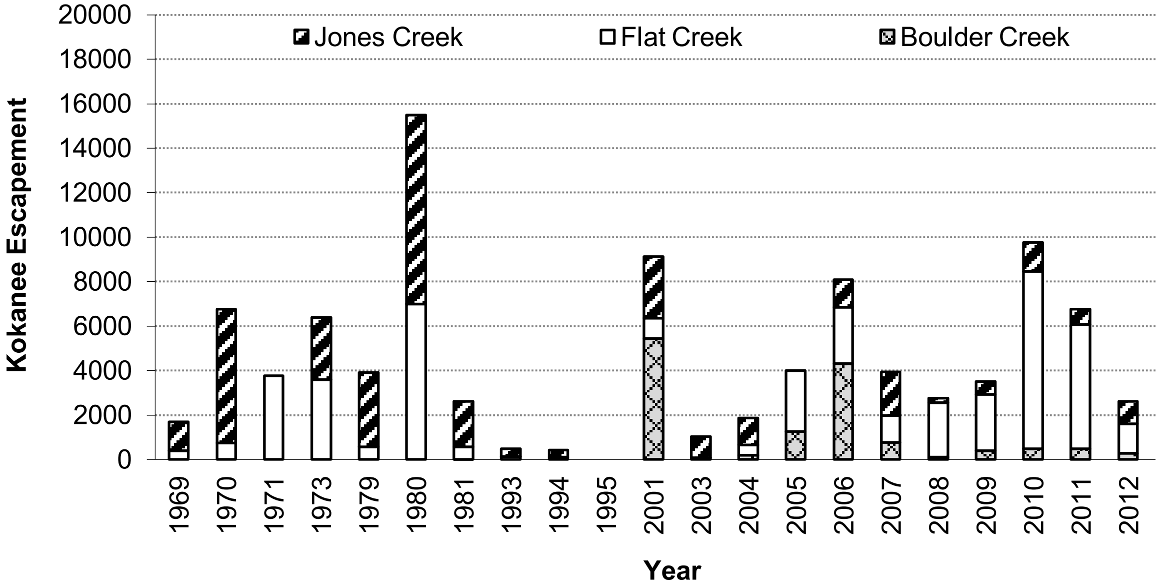


Figure 33 Annual kokanee escapement estimates for years prior to fertilization (pre-1995) and during fertilization in Wahleach Reservoir

In 2011 and 2012, spawner samples were of spent individuals in poor condition, thus spawner weights were not considered representative and condition factors were not reported. Mean fork length of kokanee spawners was 186 ± 18 mm in 2011 and 202 ± 11 mm in 2012 (Table 14). The mean age of kokanee spawners was 2.8 ± 0.6 years in 2011 and 2.9 ± 0.4 years in 2012. The mode spawning age for both years was 3+ (Figure 34). Also, over 25% of the spawners in 2011 were age 2+ (Figure 34). In both study years age 4+ spawners represented less than 10% of the total (Figure 34). The four year dominant run pattern observed is consistent with the 3+ age of the majority of spawners. The combined length frequency distribution had significant overlap in size ranges amongst the age classes with most spawners in the 201-220 mm size class (Figure 35).

Table 14 Summary of kokanee biometric data – including post-orbital hypural length (POHL), fork length (FL), weight and age – during the 2011 and 2012 spawning seasons in Wahleach Reservoir. Data are for all three index streams combined: Boulder Creek, Flat Creek, and Jones Creek. All 2012 FL data are calculated values based on a 2008-2012 FL-POHL regression equation ($y = 1.3348x - 26.766$, $R^2 = 0.8911$).

	Year	Mean	SD	Max	Min	n
POHL	2011	160	14	196	130	93
(mm)	2012	172	9	190	152	20
FL	2011	186	18	240	134	93
(mm)	2012	202	11	227	176	20
Weight	2011	71.0	21.6	159.0	27.0	93
(g)	2012	89.2	14.6	118.5	68.0	20
Age	2011	2.8	0.6	4	2	40
	2012	2.9	0.4	4	2	17

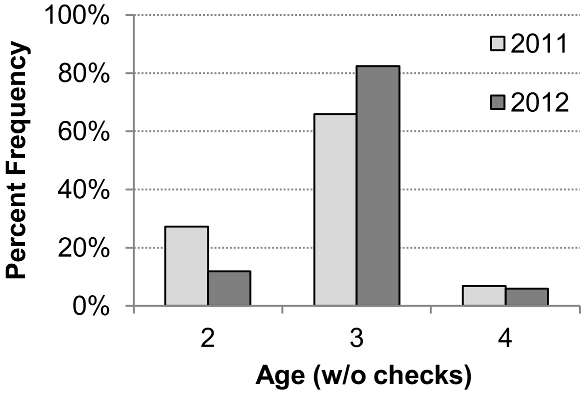


Figure 34 Age frequency distribution of kokanee spawners caught in index streams (Boulder Creek, Flat Creek and Joes Creek) of Wahleach Reservoir during 2011-2012

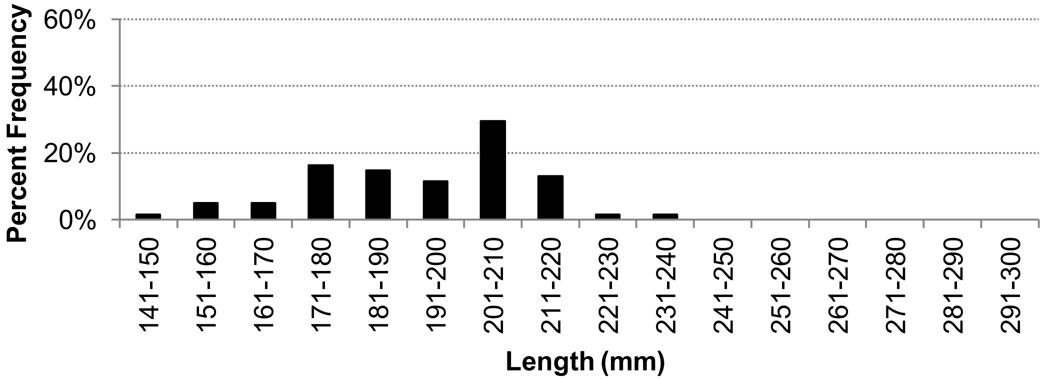


Figure 35 Combined length frequency distribution of kokanee spawners for 2011 and 2012, Wahleach Reservoir; values represent fork lengths. Values for 2011 represent measured fork lengths; values for 2012 are calculated fork lengths based on a 2008-2012 length regression equation ($y = 1.3348x - 26.766$, $R^2 = 0.8911$).

Hydroacoustics

Trawling

Four trawls were conducted through the deepest central portion of Wahleach Reservoir, yielding a total catch of 20 threespine stickleback and 1 kokanee fry (Appendix I). Trawl depths were directed near the greatest target density layer, which at the time of sampling was 8-15 meters deep. The mean lengths and weights of threespine stickle back captured during trawl sampling was 48 ± 10 mm and 1.2 ± 0.6 g, respectively. The single kokanee fry captured during trawl sampling was 56 mm long and weighed 1.5 g. Detailed trawl catch data are in Appendix I.

Pelagic Gillnetting

A total of 4 fish were caught during the pelagic gillnetting program; two kokanee were caught in the 5 m net and two rainbow trout were caught in the surface net (Appendix J). Catch per unit effort for the standard RISC nets was 0.11 fish per net hour, while CPUE for the small mesh gillnet was 0. Detailed catch information is reported in Appendix J

Acoustic Target (Fish) Size Distribution

In 2011, there was size overlap between kokanee fry and threespine stickleback (see “Nearshore Gillnetting and Minnow Trapping” and “Trawling” under Section 3 “Results”). The limited kokanee fry size data for 2011 (n=1) indicated kokanee maintained a size advantage and contributed primarily to the larger end of the acoustic distribution for the small target group; this is similar to previous years (Squires and Stables 2009; Weir and Sebastian 2010; Harris *et al*. 2011). Understanding and accounting for where each species is expected to fall under the acoustic size distribution allows for refinement of the small fish population, so we can isolate the majority of kokanee fry. Acoustic size distributions are shown in Figure 36. Even with limited empirical size data, analysis of the acoustic distribution at depth alongside temperature and dissolved oxygen data allows for refinement of the total population; this is discussed further in the Section “Acoustic Target (Fish) Density and Vertical Distribution”.

In 2011, the acoustic target distribution was tri-modal (Figure 36); two modes were observed in the small fish group (< -46 dB; kokanee fry and threespine stickleback), and a single mode was observed in the large fish group (> -46 dB; age 1 to 3+ kokanee, rainbow trout and cutthroat trout). The secondary mode in the small fish group peaks at approximately -50 dB; this is assumed to be primarily kokanee fry given their larger body size. In 2012, the distribution of targets was bimodal corresponding with the small (< -50 dB) and large (> -50 dB) size fish groups (Figure 36). The distribution of targets in 2012 has a greater magnitude in terms of the number of targets and the peak in the small fish group was shifted a several decibels lower compared to 2011; their differences are likely functions of the survey occurring earlier in the season during 2012 (i.e. August 26, 2011 versus July 18, 2012).

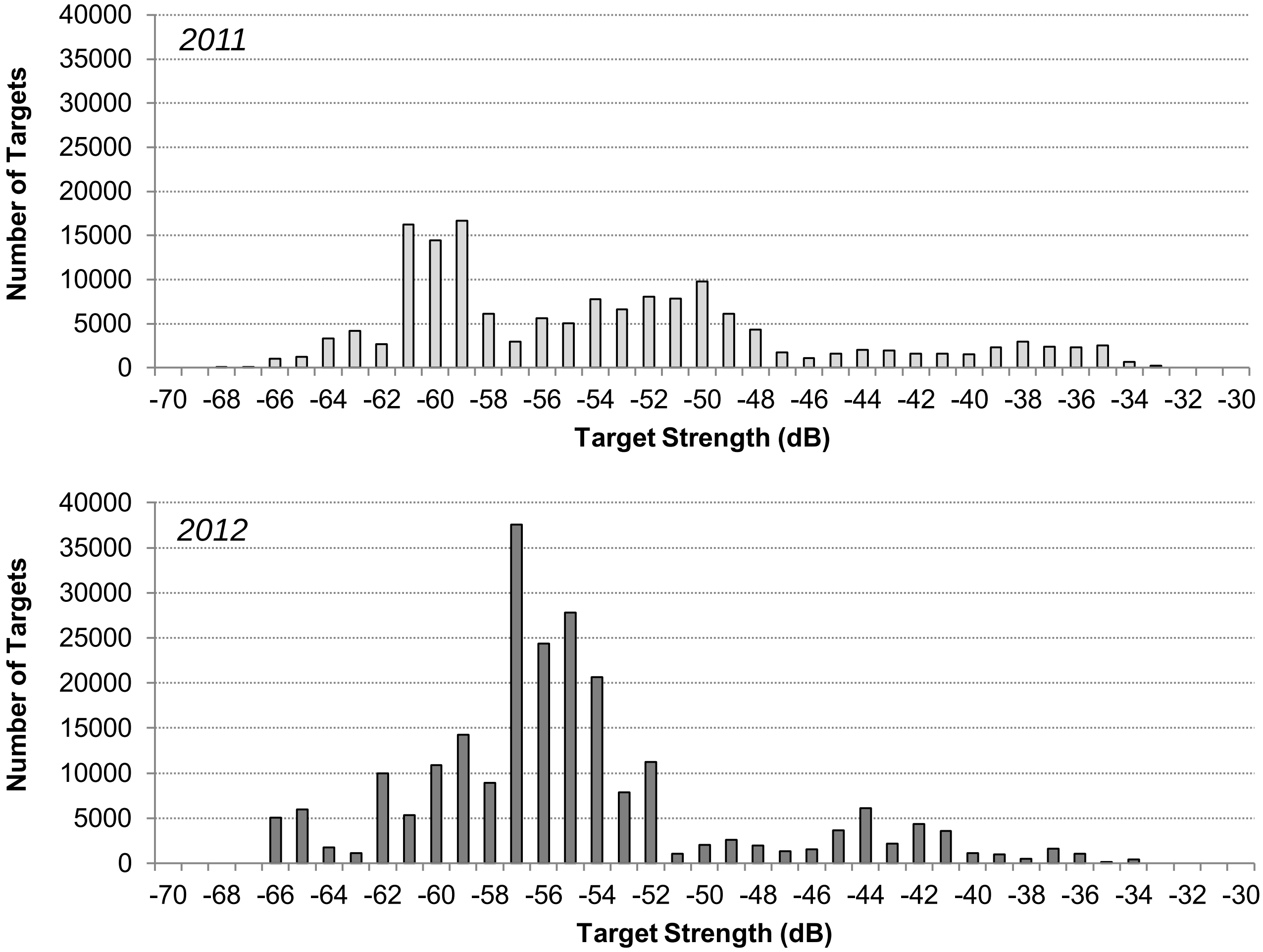


Figure 36 Wahleach Reservoir fish acoustic target distributions for August 26, 2011 and July 18, 2012. The number of targets represents acoustic density data expanded by area to produce a population by acoustic decibel bin

Acoustic Target (Fish) Density and Lateral Distribution

Detailed density data are located in Appendix G. Total small fish (<-46 dB) densities ranged from 173-1003 fish·ha^{-1} in 2011 (Figure 37). The average density of small fish per transect was 462 ± 309 fish·ha^{-1} (± SD). The greatest densities were found in the south basin of the reservoir, particularly along transects 1 and 3 (1003 fish·ha^{-1} and 1002 fish·ha^{-1}, respectively). In the north basin, small fish densities ranged from 173-281 fish·ha^{-1} along transects 7 through 11.

In 2012, total densities by transect for the small fish group ranged from 232-974 fish·ha^{-1} (Figure 37). The average density of small fish per transect was 617 ± 221 fish·ha^{-1} (± SD). Small fish were relatively evenly distributed across the reservoir with the greatest densities of small fish weighted towards the south basin.

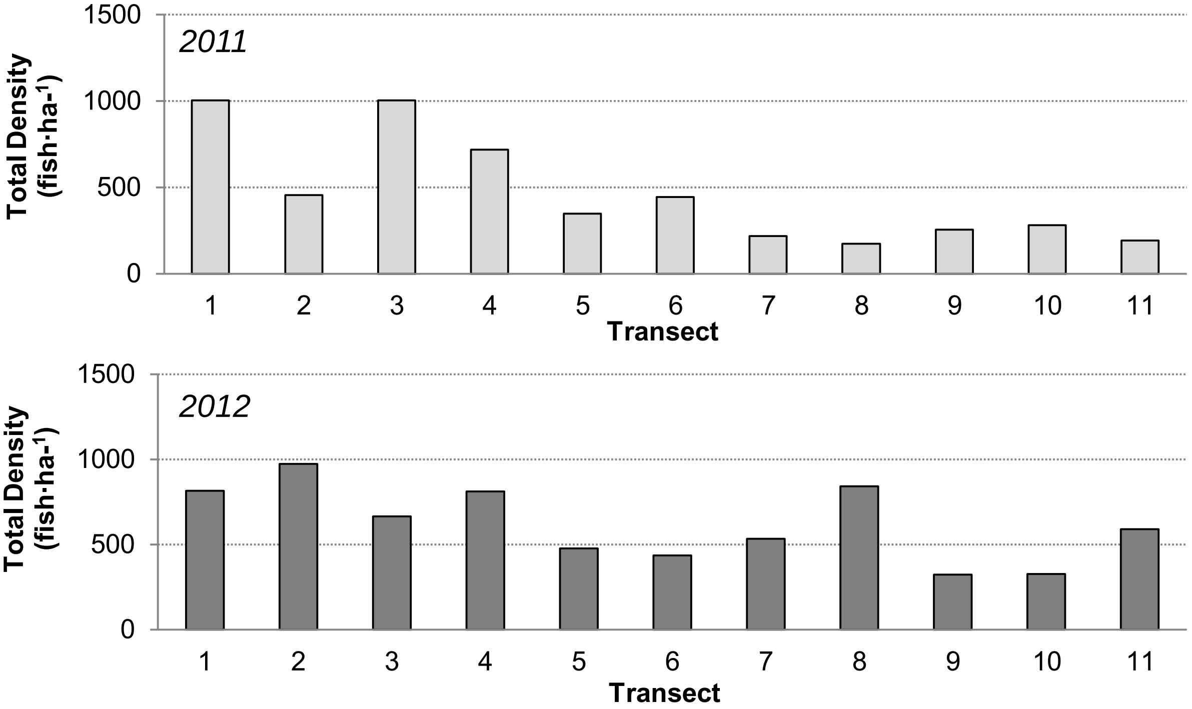


Figure 37 Wahleach Reservoir density distribution by transect for small fish (<-46 dB 2011; <-50 dB 2012) for August 26, 2011 and July 18, 2012

In 2011, large fish (> -46 dB) densities were relatively evenly distributed throughout the reservoir (Figure 38). The average density of large fish per transect was 105 ± 44 fish·ha^{-1} (± SD). Transect 2 in the south basin had the greatest density of large fish at 178 fish·ha^{-1}, while the lowest density occurred along transect 1 with 21 fish·ha^{-1}.

In 2012, large fish (> -50 dB) were found at greater densities in the north basin (Figure 38). The average density of large fish per transect was 106 ± 77 fish·ha^{-1} (± SD). In the south basin, transect 1 had zero large fish targets, while transects 2 through 5 had low or very low densities of large fish (ranging from 20-87 fish·ha^{-1}). The greatest density of large fish was along transect 9 with 224 fish·ha^{-1}. Similarly, transect 7 had 222 fish·ha^{-1}. Transect 7 was the only transect where large fish targets were observed at the surface; the earlier timing of the hydroacoustics survey in 2012 meant that surface water temperatures were several degrees cooler than in previous years. During the limnology sampling session one week after the hydroacoustics survey, the maximum mean water temperature at the surface was 16.15°C.

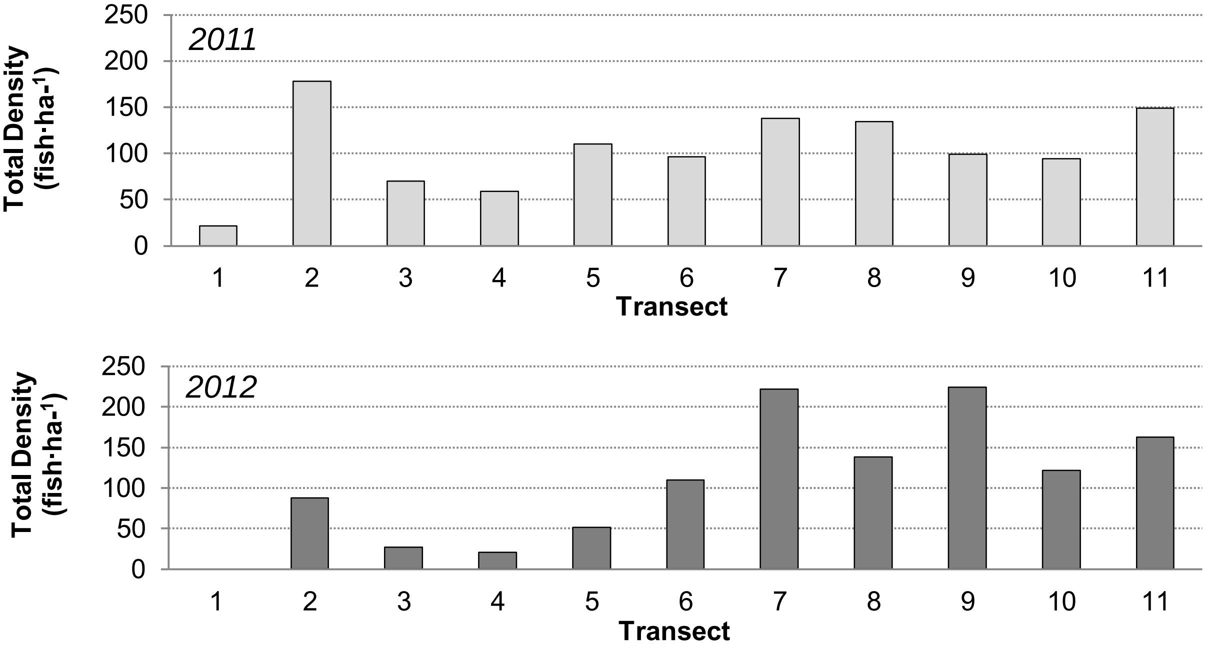


Figure 38 Wahleach Reservoir density distribution by transect for large fish in a) 2011 (>-46 dB) and b) 2012 (>-50 dB) for August 26, 2011 and July 18, 2012

<u>Acoustic Target (Fish) Density and Vertical Distribution</u>

Figure 39 shows average fish density by depth alongside temperature and dissolved oxygen profiles, recorded in proximity (August 29, 2011 and July 24, 2012) to the acoustic surveys. Detailed density data are located in Appendix G.

Dissolved oxygen levels in 2011 and 2012 were greater than 9 mg/L at all depths from 0-20 m; these levels would not be limiting for fish in Wahleach Reservoir, and thus were not commented on in detail as they relate to fish distributions observed during the hydroacoustic surveys.

In 2011, the average density by depth distribution for small fish (< -46 dB) reached a maximum of 146 fish·ha^{-1} in the 2-4 m stratum with a secondary peak of 125 fish·ha^{-1} in the 6-8 m stratum (Figure 39). Average densities declined with depth to 1-2 fish·ha^{-1} below 18 meters. The maximum average density observed in the 2-4 m stratum occurred in water greater than 19.2-22.8°C, while the secondary peak in the 6-8 m stratum occurred in cooler waters of 15.8-17.6°C. When viewed in the context of temperature data, the average densities of small fish targets were likely a function of species distributions; the majority of targets near the surface were likely threespine stickleback, while the majority of deeper targets were likely kokanee fry with an unknown contribution of threespine stickleback.

Average large fish densities by depth for 2011 (> -46 dB) had a single mode ranging from 8-20 m (Figure 39). The greatest densities occurred in the 10-12 m and 12-14 m strata with an average of 41 fish·ha^{-1} and 43 fish·ha^{-1}, respectively; these densities corresponded with water temperatures in the 13-14°C range.

In 2012, the average small fish (< -50 dB) density distribution was bimodal (Figure 39). The maximum average density of 279 fish·ha^{-1} occurred above the thermocline in the 2-4 m stratum. The rapid change in temperature at 4 m also marked a rapid decrease in the average small fish density to 102 fish·ha^{-1} in the 4-6 m stratum; average densities continued to decline with depth reaching 15 fish·ha^{-1} by the 16-18 m stratum. The secondary mode evident in the small fish density distribution occurred at depths below 16 m corresponding with water temperatures less than 8°C. The peak density was in the 20-22 m layer with an average of 28 fish·ha^{-1}.

The large fish (> -50 dB) distribution had a single mode covering depths from 2 m to 18 m (Figure 39) with the greatest density (29 fish·ha^{-1}) in the 8-10 m stratum. Overall, large fish inhabited water temperatures ranging from approximately 8-16°C with the majority of targets below the thermocline in depths 4-10 m with 10-15°C water. Figure 40 presents a nice summary of the acoustic target data according to average densities by decibel size and depth for 2011 and 2012.

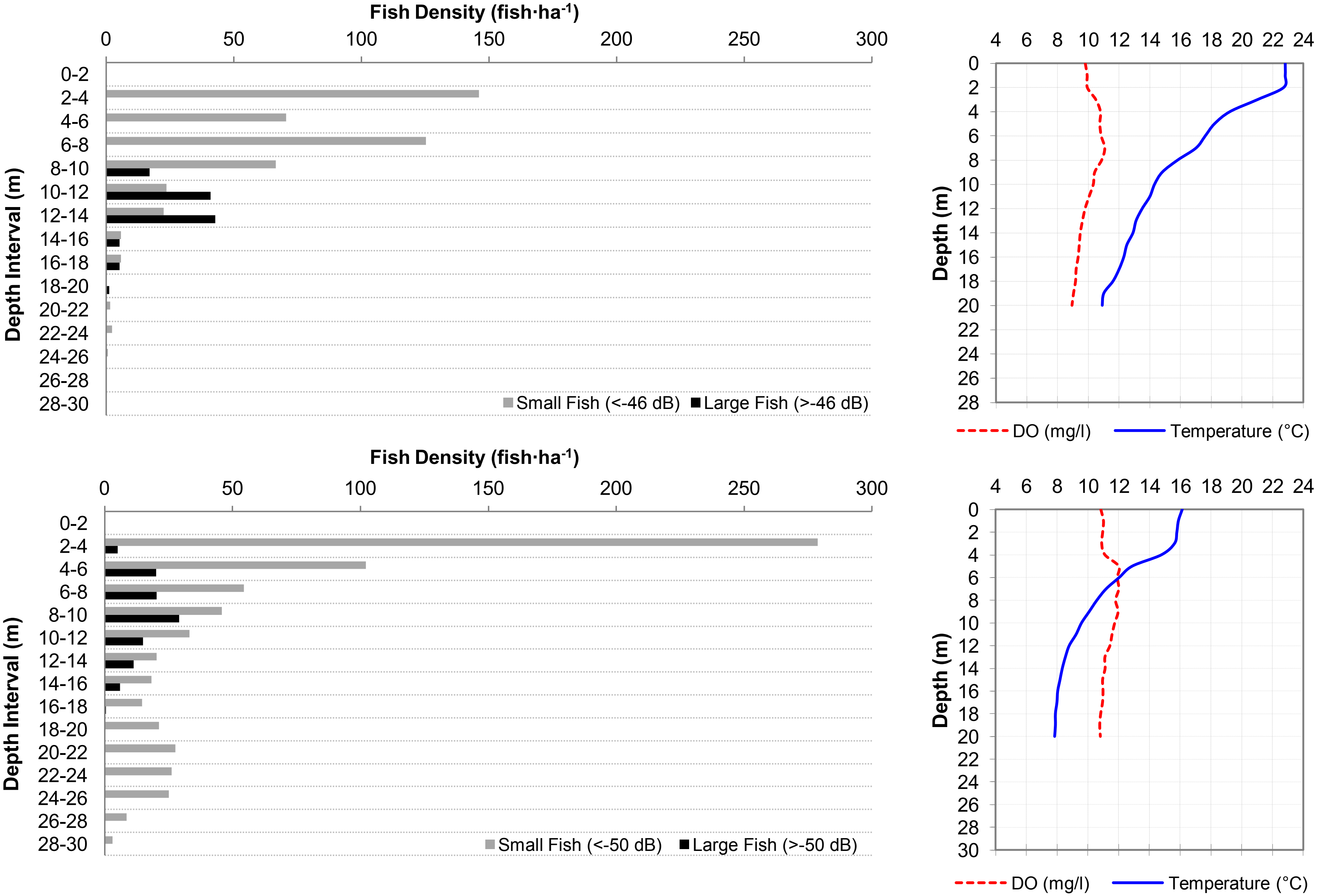


Figure 39 Wahleach Reservoir average fish density distributions by depth from August 26, 2011 and July 18, 2012 hydroacoustic surveys relative to temperature and dissolved oxygen profiles from August 29, 2011 and July 24, 2012 limnology sessions

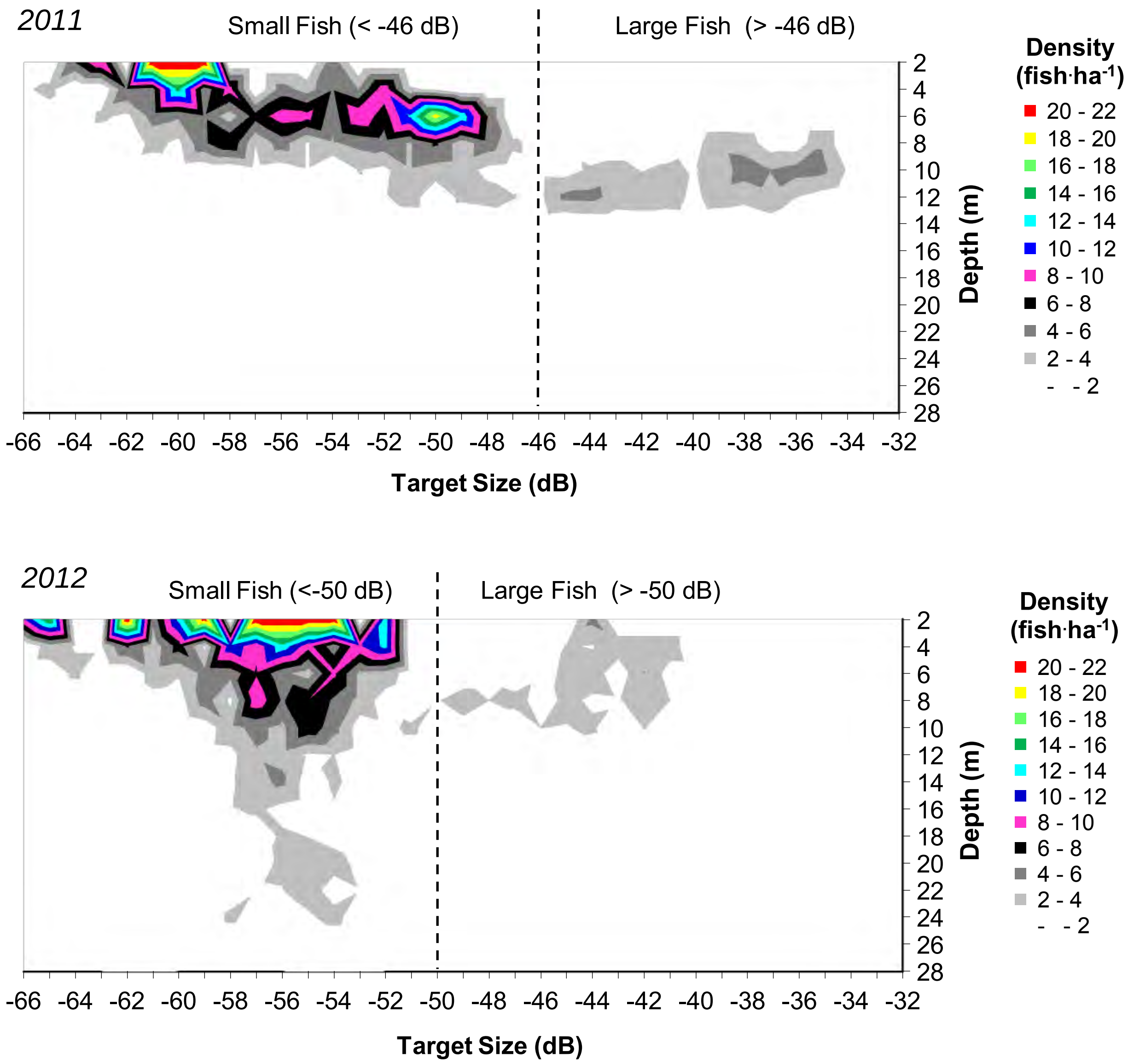


Figure 40 Average target density (fish·ha^{-1}) by decibel size and depth from August 26, 2011 and July 18, 2012 hydroacoustic surveys on Wahleach Reservoir

Wahleach Reservoir Acoustic Target (Fish) Populations

The total fish population estimate for all species in Wahleach Reservoir was 171,600 individuals (95% CI = 110,800-225,900) for 2011, and 238,400 individuals (95% CI = 197,000-285,500) for 2012 (Table 15). The small fish group made up of kokanee fry and threespine stickleback were the majority of the population (Table 15). The large fish component, which represented age 1 to 3+ kokanee, rainbow trout, and cutthroat trout was 23,600 individuals (95% CI = 17,500-31,200) for 2011, and 33,000 individuals (95% CI = 22,100-43,400) for 2012 (Table 15). Due to the timing hydroacoustic surveys (i.e.

August 2011, July 2012), these population estimates included kokanee spawners; whereas in previous years, acoustic surveys were conducted in late September when mature kokanee would have left the reservoir for stream spawning habitats (see Harris *et al*. 2007, Harris *et al*. 2011). Detailed population data are presented in Appendix H.

Table 15 Wahleach Reservoir fish population estimates based on hydroacoustic target size data for 2011 and 2012

Year	Total Population Estimate	Small Fish Component (< -46 2011; < -50 dB 2012)	Large Fish Component (> -46 2011; > -50 dB 2012)
2011	171,600	148,000	23,600
2012	238,400	205,400	33,000

4. Discussion

The importance of monitoring to the success of restoration projects has long been recognized. Monitoring allows for adaptive management and for the effectiveness of restoration strategies to be evaluated. The purpose of this report is to provide a summary of conditions relevant to the Wahleach Reservoir Fertilization Project for 2011 and 2012.

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. In 2011 and 2012, Wahleach Reservoir was straddling the range of ultra-oligotrophic and oligotrophic productivity (Table 16).

Table 16 Trophic state classification of Wahleach Reservoir during fertilization in 2011-2012 using criteria defined by Wetzel (2001) and Wetzel (1983)

Parameter		Fertilization Year		Trophic Classification			
		2011	2012	Ultra-Oligotrophic	Oligotrophic	Mesotrophic	Eutrophic
TP	Mean ± SD	4 ± 1	5 ± 1	-	8	27	84
(µg/L)	Range	1-5	3-7	<1-5	3-18	11-96	16-386
TN	Mean ± SD	177 ± 95	207 ± 50	-	661	753	1875
(µg/L)	Range	80-390	135-273	<1-250	307-1630	361-1387	393-6100
Secchi	Mean ± SD	4.30 ± 1.61	4.89 ± 1.38	-	9.9	4.2	2.5
(m)	Range	2.93-6.58	3.45-7.10	-	5.4-29.3	1.5-8.1	0.8-7.0

The project's fertilization strategy utilizes the known link between nutrient loading, algal production, and food availability for planktivorous fish (e.g. Vollenwieder 1976). During the 2011 and 2012, fertilization years mean annual phytoplankton abundance was approximately 50% greater than in baseline years, while biovolume was about two times greater. Chrysophytes and cryptophytes were the dominant phytoplankton class in all years; these include species such as *Ochromonas Chrysochromulina*, *Dinobryon*, *Chroomonas,* and small microflagellates that are in the edible size range for zooplankton. The phytoplankton community in 2011 was unique with an exceptional proportion of chrysophytes and cryptophytes and all other classes having only minor contributions. In May 2011, the north basin sample had an unusually high abundance of chrysophytes and cryptophytes (34,896 cells/mL); abundance was nearly 10-times greater than the south basin sample for that month.

Abundance and biovolume of phytoplankton are affected not only by nutrient loading but also by factors such as grazing by zooplankton. The phytoplankton community during fertilization years had a significant biovolume of edible species for zooplankton (data on file). All major zooplankton groups have increased since the nutrient restoration project began; and the appearance of *Daphnia* – a large bodied zooplankter that a preferred forage species for kokanee (Thompson 1999) – in Wahleach is one of the most significant results observed during fertilization years. In 2011, zooplankton density was the highest on record. And although 2012 zooplankton density was low compared to other fertilization years, *Daphnia* abundance remained stable. Higher proportions of *Daphnia* within the zooplankton community have been established in earlier years of the project and continue to grow. Overall, zooplankton results represent a significant increase in food availability for planktivores relative to baseline years. One of the goals of the nutrient restoration project was to re-establish *Daphnia* in the zooplankton assemblage; the data from 2011 and 2012 indicate this is being accomplished.

Increased phytoplankton and zooplankton productivity have translated into increased fish abundance and biomass since the program's inception. Assessments of Wahleach Reservoirs' fish populations 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. Gillnetting and spawner data from 2011 and 2012 continued to provide evidence of a self-sustaining kokanee population in Wahleach Reservoir – a result directly linked to the project's combined model of nutrient additions and stocking considering kokanee were extirpated by the time nutrient additions began. Furthermore, kokanee were better condition during 2011 and 2012 than in baseline years; kokanee 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 fertilization years are evidence of increased forage potential within the zooplankton community and hence increased growth potential in the kokanee population. Rainbow trout caught in 2011 and 2012 were also in better condition than during baseline years. And although length-at-age trends remained similar between eras, length-weight relationships show rainbow trout had larger weights for a given length during the fertilization period.

An unusually large drawdown was recorded from February 13 through March 30, 2011. For 36 days the reservoir level dropped below 627 m to a low of 624.3 m, nearly 4 m below the minimum operating level of 628 m. Perrin and Stables (2000) suggested that draw downs 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 and coincided with the absence of a rainbow trout cohort for that year as reported by 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 as observed in 2011. Initially, based on the presence of age 1+ fish captured during the 2012 nearshore gillnetting program, recruitment failure in the rainbow trout population does not appear to have occurred in 2011. The potential effects on fish populations from the large draw down observed in 2011 will be further examined in the upcoming review report.

Results of the assessments for cutthroat in 2011 and 2012 were similar and indicate the condition factor of the individuals in the population is stable. Sterile cutthroat trout were stocked in Wahleach Reservoir to control threespine stickleback numbers as the biomanipulation component of the project. Threespine stickleback have been known to counteract the effects of fertilization 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 2011 and 2012. As well, the condition of threespine stickleback caught in 2011 and 2012 was lower than in years prior to the stocking of cutthroat trout. 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 in combination with hydroacoustics have been used in attempt to determine species specific abundances in pelagic habitat, particularly between 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). This was due to the difficulty of trawling the shallow and variable bathymetry of the small reservoir, and the inconsistent nature and spatial heterogeneity of targets in the water column. In order for trawling to be safe, to effectively capture a sufficient sample size, and to adequately represent the entire small fish population, the target distribution would have to consist of a distinct concentrated layer well off the reservoir bottom. Data to date show this situation is unusual in Wahleach, and while it occurred in August 2011, it had deteriorated by September when trawling occurred. It is recommended that future trawl surveys occur in August to hopefully capitalize on this distribution. August surveys have the additional benefit of a strong thermocline and warm surface temperatures to assist in separating kokanee fry from threespine stickleback according to habitat preferences. Species partitioning by size, depth and temperature provides an opportunity to refine kokanee population estimates from hydroacoustics. Further analyses on this subject will be presented in the upcoming review report.

Hydroacoustics estimates of fish abundance for 2011 and 2012 were 171,600 and 238,400 respectively. Of which 148,000 and 205,400 represented kokanee fry and threespine stickleback, and 23,600 and 33,000 represented age 1+ and older kokanee, rainbow trout and cutthroat trout; these estimates are similar to those reported by Harris *et al*. (2011) for 2009 and 2010. And although the large fish component appears to follow an increasing trend in recent years when compared to Harris *et al*. (2011), it should be noted that there is substantial overlap in confidence intervals and the earlier timing of the 2011 and 2012 surveys mean kokanee spawners were included in the population; in previous years, hydroacoustic surveys were conducted in September when spawners had left the reservoir and as such would result in a lower population estimate. While simple, such estimates provide sufficient insight to indicate a relatively stable fish population over recent years and should be taken in the context of a previously extirpated kokanee population. Further refinement of data collection methods for programs that support hydroacoustic analyses, in addition to more comprehensive analyses (such as species specific population estimates) over a longer time series in the upcoming review report will facilitate a better understanding of the ecological dynamics in Wahleach Reservoir.

Overall, monitoring data from 2011 and 2012 have shown positive results in terms of growth and abundance of kokanee – supporting bottom-up effects of nutrient additions. Results also support the biomanipulation portion of the experiment achieved through top-down predatory control of threespine stickleback. The Wahleach Reservoir Nutrient Restoration Project is based on known links between nutrient availability and the response in productivity; the outcome of which has been to restore Wahleach Reservoir to its former potential and add to the body of scientific literature.

5. Recommendations

- Continue annual fertilization 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 these results to adaptively manage the fertilization program and approach.

- Complete analysis of chlorophyll *a* samples.

- Complete analysis of phytoplankton edibility, which will further refine our measures of success and better understand the mechanisms leading to restoration of the kokanee population.

- Take silica samples during August and/or September limnology session corresponding with the general timing of peak diatom abundance to ensure silica limitation is avoided.

- Continue with hydroacoustic program in August to ensure consistency of the time-series dataset.

- Complete a trawl survey during hydroacoustics in the month of August when thermal stratification is strongest.

- Complete pelagic gillnetting during hydroacoustics for validation of results including a small mesh size gillnets.

- Continue annual nearshore gillnetting and minnow trapping program in October to ensure consistency of the time-series dataset; for future years, increasing the number of minnow traps set is recommended, since catch rates have been too low to be statistically useful.

- Continue annual kokanee spawner surveys on index streams.

- 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 biomanipulation component of the project. This would be a reasonable task to include with the upcoming review report.

- Continue to abstain from kokanee and rainbow trout stocking.

- Conduct a creel survey to look at angler effort, harvest rates, and angler satisfaction. A creel survey of the recreational fishery was initiated in 2011 and again in 2012, but was ultimately suspended due to road failures prohibiting access to the reservoir. This activity will be conducted in subsequent years of the project.

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Appendix A List of phytoplankton species found in Wahleach Reservoir, 2011 and 2012

Species	2011 LS1-NB	2011 LS2-SB	2012 LS1-NB	2012 LS2-SB
Bacillariophyceae (diatoms)				
Achnanthidium spp.	+	+	+	+
Navicula sp.	+	+	+	
Synedra acus	+	+	+	+
Synedra nana	+	+	+	
Synedra ulna			+	
Cyclotella comta	+	+	+	+
Cyclotella glomerata	+	+	+	+
Cyclotella stelligera	+	+	+	+
Rhizosolenia sp.	+	+	+	+
Tabellaria fenestrata	+	+	+	+
Tabellaria flocculosa	+	+	+	
Fragilaria capucina	+	+	+	+
Synedra acus var angustissima		+		
Fragilaria construens			+	
Asterionella formosa			+	+
Chryso- & Cryptophyceae (flagellates)				
Chromulina sp.	+	+	+	+
Chrysochromulina sp.	+	+	+	+
Chryptomonas spp.	+	+	+	+
Boda spp.	+	+		
Ochromonas sp.	+	+	+	+
Mallomonas sp.	+	+	+	+
Kephyrion sp.	+	+	+	+
Dinobryon sp.	+	+	+	+
Bitrichia sp.	+			
Chrysococcus sp.	+	+	+	+
Chroomonas acuta	+	+	+	+
Komma sp.	+	+	+	+
Small microflagellates	+	+	+	+
Dinophyceae (dinoflagellates)				
Peridinium spp.	+	+	+	+
Gymnodinium sp. (small)	+	+	+	+
Gymnodinium sp. (large).	+	+	+	+

Species	2011 LS1-NB	2011 LS2-SB	2012 LS1-NB	2012 LS2-SB
Chlorophyceae (coccoid greens, desmids, etc.)				
Ankistrodesmus sp.	+	+	+	+
Chlorella sp.	+	+	+	+
Crucigenia sp.	+	+		
Tetraedron sp.	+	+	+	+
Coelastrum sp.	+	+	+	+
Botryococcus sp.	+	+	+	+
Planctosphaeria sp.	+	+		
Sphaerocystis sp.	+	+	+	
Clamydocapsa sp.	+	+		+
Elakatothrix sp.	+	+	+	+
Staurastrum sp.	+	+		
Cosmarium sp.	+	+	+	+
Dichtyosphaerium	+	+		
Stichococcus minutissimus	+	+		
Cateria sp.	+			
Closterium sp.	+			
Euglena sp.	+			+
Gleotila sp.	+			
Gyromitus sp.	+	+	+	+
Oocystis sp.	+	+		
Nephroselmis sp.	+	+		
Planctonema sp.	+			
Pyramimonas sp.	+		+	+
Stichicoccus minutissimus	+			
Scourfieldia sp.	+	+	+	+
Scenedesmus sp.	+		+	+
Monomastic sp.	+	+	+	
Phacus sp.		+		
Spondylosium sp.				+
Coccomyxa sp.			+	
Cyanophyceae (blue-greens)				
Synechococcus sp. (coccoid)	+	+	+	+
Synechococcus sp (rod)	+	+	+	+
Synechocystis sp.	+	+	+	+
Merismopedia sp.	+		+	+
Microcystis sp.	+	+	+	+
Aphanothecae sp.	+	+		
Anabaena spp.	+	+	+	+
Total	61	53	48	43
Annual Total (both stations combined)		**63**		**51**

Appendix B Phytoplankton abundances and biovolumes

Table B1 Phytoplankton seasonal (May-October) abundance (cells/mL) and biovolume (mm^3/L) at LS1 in the north basin of Wahleach Reservoir, 2011 and 2012

Station:	LS1-NB					
Date:	31-May-11	11-Jul-11	26-Jul-11	26-Aug-11	5-Oct-11	25-Oct-11
Species	**Abundance (cells/mL)**					
Bacillariophyceae (diatoms)						
Achnanthidium spp.	-	-	-	13.82	-	10.14
Navicula sp.	-	-	-	-	13.82	-
Synedra acus	-	38.01	15.21	27.65	-	-
Synedra nana	-	-	15.21	-	41.47	-
Cyclotella comta	-	-	-	13.82	-	-
Cyclotella glomerata	-	152.05	15.21	41.47	-	-
Cyclotella stelligera	-	-	-	13.82	13.82	-
Rhizosolenia sp.	-	-	30.41	-	-	-
Tabellaria fenestrata	-	-	-	-	-	20.27
Tabellaria flocculosa	-	-	-	-	-	10.14
Fragilaria capucina	-	38.01	76.03	41.47	-	10.14
Group total	**0.00**	**228.07**	**152.07**	**152.05**	**69.11**	**50.69**
Chryso- & Cryptophyceae (flagellates)						
Chromulina sp.	-	38.01	15.21	13.82	13.82	20.27
Chrysochromulina sp.	-	95.03	15.21	27.65	41.47	50.68
Chryptomonas spp.	-	38.01	106.44	13.82	96.76	30.41
Boda spp.	-	-	30.41	13.82	-	-
Ochromonas sp.	34592.08	7602.65	4105.43	55.29	165.88	172.33
Mallomonas sp.	-	-	30.41	-	-	30.41
Kephyrion sp.	-	-	-	-	-	-
Dinobryon sp.	152.05	-	3953.38	7851.45	4146.90	1591.49
Bitrichia sp.	-	-	-	-	-	10.14
Chrysococcus sp.	-	57.02	45.62	27.65	179.70	-
Chroomonas acuta	-	133.05	45.62	82.94	96.76	40.55
Komma sp.	-	-	-	-	-	10.14
Small microflagellates	152.05	114.04	440.95	234.99	1244.07	364.93
Group total	**34896.18**	**8077.81**	**8788.68**	**8321.43**	**5985.36**	**2321.35**
Dinophyceae (dinoflagellates)						
Peridinium spp.	-	779.27	152.05	-	13.82	10.14
Gymnodinium sp. (small)	-	19.01	45.62	13.82	27.65	20.27
Gymnodinium sp. (large).	-	19.01	15.21	-	-	30.41
Group total	**0.00**	**817.29**	**212.88**	**13.82**	**41.47**	**60.82**

Station:	LS1-NB					
Date:	31-May-11	11-Jul-11	26-Jul-11	26-Aug-11	5-Oct-11	25-Oct-11
Species	**Abundance (cells/mL)**					
Chlorophyceae (coccoid greens, desmids, etc.)						
Ankistrodesmus sp.	-	-	-	-	13.82	-
Chlorella sp.	-	38.01	106.44	69.12	179.70	81.09
Crucigenia sp.	-	-	-	-	-	-
Tetraedron sp.	-	-	-	-	13.82	-
Coelastrum sp.	-	-	-	-	-	-
Botryococcus sp.	-	-	-	-	-	-
Planctosphaeria sp.	-	-	-	69.12	-	-
Sphaerocystis sp.	-	-	-	-	-	-
Clamydocapsa sp.	-	-	-	-	-	-
Elakatothrix sp.	-	-	-	13.82	-	10.14
Staurastrum sp.	-	-	-	-	-	-
Cosmarium sp.	-	-	-	-	13.82	-
Dichtyosphaerium	-	-	-	-	-	-
Stichococcus minutissimus	-	114.04	-	-	-	-
Cateria sp.	-	-	-	-	13.82	-
Closterium sp.	-	-	-	-	-	10.14
Euglena sp.	-	-	-	-	27.65	-
Gleotila sp.	-	-	-	-	-	40.55
Gyromitus sp.	-	-	136.85	27.65	55.29	30.41
Oocystis sp.	-	-	91.23	-	82.94	10.14
Nephroselmis sp.	-	-	-	13.82	41.47	-
Planctonema sp.	-	-	-	-	27.65	-
Pyramimonas sp.	-	-	-	-	-	20.27
Stichicoccus minutissimus	-	-	851.50	138.23	-	-
Scourfieldia sp.	-	-	30.41	27.65	41.47	10.14
Scenedesmus sp.	-	-	76.03	27.65	55.29	-
Monomastic sp.	-	-	-	-	27.65	-
Group total	**0.00**	**152.05**	**1292.46**	**387.06**	**594.39**	**212.88**
Cyanophyceae (blue-greens)						
Synechococcus sp (rod)	228.08	95.03	60.82	55.29	345.58	40.55
Synechococcus sp. (coccoid)	228.08	209.07	106.44	69.12	138.23	91.23
Synechocystis sp.	-	190.07	106.44	-	55.29	111.51
Merismopedia sp.	-	-	-	-	-	-
Microcystis sp.	-	57.02	-	-	442.34	3041.06
Aphanothecae sp.	-	-	-	-	2419.03	10.14
Anabaena spp.	-	-	-	-	-	-
Group total	**456.16**	**551.19**	**273.70**	**124.41**	**3400.47**	**3294.49**
TOTAL	**35352.34**	**9826.41**	**10719.79**	**8998.77**	**10090.80**	**5940.23**

Station:	LS1-NB					
Date:	30-May-12	27-Jun-12	25-Jul-12	29-Aug-12	26-Sep-12	31-Oct-12
Species	**Abundance (cells/mL)**					
Bacillariophyceae (diatoms)						
Achnanthidium spp.	30.41	-	-	-	-	-
Fragilaria capucina	50.68	20.27	-	-	-	-
Fragilaria construens	30.41	10.14	-	-	-	-
Cyclotella glomerata	131.78	20.27	76.03	-	-	30.41
Cyclotella stelligera	70.96	-	-	-	-	-
Cyclotella comta	60.82	-	-	-	12.67	-
Tabellaria fenestrata	10.14	10.14	-	-	1393.82	10.14
Tabellaria flocculosa	20.27	-	-	-	-	-
Navicula sp.	20.27	-	-	-	-	-
Synedra ulna	-	40.55	-	-	-	-
Synedra nana	-	40.55	-	-	-	-
Synedra acus	-	60.82	-	-	-	-
Rhizosolenia sp.	-	101.37	-	466.30	2141.41	202.74
Asterionella formosa	-	-	-	739.99	722.25	1682.72
Group total	**425.75**	**304.11**	**76.03**	**1206.29**	**4270.16**	**1926.01**
Chryso- & Cryptophyceae (flagellates)						
Chromulina sp.	-	-	-	1236.70	25.34	30.41
Chrysochromulina sp.	334.52	841.36	-	60.82	126.71	10.14
Chryptomonas spp.	20.27	20.27	38.01	50.68	88.70	30.41
Komma sp.	10.14	30.41	-	30.41	25.34	20.27
Chroomonas acuta	30.41	172.33	114.04	182.46	88.70	50.68
Ochromonas sp.	2027.37	5828.70	15205.31	3101.88	760.27	70.96
Kephyrion sp.	10.14	-	-	10.14	-	-
Dinobryon sp.	40.55	1236.70	-	10.14	950.33	2939.69
Chrysococcus sp.	152.05	40.55	-	-	-	-
Small microflagellates	719.72	881.91	532.19	172.33	418.15	760.27
Mallomonas sp.	-	-	-	-	12.67	10.14
Group total	**3345.17**	**9052.23**	**15889.55**	**4855.56**	**2496.20**	**3922.97**
Dinophyceae (dinoflagellates)						
Peridinium spp.	20.27	50.68	38.01	-	25.34	-
Gymnodinium sp. (large).	10.14	-	-	-	-	-
Gymnodinium sp. (small)	10.14	-	38.01	-	12.67	-
Group total	**40.55**	**50.68**	**76.03**	**0.00**	**38.01**	**0.00**

Station:	LS1-NB					
Date:	30-May-12	27-Jun-12	25-Jul-12	29-Aug-12	26-Sep-12	31-Oct-12
Species	**Abundance (cells/mL)**					
Chlorophyceae (coccoid greens, desmids, etc.)						
Ankistrodesmus sp.	-	10.14	76.03	10.14	-	10.14
Elakatothrix sp.	-	10.14	76.03	-	-	-
Chlorella sp.	70.96	70.96	304.11	50.68	114.04	81.09
Tetraedron sp.	20.27	20.27	-	-	-	-
Scenedesmus sp.	-	10.14	38.01	-	-	-
Sphaerocystis sp.	-	10.14	190.07	-	-	-
Cosmarium sp.	-	10.14	-	-	-	-
Coccomyxa sp.	-	10.14	-	-	-	-
Coelastrum sp.	-	20.27	-	10.14	12.67	-
Gyromitus sp.	20.27	-	-	-	25.34	20.27
Monomastic sp.	10.14	-	-	-	-	-
Pyramimonas sp.	10.14	-	-	-	-	-
Botryococcus sp.	-	-	-	131.78	25.34	-
Scourfieldia sp.	-	-	-	-	38.01	30.41
Group total	**131.78**	**172.33**	**684.24**	**202.74**	**215.41**	**141.92**
Cyanophyceae (blue-greens)						
Synechococcus sp. (coccoid)	567.66	810.95	-	81.09	38.01	172.33
Synechococcus sp (rod)	253.42	202.74	-	202.74	63.36	202.74
Synechocystis sp.	81.09	70.96	-	30.41	126.71	40.55
Microcystis sp.	-	-	16915.91	-	3547.91	2027.37
Anabaena spp.(cell)	-	-	-	-	253.42	-
Merismopedia sp.	-	-	-	-	405.47	-
Group total	**902.18**	**1084.65**	**16915.91**	**314.24**	**4434.88**	**2442.99**
TOTAL	**4845.42**	**10663.99**	**33641.74**	**6578.83**	**11454.67**	**8433.88**

Station:	LS1-NB					
Date:	31-May-11	11-Jul-11	26-Jul-11	26-Aug-11	5-Oct-11	25-Oct-11
Species	**Biovolume (mm^3/L)**					
Bacillariophyceae (diatoms)						
Achnanthidium spp.	-	-	-	0.0011	-	0.0008
Navicula sp.	-	-	-	-	0.0069	0.0051
Synedra acus	-	0.0038	0.0015	0.0028	-	-
Synedra nana	-	-	0.0011	-	0.0031	-
Cyclotella comta	-	-	-	0.0048	-	-
Cyclotella glomerata	-	0.0076	0.0008	0.0021	-	-
Cyclotella stelligera	-	-	-	0.0021	0.0021	-
Rhizosolenia sp.	-	-	0.0015	-	-	-
Tabellaria fenestrata	-	-	-	-	-	0.0101
Tabellaria flocculosa	-	-	-	-	-	-
Fragilaria capucina	-	0.0038	0.0076	0.0041	-	0.0010
Group total	**0.0000**	**0.0152**	**0.0125**	**0.0170**	**0.0121**	**0.0170**
Chryso- & Cryptophyceae (flagellates)						
Chromulina sp.	-	0.0008	0.0003	0.0003	0.0003	0.0004
Chrysochromulina sp.	-	0.0071	0.0011	0.0021	0.0031	0.0038
Chryptomonas spp.	-	0.0190	0.0532	0.0069	0.0484	0.0152
Boda spp.	-	-	0.0030	0.0014	-	-
Ochromonas sp.	8.6480	1.9007	1.0264	0.0138	0.0415	0.0431
Mallomonas sp.	-	-	0.0213	-	-	0.0213
Kephyrion sp.	-	-	-	-	-	-
Dinobryon sp.	0.0304	-	0.7907	1.5703	0.8294	0.3183
Bitrichia sp.	-	-	-	-	-	0.0020
Chrysococcus sp.	-	0.0057	0.0046	0.0028	0.0180	-
Chroomonas acuta	-	0.0100	0.0034	0.0062	0.0073	0.0030
Komma sp.	-	-	-	-	-	0.0010
Small microflagellates	0.0023	0.0017	0.0066	0.0035	0.0187	0.0055
Group total	**8.6807**	**1.9450**	**1.9106**	**1.6073**	**0.9667**	**0.4136**
Dinophyceae (dinoflagellates)						
Peridinium spp.	-	0.2727	0.0532	-	0.0048	0.0035
Gymnodinium sp. (small)	-	0.0095	0.0228	0.0069	0.0138	0.0101
Gymnodinium sp. (large).	-	0.0285	0.0228	-	-	0.0456
Group total	**0.0000**	**0.3107**	**0.0988**	**0.0069**	**0.0186**	**0.0592**

Station:	LS1-NB					
Date:	31-May-11	11-Jul-11	26-Jul-11	26-Aug-11	5-Oct-11	25-Oct-11
Species	**Biovolume (mm^3/L)**					
Chlorophyceae (coccoid greens, desmids, etc.)						
Ankistrodesmus sp.	-	-	-	-	0.0011	-
Chlorella sp.	-	0.0008	0.0021	0.0014	0.0036	0.0016
Crucigenia sp.	-	-	-	-	-	-
Tetraedron sp.	-	-	-	-	0.0007	-
Coelastrum sp.	-	-	-	-	-	-
Botryococcus sp.	-	-	-	-	-	-
Planctosphaeria sp.	-	-	-	0.0691	-	-
Sphaerocystis sp.	-	-	-	-	-	-
Clamydocapsa sp.	-	-	-	-	-	-
Elakatothrix sp.	-	-	-	0.0035	-	0.0025
Staurastrum sp.	-	-	-	-	-	-
Cosmarium sp.	-	-	-	-	0.0069	-
Dichtyosphaerium	-	-	-	-	-	-
Stichococcus minutissimus	-	0.0008		-	-	-
Cateria sp.	-	-	-	-	0.0031	-
Closterium sp.	-	-	-	-	-	0.0030
Euglena sp.	-	-	-	-	0.0691	-
Gleotila sp.	-	-	-	-	-	0.0030
Gyromitus sp.	-	-	0.0308	0.0062	0.0124	0.0068
Oocystis sp.	-	-	0.0456		0.0415	0.0051
Nephroselmis sp.	-	-	-	0.0017	0.0052	-
Planctonema sp.	-	-	-	-	0.0097	-
Pyramimonas sp.	-	-	-	-	-	0.0024
Stichicoccus minutissimus	-	-	0.0060	0.0010	-	-
Scourfieldia sp.	-	-	0.0020	0.0018	0.0027	0.0007
Scenedesmus sp.	-	-	0.0046	0.0017	0.0033	-
Monomastic sp.	-	-	-	-	0.0083	-
Group total	**0.0000**	**0.0016**	**0.0911**	**0.0864**	**0.1676**	**0.0251**
Cyanophyceae (blue-greens)						
Synechococcus sp (rod)	0.0010	0.0019	0.0012	0.0011	0.0069	0.0008
Synechococcus sp. (coccoid)	0.0046	0.0010	0.0005	0.0003	0.0007	0.0005
Synechocystis sp.	-	0.0019	0.0011	-	0.0006	0.0011
Merismopedia sp.	-	-	-	-	0.0088	-
Microcystis sp.	-	0.0001	-	-	0.0024	0.0030
Aphanothecae sp.	-	-	-	-	-	0.0010
Anabaena spp.	-	-	-	-	-	-
Group total	**0.0056**	**0.0049**	**0.0028**	**0.0014**	**0.0194**	**0.0064**
TOTAL	**8.6863**	**2.2774**	**2.1158**	**1.7190**	**1.1844**	**0.5213**

Station:	LS1-NB					
Date:	30-May-12	27-Jun-12	25-Jul-12	29-Aug-12	26-Sep-12	31-Oct-12
Species	**Biovolume (mm^3/L)**					
Bacillariophyceae (diatoms)						
Achnanthidium spp.	0.0024	-	-	-	-	-
Fragilaria capucina	0.0051	0.0020	-	-	-	-
Fragilaria construens	0.0024	0.0008	-	-	-	-
Cyclotella glomerata	0.0066	0.0010	0.0038	-	-	0.0015
Cyclotella stelligera	0.0106	-	-	-	-	-
Cyclotella comta	0.0213	-	-	-	0.0044	-
Tabellaria fenestrata	0.0051	0.0051	-	-	0.6969	0.0051
Tabellaria flocculosa	0.0101	-	-	-	-	-
Navicula sp.	0.0101	-	-	-	-	-
Synedra ulna	-	0.0405	-	-	-	-
Synedra nana	-	0.0030	-	-	-	-
Synedra acus	-	0.0061	-	-	-	-
Rhizosolenia sp.	-	0.0051	-	0.0233	0.1071	0.0101
Asterionella formosa	-	-	-	0.0740	0.0722	0.1683
Group total	**0.0738**	**0.0637**	**0.0038**	**0.0973**	**0.8806**	**0.1850**
Chryso- & Cryptophyceae (flagellates)						
Chromulina sp.	-	-	-	0.0247	0.0005	0.0006
Chrysochromulina sp.	0.0251	0.0631	-	0.0046	0.0095	0.0008
Chryptomonas spp.	0.0101	0.0101	0.0190	0.0253	0.0443	0.0152
Komma sp.	0.0010	0.0030	-	0.0030	0.0025	0.0020
Chroomonas acuta	0.0023	0.0129	0.0086	0.0137	0.0067	0.0038
Ochromonas sp.	0.5068	1.4572	3.8013	0.7755	0.1901	0.0177
Kephyrion sp.	0.0005	-	-	0.0005	-	-
Dinobryon sp.	0.0081	0.2473	-	0.0020	0.1901	0.5879
Chrysococcus sp.	0.0152	0.0041	-	-	-	-
Small microflagellates	0.0108	0.0132	0.0080	0.0026	0.0063	0.0114
Mallomonas sp.	-	-	-	-	0.0089	0.0071
Group total	**0.5800**	**1.8110**	**3.8369**	**0.8520**	**0.4588**	**0.6466**
Dinophyceae (dinoflagellates)						
Peridinium spp.	0.0071	0.0177	0.0133	-	0.0089	-
Gymnodinium sp. (large).	0.0152	-	-	-	-	-
Gymnodinium sp. (small)	0.0051	-	0.0190	-	0.0063	-
Group total	**0.0274**	**0.0177**	**0.0323**	**0.0000**	**0.0152**	**0.0000**

Station:	LS1-NB					
Date:	30-May-12	27-Jun-12	25-Jul-12	29-Aug-12	26-Sep-12	31-Oct-12
Species	**Biovolume (mm^3/L)**					
Chlorophyceae (coccoid greens, desmids, etc.)						
Ankistrodesmus sp.	-	0.0008	0.0061	0.0008	-	0.0008
Elakatothrix sp.	-	0.0025	0.0190	-	-	-
Chlorella sp.	0.0014	0.0014	0.0061	0.0010	0.0023	0.0016
Tetraedron sp.	0.0010	0.0010	-	-	-	-
Scenedesmus sp.	-	0.0006	0.0023	-	-	-
Sphaerocystis sp.	-	0.0030	0.0570	-	-	-
Cosmarium sp.	-	0.0051	-	-	-	-
Coccomyxa sp.	-	0.0015	-	-	-	-
Coelastrum sp.	-	0.0101	-	0.0051	0.0063	-
Gyromitus sp.	0.0046	-	-	-	0.0057	0.0046
Monomastic sp.	0.0030	-	-	-	-	-
Pyramimonas sp.	0.0012	-	-	-	-	-
Botryococcus sp.	-	-	-	0.0857	0.0165	-
Scourfieldia sp.	-	-	-	-	0.0025	0.0020
Group total	**0.0113**	**0.0262**	**0.0905**	**0.0925**	**0.0333**	**0.0090**
Cyanophyceae (blue-greens)						
Synechococcus sp. (coccoid)	0.0028	0.0041	-	0.0004	0.0002	0.0009
Synechococcus sp (rod)	0.0051	0.0041	-	0.0041	0.0013	0.0041
Synechocystis sp.	0.0008	0.0007	-	0.0003	0.0013	0.0004
Microcystis sp.	-	-	0.0169	-	0.0071	0.0041
Anabaena spp.(cell)	-	-	-	-	0.0038	-
Merismopedia sp.	-	-	-	-	0.0081	-
Group total	**0.0087**	**0.0088**	**0.0169**	**0.0048**	**0.0217**	**0.0094**
TOTAL	**0.7011**	**1.9274**	**3.9804**	**1.0466**	**1.4097**	**0.8499**

Table B2 Phytoplankton seasonal (May-October) abundance (cells/mL) and biovolume (mm^3/L) at LS2 in the south basin of Wahleach Reservoir, 2011 and 2012

Station:	LS2-SB					
Date:	31-May-11	11-Jul-11	26-Jul-11	26-Aug-11	05-Oct-11	25-Oct-11
Species	**Abundance (cells/mL)**					
Bacillariophyceae (diatoms)						
Synedra acus	-	-	65.17	11.70	-	-
Synedra acus var angustissima	-	25.34	-	-	-	-
Synedra nana	20.27	-	65.17	11.70	-	30.41
Cyclotella comta	-	-	21.72	11.70	-	-
Cyclotella glomerata	-	50.68	21.72	11.70	-	30.41
Cyclotella stelligera	-	-	-	11.70	-	-
Rhizosolenia sp.	-	-	-	11.70	-	-
Tabellaria fenestrata	10.14	-	-	-	-	-
Tabellaria flocculosa	-	-	-	-	-	-
Navicula sp.	-	-	-	-	10.14	20.27
Achnanthidium spp.	-	-	-	-	10.14	10.14
Fragilaria capucina	10.14	50.68	108.61	35.09	-	10.14
Group total	**40.55**	**126.70**	**282.38**	**105.27**	**20.27**	**101.37**
Chryso- & Cryptophyceae (flagellates)						
Chromulina sp.	60.82	76.03	-	11.70	10.14	20.27
Chrysochromulina sp.	101.37	25.34	43.44	23.39	40.55	20.27
Chryptomonas spp.	10.14	76.03	108.61	35.09	20.27	30.41
Boda spp.	-	-	21.72	11.70	-	-
Ochromonas sp.	2838.32	9630.03	8254.31	35.09	40.55	162.19
Mallomonas sp.	-	-	-	-	-	20.27
Kephyrion sp.	-	25.34	-	-	-	-
Dinobryon sp.	50.68	329.45	304.11	4152.22	2027.37	3081.61
Chroomonas acuta	131.78	152.05	86.89	35.09	30.41	70.96
Chrysococcus sp.	-	101.37	21.72	35.09	40.55	-
Komma spp.	-	-	-	-	-	10.14
Small microflagellates	608.21	810.95	325.83	198.84	506.84	446.02
Group total	**3801.32**	**11226.59**	**9166.63**	**4538.20**	**2716.68**	**3862.15**
Dinophyceae (dinoflagellates)						
Peridinium spp.	-	25.34	-	11.70	10.14	-
Gymnodinium sp. (small)	10.14	-	43.44	11.70	10.14	20.27
Gymnodinium sp. (large).	10.14	-	21.72	-	10.14	20.27
Group total	**20.28**	**25.34**	**65.17**	**23.39**	**30.41**	**40.55**

Station:	LS2-SB					
Date:	31-May-11	11-Jul-11	26-Jul-11	26-Aug-11	05-Oct-11	25-Oct-11
Species	**Abundance (cells/mL)**					
Chlorophyceae (coccoid greens, desmids, etc.)						
Ankistrodesmus sp.	-	-	-	-	-	10.14
Chlorella sp.	70.96	101.37	152.05	46.79	70.96	81.09
Crucigenia sp.	-	-	-	-	-	-
Tetraedron sp.	-	-	-	-	-	10.14
Coelastrum sp.	-	-	-	-	10.14	-
Botryococcus sp.	-	-	-	-		-
Planctosphaeria sp.	-	-	-	128.66	40.55	-
Sphaerocystis sp.	-	-	-	-	40.55	-
Clamydocapsa sp.	-	-	-	-	-	-
Elakatothrix sp.	-	-	-	-	-	10.14
Staurastrum sp.	-	-	-	-	-	
Cosmarium sp.	-	-	-	-	-	20.27
Dichtyosphaerium	-	-	-	-	-	-
Stichococcus minutissimus	-	278.76	-	116.96	-	-
Scourfieldia sp.	50.68	76.03	21.72	11.70	-	30.41
Nephroselmis sp.	-	-	65.17	11.70	-	-
Gyromitus sp.	-	-	86.89	23.39	10.14	30.41
Phacus sp.	-	-	-	-	-	10.14
Oocystis sp.	-	-	-	-	-	10.14
Monomastic sp.	-	-	-	-	-	-
Group total	**121.64**	**456.16**	**325.83**	**339.20**	**172.33**	**212.87**
Cyanophyceae (blue-greens)						
Synechococcus sp (rod)	40.55	304.11	130.33	58.48	121.64	415.61
Synechococcus sp. (coccoid)	567.66	152.05	65.17	81.87	81.09	40.55
Synechocystis sp.	20.27	101.37	43.44	-	30.41	111.51
Microcystis sp.	-	8869.76	-	-	1267.11	4308.17
Aphanothecae sp.	-	-	-	-	-	-
Anabaena spp.	-	-	-	-	-	-
Group total	**628.48**	**9427.29**	**238.94**	**140.36**	**1500.26**	**4875.84**
TOTAL	**4612.27**	**21262.08**	**10078.95**	**5146.41**	**4439.95**	**9092.77**

Station:	LS2-SB					
Date:	30-May-12	27-Jun-12	25-Jul-12	29-Aug-12	26-Sep-12	31-Oct-12
Species	**Abundance (cells/mL)**					
Bacillariophyceae (diatoms)						
Achnanthidium spp.	10.14	-	-	-	-	-
Synedra acus	20.27	-	-	-	-	-
Cyclotella glomerata	40.55	30.41	-	30.41	-	-
Cyclotella stelligera	10.14	-	-	-	-	-
Tabellaria fenestrata	70.96	-	-	-	1935.22	973.14
Rhizosolenia sp.	-	50.68	-	324.38	829.38	-
Cyclotella comta	-	-	-	10.14	-	10.14
Asterionella formosa	-	-	-	212.87	1700.23	2128.74
Fragilaria capucina	-	-	-	10.14	13.82	-
Group total	**152.05**	**81.09**	-	**587.94**	**4478.65**	**3112.02**
Chryso- & Cryptophyceae (flagellates)						
Chromulina sp.				963.00	27.65	-
Chrysochromulina sp.	293.97	375.06	-	30.41	41.47	20.27
Chryptomonas spp.	10.14	30.41	-	30.41	13.82	40.55
Komma sp.	10.14	20.27	-	10.14	27.65	10.14
Chroomonas acuta	60.82	91.23	-	60.82	41.47	30.41
Ochromonas sp.	902.18	1317.79	-	2230.11	69.12	50.68
Kephyrion sp.	40.55	-	-	-	-	-
Dinobryon sp.	40.55	182.46	-	162.19	1313.19	3547.91
Chrysococcus sp.	20.27	40.55	-	-	-	-
Small microflagellates	496.71	608.21	-	405.47	179.70	658.90
Mallomonas sp.	-	-	-	10.14	13.82	-
Group total	**1875.32**	**2666.00**	-	**3902.70**	**1727.88**	**4358.86**
Dinophyceae (dinoflagellates)						
Peridinium spp.	-	30.41	-	10.14	13.82	-
Gymnodinium sp. (large).	-	10.14	-	10.14	13.82	-
Gymnodinium sp. (small)	10.14	10.14	-	10.14	27.65	-
Group total	**10.14**	**50.68**	-	**30.41**	**55.29**	**0.00**

Station:	LS2-SB					
Date:	30-May-12	27-Jun-12	25-Jul-12	29-Aug-12	26-Sep-12	31-Oct-12
Species	**Abundance (cells/mL)**					
Chlorophyceae (coccoid greens, desmids, etc.)						
Ankistrodesmus sp.	-	20.27	-	10.14	-	10.14
Elakatothrix sp.	-	-	-	10.14	-	-
Chlorella sp.	30.41	101.37	-	40.55	96.76	101.37
Tetraedron sp.	20.27	10.14	-	-	-	-
Coelastrum sp.	10.14	10.14	-	-	13.82	-
Gyromitus sp.	20.27	-	-	-	27.65	20.27
Pyramimonas sp.	20.27	-	-	-	-	-
Scenedesmus sp.	-	10.14	-	10.14	-	-
Clamydocapsa sp.	-	10.14	-	-	-	-
Cosmarium sp.	-	-	-	10.14	-	-
Botryococcus sp.	-	-	-	50.68	-	10.14
Scourfieldia sp.	-	-	-	-	27.65	40.55
Euglena sp.	-	-	-	-	13.82	-
Spondylosium sp.	-	-	-	-	-	40.55
Group total	**101.37**	**162.19**	-	**131.78**	**179.70**	**223.01**
Cyanophyceae (blue-greens)						
Synechococcus sp. (coccoid)	527.12	658.90	-	30.41	41.47	162.19
Synechococcus sp (rod)	273.70	141.92	-	283.83	55.29	10.14
Synechocystis sp.	81.09	202.74	-	70.96	207.35	50.68
Anabaena spp.	-	-	-	324.38	276.46	-
Merismopedia sp.	-	-	-	162.19	-	-
Microcystis sp.	-	-	-	-	7464.42	4054.75
Group total	**881.91**	**1003.55**	-	**871.77**	**8044.99**	**4277.76**
TOTAL	**3020.79**	**3963.52**	-	**5524.60**	**14486.51**	**11971.65**

Station: Date: **Species**	LS2-SB 31-May-11 **Biovolume (mm^3/L)**	 11-Jul-11	 26-Jul-11	 26-Aug-11	 05-Oct-11	 25-Oct-11
Bacillariophyceae (diatoms)						
Synedra acus	-	-	0.0065	0.0012	-	-
Synedra acus var angustissima	-	0.0038	-	-	-	-
Synedra nana	0.0015	-	0.0049	0.0009	-	0.0023
Cyclotella comta	-	-	0.0076	0.0041	-	-
Cyclotella glomerata	-	0.0025	0.0011	0.0006	-	0.0015
Cyclotella stelligera	-	-	-	0.0018	-	-
Rhizosolenia sp.	-	-	-	0.0006	-	-
Tabellaria fenestrata	0.0051	-	-	-	-	-
Tabellaria flocculosa	-	-	-	-	-	-
Navicula sp.	-	-	-	-	0.0051	0.0101
Achnanthidium spp.	-	-	-	-	0.0008	0.0008
Fragilaria capucina	0.0010	0.0051	0.0109	0.0035	-	0.0010
Group total	**0.0076**	**0.0114**	**0.0310**	**0.0126**	**0.0059**	**0.0158**
Chryso- & Cryptophyceae (flagellates)						
Chromulina sp.	0.0012	0.0015	-	0.0002	0.0002	0.0004
Chrysochromulina sp.	0.0076	0.0019	0.0033	0.0018	0.0030	0.0015
Chryptomonas spp.	0.0051	0.0380	0.0543	0.0175	0.0101	0.0152
Boda spp.	-	-	0.0022	0.0012	-	-
Ochromonas sp.	0.7096	2.4075	2.0636	0.0088	0.0101	0.0405
Mallomonas sp.	-	-	-	-	-	0.0142
Kephyrion sp.	-	0.0013	-	-	-	-
Dinobryon sp.	0.0101	0.0649	0.0608	0.8304	0.4055	0.6163
Chroomonas acuta	0.0099	0.0114	0.0065	0.0026	0.0023	0.0053
Chrysococcus sp.	-	0.0101	0.0022	0.0035	0.0041	-
Komma spp.	-	-	-	-	-	0.0010
Small microflagellates	0.0091	0.0122	0.0049	0.0030	0.0076	0.0067
Group total	**0.7526**	**2.5488**	**2.1977**	**0.8690**	**0.4429**	**0.7012**
Dinophyceae (dinoflagellates)						
Peridinium spp.	-	0.0089	-	0.0041	0.0035	-
Gymnodinium sp. (small)	0.0051	-	0.0217	0.0058	0.0051	0.0101
Gymnodinium sp. (large).	0.0152	-	0.0326	-	0.0152	0.0304
Group total	**0.0203**	**0.0089**	**0.0543**	**0.0099**	**0.0238**	**0.0405**

Station:	LS2-SB					
Date:	31-May-11	11-Jul-11	26-Jul-11	26-Aug-11	05-Oct-11	25-Oct-11
Species	**Biovolume (mm^3/L)**					
Chlorophyceae (coccoid greens, desmids, etc.)						
Ankistrodesmus sp.	-	-	-	-	-	0.0008
Chlorella sp.	0.0014	0.0020	0.0030	0.0009	0.0014	0.0016
Crucigenia sp.	-	-	-	-	-	-
Tetraedron sp.	-	-	-	-	-	0.0005
Coelastrum sp.	-	-	-	-	0.0051	-
Botryococcus sp.	-	-	-	-	-	-
Planctosphaeria sp.	-	-	-	0.1287	0.0405	-
Sphaerocystis sp.	-	-	-	-	0.0122	-
Clamydocapsa sp.	-	-	-	-	-	-
Elakatothrix sp.	-	-	-	-	-	0.0025
Staurastrum sp.	-	-	-	-	-	-
Cosmarium sp.	-	-	-	-	-	0.0101
Dichtyosphaerium	-	-	-	-	-	-
Stichococcus minutissimus	-	0.0020	-	0.0008	-	-
Scourfieldia sp.	0.0033	0.0049	0.0014	0.0008	-	0.0020
Nephroselmis sp.	-	-	0.0081	0.0015	-	-
Gyromitus sp.	-	-	0.0195	0.0053	0.0023	0.0068
Phacus sp.	-	-	-	-	-	0.0071
Oocystis sp.	-	-	-	-	-	0.0051
Monomastic sp.	-	-	-	-	-	-
Group total	**0.0047**	**0.0089**	**0.0321**	**0.1379**	**0.0615**	**0.0366**
Cyanophyceae (blue-greens)						
Synechococcus sp (rod)	0.0008	0.0061	0.0026	0.0012	0.0024	0.0083
Synechococcus sp. (coccoid)	0.0028	0.0008	0.0003	0.0004	0.0004	0.0002
Synechocystis sp.	0.0002	0.0010	0.0004	-	0.0003	0.0011
Microcystis sp.	-	0.0089	-	-	0.0013	0.0043
Aphanothecae sp.	-	-	-	-	-	-
Anabaena spp.	-	-	-	-	-	-
Group total	**0.0038**	**0.0168**	**0.0034**	**0.0016**	**0.0044**	**0.0139**
TOTAL	**0.7890**	**2.5948**	**2.3185**	**1.0310**	**0.5385**	**0.8081**

Station:	LS2-SB					
Date:	30-May-12	27-Jun-12	25-Jul-12	29-Aug-12	26-Sep-12	31-Oct-12
Species	**Biovolume (mm^3/L)**					
Bacillariophyceae (diatoms)						
Achnanthidium spp.	0.0008	-	-	-	-	-
Synedra acus	0.0020	-	-	-	-	-
Cyclotella glomerata	0.0020	0.0015	-	0.0015	-	-
Cyclotella stelligera	0.0015	-	-	-	-	-
Tabellaria fenestrata	0.0355	-	-	-	0.9676	0.4866
Rhizosolenia sp.		0.0025	-	0.0162	0.0415	-
Cyclotella comta	-	-	-	0.0035	-	0.0035
Asterionella formosa	-	-	-	0.0213	0.1700	0.2129
Fragilaria capucina	-	-	-	0.0010	0.0014	-
Group total	**0.0419**	**0.0041**	-	**0.0436**	**1.1805**	**0.7030**
Chryso- & Cryptophyceae (flagellates)						
Chromulina sp.	-	-	-	0.0193	0.0006	-
Chrysochromulina sp.	0.0220	0.0281	-	0.0023	0.0031	0.0015
Chryptomonas spp.	0.0051	0.0152	-	0.0152	0.0069	0.0203
Komma sp.	0.0010	0.0020	-	0.0010	0.0028	0.0010
Chroomonas acuta	0.0046	0.0068	-	0.0046	0.0031	0.0023
Ochromonas sp.	0.2255	0.3294	-	0.5575	0.0173	0.0127
Kephyrion sp.	0.0020	-	-	-	-	-
Dinobryon sp.	0.0081	0.0365	-	0.0324	0.2626	0.7096
Chrysococcus sp.	0.0020	0.0041	-	-	-	-
Small microflagellates	0.0075	0.0091	-	0.0061	0.0027	0.0099
Mallomonas sp.	-	-	-	0.0071	0.0097	-
Group total	**0.2779**	**0.4313**	-	**0.6455**	**0.3087**	**0.7572**
Dinophyceae (dinoflagellates)						
Peridinium spp.	-	0.0106	-	0.0035	0.0048	-
Gymnodinium sp. (large).	-	0.0152	-	0.0152	0.0207	-
Gymnodinium sp. (small)	0.0051	0.0051	-	0.0051	0.0138	-
Group total	**0.0051**	**0.0309**	-	**0.0238**	**0.0394**	**0.0000**

Station:	LS2-SB					
Date:	30-May-12	27-Jun-12	25-Jul-12	29-Aug-12	26-Sep-12	31-Oct-12
Species	**Biovolume (mm^3/L)**					
Chlorophyceae (coccoid greens, desmids, etc.)						
Ankistrodesmus sp.	-	0.0016	-	0.0008	-	0.0008
Elakatothrix sp.	-	-	-	0.0025	-	-
Chlorella sp.	0.0006	0.0020	-	0.0008	0.0019	0.0020
Tetraedron sp.	0.0010	0.0005	-	-	-	-
Coelastrum sp.	0.0051	0.0051	-	-	0.0069	-
Gyromitus sp.	0.0046	-	-	-	0.0062	0.0046
Pyramimonas sp.	0.0024	-	-	-	-	-
Scenedesmus sp.	-	0.0006	-	0.0006	-	-
Clamydocapsa sp.	-	0.0056	-	-	-	-
Cosmarium sp.	-	-	-	0.0051	-	-
Botryococcus sp.	-	-	-	0.0329	-	0.0066
Scourfieldia sp.	-	-	-	-	0.0018	0.0026
Euglena sp.	-	-	-	-	0.0346	-
Spondylosium sp.	-	-	-	-	-	0.0101
Group total	**0.0137**	**0.0154**	-	**0.0428**	**0.0514**	**0.0268**
Cyanophyceae (blue-greens)						
Synechococcus sp. (coccoid)	0.0026	0.0033	-	0.0002	0.0002	0.0008
Synechococcus sp (rod)	0.0055	0.0028	-	0.0057	0.0011	0.0002
Synechocystis sp.	0.0008	0.0020	-	0.0007	0.0021	0.0005
Anabaena spp.	-	-	-	0.2919	0.0041	-
Merismopedia sp.	-	-	-	0.0032	-	-
Microcystis sp.	-	-	-	-	0.0149	0.0081
Group total	**0.0089**	**0.0082**	-	**0.3017**	**0.0225**	**0.0096**
TOTAL	**0.3474**	**0.4899**	-	**1.0574**	**1.6025**	**1.4966**

Appendix C List of zooplankton species identified in Wahleach Lake Reservoir, 2007-2012

Species	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
CLADOCERA						
Alona sp.		r	r	r	r	r
Alonella nana		r				r
Bosmina longirostris	+	+	+	+	+	+
Chydorus sphaericus	r	r	r	r	r	r
Daphnia rosea	+	+	+	+	+	+
Holopedium gibberum	+	+	+	+	+	+
Leptodora kindtii	+	+	+	+	+	+
Pleuroxus sp.						r
Scapholeberis mucronata			r	r	r	r
COPEPODA						
Cyclops vernalis	+	+	+	+	+	+
Macrocyclops fuscus	r	r	r	r	r	r
Leptodiaptomus ashlandi		+				
TOTAL	**7**	**10**	**9**	**9**	**9**	**11**

r = rare species

Appendix D Hydroacoustic equipment specifications and data analysis parameters used for Wahleach Reservoir surveys, 2011-2012

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	2011 analysis threshold	-61 to -26 dB
		2012 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 E 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	_	-45	97	109
-27	852	960	-46	86	96
-28	755	851	-47	76	85
-29	669	754	-48	68	75
-30	593	668	-49	60	67
-31	526	592	-50	53	59
-32	466	525	-51	47	52
-33	413	465	-52	42	46
-34	366	412	-53	37	41
-35	325	365	-54	33	36
-36	288	324	-55	29	32
-37	255	287	-56	26	28
-38	226	254	-57	23	25
-39	201	225	-58	20	22
-40	178	200	-59	18	19
-41	158	177	-60	16	17
-42	140	157	-61	14	15
-43	124	139	-62	13	13
-44	110	123			

Appendix F Wahleach Reservoir habitat areas used for hydroacoustic data analysis

Areas in 2011 begin at 368 ha for the 2 m depth stratum, based on a survey pool elevation of 640 m. In 2012, areas begin at 397 ha for the 2 m stratum, based on a survey pool elevation of 642 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 2011 and 2012.

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

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 G Wahleach Reservoir acoustic survey transect densities (fish·ha^{-1}) by 2 meter depth intervals during 2011 (a-b) and 2012 (c-d) for small fish [<-46 (2011), <-50 dB (2012)] and large fish [>-46 (2011), >-50 dB (2012)]

a) 2011 (< -46 dB)

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

b) 2011 (< -46 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	0	0	0	**0**
8	21	112	21	0	17	0	0	6	0	0	10	**17**
10	0	10	43	40	58	59	59	43	20	54	64	**41**
12		56	0	19	24	21	62	53	79	40	75	**43**
14		0	0	0	11	11	6	14	0			**5**
16			6	0	0	6	4	19	0			**5**
18			0	0	0	0	7	0				**1**
20			0	0	0	0	0	0				**0**
22			0	0	0	0	0	0				**0**
24				0		0	0					**0**
26						0						**0**
28												
Total	**21**	**178**	**70**	**59**	**110**	**96**	**138**	**135**	**99**	**94**	**149**	

Depth intervals 0 = from 0.0 to 2.0m
Light grey area = max bottom or analysis depth

c) 2012 (<-50 dB)

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

c) 2012 (>-50 dB)

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

Depth intervals 0 = from 0.0 to 2.0m
Light grey area = max bottom or analysis depth

Appendix H Maximum likelihood estimates (MLE) and bounds (95% confidence intervals; UB = upper bound, LB = lower bound) for Wahleach Reservoir hydroacoustic surveys on August 26, 2011 and July 18, 2012, based on Monte Carlo simulations

a) 2011 (-61 to -26 dB)

Depth (m)	n	Average Density (fish·ha^{-1})	SD	SE	Area (ha)	Population (# fish)		
2	11	146	226.8	68.4	368	53742		
4	11	71	52.4	15.8	334	23556		
6	11	125	149.0	44.9	295	36935		
8	11	83	51.3	15.5	264	22023		
10	11	65	38.5	11.6	234	15101		
12	10	65	38.3	12.1	201	13125		
14	8	11	12.2	4.3	174	1897		
16	7	11	10.3	3.9	145	1577		
18	6	1	3.0	1.2	117	145		
20	6	2	3.9	1.6	69	109	UB=	225,900
22	6	2	5.3	2.2	26	57	MLE=	171,600
24	3	1	1.0	0.6	12	7	LB=	110,800

b) 2012 (-66 to -26 dB)

Depth (m)	n	Average Density (fish·ha^{-1})	SD	SE	Area (ha)	Population (# fish)		
2	11	284	171.8	51.8	397	112696		
4	11	122	73.4	22.1	368	45033		
6	11	75	37.1	11.2	334	24989		
8	11	75	35.2	10.6	295	22103		
10	11	48	29.7	9.0	264	12706		
12	10	32	15.0	4.7	234	7434		
14	10	24	16.2	5.1	201	4904		
16	8	15	12.7	4.5	174	2632		
18	6	21	10.3	4.2	145	3074		
20	6	28	18.8	7.7	117	3237		
22	6	26	15.3	6.3	69	1812	UB=	285,500
24	6	25	18.0	7.4	26	654	MLE=	238,400
26	2	9	0.5	0.3	12	103	LB=	197,000

c) 2011 (>-46 dB)

Depth (m)	n	Average Density (fish·ha^{-1})	SD	SE	Area (ha)	Population (# fish)
8	11	17	32.6	9.8	264	4499
10	11	41	21.7	6.5	234	9579
12	10	43	26.3	8.3	201	8591
14	8	5	5.9	2.1	174	908
16	7	5	6.9	2.6	145	741
18	6	1	3.0	1.2	117	145

UB= 31,200
MLE= 23,600
LB= 17,500

d) 2012 (>-50 dB)

Depth (m)	n	Average Density (fish·ha^{-1})	SD	SE	Area (ha)	Population (# fish)
2	11	5	16.7	5.0	397	2005
4	11	20	24.7	7.4	368	7437
6	11	20	31.8	9.6	334	6781
8	11	29	24.3	7.3	295	8594
10	11	15	20.4	6.2	264	3949
12	10	11	13.8	4.4	234	2667
14	10	6	6.4	2.0	201	1215
16	8	1	1.3	0.5	174	79

UB= 43,400
MLE= 33,000
LB= 22,100

Appendix I Trawl catch (a) and effort (b) for Wahleach Reservoir, September 20, 2011

a)

Date	Trawl #	Species	Fork Length (mm)	Weight (g)
20-Sep-11	3	TSB	57	2.0
20-Sep-11	3	TSB	58	1.0
20-Sep-11	3	TSB	50	1.5
20-Sep-11	2	TSB	49	1.0
20-Sep-11	2	TSB	59	2.0
20-Sep-11	2	TSB	56	2.0
20-Sep-11	2	TSB	48	1.0
20-Sep-11	2	TSB	51	1.5
20-Sep-11	2	TSB	47	0.5
20-Sep-11	2	TSB	31	0.5
20-Sep-11	2	KO	56	1.5
20-Sep-11	4	TSB	55	1.5
20-Sep-11	4	TSB	54	1.5
20-Sep-11	4	TSB	54	1.5
20-Sep-11	4	TSB	53	2.0
20-Sep-11	4	TSB	35	0.5
20-Sep-11	4	TSB	25	0.5
20-Sep-11	1	TSB	53	1.4
20-Sep-11	1	TSB	52	1.1
20-Sep-11	1	TSB	29	0.3
20-Sep-11	1	TSB	53	1.3

b)

Trawl #	Depth Fished (m)	Targeted Layer (m)	Catch		Duration (min)
			TSB	KO	
1	8-10	8-10	4	0	40
2	10-15	12-14	7	1	40
3	10-15	12-14	3	0	40
4	10-15	12-14	6	0	40

Appendix J Pelagic gillnetting catch (a) and effort (b) for Wahleach Reservoir, July18-19, 2012

a)

Date	Net Depth (m)	Species	Fish #	Fork Length (mm)	Weight (g)	Sex	Maturity	Clip	Age	CF
19-Jul-12	0	RB	1	240	130.5	F	MT	NC	3+	0.94
19-Jul-12	0	RB	2	160	43.0	F	IM	NC	2+	1.05
19-Jul-12	5	KO	3	300	250.0	M	MT	NC	4+	0.93
19-Jul-12	5	KO	4	122	16.5	F	IM	NC	1+	0.91

b)

Set Date	Pull Date	Site	Gear/Number	Depth (m)	Set Time	Pull Time	Net Area (m^2)	Total Hours	Total Catch	CPUE (fish per net hour)
18-Jul-12	19-Jul-12	LS1	GN (3)	0, 5, 10	20:12	8:15	669	12.05	4	0.11
18-Jul-12	19-Jul-12	LS1	WOD (1)	4	20:12	8:15	223	12.05	0	0.00