Wahleach Project Water Use Plan

Wahleach Reservoir Fertilization Program

Implementation Year 1 - 2

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THE WAHLEACH RESERVOIR FERTILIZATION PROGRAM, 2004-2006
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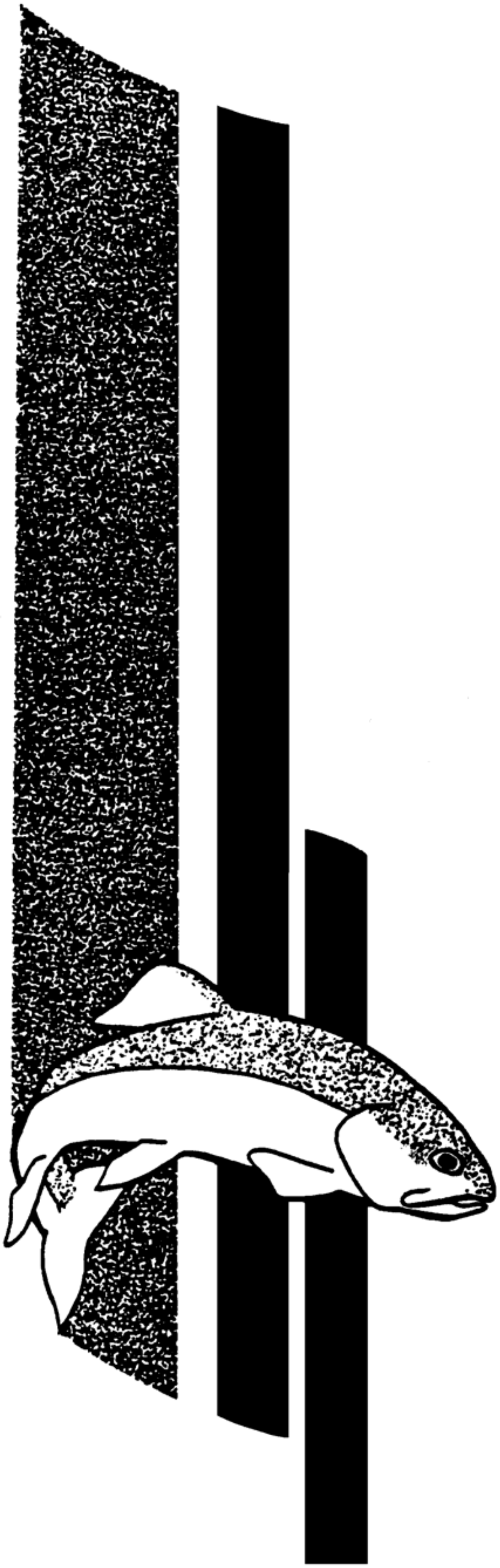

THE WAHLEACH RESERVOIR FERTILIZATION PROGRAM, 2004-2006

by

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Executive Summary

Fertilization of Wahleach Reservoir was completed in 2004-2006 to restore productivity to the reservoir where large water level fluctuations and altered hydraulic regime have reduced littoral and pelagic productivity to unnaturally low levels. Agricultural grade fertilizers were added in twenty weekly applications between June and October of each year. A suite of physical, chemical and biological parameters, used to examine the ecosystem response, were examined on a monthly basis from June through October. This report summarizes results of the limnological program and the fish stock assessments.

Nutrient loading to the reservoir was variable during each study year. Between 4.7-5.5 MT of 10-34-0 liquid ammonium polyphosphate and 13.2-17.0 of 28-0-0 urea-ammonium-nitrate was added to the reservoir in 2004-2006. The total phosphorus load increase from ~186 mg·P·m^{-2} to ~204 mg·P·m^{-2} in 2006. Nitrogen loading also increased during the study period from ~1070 mg·N·m^{-2} to ~1520 mg·N·m^{-2} in 2006. During each year of the experiment the molar N:P ratio increase from 13.1 to 13.6 and finally to 14.9 in 2006.

Water chemistry indicated that the fertilizer was rapidly taken up by the phytoplankton assemblage. Dissolved inorganic phosphorous (SRP) ranged from 1.4-2.7 µg·L^{-1}, which is below the concentration known to limit phytoplankton growth. Dissolved inorganic nitrate+nitrite concentrations were below 10 µg·L^{-1} in the summer growing season, again below the concentration known to limit phytoplankton growth. The phytoplankton community responded to increased nutrient loading in 2006 by nearly a 2 fold increase in cell densities and nearly a 3 fold increase in phytoplankton biomass. The phytoplankton community was composed of a mixed assemblage of Chryosphytes/Chryptophytes (heterotrophic nanoflagellates) and by Bacillariophytes (diatoms). The nanoflagellates (2.0-20.0 µm) are the preferred size class of phytoplankton that are consumed by herbivorous zooplankton and a healthy contribution of flagellates are considered necessary for optimal growth of key zooplankton species.

The zooplankton community was composed of cladocerans, copepods, a mixed assemblage of rotifers and the occasional ostracod, a benthic invertebrate. The zooplankton assemblage was numerically dominated by cladocerans, principally by large *Daphnia* sp. which accounted for up to 90% of the community. Densities of *Daphnia* sp. increased in 2006 and are now over 14 fold higher than densities in 1999. Seasonal average total zooplankton biomass more than doubled over the study period, from 20.2 µg·L^{-1} in 2004 to 54.5 µg·L^{-1} in 2006. The biomass was largely dominated by other cladocerans and *Daphnia* sp which accounted for between 95 and 99% of the total zooplankton biomass in 2004, 2005 and 2006.

The continued “top down” pressure on the stickleback population by sterile cutthroat throat has reduced the stickleback population and has decreased the forage pressure on the zooplankton community. In turn, the kokanee have responded to favorable food availability as spawner numbers are now approaching 9000

spawners, from 0 spawners at the start of the experiment in 1995. Spawners were found at all three index creeks with the highest number of spawners observed in Boulder Creek likely due to imprinting of stocked kokanee. 2004 was the last year of kokanee stocking and in 2005 and 2006 stocking was ceased which will allow for determination of natural recruitment in Wahleach Reservoir. The large numbers of spawners are a result of stocking and successful rearing to adult stage through fertilization.

A hydroacoustic survey was completed in 2006 and average aerial transect fish densities was approximately 99 $\text{fish}\cdot\text{ha}^{-1}$ and ranged from 0 to 268 $\text{fish}\cdot\text{ha}^{-1}$. These densities were far lower than densities computed from surveys conducted in the 1990's and in 2000. It is highly possible that the 2006 survey may have underestimated fish in the shallower portions of the reservoir which accounted for 38% of the total reservoir area. The abundance estimate for all fish from the average aerial density is approximately 19,000. This is considered very low in respect of the previous population estimate of 424,263 in 2000. There is a strong likelihood that the near shore habitat which was not sampled may have contained a large component of stickleback which would significantly increase the 2006 abundance estimate. From changes in seasonal G trap catch rate data there is supporting evidence that stickleback are more numerous in near shore habitats in spring and early summer than in the fall. This would be consistent with the previous survey data which surveyed into these shallow habitats.

A combination of optimal forage and rearing conditions by fertilization and reduced competition for herbivorous zooplankton by sticklebacks, suggests that pelagic conditions are favorable for kokanee and rainbow trout restoration. Currently the

Acknowledgements

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Thanks to Deborah McNicol of the British Columbia Conservation Foundation for contract management. From the UBC MOE office, Debbie Aird provided administrative and computer support and to Jennie Hutchinson for corporate services support. From the Lower Mainland Regional MOE office, Greg Wilson provided helpful advice, support and valuable experience with the fertilization program. The continued support and encouragement for the fertilization research program from Dr. Ted Down, Manager of the Fisheries Science Section, is greatly appreciated.

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1 Introduction

The Wahleach Reservoir Fertilization Project draws on 30 years of history of lake and stream fertilization efforts in British Columbia (Stockner 1981, Stockner and MacIsaac 1996, Stockner and Ashley 2003). Several federal (Department of Fisheries and Oceans, DFO) and provincial (Ministry of Environment, MOE) fertilization experiments and projects have been conducted since the late 1960s (see review in Wilson et al 2003). They have examined and, in some cases, offset the effects of habitat loss, excessive harvest, introduced exotic species and impoundment (Johnston et al 1999, Ashley and Slaney 1997, Ashley et al 1999, Larkin et al 1999, Wilson et al 2000). The Wahleach Reservoir Fertilization Project addresses some of the ecological consequences of the Wahleach Dam and associated hydroelectric system.

The Wahleach Reservoir was created by the construction of a dam at the outlet in 1952 by the BC Electric Company. In the years following dam construction, the ecosystem typically undergoes a “trophic upsurge” in productivity due to increased nutrient loading from leaching and mineralization of nutrients from newly flooded vegetation and soils. Following approximately 20 years of high productivity, the reservoir enters the next stage in its ontogeny called “trophic depression”. This is caused by the burial of organic matter, the absorption of nutrients by dissolved organic matter and by the loss of inorganic and organic nutrients from rapid flushing (Schallenberg 1993) or from deep water removal. Eventually low productivity will limit food availability for higher trophic levels resulting in a collapse of fish stocks (Ney 1996).

In recent years, the restoration of Wahleach Reservoir has focused on fertilization (nutrient addition) in combination with biomanipulation of the food web by fish stocking. This is the first fertilization project in BC that was delivered coupled with a biomanipulation experiment. The objective of this approach was to restore historical populations of kokanee (*Oncorhynchus nerka*) and rainbow trout (*Oncorhynchus mykiss*) in Wahleach Reservoir. In 1993, when the first phase of this experiment was initiated, kokanee spawners were absent and the rainbow trout fishery had collapsed because of stunting (<20 cm fish) and poor condition. The goal of fertilization is to restore nutrient availability to optimize food resources for higher trophic levels. It is well established that fertilization can compensate for the loss of ecosystem productivity caused by the construction of dams and for the loss of nutrients from the deep water outtake. Nutrient loading can increase the production of large herbivorous zooplankton called *Daphnia*, the preferred forage species in the diet of kokanee salmon (Thompson 1999, Perrin and Stables 2000) and in turn increase planktivorous fish production. The goal of the biomanipulation component of the program was to manipulate the food web to allow the effects of fertilization to flow more freely through the planktonic food web to kokanee salmon. This was accomplished by the introduction of sterile cutthroat trout to prey upon stickleback populations, thus decreasing the stickleback populations and decreasing the forage pressure on *Daphnia* sp .

The Wahleach Water Use Plan Consultative Committee (WAH WUP CC) recommended that the Wahleach Fertilization/Biomanipulation Program continue to compensate for losses in productivity in the reservoir associated with the operational related impacts of reservoir fluctuations and nutrient flushing. The WUP started in 2004 and this report summarizes the first three years of the fertilization program as a WUP program.

2. Study Area

Wahleach Reservoir (49º10'W, 121º40'N) is located in the Skagit Range of the Cascade Mountains in British Columbia, southwest of Hope BC (Fig. 1). The reservoir was formed by the construction of the Wahleach dam in 1952. The dam increased the original lake volume from approximately 17 x 10^6 m^3 to a storage volume of approximately 60 x 10^6 m^3 at full pool. The surface area increased from approximately 282 ha to 410 ha after impoundment and the water surface elevation increased from 628.5 m to 641.6 m. Wahleach Lake Reservoir is 6.1 km long and 0.65 km wide at full pool (Fig. 1). Maximum depth at full pool is 26.6 m. The annual drawdown occurs from fall to early spring when power generation is required and is recharged in the spring and early summer by melting snow pack. The reservoir is dimictic and typically has ice cover from December through March. It is thermally stratified in June to October and maximum surface water temperatures are typically approximately 24ºC.

The reservoir was typical of old aging reservoirs having low total phosphorus concentrations (<5 $\mu g \cdot L^{-1}$), low plankton biomass (<5 $\mu g \cdot L^{-1}$) and plankton communities largely composed of small organisms leading to long food chains. The predominance of microbial food webs results in low food availability for higher trophic levels and sub-optimal rearing conditions for planktivorous fish (Stockner and Porter, 1988). Although originally barren of fish, the original Wahleach Lake was stocked with rainbow trout (*Oncorhynchus mykiss*) and kokanee (*Oncorhynchus nerka*) eggs between 1926 and 1938. At some point, threespine stickleback (*Gasterosteus aculeatus*) were illegally introduced in the reservoir and populations thrived because there were no other fish in the reservoir that could prey on stickleback and control the population. Sticklebacks consume the same zooplankton food organisms as kokanee (Scott and Crossman 1973) and it is likely that the competition for this food resource may have contributed to the collapse of kokanee.

3. Methods

3.1 Fertilizer Additions

Between 4.73 and 5.50 MT of agricultural grade liquid ammonium polyphosphate (10-34-0: N-P_2O_5-K_2O; % by weight) and between 13.2 MT and 17.0 MT of agricultural grade urea-ammonium nitrate (28-0-0: N-P_2O_5-K_2O; % by weight) was added to Wahleach Reservoir over a 20 week period in June through October.

The two types of fertilizer were delivered as liquid products in bulk to a tank farm located south of the boat launch at the reservoir (Fig. 1). A tanker truck supplied product to the bottom of the Jones Lake road where it was transferred to a septic tank truck that ferried the fertilizer up the hill to the tank farm. The fertilizers are kept separate during delivery and while stored at the tank farm. The fertilizer was discharged from the boat with a battery powered bilge-pump into the wash from a 24 ft Alumaweld Jet boat. The required load of fertilizer was pumped from the tank farm to a holding tank in the boat through a 1 inch reinforced pressure hose using a Honda pump and in-line accumulating water meter. The fertilizer was dispensed into the reservoir followed an “S” shaped pattern over the entire reservoir surface at a boat speed of approximately 4 knots.

In 2006, a new tank farm was constructed to replace the aging facility which consisted simply of a berm and a chain link fence with locking gate. A new tank farm was constructed by BC Sheds Plus, Cloverdale, BC consisting of a 20ft x 30ft cedar sided shed with a liner to contain spills and a metal roof. We are in the process of securing signage for the facility which will describe the fertilization program on Wahleach Reservoir and will serve as an outreach tool for the program.

The fertilizer blends, timing of the additions, and the amounts added to the reservoir were adjusted seasonally to mimic natural spring phosphorus loadings, to compensate for biological uptake of dissolved inorganic nitrogen as the summer progresses, and to maintain a nitrogen to phosphorus (N:P) ratio for optimum algal growth.

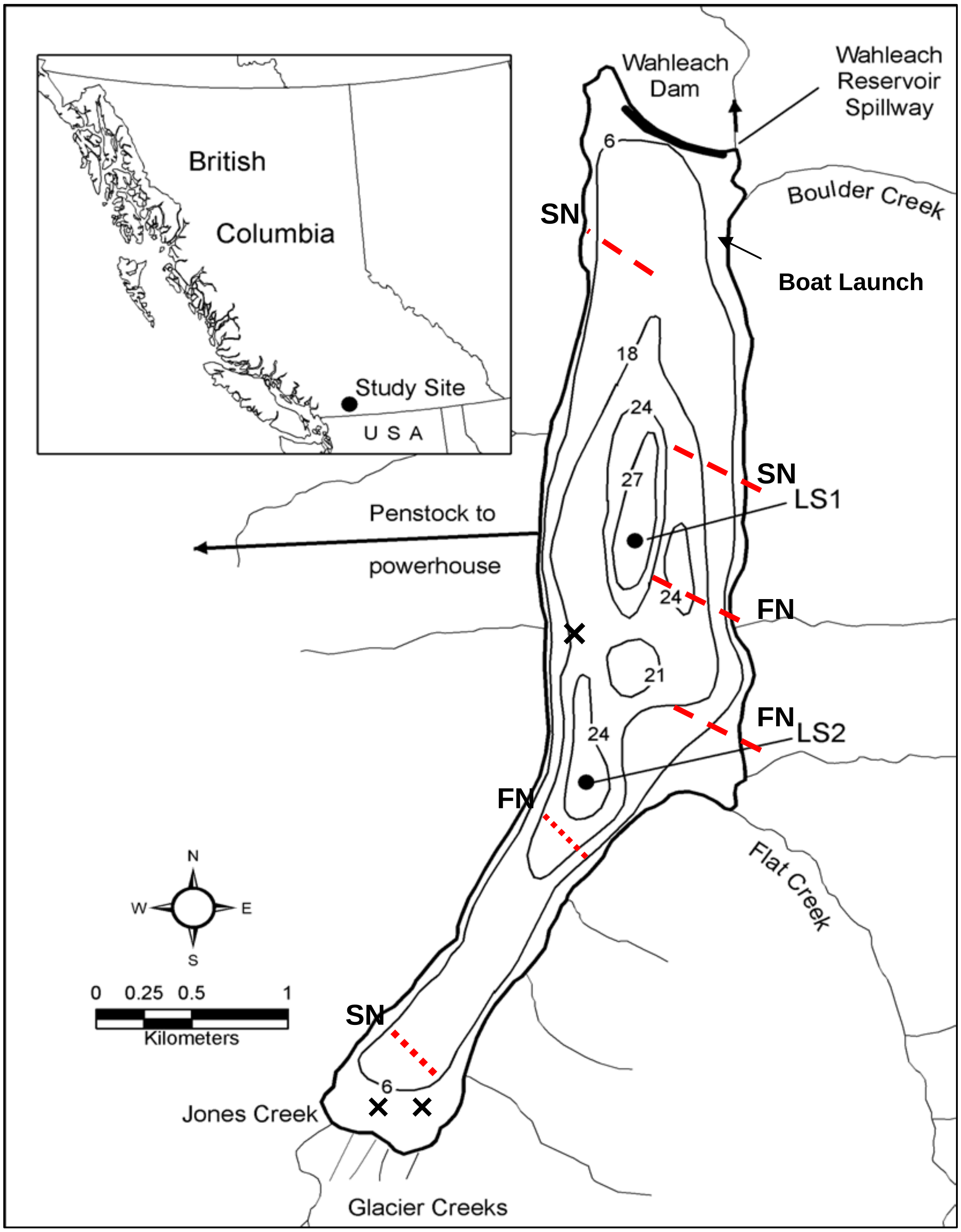


Figure 1 Map of study site showing limnological sampling sites (LS1 and LS2), bathymetric contour lines as depths (m) at full pool and the three Creeks (Jones, Flat and Boulder Creeks) used for enumeration of kokanee spawners. Dashed line indicate location of gillnet sets (SN=sinking net, FN=floating net) and × indicates location of minnow traps.

Photo 1. Old tank farm, consisting of a concrete berm covered with a tarp, and chain link fence.

Photo 2. New tank farm constructed in 2006. Facility is a cedar shed with a metal roof to withstand heavy snow loads and a locking door.

Weekly phosphorus loading started in June, at approximately 5.5-6 mg·P·m-^{2}, and increased to peaks of 16.5–19.5 mg·P·m^{-2} in mid-July, before steadily declining to 3.7-4 mg·P·m^{-2} in October (Fig. 3). Weekly nitrogen loadings began at <5 mg-N·m^{-2} in the spring and increased to 96 mg·N·m^{-2} in August/September for 2004 and 2005, and to 133 mg·N·m^{-2} in the summer of 2006 (Fig. 4).

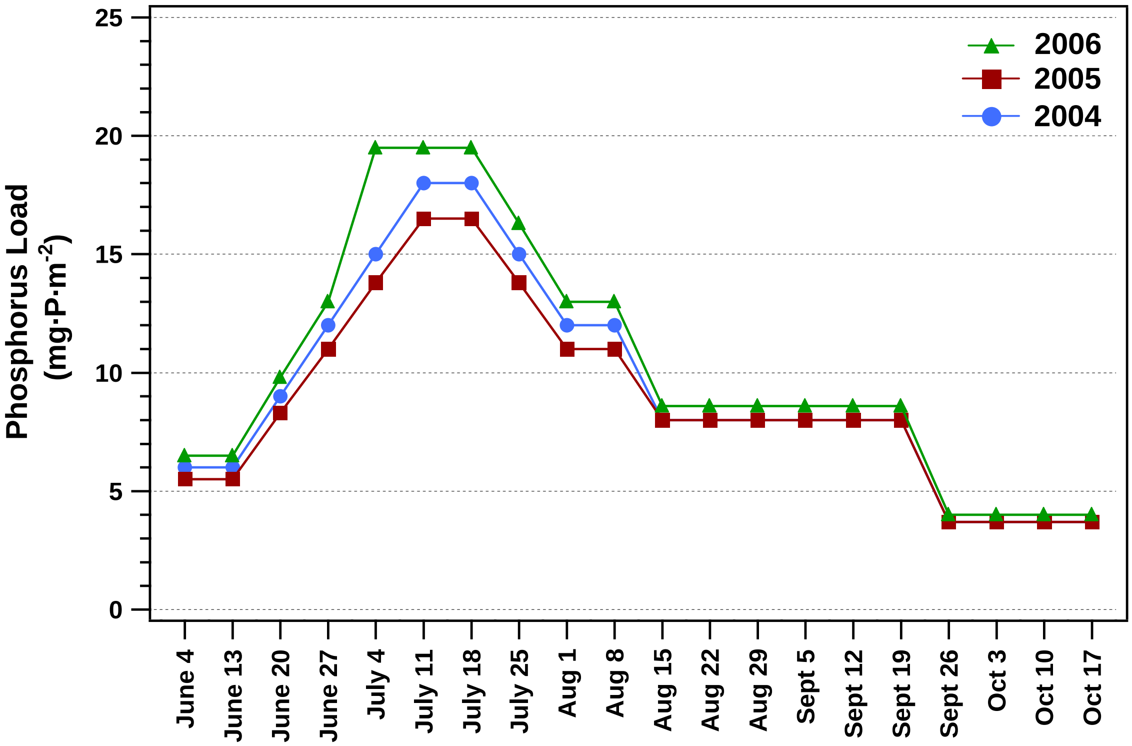


Figure 2. Weekly loading of phosphorus in Wahleach Reservoir, 2004-2006.

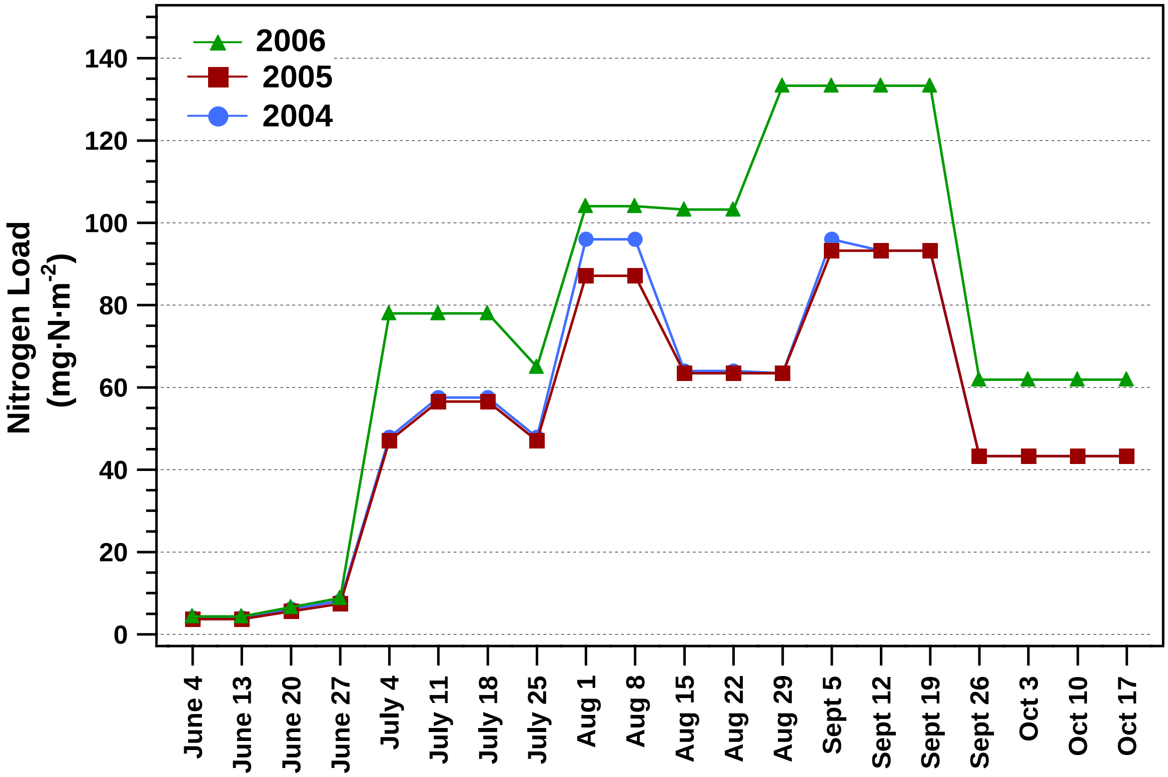


Figure 3. Weekly loading of nitrogen in Wahleach Reservoir, 2004-2006.

The annual P load from fertilizer was 176–204 mg·P·m^{-2} (Table 1). In 2006, the annual phosphorus loading rate was increased based on the recommendation by Perrin et al (2006) that in order to improve the production of the *Daphnia* sp, zooplankton that are crucial for sustaining planktivorous kokanee populations (Perrin et al 2006), the annual loading rates must not be less than 200 mg·P·m^{-2}. These loading rates were in the range of those used in fertilization experiments at other oligotrophic lakes (102–164 mg·P·m^{-2} by Langeland and Reinertsen (1982), 27-100 mg·P·m^{-2} by Clarke et al (1997), 100–600 mg·P·m^{-2} by Johnston et al (1999), 66–100 mg P·m^{-2} by Stockner and MacIsaac (1996) and 271 mg P·m^{-2} by Ashley et al (1999)). As a consequence of the higher P loading in 2006, the annual nitrogen load was also increased (Fig. 3). Nitrogen must be added concurrently to ensure that epilimnetic N concentrations remain above ~20 µg L^{-1}, the concentration of nitrogen considered limiting to phytoplankton growth (Wetzel 2001) and to ensure that the N:P ratio remains high. Low N:P ratios may promote the growth of large blue-green algae, which can be toxic (Schindler, 1977 Watson and Kalff 1981; Pick and Lean 1987; Stockner and Shortreed 1988, 1989) and unpalatable to zooplankton and are therefore considered carbon sinks.

Table 1. Annual fertilizer additions to Wahleach Reservoir, 2004-2006.

Year	Fertilizer added		Nutrient load				Molar Ratio
	10-34-0	28-0-0	Phosphorus		Nitrogen		N:P
	(mt)	(mt)	(kg)	(mg·P·m^{-2})	(kg)	(mg·N·m^{-2})	
2004	5.01	13.5	743	185.9	4288	1072	13.1
2005	4.73	13.2	702	175.6	4178	1045	13.6
2006	5.50	17.0	836	204.1	5324	1519	14.9

The molar nitrogen:phosphorus ratio in the added fertilizer was 13.1 in 2004, increasing to 13.6 in 2005 and 14.9 in 2006. These molar ratios are lower than those reported by Perrin et al (2006) used in earlier years of the Wahleach Fertilization Program (25.6-18.3) but their study suggested that the ratio may be dropped to 13 without undesirable effect. Lower N:P ratios reduce the nitrogen requirements and therefore lower the cost of fertilizer for a given load of phosphorus. Careful monitoring of the water chemistry results and the phytoplankton community composition must ensure that the lower ratios do not promote the growth of nitrogen fixing algae (blue-green algae).

Annual heavy metal loading from this high quality, food grade fertilizer is discussed in detail in Wilson et al (2003).

3.2 Reservoir Operations

Daily average inflow to Wahleach Reservoir, outflow, and day end elevations were provided by the Power Supply Resource Management Office of BC Hydro.

3.3 Physical and Chemical

Once a month from June-October, physical measurements and chemical samples were collect from each of the two reservoir sampling sites shown in Figure 1. The two stations were the same as those used in earlier studies in 1993-2003 (e.g. Inglis 1995, Perrin 1997, Perrin and Stables 2000). The two sites were considered duplicate data for any given parameter, allowing for calculation of a mean and standard deviation.

Vertical profiles of dissolved oxygen ($mg \cdot L^{-1}$) and temperature (ºC) and were taken *in situ* with an YSI temperature-dissolved oxygen meter air-calibrated on site. A YSI model 58 was used in 2004 & 2005 and a YSI model 550A was used in 2006. The thermocline was identified by the inflection point from temperature profiles. Measurements were taken every meter from the surface to the bottom of the thermocline, then at 2 m intervals down to the bottom. The Secchi disk depth was measured on the shady side of the boat using a standard 20-cm disk without a viewing chamber. The Secchi depth was the mean of the point where the disk disappears upon lowering and reappears upon raising.

In 2004 and 2005, discrete water samples were collected at 1m and 20 m with a Van Dorn water sampler. This sampling methodology was altered in 2006. The bottom sample was replaced with a composite water sample of the mixed layer depth. This composite sample of the mixed layer represents the actual region of the water column where phytoplankton cycle and where positive phytoplankton growth occurs. It represents the mean water properties that phytoplankton are exposed to. In 2006, the mixed layer composite water sample of the epilimnion was collected with an integrated sampler (21 m long 3.5 cm diameter hose) and a single water sample was taken at 1 m with a Van Dorn water sampler.

The water samples were collected for pH, analysis of TP (total phosphorus), TDP (total dissolved phosphorus), TN (total nitrogen), nitrate + nitrite-nitrogen (NO_3 + NO_2-N) determination and during mid summer only, silicic acid. Ammonium (NH_4-N) analysis was not completed in 2006 because generally ammonium concentrations are below detection level in pristine oligotrophic systems and analysis must be completed within 24 hours, a requirement that the laboratory can not meet. All samples were stored in the dark and on ice in a cooler until further processing in the field. The dissolved fractions were field filtered through a 0.45 µm combusted GF/F filter and the filtrate was collected in clean bottles provided by the Maxxam Laboratory, Burnaby, BC. Samples collected for TP, TDP, TN, and NO_3 + NO_2-N analysis were submitted within 24 hours to the laboratory. The dissolved P fractions (all in TDP) included orthophosphate, polyphosphates and organic phosphates (Strumm and Morgan 1981). SRP always includes the orthophosphate ion which is considered biologically available, but it can also include acid-labile P compounds (Harwood et al 1969) and may overestimate biologically available P (Rigler 1968, Bothwell 1989). Samples for TP and TDP analysis were digested and analysed according to Menzel and Corwin 1965. SRP was analysed using the molybdenum blue method (Murphy and Riley 1962). TN analysis was completed by methods outlined in APHA (1995). NO_3 + NO_2-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).

3.4 Phytoplankton Enumeration

A depth integrated water sample was collected from each station in glass amber jars, preserved with acid-Lugol's solution, and stored in a cool and dark location until the algal cells could be counted. Prior to the enumeration, the samples were gently shaken for 60 seconds and allowed to settle in 25 mL chambers for a minimum of 8 hrs (Utermohl 1957). Counts of algal cells, by taxa, were done using a Carl Zeiss© inverted phase-contrast plankton microscope. Counting followed a 2-step process. Initially, several random fields (5-10) were examined at low power (250x magnification) for large microplankton (20-200 μm) including colonial diatoms, dinoflagellates, and filamentous blue-greens. A second step involved counting all cells at high power (1,560x magnification) within a single random transect that was 10 to 15 mm long. This high magnification permitted quantitative enumeration of minute (<2 μm) autotrophic picoplankton sized cells (Cyanophyceae), and the small nanoflagellates (2.0-20.0 μm) of the Chrysophyceae and Cryptophyceae. Between 250-300 cells were consistently enumerated in each sample to assure statistical accuracy of counting results (Lund et al 1958). The compendium of Canter-Lund & Lund (1995) was used as the taxonomic reference. A list of phytoplankton species and their respective biovolume used for the computation of population and class biomass for Wahleach Reservoir appears in Appendix 1.

3.5 Zooplankton

Duplicate macrozooplankton samples were collected with a vertically hauled 157-μm mesh Wisconsin plankton net with a 25 cm throat diameter and an 80 μm window for straining water from the cod-end. The depth of each haul was 20 m. The net was raised at a speed of approx. 0.5 $m \cdot sec^{-1}$. The zooplankton were washed into the cod-end of the net and anaesthetized in a wash of Club Soda before being preserved with 70% ethanol. The carbon dioxide anesthetization was conducted to prevent egg shedding while the sample was being mixed with the preservative.

Samples were analyzed for species composition, density, biomass (estimated from empirical length-weight regressions, McCauley 1984), and cladoceran fecundity. 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 level and counted until up to 200 organisms of the predominant species were recorded. If 150 organisms were counted by the end of a split, a new split was not started. The lengths of 30 organisms of each species were measured for use in biomass calculations, using a mouse cursor on a live television image of each organism. Lengths were converted to biomass (µg dry-weight) using empirical length-weight regression from McCauley (1984). The number of eggs carried by gravid females and the lengths of these individuals were recorded for use in fecundity estimations.

Rare species, e.g., *Alona sp*. or *Alonella sp.*, were counted and measured as “Other Copepods” or “Other Cladocerans” as appropriate. Zooplankton species were identified with reference to taxonomic keys (Sandercock and Scudder 1996, Pennak 1989, Wilson 1959, Brooks 1959).

3.6 Fish Stocking

Approximately 50,000 unmarked kokanee were introduced in the spring of 2004, the last year kokanee were stocked in the reservoir. The brood stock was from wild adults collected at the Meadow Creek facility located upstream of Kootenay Lake. The stocking of sterile cutthroat trout has continued to ensure the stickleback population remain supressed. Approximately 600 unclipped fish were stocked in 2004 and 3000 unclipped fish were stocked in 2005 and 2006, all were yearling with an average weight of 65 grams. Stocking was completed in the end of July in 2004, the end of June in 2005 and the beginning of May in 2006, and the average weight of the yearling was 65 g. The brood stock for the cutthroat throut was from fish collected from the Taylor River on Vancouver Island more than 12 years ago. All fish were reared at the Fraser Valley hatchery in Abbotsford, BC and were transferred by truck in oxygenated tanks to the reservoir for release.

Triploiding of the cutthroat trout followed standard procedures developed at the Fraser Valley Trout hatchery (C. Rosenau, Ministry of Fisheries, Abbotsford BC., pers. comm.). After 35 minutes post-fertilization at 10°C, the eggs were incubated at 9500 psi in a pressure shocker for 5 minutes. The eggs were then removed and incubated in jars or trays to the eyed stage. Dead or weak eggs (poorly defined eyes) were sorted from live eggs (having well defined eyes) that were transferred to troughs and grown to size. Triploiding produces sterile fish that grow faster and larger than normal diploid fish because they do not divert energy into reproduction (T. Yesaki, Ministry of Fisheries, Victoria, BC, pers. comm.). Triploided fish can contribute to a sport fishery but they do not interbreed with wild stocks. Female triploids are hormonally and functionally sterile while male triploids are infertile but still produce hormones that cause deterioration associated with maturation.

3.7 Spawner Surveys

Escapements were enumerated by visual counts of adult fish in three tributaries, Boulder Creek, Upper Jones (Wahleach) Creek and Flat Creek (Fig. 1). Boulder Creek (121˚36’16”W, 49˚14’51”N) is a 9.1 km class 3 stream, with a channel width of 1.5-5m wide. Flat Creek (121˚36’24”W, 49˚13’2”N) is a glacially-fed 6.4 km class 3 stream, which is 1.5-5 m wide. Jones Creek (121˚38’6”W, 49˚12’14”N) is a 12.5 km class 4 stream, which is less than 1.5 m wide. Spawner surveys of Jones Creek were not conducted in 2005 due to safety reasons (S. Reddekopp, per. com). The first 600 m of Boulder Creek, 1000 m of Flat Creek and 400 m of Jones Creek from the confluence were enumerated. Kokanee salmon have been observed at Glacier Creek, one of many small creeks at the south end of the Reservoir, but the three selected creeks will serve as an index of kokanee spawners so that trends over time can be monitored. The surveys were conducted weekly over a 5-7 week period in the fall of each year. During each trip only two tributaries were counted when the numbers of fish were high due to the time limitations. A two or three person crew completed the surveys by walking up the middle of each creek and visually counting live and dead fish. Cumulative fish days are determined as the fish days under the live count curve. Extrapolations are made between actual counts to determine spawner numbers on those days not sampled. Annual escapement estimates were determined from a modified Irvine et al (1993) area-under-the-curve (AUC) model, which integrated kokanee spawner counts, the stream residency time and an estimate of counter efficiency. Stream residency time is the average number of days a spawning fish will spend in the stream during the spawning period (Irvine et al 1993). Originally, the stream residency time of 10 days was taken from a literature estimate of sockeye, assuming it would be similar for kokanee (Greenbank 2002), however, the Mission Creek spawning channel on Okanagan Lake found that residence time varied between 6-15 days with an average of about 10.2 days (Andrusak 2004), thus providing further support for using a 10 day residence time for Wahleach Reservoir.

Data collected from randomly selected fresh carcasses included sex of fish and fork length (mm). Carcass counts also were made during each trip. Field personal were supplied with bear spray, bear bangers, bear bells and a satellite telephone.

In 2004 and 2005 the counts were completed by Ministry of Environment personnel. In 2006, in collaboration with the British Columbia Institute of Technology (BCIT) Fish and Wildlife program, three students and MOE staff completed the surveys as part of their programs requirement for field studies. This opportunity allowed for MOE staff to provide training opportunities for young technician and biologists.

3.8 Gillnetting and Minnow Trapping

The primary objective of gillnetting was to provide catch per unit effort data and size-at-age, as well as to document changes in fish species composition and confirm presence/absence. A variety of net mesh sizes (25-102 mm) and Gee traps must be employed and sampling conducted in a variety of habitat types at different times of the year to ensure untruncated/unbiased population age and size estimates. This was not possible due to the budgetary constraints of the project. However, a standardized annual gillnet effort focused on catchable size salmonids combined with hydroacoustic surveys was used in order to reduce the equipment requirements and effort necessary, but still allow for monitoring of the effects of fertilization on the reservoir fish populations.

Gillnetting sampling sessions were completed in the spring of 2004 and 2005 (3 June 2004, 7 June 2004) and in the fall of 2006 (21 October 2006). A springtime gillnetting session was planned for the end of June 2006 but was cancelled due to extremely warm water temperatures. During each sampling trip, three sinking and three floating gillnets were set in the Reservoir (Fig. 1). Each net consisted of panels of six different mesh sizes (25, 89, 51, 76, 38, 64 mm stretch mesh) and in total was 28 m long and 2 m deep. All nets extended perpendicular from the shore. The floating nets were set in 3 m of water and the sinking nets were weighted to the bottom to the 10 m contour. Six baited Gee traps, baited with salmon roe, were also set in the evening and retrieved in the morning (Fig. 1). The traps sat on the bottom in approximately 2 m of water, a depth favored by sticklebacks. All gillnets and Gee traps were set in the late afternoon, fished overnight, and were retrieved the next morning. The minimum set time was 16 hours. Data from all nets were combined for calculation of mean catch per unit effort (CPUE) by species. Individual nets were not treated as replicates.

Captured fish were identified using the Field Key to the Freshwater Fishes of British Columbia (McPhail and Carveth, 1993), with weight (on an electronic balance, or a Pasula spring scale for fish >600 g) and fork length recorded for each. Maturity stage (immature, maturing, mature, spawning, spent, resting) was visually determined from all kokanee, rainbow and cutthroat trout. Scale samples from each kokanee were taken, processed, and read as described in Ward and Slaney (1988). Scales were pressed into acetate and the imprint read under 30x magnification, with age determined by counting annuli. Condition factors were calculated which was defined as $W/L^3 \cdot 10^5$ where W = weight in grams, L = fork length in mm. Aging data for 2004 and 2005 are currently being processed and will be examined in future reports.

3.9 Hydroacoustics

Hydroacoustic surveys have formed the basis of stock assessments in lakes and reservoirs for many years. A survey was completed in late July which determined stock distributions, size and abundance. A Simrad 120 kHz split beam echosounder with a downward looking 7.0 degree transducer was employed to collect the survey data. The transducer was towed along side of the survey boat at a depth of 0.5m, survey data was collected at 2pps along transects lines and stored on hard disk of a notebook computer. A Lowrance Sounder / GPS plotter was used to navigate along 11 predetermined transect lines at a boat speed of ~$1.5 m \cdot s^{-1}$, Fig. 5.

Split beam data was analyzed using Simrad EP500 version 5.3 processing software. This software calculates fish density per hectare ($fish \cdot ha^{-1}$) and fish target strength (TS) simultaneously by applying 20 and 40 log R Time Varied Gain (TVG) functions.

The resulting echo integration and trace tracking outputs were collated in a Microsoft excel workbook providing estimates of fish density by 5m strata layers and estimates of fish size by 12 -3 decibel (dB) TS bins. A fish abundance estimate was derived by multiplying the average aerial transect density by the reservoir area corresponding to the mean depth of the fish layer. Stratum habitat areas for the reservoir were calculated from a regression model developed by Limnotek and adjusted to the pool elevation at the time of survey, Perrin and Stables 2001.

Trawls are often used to sample kokanee and juvenile sockeye salmon (e.g. Enzenhofer and Hume 1989) but are impractical in Wahleach Reservoir because it is shallow, there are numerous snags, and fish can congregate close to the bottom.

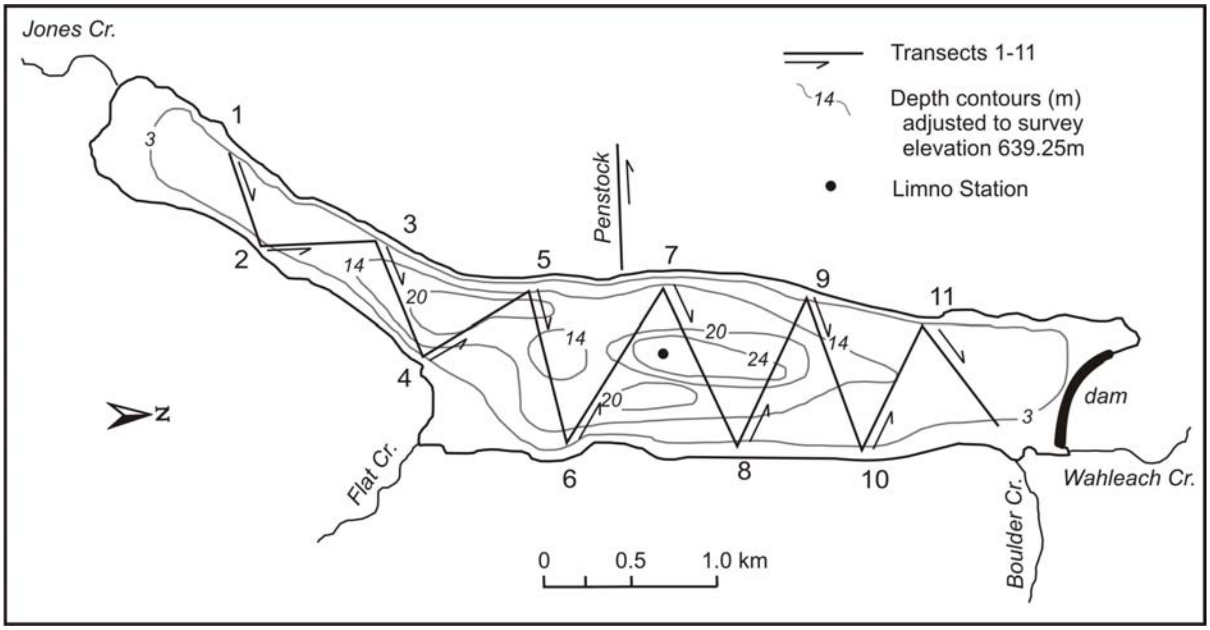


Figure 4. Wahleach Reservoir acoustic survey transect locations July, 2006.

4. Results

4.1 Reservoir elevation

The reservoir is generally recharged in May to July through snow melt and the reservoir is held relatively constant during the fertilization period (Fig. 5). The drawdown which occurs from November to April was 15.6 m, 11.8 m and 10.7 m for 2004, 2005 and 2006. The minimum reservoir level in 2004 was below the long term mean and below the elevation level recommended by Perrin and Stables (2000) to protect habitat for spawning rainbow trout. Following record drawdowns in 1996 to 624.6 m an entire year class of rainbow trout was absent from the reservoir possibly due to restricted access to spawning sites. Minimum elevations vary annual but generally occur in mid-April while the maximum level occurs from July to September. Refill rates were similar for 2004 and 2006 while in 2005 the elevation of the reservoir was below the long term average approximately from June-October.

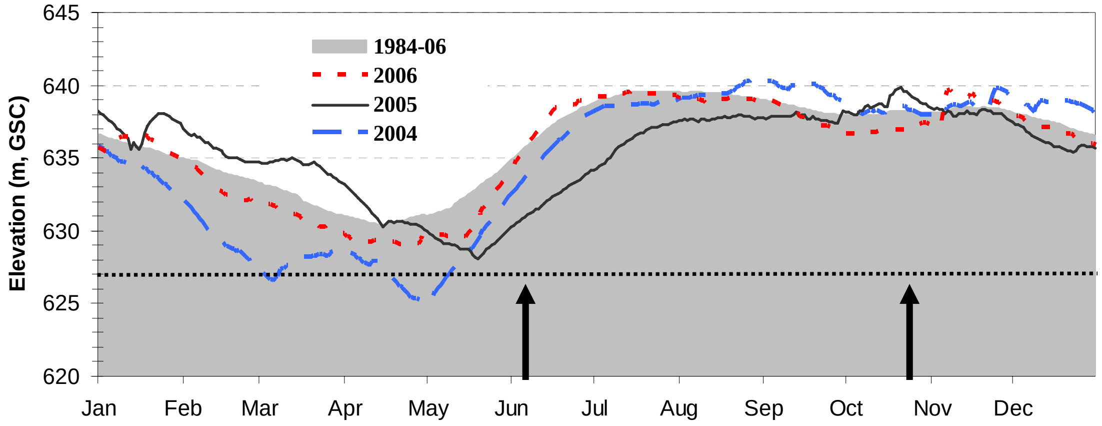


Figure 5. Water surface elevation (m) of Wahleach Reservoir, 2004-2006. Shaded area in figure represents mean elevation from 1984-2006, arrows indicate the start and end date of fertilization and dashed line at 627 m elevation is the water surface recommended by Perrin and Stables (2000) for successful spawning.

4.2 Physical Parameters

At the beginning of each field season surface temperatures were ranged from 12-14ºC and weak temperature stratification was present (Fig. 7). In the summer the surface temperatures reached 18.5ºC in 2004, 22.5ºC in 2005, and 18.3ºC in 2006. There was little variation in hypolimnetic waters, varying in temperature by less than 2ºC over the three year study period. By September and October the thermocline was deepening, the density differences were weakening and fall turn over was immanent (Fig. 6).

Wahleach Reservoir was well oxygenated from the surface to the bottom of the reservoir in all study years (Fig. 6). DO concentrations were between 9-11 mg·L^{-1} from the surface to the hypolimnion and the orthograde profiles are indicative of oligotrophic conditions. In the fall of 2004 and to a lesser extent in the fall of 2005, DO decreased in the hypolimnion to 2-3 mg·L^{-1}. This clinograde type profile shows consumption of DO (DO demand) likely associated with decomposition of organic matter that was produced in the summer months. Oxygen demand from bottom sediments would have contributed to the oxygen concentration gradient near the sediment – water interface.

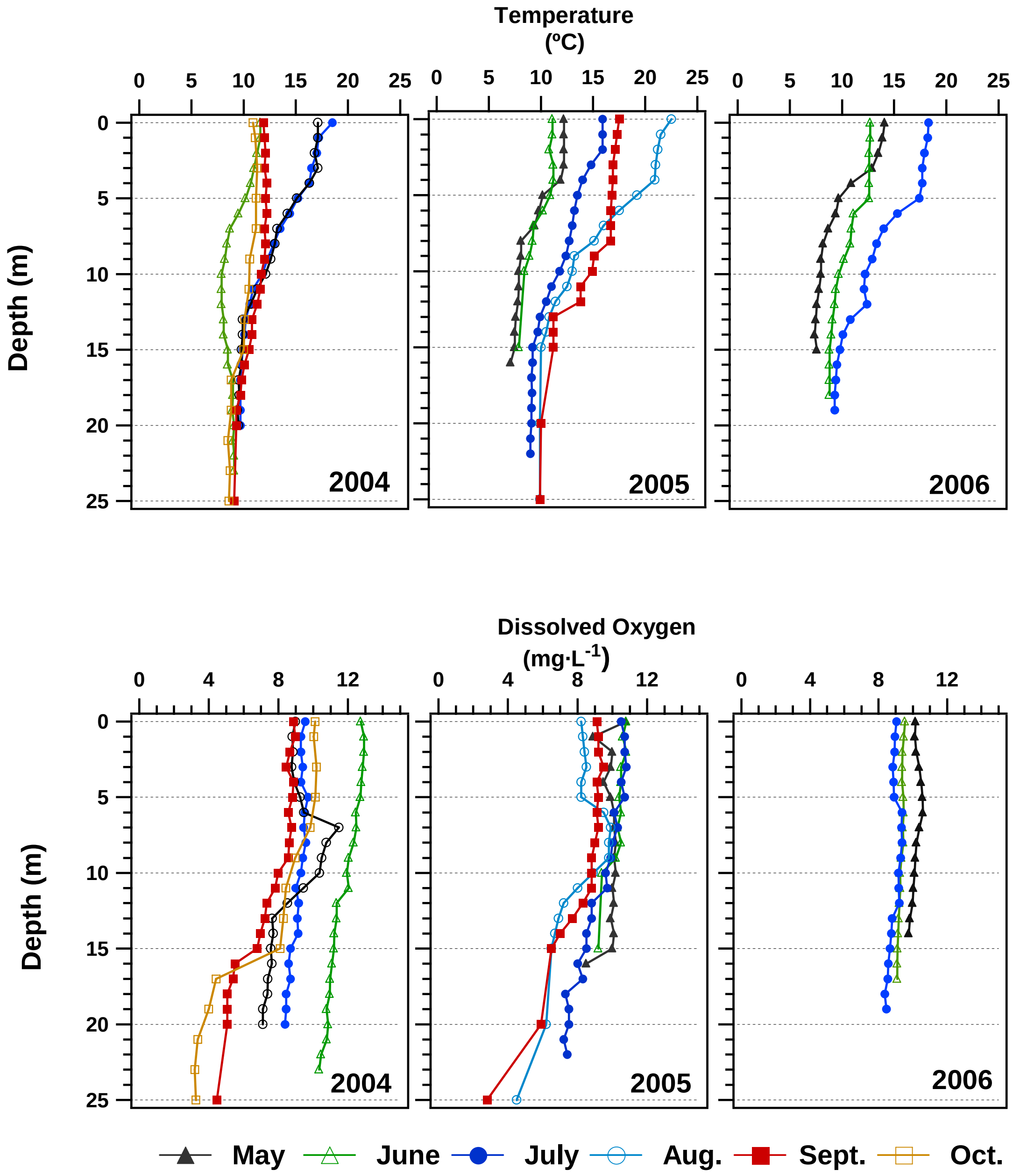


Figure 6. Vertical profiles of temperature and dissolved oxygen in Wahleach Reservoir, 2004-2006.

4.3 Water Chemistry

The mean pH was 7.5 in 2004, 6.6 in 2005 and 7.0 in 2005 (Table 2). The mean pH for the study period was 7.0, which was similar to previously reported values by Perrin and Stables (2000). The pH was the same for the surface and deep samples.

Table 2. Mean concentration or measurement of chemical parameters and Secchi depth in Wahleach Reservoir, 2004-2006.

Parameter	**Mean concentration or measurement**					
	2004		**2005**		**2006**	
	1 m	**20 m**	**1 m**	**20 m**	**1 m**	**ML***
Secchi depth (m)	4.6	-	4.4	-	3.9	-
Chl a ($\mu g \cdot L^{-1}$)	2.4	-	2.1	-	6.4	-
pH	7.5	7.5	6.6	6.5	7.0	7.1
DO						
Alkalinity ($mg \cdot L^{-1}$)	-	-	10.9	10.6	10.6	11.0
Silicic Acid ($mg \cdot L^{-1}$)	5.1	4.9	5.1	5.1	2.9	2.8
TP ($\mu g \cdot L^{-1}$)	6.5	4.7	4.1	4.2	6.4	6.5
TDP ($\mu g \cdot L^{-1}$)	4.0	4.8	2.5	2.0	3.1	3.5
SRP ($\mu g \cdot L^{-1}$)	1.8	2.0	2.7	2.5	1.4	1.9
TN ($\mu g \cdot L^{-1}$)	156.7	146.7	167.0	197.0	149.2	158.5
NO_3-N ($\mu g \cdot L^{-1}$)	38.8	56.5	33.7	78	48	52
TN:TP	24.2	31.5	40.8	47.0	23.2	24.4

* Mixed layer depth as determined by temperature profiles

The inorganic nutrients, phosphorus and nitrogen, are known to control lake productivity (Schindler, 1977, Hecky and Kilham 1998, Guildford and Hecky 2000) and many forms (total and inorganic) of both nutrients need to be studied when water monitoring is completed. Total phosphorus concentrations are an indicator of biomass and trophic state and in Wahleach Reservoir they ranged from 4.1-6.5 $\mu g \cdot L^{-1}$, which is indicative of an oligotrophic system (Wetzel 2001). There was a modest decrease in TP in 2005 to 4.1 $\mu g \cdot L^{-1}$ likely due to reduced fertilizer loading (Table 2). While TP is a measure of biomass and trophic state, it is not the form of phosphorus which is biologically available to phytoplankton. SRP concentrations ranged from 1.4-2.7 $\mu g \cdot L^{-1}$, which are below the concentrations known to limit phytoplankton growth. This suggests that the phosphorus added to the epilimnion as fertilizer is immediately taken up by phytoplankton.

Epilimnetic concentrations of total and dissolved forms of nitrogen were also low (Table 2). Total nitrogen concentrations ranged from 149 ± 20 $\mu g \cdot L^{-1}$ in 2006 to 167 ± 19 $\mu g \cdot L^{-1}$ in 2005, which is extremely low and indicative of ultraoligotrophic conditions (Wetzel 2001). Of the utilizable forms of nitrogen by phytoplankton, ammonium followed by nitrate are the inorganic forms that are most readily available. Ammonium is generated by bacterial decomposition of organic matter and by excretion of waste products or “sloppy” feeding of aquatic animals. Ammonium concentrations are generally undetectable by chemical analysis as ammonium is quickly taken up by phytoplankton and is quickly converted to nitrite by bacteria in oxygenated waters , hence nitrate-N (NO_3+NO_2-N) becomes the most important form of dissolved N supporting algal growth (Wetzel 2001). The mean epilimnetic NO_3-N concentrations were 38 ± 10 $\mu g \cdot L^{-1}$, decreasing to 34 ± 18 $\mu g \cdot L^{-1}$ in 2005 and increasing in 2006 to 48 ± 17 $\mu g \cdot L^{-1}$. The high measure of variance reflects the strong seasonal cycle of dissolved nitrogen concentrations in Wahleach Reservoir (Fig. 8). Nitrate concentrations that are <20 $\mu g \cdot L^{-1}$ are generally considered limiting to phytoplankton growth (Wetzel 2001). Early in the spring nitrate concentrations were over 100 $\mu g \cdot L^{-1}$, well above concentrations that limit phytoplankton growth but within one month, the concentrations dropped below 20 $\mu g \cdot L^{-1}$, where they stayed for the entire summer growth season despite weekly additions of nitrogen. Experience from the Kootenay Lake South Arm Nitrogen Fertilization Project have shown that it is difficult to restore nitrogen concentrations once it has “bottomed out” (E. Schindler, per. comm.). In response to the results from the 2004 and 2005 monitoring program, particularly the nitrogen limitation from July to September, the fertilizer loading strategy was adjusted for the 2006 field season. The mean N:P ratio was increased but despite this change the dissolved nitrogen concentrations still dropped to limiting levels. For 2007, in addition to an adapted fertilizer loading strategy, we are planning to add a second sampling trip between the monthly June and July trips, so we can respond to rapidly changing dissolved nitrogen concentrations and adaptively manage the fertilizer addition strategy.

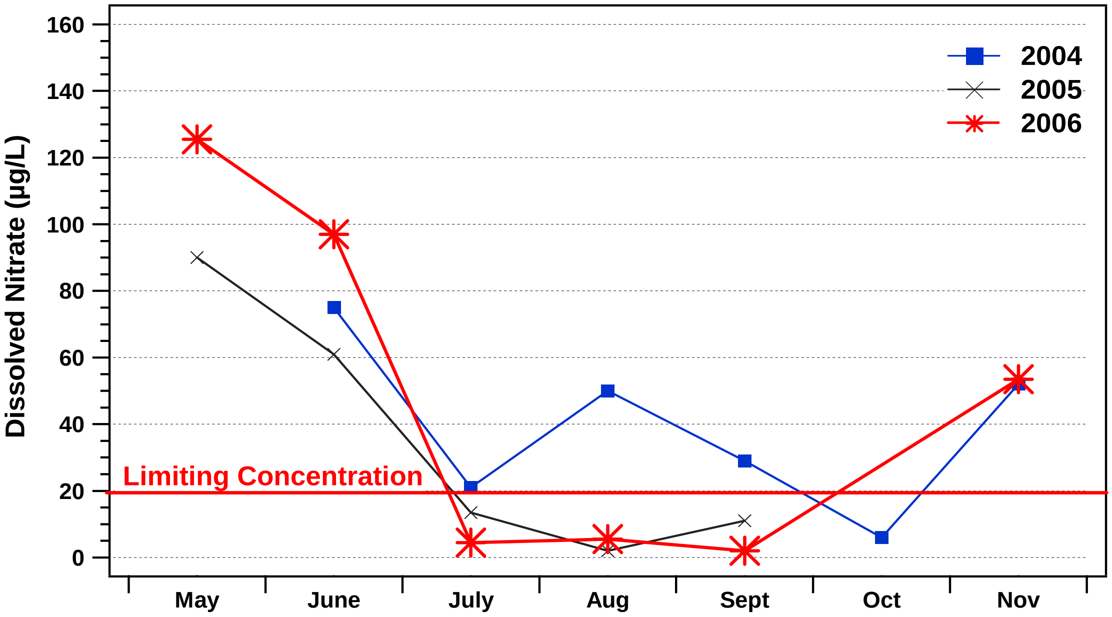


Figure 7. Mean dissolved nitrate concentrations at 1 m in Wahleach Reservoir, 2004-2006.

Silicic acid is used by diatoms to build their silica frustule (cell wall) and can be limiting to growth at 0.5 mg·L^{-1} (Wetzel 2001). Silicic acid concentrations in mid summer ranged from 5.3 ± 0.15 mg·L^{-1} in 2004 and 2005, dropping to 2.8 ± 0.03 mg·L^{-1} in 2006. These concentrations are well above the minimum concentrations for growth. Unfortunately, silicic acid was sampled only once a season and in 2004 and 2005 the sample was obtained before the seasonal rise in diatoms. A better understanding of silica dynamics is needed.

The TN:TP ratio is used as a measure of nutrient limitation in a lake, though care must be taken in interpretation of the ratios because if total nutrients contain a large contribution of refractory organics and inorganic particulates then TN:TP ratios may be misleading. Based on the low concentrations of both TN and TP, it would appear that for Wahleach Reservoir these ratios are valid. Guildford and Hecky (2000) found that phytoplankton growth was N limited when molar ratios TN:TP <20, and growth was P limited when molar TN:TP > 50. Spring sampling in Wahleach Reservoir revealed a molar TN:TP of 40-100 in surface waters, suggesting that in 2004 and 2005 the phytoplankton community was mainly P-limited but in 2006, some phytoplankton species may have been N limited or N stressed (Fig. 8). In the summer, the TN:TP was extremely low, indicating sustained N deficiency in 2004 and 2006. In the fall in 2004 and 2005, the TN:TP increased indicating potential P deficiency whereas in 2006 TN:TP suggest potential N deficiency. Considerable interannual variability was observed in TN:TP values where TN:TP in the spring of 2006 was less than half the TN:TP in the spring of 2004. Since the ratio that will inhibit growth is species dependent, varying from as low as 7:1 for some diatoms (Rhee and Gotham 1980) to 50:1 for blue-green algae (Healey 1985), it is important to carefully manipulate N:P ratios to favor the growth of edible phytoplankton species.

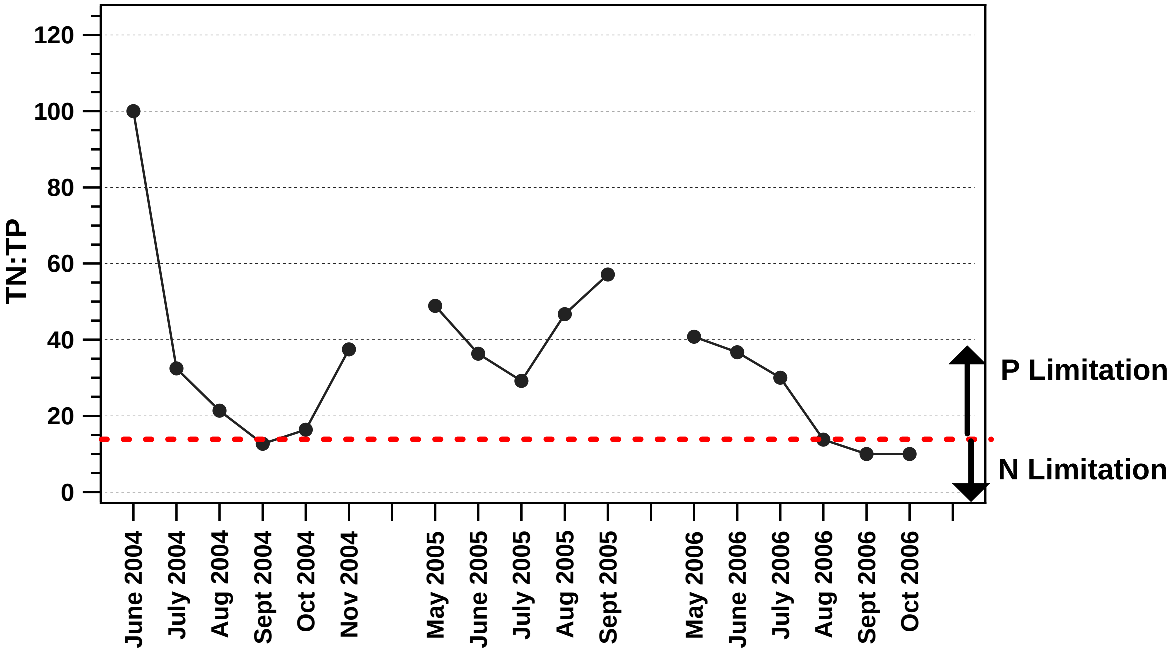


Figure 8. Mean TN:TP (wt:wt) ratios in the epilimnion of Wahleach Reservoir, 2004-2006. Red dashed lines indicate ratio that suggests either N or P limitation.

4.4 Phytoplankton

Phytoplankton cell densities ranged from 2,320 cells·ml^{-1} in 2004 (one station only; no measure of variance available) to 3,770 ± 400 cells·ml^{-1} in 2006 (Fig. 9). Although densities increased ~50% in 2006 from 2004, likely due to higher fertilizer loading in 2006, the densities were on average 30% lower than the densities observed in oligotrophic Okanagan Lake (Stockner *in* Andrusak et al 2004). The low densities observed in 2004 and 2005 are similar to densities found for unfertilized Elsie Lake, a fast flushing ultra-oligotrophic coastal system (Perrin and Harris, 2006) suggesting that the fertilizer loading in 2004 and 2005, which were below the levels recommended by Perrin et al (2006), may have had limited effect on productivity. Phytoplankton biomass ranged from 0.53 mm^{3}·ml^{-1} in 2004 to 1.47 ± 0.09 mm^{3}·ml^{-1} in 2006 (Fig. 9). Despite fertilization of Wahleach, the low density and biomass clearly reflect a phytoplankton community typical of oligotrophic conditions (Wetzel 2001).

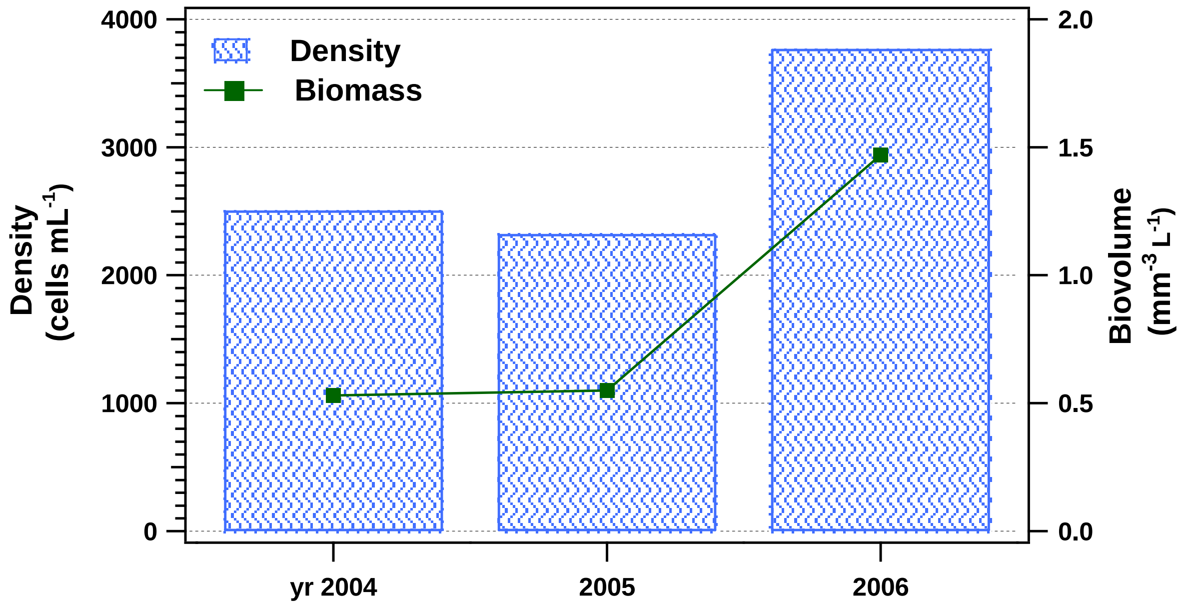


Figure 9. Annual mean density and biomass of phytoplankton community in Wahleach Reservoir, 2004-2006.

A total of 53 species of phytoplankton were found in Wahleach Reservoir during the study period. Mean phytoplankton density and biomass by phytoplankton classes in Wahleach Reservoir in 2004-2005 are provided in Appendix 2. Phytoplankton species assemblages were very similar among the study years (Fig. 10). Chrysophytes and cryptophytes, both nanoflagellates, were the most abundant class followed closely by diatoms (Bacillariophytes), cyanobacteria (Cyanophytes), green algae (Chlorophytes) and dinoflagellates (Dinophytes) and (Fig. 11). The time-series illustrates quite clearly that the Chrysophytes/Cryptophytes and the diatoms, which accounted for over 86% of the density and 69% of the biomass, were the principle groups of phytoplankton taxa in Wahleach Reservoir.

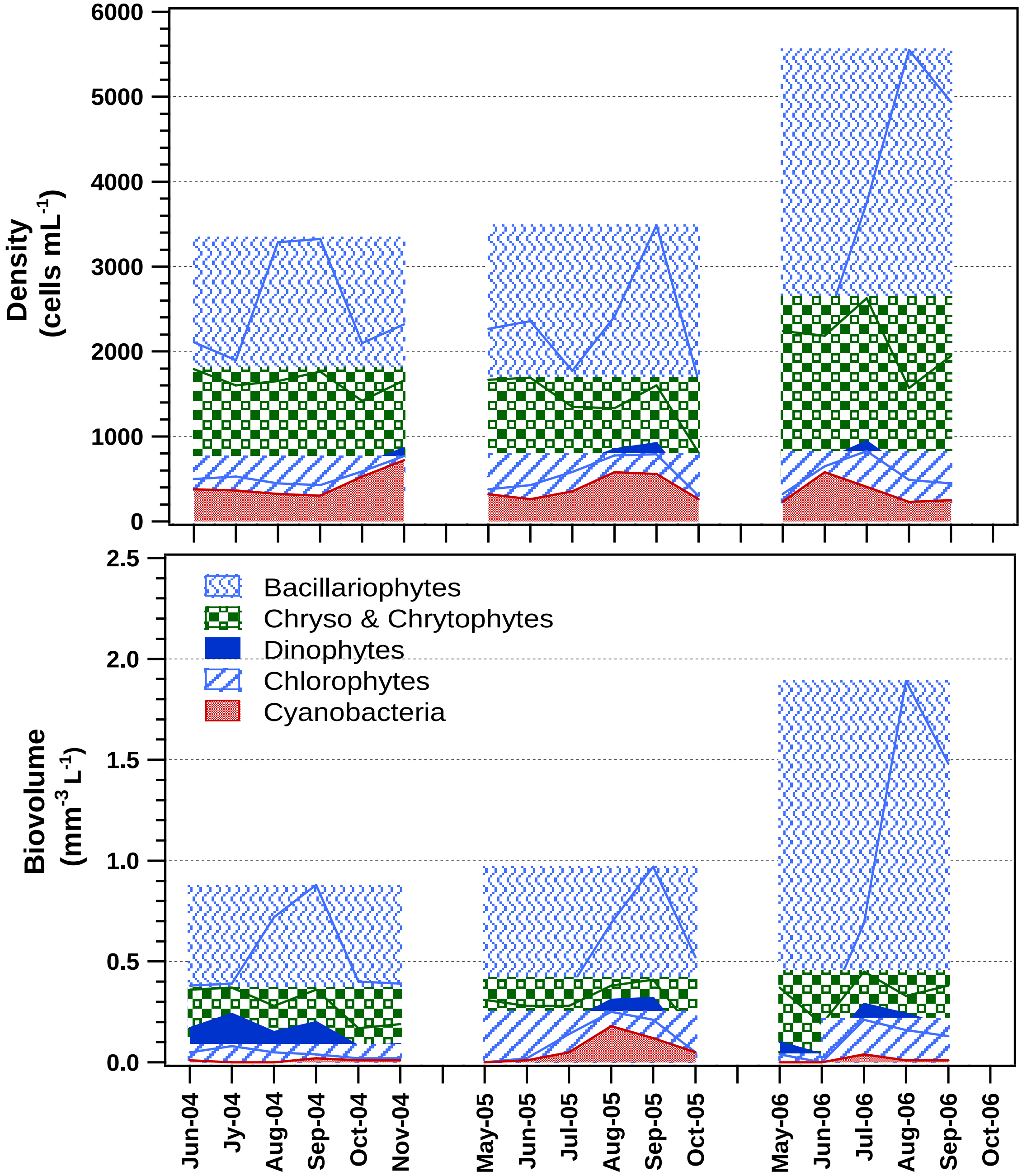


Figure 10. Mean seasonal densities and biomass of the major phytoplankton classes in Wahleach Reservoir, 2004-2006.

Chrysoflagellates and Chryptoflagellates account for between 39 and 47% of the abundance (Fig. 11) and between 13 and 25% of the biomass (Fig. 12). There was a great diversity of nanoflagellates ranging in size from 2-20 μm, and the most common genera were *Chromulina* sp., *Chrysochromulina* sp., *Dinobryon* sp., *Rhodomonas* sp., and a mixed assemblage of unidentified small microflagellates.

Chrysoflagellates and Chryptoflagellates are the size class of phytoplankton that are readily consumed by *Daphnia*, which in turn is the preferred food source of kokanee salmon (Thompson (1999) and Perrin et al (2006).

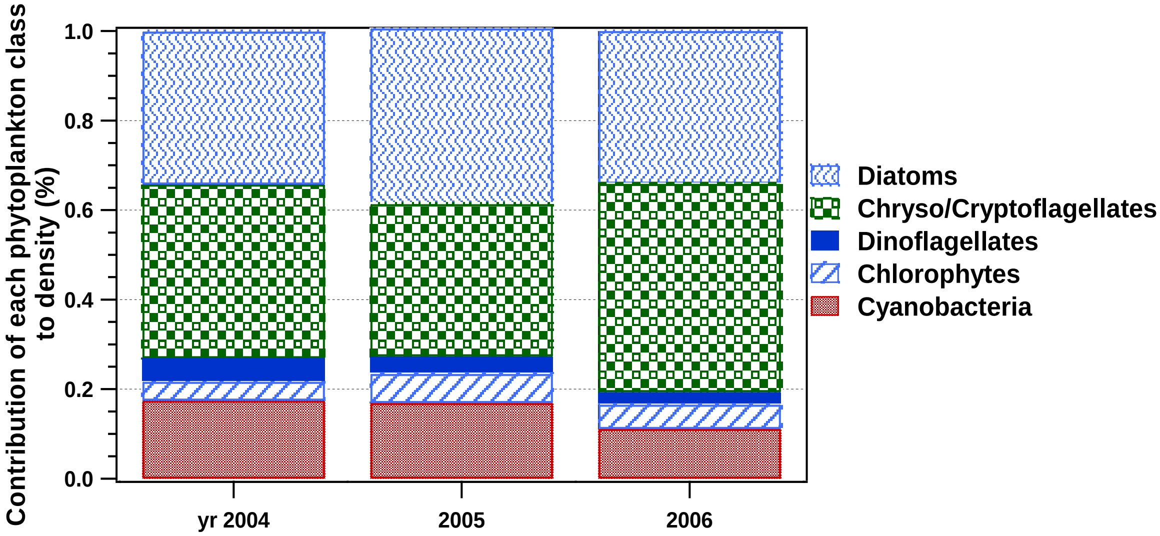


Figure 11. Contribution of phytoplankton classes to the monthly mean density in Wahleach Reservoir, 2004-2006.

Diatoms were the second most common phytoplankton class, accounting for between 34 and 39% of the density (Fig. 11) and between 40 and 45% of the biomass (Fig. 12). The following genera were commonly observed in the reservoir; chain forming *Rhizosolenia* sp, *Tabellaria fenestrate*, *Asterionella formosa* var1, *Cyclotella glomerata* and *Cyclotella stelligera*. Generally long chain forming diatoms are too large to be effectively consumed by herbivorous *Daphnia* sp and in deep systems or systems with little littoral zone, the carbon in these large cells (also called microplankton) are considered to be carbon sinks. However in Wahleach Reservoir, it is likely that the pelagic fertilization and littoral benthic process are strongly linked and nutrients that are taken up by pelagic phytoplankton may eventually sink and settle to the sediment, increasing the food availability for detritivores.

The blue-green algae (Cyanophytes) were the next more common taxa, accounting for between 11 and 17% of the abundance (Fig. 11) but due to their small size they make only a small contribution (<10%) to biomass (Fig. 12). The following genera were commonly observed in the reservoir; *Synechococcus* sp., *Oscillatoria* sp., *Merisomedia sp.* and in August and September of 2005 *Microcystic* sp., a nitrogen gas fixing species was observed. At its peak, *Microcystis* represented less than 10% of biomass and was absent from the 2006 phytoplankton community. *Anabaena circinalis,* a nitrogen gas fixing species, was rarely present, nor did it never attained high densities. The presence of nitrogen fixer signals low dissolved inorganic nitrogen (DIN) concentrations and suggest low N:P ratios of epilimnetic inorganic nutrients.

Both dinoflagellates (Dinophyceae) and green algae (Chlorophytes) were not common and they never attained large populations, but because of the large size of dinoflagellates, they did account for up to 21% of the phytoplankton biomass (Fig. 13). The dinoflagellates community was composed of *Peridinium* sp. and *Gymnodinium* sp. while the green algae were largely composed of *Elakatothrix* sp. and *Chorella* sp.

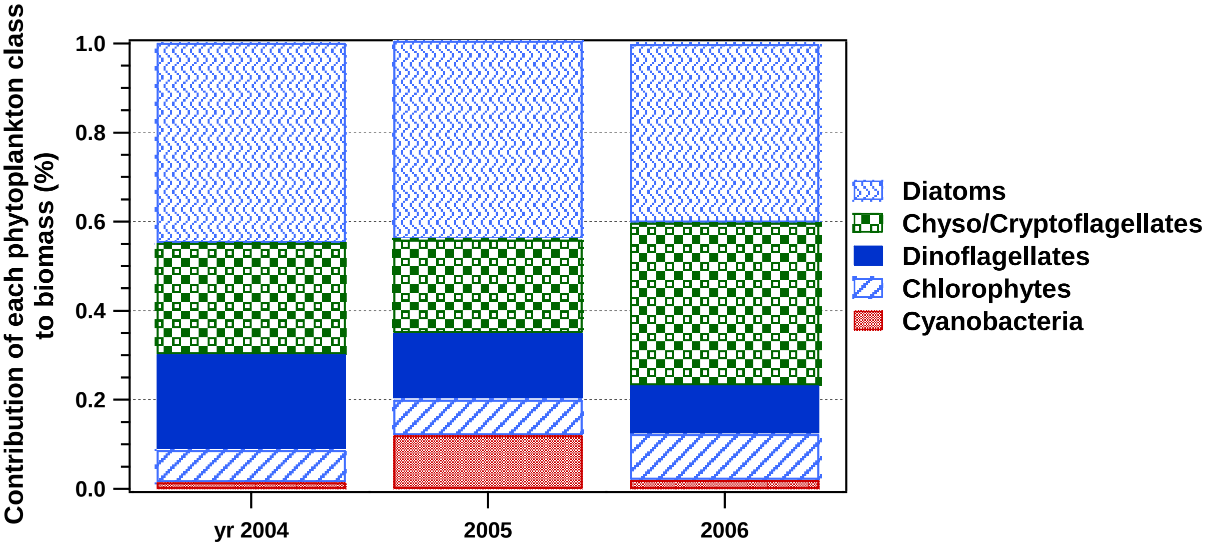


Figure 12. Contribution of phytoplankton classes to the monthly mean biomass in Wahleach Reservoir, 2004-2006.

The most noteworthy seasonal event, occurring during mid to late summer of each study year, was a 'mini' diatom bloom of *Tabellaria* and *Rhizosolenia* sp., both 'inedible' diatom species (Fig. 10). *Rhizosolenia* sp. was predominant before fertilization and during fertilization in 1995-1997 (Perrin et al 2006) and densities observed in 2004-2006 were similar to those of previous years of fertilization. There was a small spring and fall bloom of Chrysophytes and Chryptophytes, largely dominated by the hetertrophic nanoflagellate *Dinobryon divengens* and a mixed assemblage of unidentified microflagellates. A small increase in the minute cyanobacteria *Synechococcus* sp. was observed in the fall of 2004 and 2005 and early summer of 2006. *Synechococcus* are commonly found in all lakes and reservoirs. There were no major peaks or bloom, and little seasonal variation in the other phytoplankton taxa.

4.5 Zooplankton

The zooplankton community was composed of cladocerans, copepods, a mixed assemblage of rotifers and the occasional ostracod, a benthic invertebrate. Table 3 lists the cladoceran species that were identified in the reservoir, including two cyclopoid and one calanoid copepod species (Table 3). Six species of rotifers were identified but the densities are not reported because the sampling methodology underestimates these minute crustaceans.

Table 3. List of zooplankton species identified in Wahleach Reservoir in 2004 - 2006.

	2004	2005	2006
Cladocera			
Alona guttata			+
Alonella nana			+
Alonella sp	+	+	
Chydorus sphaericus	+	+	+
Daphnia rosea	+	+	+
Bosmina longirostris			+
Eubosmina longispina	+	+	
Holopedium gibberum	+	+	+
Leptodora kindtii			+
Scapholeberis mucronata			+
Copepoda			
Cyclops vernalis (cyclopoid)	+	+	+
Macrocyclops fuscuc-(cyclopoid)			+
Epischura nevadensis (calanoid)			+

Five species of cladocera were present in 2004 and in 2005 and eight species in 2006 (Table 3). *Daphnia rosea* (Sars), *Holopedium gibberum* (Zaddach), *Eubosmina longispina* (Leydig), were common, while other species were observed sporadically. *Daphnia* spp. were not identified to species for density counts.

The copepod *Cyclops vernalis* and cladocerans *Daphnia* sp., and *Holopedium gibberum* were numerically dominated the zooplankton assemblage during the study period. *Cylops vernalis* was present in all three sampling season and *Macrocyclops fuscuc* was present in 2006. *Epischura nevadensis* (Lillj.), a calanoid copepod, was present in 2006.

The seasonal average zooplankton densities in Wahleach Reservoir increased from 2004 to 2006. In 2004 the seasonal average zooplankton density for the whole reservoir was 4.7 individuals·L^{-1}, in 2005 densities decreased to 3.5 individuals·L^{-1} and in 2006 zooplankton density increased almost two fold to 10.0 individuals·L^{-1}. (Fig. 13).

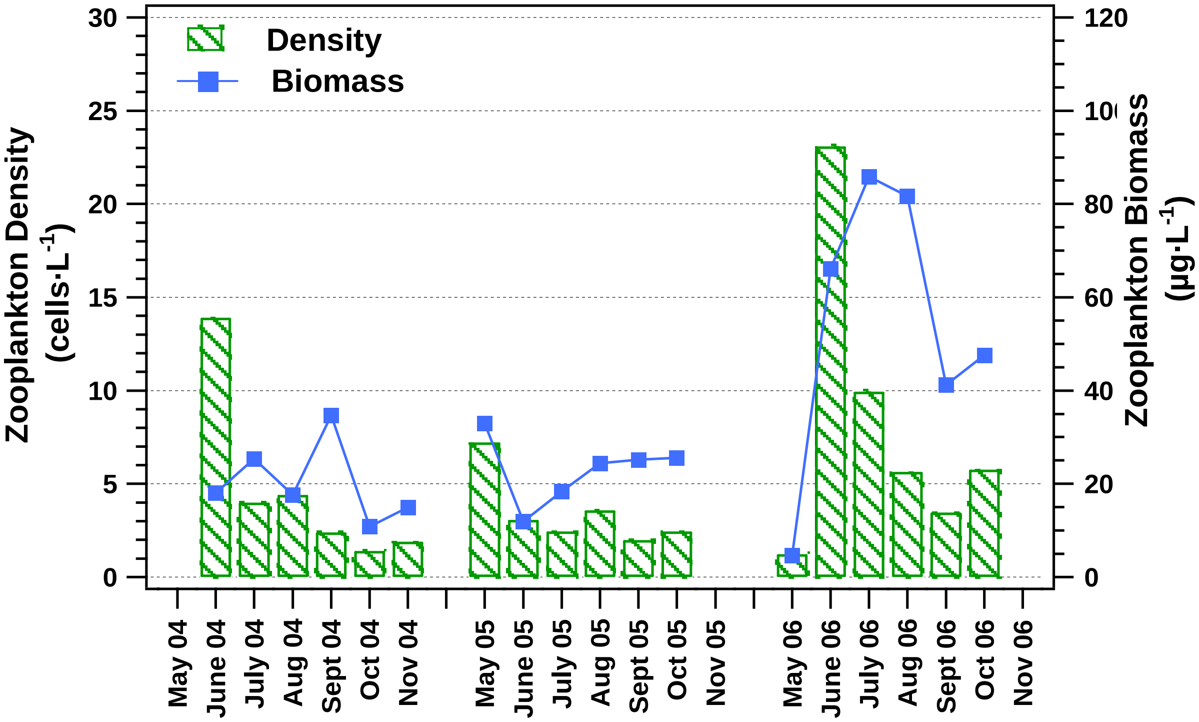


Figure 13. Mean growing season zooplankton densities and biomass in Wahleach Reservoir, 2002-2004.

The zooplankton density was numerically dominated by cladocerans (other cladocera and *Daphnia*), which averaged between 79 and 91% of the zooplankton community (Fig. 14). This finding is consistent with values reported for earlier years of the fertilization program (Perrin et al 2006). During the sampling period (2004-2006) cladocera other than *Daphnia* accounted for between 54% and 63% of the zooplankton community, while *Daphnia* accounted for between 17% and 30% of the total zooplankton density. Other cladocera were mainly dominated by *Eubosmina longispina*, *Chydorus* sp. and *Holopedium gibberum.* Populations of cladocera other than *Daphnia sp* peaked early in the growing season in June and July, until *Daphnia* sp. emerged in August and numerically dominated the zooplankton assemblage well into the fall (Fig. 14). The density of cladocera other than *Daphnia* doubled during the study period, from approximately 3 individual·L^{-1} to 5 individual·L^{-1} in 2006. During this same period the density of *Daphnia rosea* also doubled, from approximately 1 individual·L^{-1} to 2 individual·L^{-1}. While the actual density of *Daphnia rosea* is low, the densities are nearly 14 fold higher relative to earlier densities of less than 0.17 1 individual·L^{-1} reported in 1999 (Perrin et al 2006).

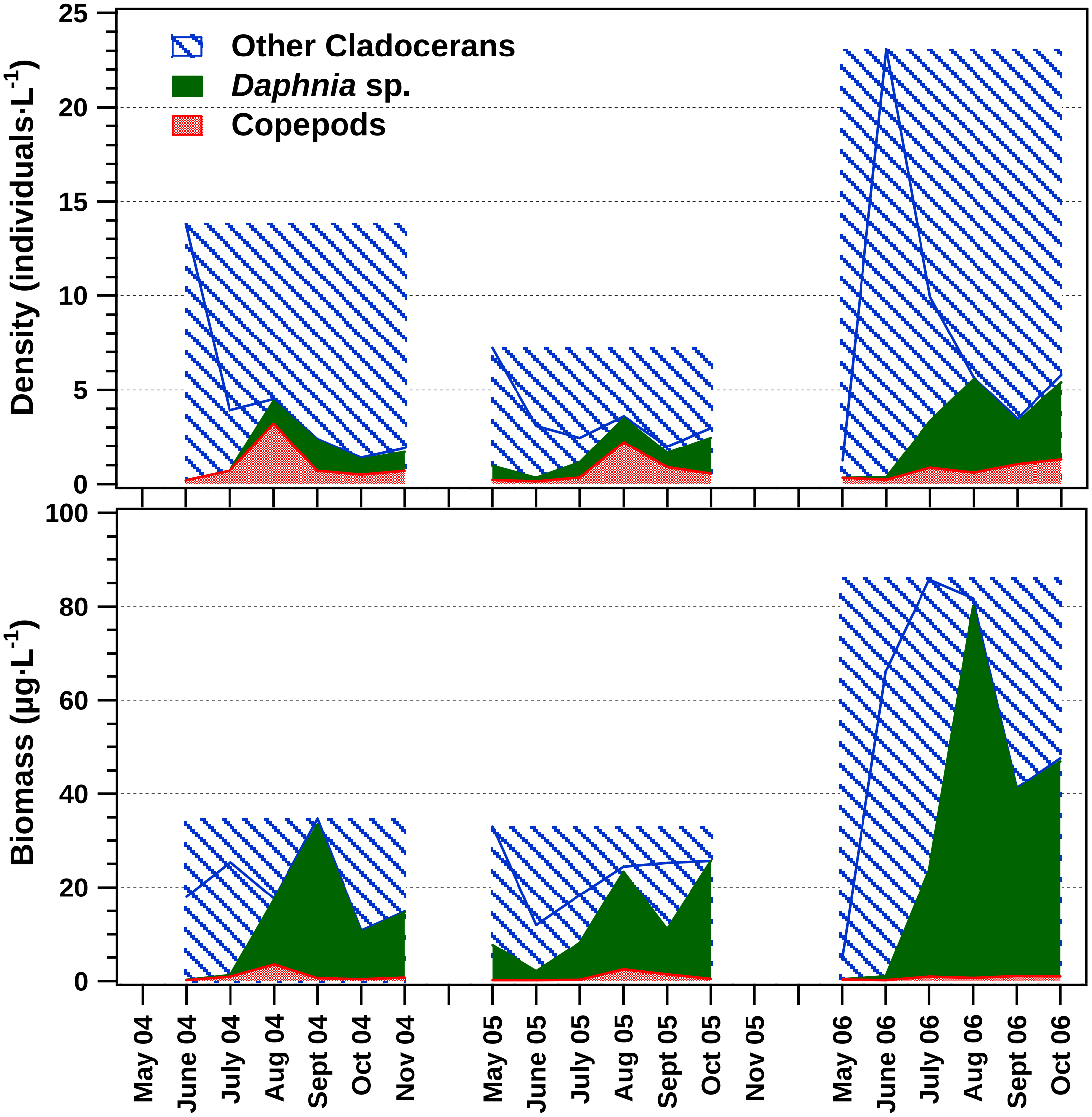


Figure 14. Mean contribution of cladocerans and copepods to zooplankton density in Wahleach Reservoir, 2004-2006.

Copepod densities in Wahleach Reservoir were generally low, accounting for <20% of the zooplankton assemblage during the study period. The highest densities were observed in 2004 with approximately 1 individual·L^{-1} and lowest in 2006 with just 0.5 individual·L^{-1}. The highest densities recorded during the study period occurred in August 2004, where densities were over 3 individual·L^{-1}, accounting for over 70% of the zooplankton community.

Seasonal average total zooplankton biomass more than doubled over the study period, from 20.2 $\mu g \cdot L^{-1}$ in 2004 to 54.5 $\mu g \cdot L^{-1}$ in 2006 (Fig. 14). The biomass was largely dominated by other cladocerans and *Daphnia* sp which accounted for between 95 and 99% of the total zooplankton biomass in 2004, 2005 and 2006 (Fig. 15). Although *Daphnia* sp. was present in samples during the entire season in 2005 and 2006, it dominated the biomass from August to October, where *Daphnia* sp accounted for >95% of the biomass (Fig. 15). The highest total zooplankton biomass of >80 $\mu g \cdot L^{-1}$ was observed in July & August 2006, when *Daphnia* accounted for up to 90% of total biomass (Fig. 15).

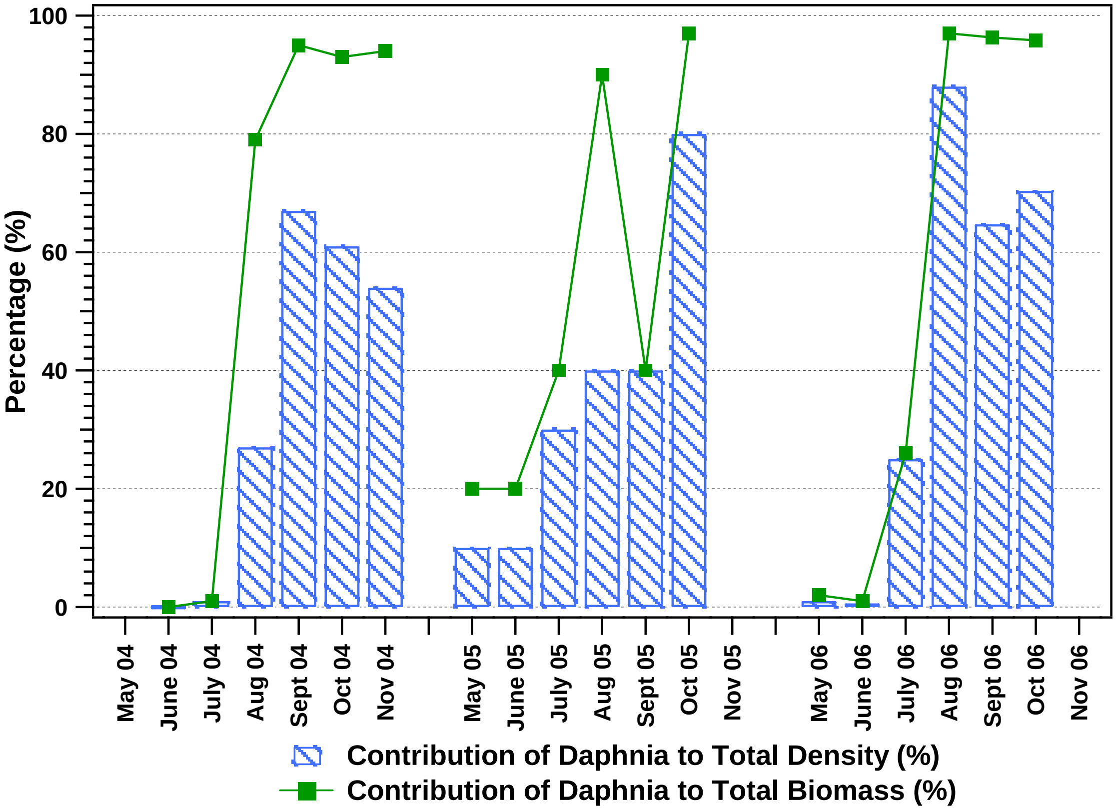


Figure 15. Contribution of *Daphnia* sp to total zooplankton density and biomass, expressed as a percentage, for 2004-2006.

4.6 Spawner Surveys

The number of kokanee spawners has increased over the study period, where cumulative numbers range from approximately 1,800 in 2004 to over 8,000 in 2006 (Fig. 16). Escapement is approaching values found in 2001, when over 9,000 spawners were recorded. Given that Jones Creek was not enumerated in 2005, the actual number of spawners were likely higher than 3,900 but given the high interannual variability it is difficult to estimate the number of spawners in Jones Creek. For instance, Boulder Creek accounted for 53% of total spawners in 2006 but only 11% in 2004.

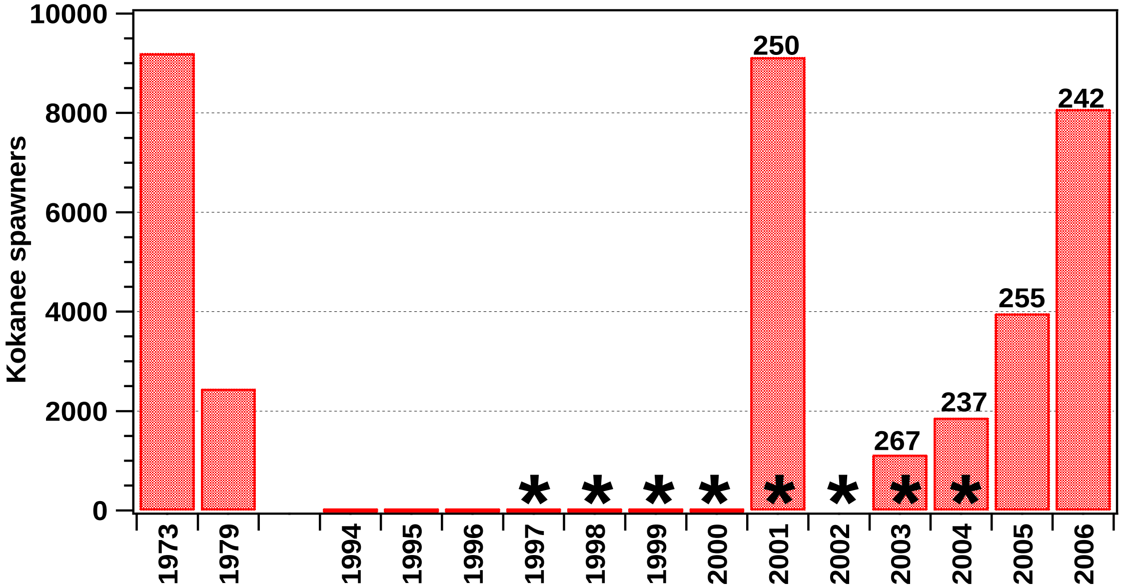


Figure 16. Total number of kokanee spawners in Wahleach Reservoir, 1973-2006. The numbers above the bars are mean fork lengths (mm) of spawners and the star (*) indicates years of kokanee stocking.

During 2006, minimal large woody debris was observed in Boulder Creek and crown closure was limited at 5%. In the lower reaches of Boulder Creek the substrate was a mixture of gravel and fine sediments that may provide some spawning habitat for kokanee salmon. In Flat Creek, coarse woody debris was present throughout the channel. The creek has large sections of fine sediments and few spawning gravels generally located in tail-out pools within 1 km from Flat Creek’s confluence with Wahleach Reservoir. Throughout the 1 km study site, there is medium crown closure providing both shady and open sections. In Wahleach/Jones Creek, course woody debris was present throughout the creek. The confluence with the reservoir runs through a mud flat with cover largely composed of sediments however, small pools of gravel were observed within 350 m of the streams confluence. Throughout the creek there is high crown closure providing areas of shade.

Escapements have increased dramatically in Boulder Creek, from approximately 200 spawners in 2004 to over 4,300 in 2006 and the number of spawners in Flat Creek have seen a 5 fold increase, from approximately 450 spawners in 2004 to over 2,500 in 2006 (Fig. 17). Escapements have remained unchanged in Jones Creek where approximately 1,200 spawners used the creek in 2004 and 2006 (Fig. 17). The large dramatic increases observed in Boulder Creek and Flat Creek are likely due to the proximity of the creeks to the area of stocking. It is well documented that several species of hatchery-reared salmonids, including sockeye salmon, will return to spawn in their stream of release (Scholz et al 1992). In Wahleach Reservoir the fish were stocked into the reservoir from the boat launch which is immediately south of the confluence of Boulder Creek and approximately 5 km north of Flat Creek (Fig. 1). Imprinting likely explains the dramatic increases of kokanee in Boulder Creek and Flat Creek because these streams are most readily accessible.

Imprinting may also explain why kokanee spawners in Wahleach Reservoir chose a stream with sub-optimal habitat. Spawning habitat in Boulder Creek is largely composed of large cobbles and boulders and limited gravel offering sub-optimal spawning habitat which would likely impede spawning success yet large numbers of spawners were observed in this creek. In addition, in terms of area, Flat Creek has more available spawning habitat relative to Boulder Creek yet fewer spawners were observed in Flat Creek (~2500). This is likely due to less imprinting of stocked kokanee to Flat Creek due to its greater distance from the stocking location. In 2006, a log jam spanning the width of Flat Creek, approximately 850 m upstream from the bridge, prevented kokanee spawners from migrating upstream. No kokanee were observed above this log jam. In previous assessments, there is no mention of this structure, and it remains to be seen whether this migration barrier will be ephemeral, or a permanent structure in Flat Creek's stream channel. Despite Jones Creek having the most suitable spawning habitat for kokanee compared to Boulder Creek and Flat Creek (Greenbank 2002), low numbers of spawner in Jones is likely due to the distance from the stocking location.

In 2006, the combination of low water flows and the presence of a weir in Boulder Creek for diversion of water to augment flows in Lower Jones Creek, the migration of kokanee to the upper reaches of Boulder Creek was blocked. The weir is located approximately 400 m upstream of the confluence of the creek and no kokanee were observed upstream of the weir. As a result, access to the upper reaches of Boulder was prevented which may have prevented access to over half of the available habitat in Boulder Creek. Fortunately the substrate of the lower reaches of Boulder Creek (approximately 0-75 m from its confluence with Wahleach Reservoir) is a mixture of gravel and fine sediments, which may provide some suitable spawning habitat and 100-200 m upstream from Boulder Creek's confluence with Wahleach Reservoir, gravel substrates are present near the edges of the stream and in pool tail-outs providing some spawning opportunities (Greenbank 2002). However, Greenbank (2002) suggested that water velocities were too great in this area for kokanee spawning. Upstream of the weir the substrate is predominantly composed of boulders and large cobbles providing limited spawning potential (Greenbank 2002).

Constructed spawning channels provide optimal spawning habitat as the gravel size, gravel condition, slope and flow conditions are carefully controlled. In these constructed channels, a density of 7-8 spawning kokanee$\cdot$m^{-2} has been calculated as the optimum number of kokanee per unit of area based on the average size of Meadow Creek kokanee of approximately 230 mm (Redfish Consulting Ltd. 1999). Given that Meadow Creek kokanee were used as the brood stock for stocking of Wahleach and based on similar spawners sizes in Wahleach and Meadow Creek we can assume that the optimal number of kokanee per unit of area in Boulder Creek will not exceed 7-8 spawners$\cdot$m^{-2}, and given that Meadow Creek habitat conditions are likely much better than the limited sub-optimal conditions in Boulder Creeks we can assume that the optimal density in the Boulder Creek is likely much less than 7-8 spawners$\cdot$m^{-2}. In Boulder Creek the density was well in excess of 7-8 spawner$\cdot$m^{-2} and although it is difficult to determine exact counts of fish when hundreds are schooling together, it is estimated that the density may have been as high 100 fish$\cdot$m^{-2}, which greater exceeds the optimal number of fish per square meter. Large fall storms are common at Wahleach Reservoir and in 2006 a large storm occurred after the spawning period washing out the weir, removing the migration barrier and quite likely disturbing the redds.

Peak counts occurred between 19 - 24 September in 2004-2006 for all three tributaries.

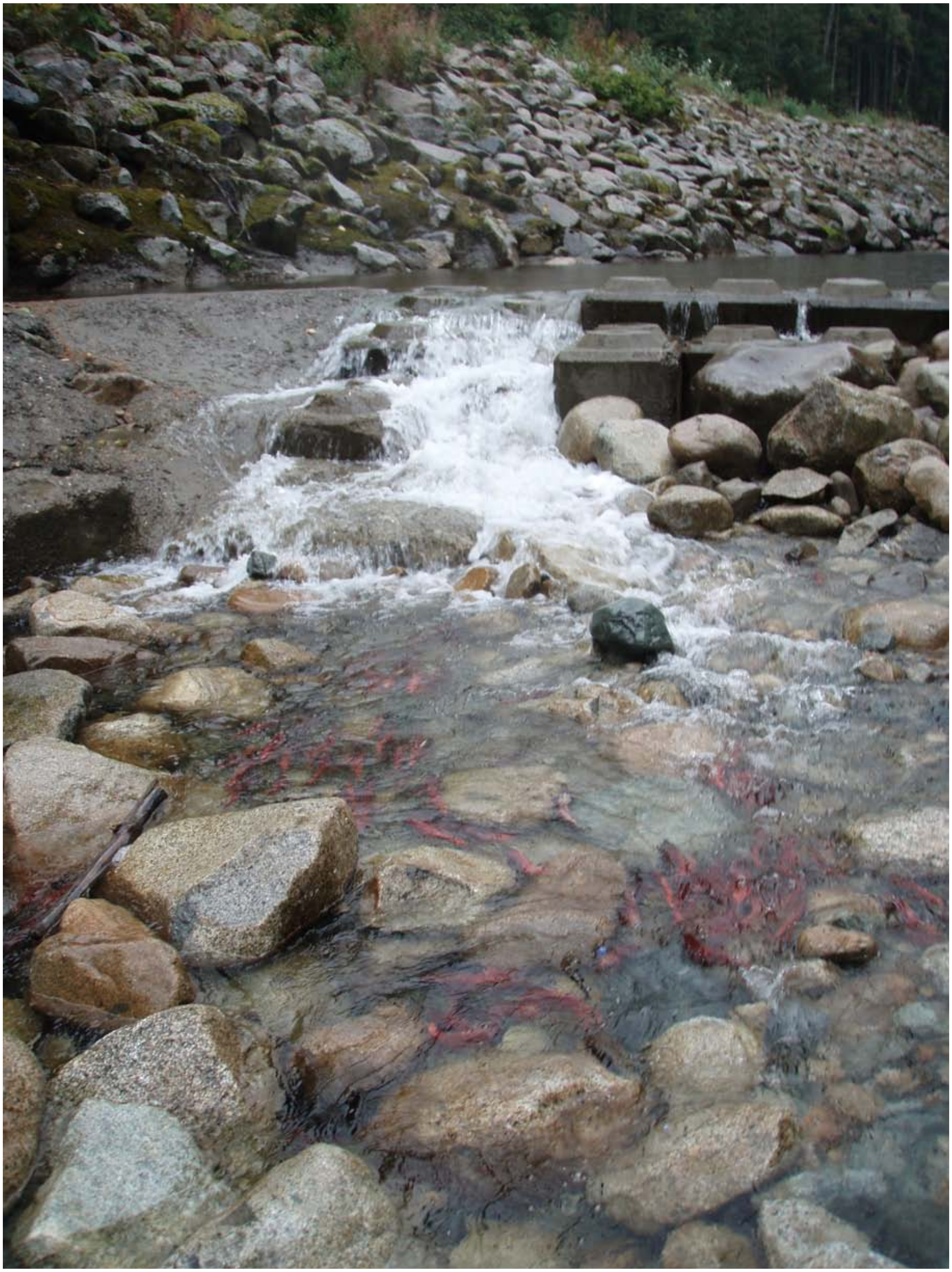


Photo 3. Upgraded weir on Boulder Creek blocking access to spawning ground, September, 2006.

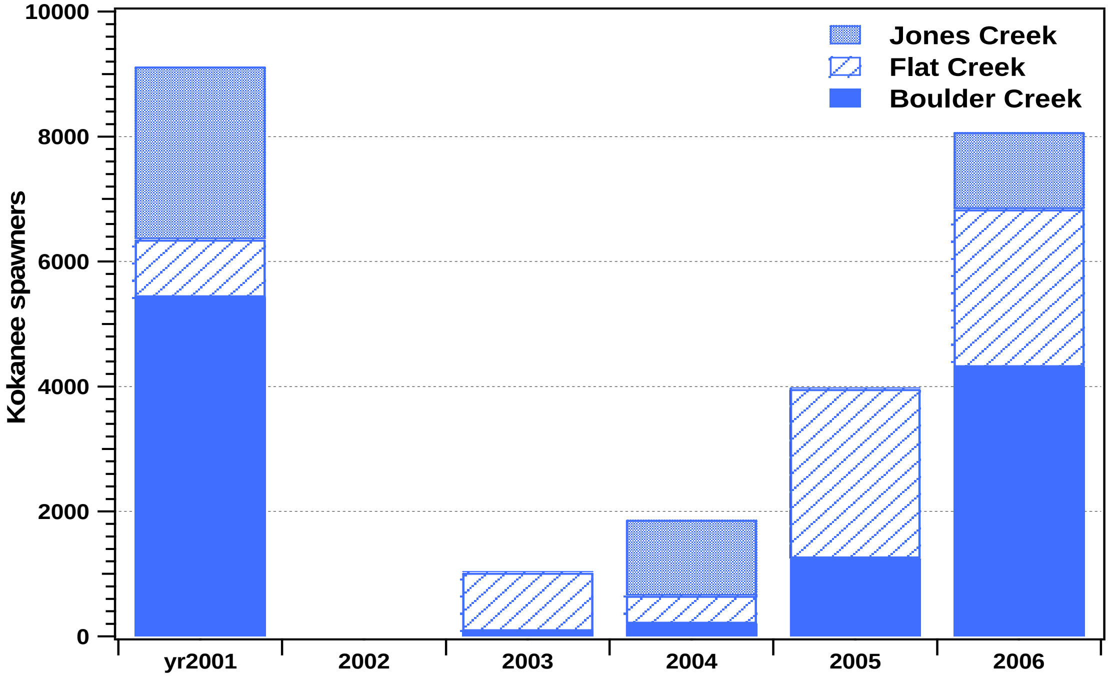


Figure 17. Total enumerated kokanee spawners by location in Wahleach Reservoir, 2001-2006.

4.7 Gillnetting and Minnow Trapping

Fish species captured in Wahleach Reservoir include rainbow trout (*O. mykiss*), kokanee (*O. nerka*) and cutthroat trout (*O. clarki clarki*). Threespine Sticklebacks (*Gasterosteus aculeatus*) were captured in the minnow traps.

The gillnetting in 2004 and 2005 was conducted in June, while in 2006 sampling was completed later in the year in October. This resulted in substantially different catch results between 2004/2005 and 2006. In 2004, a total of 298 fish were caught for a CPUE of 2.29 fish·net hr with cutthroat trout being the most numerous with 138 caught (46% of the total catch), followed by rainbow trout (40%) and kokanee (13%) (Table 4). In 2005, the number of fish caught was 211 for a CPUE of 1.81 fish fish·net hr, similar to the catch in 2004, but with rainbow trout being the most numerous species with 109 caught (52% of total catch), followed by cutthroat trout (26%) and kokanee (23%). Fish catch in 2006 was less than half the numbers observed in 2004 and 2005, with a total of 69 fish caught for a CPUE of 0.68 fish·net hr, approximately 33% of the catch rates of 2004 and 2005. The species distribution of the catch in 2006 was similar to the proportions observed in 2004 with rainbow trout accounting for 55% of the total catch, followed by cutthroat trout (28%) and kokanee (17%) (Table 4). Different catch results between seasons has previously been documented and highlights the importance to maintaining consistency in sampling methodology between years so long term trends can be accessed. Wilson et al (2000) found catches in Alouette Lake Reservoir were 47% lower in November compared to catches in September.

The total biomass from gillnetting was approximately 45.3 kg of sport fish in 2004, followed by 38.8 kg in 2005 and 14.4 kg in 2006. Catches in 2006 were approximately 32% of catches in 2004 and 37% of catches in 2005.

Table 4. Number of fish caught, percent of total catch and catch per unit effort (fish fish·net hr) for each species captured in gillnets in Wahleach Reservoir, 2004-2006.

Species	Parameter	Sampling Season & Year Spring **2004**	 Spring **2005**	 Fall **2006**
Rainbow trout	#	120	109	38
	%	40	52	55
	cpue	0.92	0.93	0.37
Cutthroat trout	#	138	54	19
	%	46	26	28
	cpue	1.1	0.46	0.19
Kokanee	#	40	48	12
	%	13	23	17
	cpue	0.31	0.41	0.12

The CPUE in the spring for wild rainbow trout increased from approximately 0.26 fish·trap hr in 1997 to over 9 fish·trap hr in 2004 and 2005 (Fig. 18) while the fall catch rate is remains similar to 1997 values (Fig. 19). Perrin et al (2006) found that after the 45-minimum size regulation was applied to the fishery in 1998 there was no clear trend in the catch rate. The highest rate of CPUE for cutthroat trout was measured in 2004 when the CPUE was 1.1 fish·trap hr, which was approximately 3 times the catch rates measured after the first year of cutthroat stocking in 1997 (Fig. 18). Catches then dropped in 2005 by half to 0.46 fish·trap hr, a catch rate that was similar to values found in 1997 and 1998, the first two years of cutthroat stocking. The CPUE for 2006 was approximately half of the catch rate of 2005, as predicted given the known relationship between spring and fall catches. The kokanee CPUE in the spring has steadily increased from 0.15 fish·trap hr to 4.1 fish·trap hr, which may suggest the kokanee population is building. In contrast, the CPUE for the fall catch peaked in 2000 and has declined in 2003 and 2006.

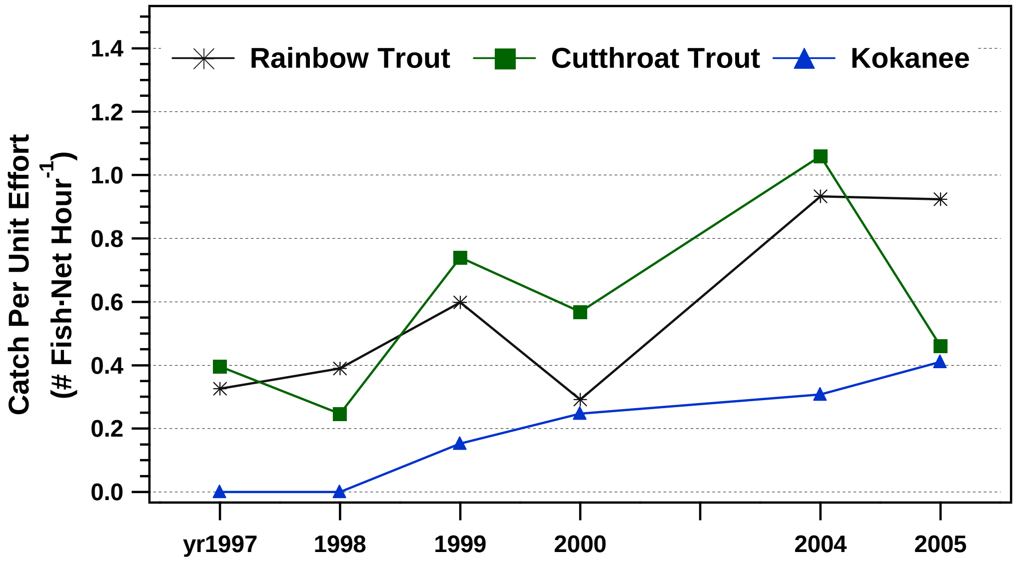


Figure 18. Gillnet catch per unit effort (CPUE) in the spring of rainbow trout, cutthroat trout and kokanee in Wahleach Reservoir, June 1997-2005.

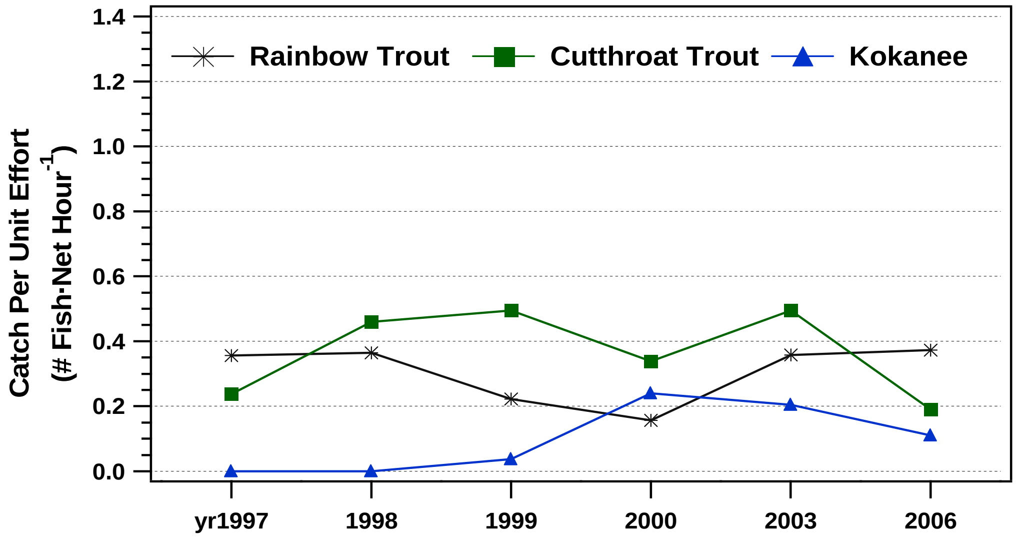


Figure 19. Gillnet catch per unit effort (CPUE) in the fall of rainbow trout, cutthroat trout and kokanee in Wahleach Reservoir, June 1997-2005.

In total, 43 sticklebacks were caught in 2004, 96 in 2005 and 47 in 2006, catches all lower than earlier years of the project where 108 and 148 fish were caught in 1993 and 1994 (Perrin and Stables, 2000). The spring gillnet catch rates of threespine sticklebacks in 2004 and 2005, were 2.5 fish·net hr (Fig. 20), which was similar to values measured in 1997 but less than the peak CPUE in 1999 of approximately 6 fish·net hr. The CPUE for sticklebacks in 2006 was 0.41 fish·net hr, lower than catches found in the spring of 2004 and 2005 but similar to catches in 2000 and 2003 (Fig. 20).

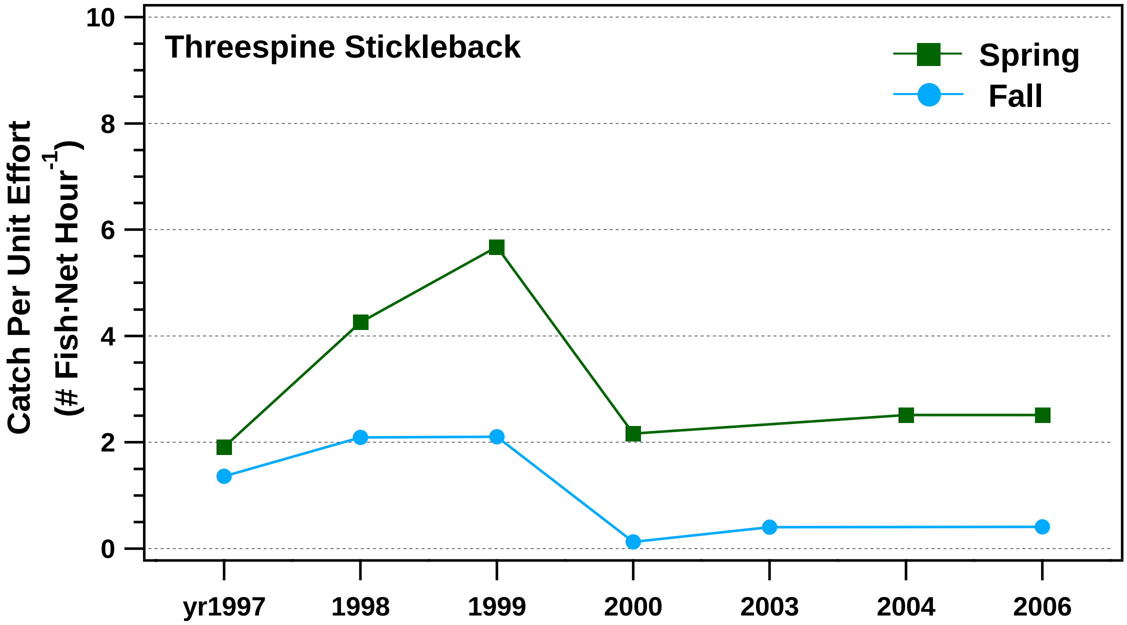


Figure 20. Gillnet catch per unit effort (CPUE) in the spring and fall of threespine sticklebacks in Wahleach Reservoir, June 1997-2005.

The mean fork length and mean weight of threespine sticklebacks decreased during each successive year of the sampling period (Fig. 21). Mean fork length decreased 14% to 44.6 ± 1.37 mm in 2005 and 24% to 39.2 ± 0.48 mm in 2006 relative to 2004 values. Weights were not recorded in 2005 but in 2006 the mean weight of stickleback decreased by 61% relative to 2004 weights (Fig. 21). This suggests that either food availability was poor, recruitment was poor or that piscivorous predators are selectively grazing the larger sticklebacks, and causing a shift in the size distribution to smaller sticklebacks.

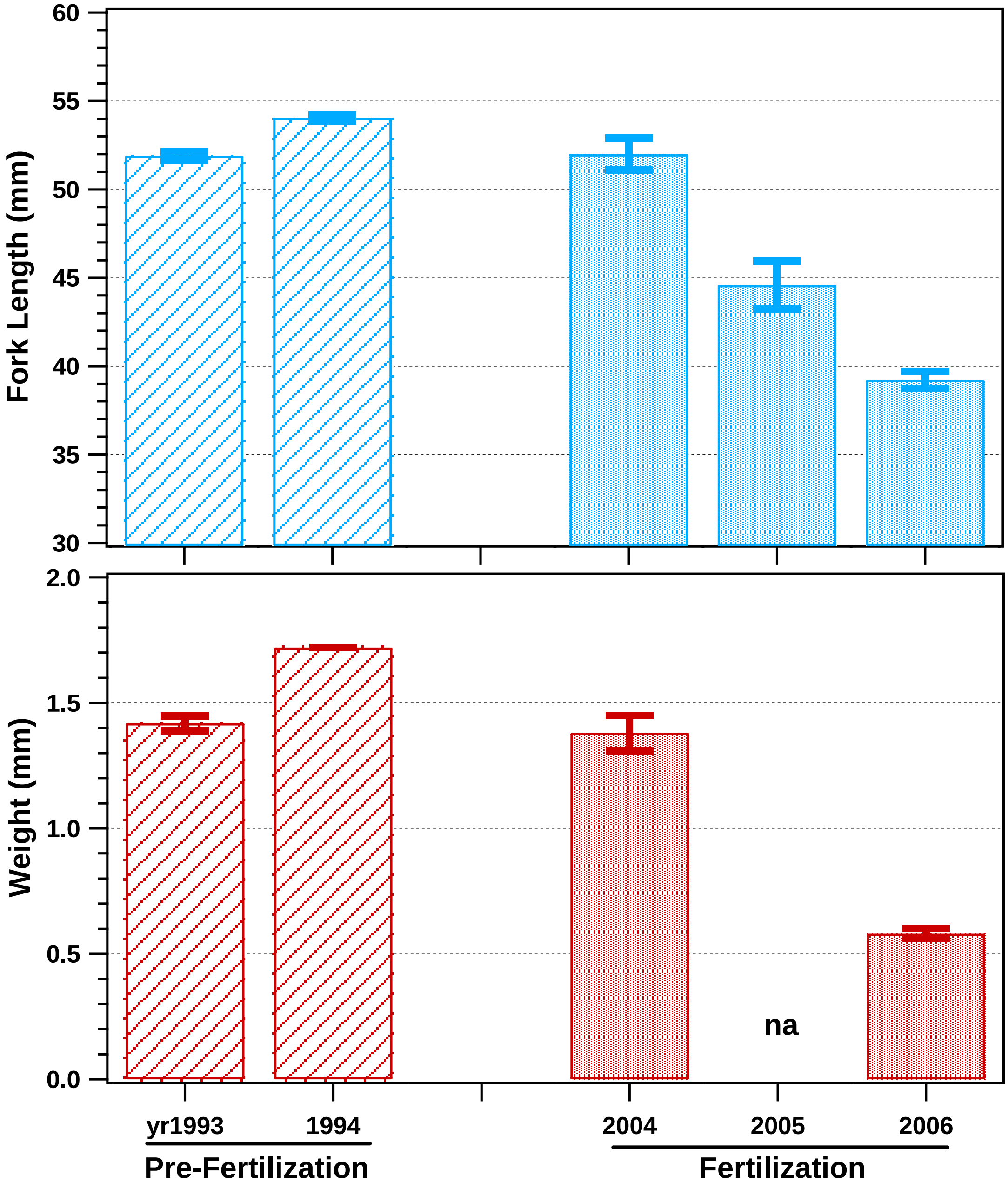


Figure 21. Mean ± SE fork length and weight for threespine sticklebacks in pre-fertilization years (1993 and 1994, hatched bars) and during fertilization years (2004-2006, solid bars) in Wahleach Reservoir. Weights are not available for 2005.

Processing of the aging data for 2004 and 2005 is currently underway and therefore was not available at the time of writing. These results will be presented in subsequent reports. Aging data is available for 2006 for rainbow trout and kokanee salmon and age frequency distribution will be examined. The rainbow trout captured ranged from age 1+ to age 6+. The age frequency distribution of rainbow trout shifted from age 2 fish before fertilization to predominance by age 2, 3 and 4 during fertilization (Fig. 22). This suggests that fertilization has lead to increased survival to older ages. The mean size of the rainbow trout range from 178.6 to 253.7 mm and 71.5-186.1 g for ages 2-4. Age 3+ fish were the most common age class caught and they were 219.9 ± 8.7 mm and 125.1 ± 14.9 g. These fish are slightly smaller than sizes reported by Perrin et al (2006). The cutthroat trout ranged in size from 250-540 mm (mean 315 ±18.7 g) and 143-1630 g (mean 365.8 ± 84.6 g). Ages are not available for the cutthroat trout. The kokanee captured range from 1+ to 4+ in age, with the majority of the fish in 2006 aged 4+ (67%). The age 4+ fish ranged in size from 185-272 mm (mean 233 mm) in fork length and 76-254 g (mean 174 g). These fish were in good shape with a condition factor averaging ranging from 1.19-1.37 (mean 1.28). 3 mature males, 3 immature males, 2 mature females and 4 immature females were found in the catch, but the small sample size may not represent the kokanee population.

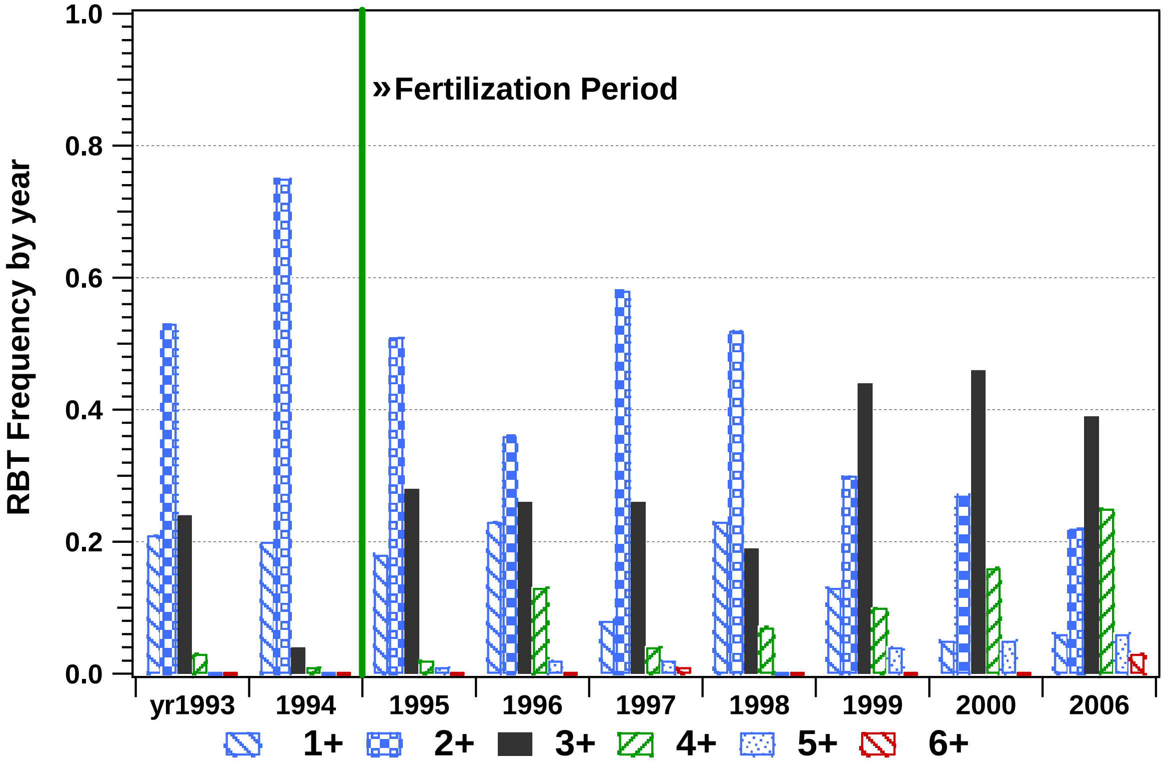
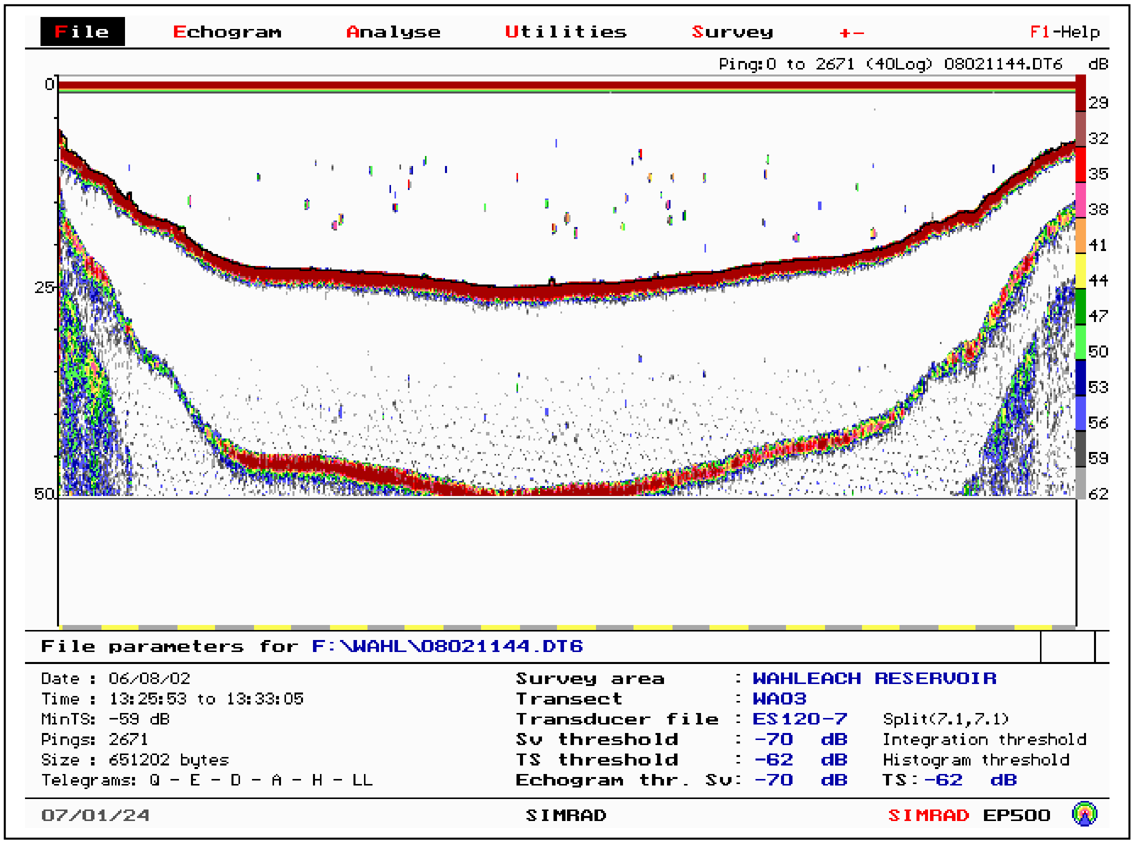


Figure 22. Age frequency distribution of rainbow trout caught in gill nets in years before fertilization (1993 and 1994) and in years after fertilization (2004-2006) in Wahleach Reservoir.

4.8 Hydroacoustics

Good weather provided optimal conditions for transecting the reservoir, surface temperatures were 18°C, the reservoir elevation was at 639.6 m and a well defined thermocline existed from 4-8 m. The survey was conducted 2 days following the July 25th new moon with data collections starting at 22:15 hrs and completed by midnight.

Eleven diagonal transects were made across the reservoir in a continuous shore to shore course starting at the southern end (Fig. 5). Survey echograms showed vertical distributions were similar to past surveys with the majority of the fish targets found in the deeper areas of the reservoir (Fig. 23). The average aerial transect fish densities was approximately 99 fish·ha^{-1} and ranged from 0 to 268 fish·ha^{-1} (Fig. 24). These densities were far lower than densities computed from surveys conducted in the 1990's and in 2000. It is highly possible that the 2006 survey may have underestimated fish in the shallower portions of the reservoir. Average depths of transect start and end points were measured from echograms to assess the extent of the habitat surveyed. The average start and end depth of transects ~9m, confirmed that a large portion of shallow habitat had been under sampled. The near shore habitat area out to the 9m contour at the time of survey represented 38% of the total reservoir area.



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File parameters for F:\WAHL\08021144.DT6

Date : 06/08/02                       Survey area       : WAHLEACH RESERVOIR
Time : 13:25:53 to 13:33:05           Transect          : WA03
MinTS: -59 dB                         Transducer file   : ES120-7   Split(7.1,7.1)
Pings: 2671                           Sv threshold      : -70  dB   Integration threshold
Size : 651202 bytes                   TS threshold      : -62  dB   Histogram threshold
Telegrams: Q - E - D - A - H - LL     Echogram thr. Sv: -70  dB   TS: -62  dB

07/01/24                              SIMRAD                       SIMRAD EP500
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Figure 23. Hydroacoustic transect echogram showing fish distributions relative to surface and bottom, the largest aggregations were found in the deeper portions of the reservoir.

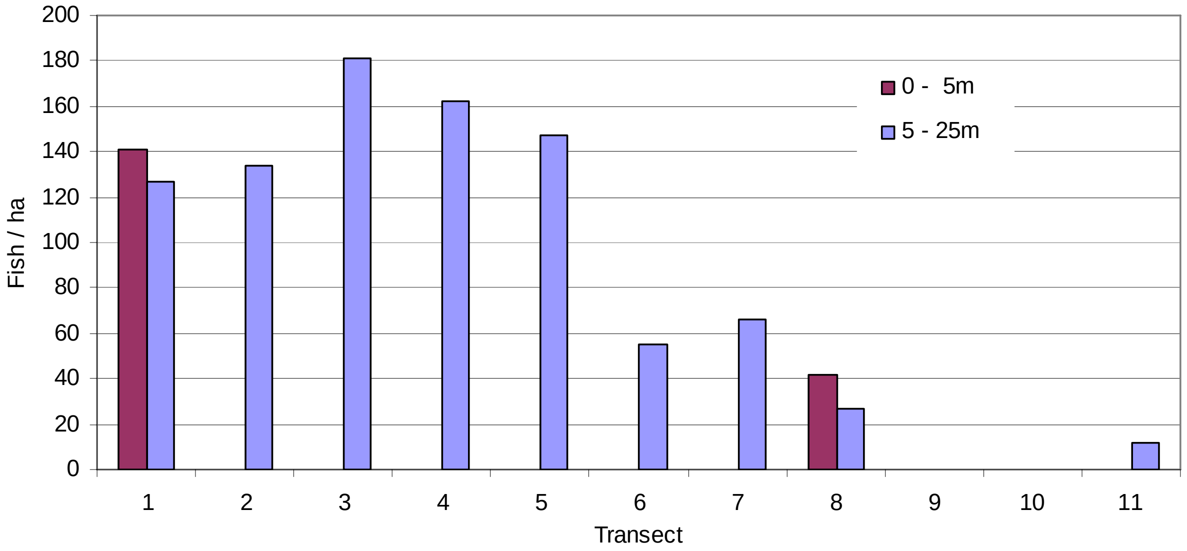

Figure 24. Wahleach Reservoir fish density distribution from acoustic survey data.

A first hand abundance estimate for all fish from the average aerial density is approximately 19,000. This is considered very low in respect of the last population estimate of 424,263 reported by Stables and Perrin in 2000 and 4 - 6 million for surveys in the 1990s. However, considering the precipitous decline between the earlier surveys and that the intent of the treatments was to reduce the stickleback population, the 2006 estimate is not out by orders of magnitude. There is a strong likelihood that the near shore habitat which was not sampled may have contained a large component of stickleback which would significantly increase the 2006 abundance estimate. From changes in seasonal G trap catch rate data there is supporting evidence that stickleback are more numerous in near shore habitats in spring and early summer than in the fall. This would be consistent with the previous survey data which surveyed into these shallow habitats. The kokanee spawner estimate for 2006 of ~9000 was also viewed to be inconsistent with the 2006 abundance estimate. If spawners for example represented 10% of the total kokanee population then there should have been approximately 80,000 kokanee in suitable reservoir habitat. From night time acoustic surveys carried out on large lakes in southern BC, kokanee are usually not found in habitats with temperatures in excess of 15°C if cooler habitats are available. In Wahleach the main fish layer as seen on echograms was found at depths greater than 5m from the surface. Temperature profile data at the time of survey indicated that the preferred temperatures < 15°C were at the depth of the main fish layer (Fig. 25). There were a very small number of targets seen above the thermocline at only two of the eleven transects and target strengths suggested these fish were small (i.e., 30 – 50mm range). A cursory assessment of target strengths from the main fish layer indicated a relatively high proportion of non-fry sized fish (eg. Age 1+ and older kokanee, rainbow trout and some cutthroat sized fish), to fry sized fish (eg. 0+ kokanee, stickleback). The proportion of very large fish targets (>300mm) was also fairly high supporting the notion that predator populations (i.e. cutthroat) are doing well.

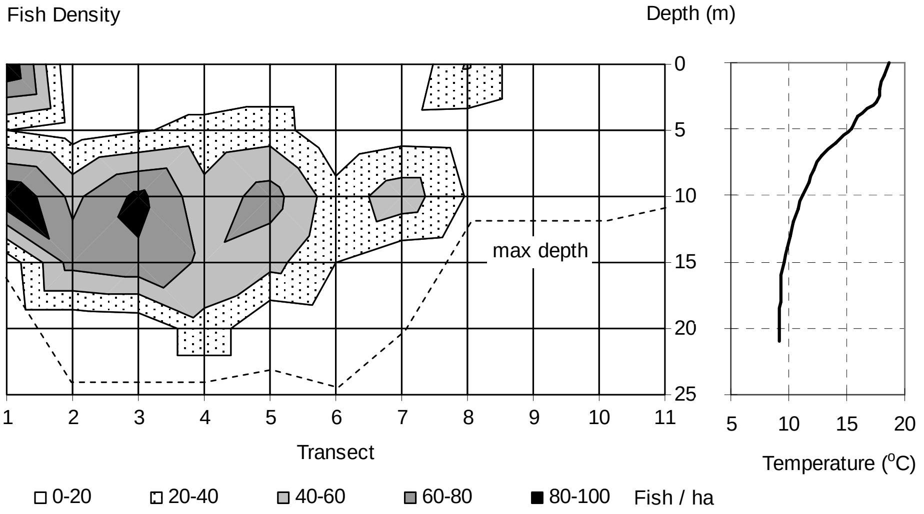

Figure 25. Wahleach Reservoir vertical fish density distribution, showing maximum bottom depth and temperature profile for July, 2006

5. Discussion

The building blocks of phytoplankton, the basis of all food chains, are carbon, nitrogen and phosphorus. Typically, although not always, phytoplankton contain these elements in ratios called Redfield Ratios, of 106 units of carbon:16 units of nitrogen:1 unit of phosphorus (Redfield 1934). As a result, in order for phytoplankton to grow, all three elements are required and if a water body is deficient in one of the building blocks then growth and ecosystem productivity are stressed and ultimately limited. While there are exceptions, the most important nutrient causing a shift from a lesser productive system to a more productive system are phosphorus and nitrogen. 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. Our fertilization strategy is utilizing this known link between nutrient loading, algal production, and food availability for planktivorous fish in the hopes that the kokanee and in turn rainbow trout stocks are successfully restored.

The importance of a monitoring component to the success of a fertilization project has long been recognized. A program monitoring the response of the ecosystem, allows for adaptive management and allows for the effectiveness of restoration strategies to be evaluated. It is not our intention to shift Wahleach Reservoir from a nutrient poor, low productivity oligotrophic system to a nutrient rich, high productivity eutrophic system. Optimally, each carbon atom assimilated should be transferred up the food chain to support higher trophic levels. Trophic classification is based on a sliding scale of productivity and uses basic parameters to determine the location of a particular lake or reservoir on the productivity scale. At the low end of the scale, lakes are called ultra-oligotrophic which are extremely nutrient poor and have low productivity while at the extreme end of the scale are nutrient rich, high productivity called hypereutrophic. Wahleach Reservoir has many users and we must ensure our restoration strategies do not negatively impact water quality for any stakeholder. It should be noted that instead of using proxy indicator parameters, one can directly determine productivity using either radio-labelled carbon, oxygen production or dissolved inorganic carbon uptake measurement, all of which require a high degree of technical expertise and considerable effort. The value of primary productivity measurements is, unlike biomass measurements that are confounded by losses such as grazing, sinking and transport or alternatively by accumulation of inedible algae, primary productivity allow for a direct assessment of the “health” or productivity of the system. Primary productivity data is not available for Wahleach, therefore, our results will be compared to criteria that are commonly used to determine the trophic state of lakes (Wetzel 2001).

Table 5 lists the range and the mean values for 4 different parameters of each trophic classification as defined by Wetzel (2001). Also included is the range and mean values found in Wahleach during the 2004–2006 period. Using this approach, Wahleach Reservoir is classified as an oligotrophic system based on TP and TN concentrations and mesotrophic based on chl *a* concentrations and Secchi depth. It should be pointed out that Secchi depth is linked to chlorophyll *a* concentrations, therefore the two parameters do not provide two separate independent assessments of trophic state. The ranges measured for chlorophyll are within the ranges reported by Perrin et al (2006). It is important to remember that large filamentous phytoplankton chains are difficult for zooplankton to assimilate and therefore when conditions favors their growth, the biomass tend to accumulate rather than being assimilated by herbivorous zooplankton. Our taxonomic analysis did identify a number of large sized phytoplankton cells, particularly in the late summer period, which were identified as carbon sinks, this may explain in part, the apparent discrepancy between the differing classification based of different parameters. Regardless, the mean and the range of the chl *a* values in Wahleach are at the low end of mesotrophy.

Table 5. General trophic state classification based on criteria defined by Wetzel (2001). All units are (µg·L^{-1}), unless otherwise stated. Highlighted cell indicates trophic classification of Wahleach Reservoir with respect to particular parameter. Table modified from Wetzel (2001).

Parameter	**Wahleach Values ***	**Trophic classification**		
		oligotrophic	**mesotrophic**	**eutrophic**
TP				
range	2 - 17	3 -18	11 - 96	16 - 386
mean	5.7	8	27	84
TN				
range	50 - 320	307 - 1630	361 - 1387	393 - 6100
mean	158	661	753	1875
Chl *a*				
range	0.9 – 6.4	0.3 – 4.5	3 - 11	3 - 78
mean	3.6 m	1.7	4.7	14
Secchi (m)				
range	2.2 – 7.1	5.4 – 29.3	1.5 – 8.1	0.8 – 7.0
mean	4.3 m	9.9	4.2	2.5

***** values based on mean of 2004, 2005 and 2006 values

Comparison with other lakes/reservoirs

Wahleach Reservoir supports a modest phytoplankton community relative to other lakes and reservoirs in BC (Table 6). The densities and biomass fall in the mid range of densities listed for lakes and reservoirs covering varying trophic classifications. Although the absolute numbers are lower than found in Arrow or Kootenay, the phytoplankton community is composed of a large fraction of edible nanoplankton (2.0-20.0 µm), the main size class filtered by *Daphnia* sp. Nutrient poor systems, such as Williston Reservoir, tend to be dominated by small unicellular picoplankton species because picoplankton have a large surface area/volume ratio that allows for highly efficient scavenging of scarce nutrients. The predominance of the picoplankter *Synechococcus* sp. suggests a major role of the microbial food web in the pelagic regions of Williston Reservoir. Unfortunately, the predominance of the microbial food web in the pelagic regions results in low forage production and sub-optimal rearing conditions for both herbivorous zooplankton such as *Daphnia* and herbivorous fishes such as kokanee. Despite higher densities in Williston Reservoir, the composition of the phytoplankton community in Wahleach Reservoir is better suited for efficient transfer of carbon up to higher trophic levels. This highlights the importance of a comprehensive monitoring program with includes phytoplankton identification.

Table 6. Comparison of phytoplankton abundance and biomass in Wahleach Reservoir with Alouette Reservoir, Arrow Lakes Reservoir, Kootenay Lake, Okanagan and Kinbasket in 2004-06. Shaded area represents fertilized systems.

System	**Phytoplankton Density** (# cells·L^{-1})	**Phytoplankton Biomass** ($mm^3 \cdot L^{-1}$)
Wahleach	2,415	0.54
Alouette	1,543	0.18
Arrow Lakes	4,806	0.72
Kootenay	5,645	1.01
Okanagan	3,249	0.74
Williston	4,650	0.30
Kinbasket	1,582	0.23

Wahleach Reservoir had lower total zooplankton densities in comparison to several other oligotrophic BC lakes (Table 7). From 2004 to 2006, Wahleach Reservoir had the lower total zooplankton density than Arrow Lakes Reservoir and Kootenay Lake, and similar densities as found in Alouette Lake. While densities of the zooplankton assemblage were low relative to other systems, the biomass concentrations in 2006 were similar.

Table 7. Seasonal average zooplankton density, biomass and percentage of *Daphnia* in zooplankton community in Wahleach Reservoir, Alouette Lake, Upper and Lower Arrow Lakes Reservoir and the North and South Basin of Kootenay Lake in 2004-2006. Values from other lakes are shown for comparison. Values are seasonal averages, calculated for samples collected between April-November in Arrow and Kootenay Lakes.

	density (#·L^{-1})			**biomass (μg·L^{-1})**		
	2004	**2005**	**2006**	**2004**	**2005**	**2006**
Total						
Wahleach	4.7	3.5	10.0	20.2	23.1	54.5
Alouette	5.9	4.2	11.5	14.9	20.3	89.9
Upper Arrow	14.3	6.7	11.6	22.4	10.4	28.0
Lower Arrow	28.7	18.9	18.6	36.0	37.2	78.0
Kootenay North	24.8	20.4	24.8	52.9	41.9	75.9
Kootenay South	28.6	20.0	24.3	54.7	43.5	73.3
Daphnia						
Wahleach	0.8	0.9	2.3	11.9	12.2	31.5
Alouette	0.00	0.6	2.7	0.03	11.29	58.41
Upper Arrow	0.1	0.1	0.6	2.05	1.18	11.49
Lower Arrow	0.3	0.9	2.3	6.29	14.82	54.63
Kootenay North	0.3	0.3	1.7	6.07	5.28	37.25
Kootenay South	0.4	0.6	1.5	6.37	10.14	35.42
***Daphnia* %**						
Wahleach	17	26	28	59	53	58
Alouette	0	14	23	0	56	65
Upper Arrow	1	1	5	9	11	41
Lower Arrow	1	5	12	11	40	70
Kootenay North	1	1	7	11	13	49
Kootenay South	1	3	6	12	23	48

Arrow Lake Reservoir and Kootenay Lake are considered to be at the more productive end of oligotrophic trophic classification due to the nutrient addition experiments occurring on both systems (Pieters et al 2003; Ashley et al 1999). Although total zooplankton densities are higher in these lakes than in Wahleach Reservoir, the densities of *Daphnia* and the percentage of the zooplankton community accounted for by *Daphnia* is numerically higher in Wahleach Reservoir than in North and South Arm of Kootenay Lake as well as in Upper Arrow, and almost at the same level as in the most productive Lower Arrow. Higher proportion of *Daphnia*, which is considered as a favourable food for kokanee, has been established in 2005 and continued to grow in 2006. One of the goals of the fertilization program, was to re-establish *Daphnia* in the zooplankton assemblage and clearly the data from 2004-2006 suggests that this goal has been accomplished.

6. Recommendations

1) Fertilization should continue to ensure optimal food availability for the stocked kokanee and rainbow trout populations. Fertilizer loading should be maintained at 200 $mg \cdot m^{-2}$ as recommended by Perrin et al (2006). The timing of the seasonal nitrogen loading needs to be shifted to prevent epilimnetic dissolved inorganic nitrogen depletion.

2) Sampling for silicic acid should be completed for the entire sampling season. Based on a limited number of silicic acid measurements (one per season), it appears that silicic acid drawdown may occur when large blooms of diatoms occurs. A better understanding of silicic acid dynamics is needed.

3) An additional water quality sampling trip needs occur between the June and July trip to allow for closer tracking of DIN concentrations. When phytoplankton are healthy they double at least once a day and therefore sampling once every 30 days during a dynamic period of the year is inadequate.

4) Size fractionated chlorophyll *a* sample should be taken to determine the relative contribution of picoplankton, nanoplankton and microplankton. Nutrient replete conditions favor the growth of diatoms that belong to the size class that are largely inedible by *Daphnia*. The phytoplankton taxonomy has shown a small bloom of large chain forming diatoms which should be monitored closely in subsequent years.

5) It is recommended that the stocking of sterile cutthroat continue to maintain “top down” control of threespine sticklebacks. It is strongly recommended that all stocked fish be marked.

6) Kokanee fecundity estimates from pre-spawning fish should be completed and regression formulas to derive fecundity from known female lengths should be derived so that estimates can be made on potential egg deposition.

7) Gillnetting sessions must occur at the same time of the year due to significantly different catch rates amongst seasons.

8) Gee traps should be set in major stump complexes and open shallow waters to assess the use of these two shallow habitats during the hydroacoustic survey period. Future hydroacoustic surveys will have to consider the seasonal near shore off shore behavior of the stickleback population, which may require some early season to fall acoustic comparisons and continuation of seasonal Gee trapping efforts.

9) In 2007, a second hydroacoustic survey will be added for the fall which will allow for comparison with historical surveys.

10) The hydroacoustic team will examine the need for a side looking acoustic survey to determine if the downward looking survey is missing near surface targets in the

deep water zone of the reservoir and to enable acoustic assessment of the near shore, shallow habitat areas. Horizontal side scanning is used when surveying shallow waters as this method samples a larger volume of water than vertical sounding. The method covers a greater area so more fish targets are detected and it’s harder for the fish to avoid the echo beam

11) A “hydroacoustic workshop” should be planned with previous contractors to discuss methodology to ensure consistency in the long term data set is maintained. A better understanding of previous acoustic surveys details would assist in determining how the change in equipment may have affected trends in acoustic population estimates. A number of questions and concerns with comparability of current and past abundance estimates and best methods to monitor species composition will be addressed in future surveys.

7. References

APHA. 1985. Standard Methods for the Examination of Water and Wastewater. 16th ed. American Public Health Association, Washington, DC.

Andrusak, H, S. Matthews, I. McGregor, K. Ashley, R.Rae, A. Wilson, D. Sebastian, G. Scholten, P Woodruff, L. Vidmanic, J. Stockner, G. Wilson, B. Jantz, J. Webster, H. Wright, C. Walters, and J. Korman. 2004. Okanagan Lake Action Plan Year 8 (2004). RD 108. Biodiversity Branch, Ministry of Water, Land and Air Protection, Province of British Columbia.

Ashley, K.I. and P.A. Slaney. 1997. Accelerating recovery of stream, river, and pond productivity by low-level nutrient replacement. *in*: Fish Habitat Rehabilitation Procedures. Watershed Restoration Program, MoELP, Watershed Restoration Technical Circular No. 9.

Ashley, K., L.C. Thompson, D. Sebastian, K.E. Smokorowski and H. Andrusak. 1999. Restoration of kokanee salmon in Kootenay Lake, a large intermontane lake, by controlled seasonal application of limiting nutrients. *in:* T. Murphy and M. Munawar. Ed. Aquatic Restoration in Canada. p. 127 – 169.

Bothwell, M.L. 1989. Phosphorus limited growth and dynamics of lotic periphyton diatom communities: areal biomass and cellular growth rate responses. Can. J. Fish. Aquat. Sci. 46: 1293-1301.

Brooks, J.L. 1959. Cladocera. pp. 587-656, *in:* W.T. Edmondson Ed., Fresh-water Biology, John Wiley and Sons, New York.

Canter-Lund, H. and J.W.G. Lund. 1995. Freshwater Algae – their microscopic world explored. BioPress Ltd., Bristol, UK, 360p.

Clarke K.K., Knoechel R. and P.M Ryan, 1997. Influence of trophic role and life-cycle duration on timing and magnitude of benthic macroinvertebrate response to whole-lake enrichment. Can. J. Fish. Aquatic. Sci. 54:89-95.

Enzenhofer, H. J., and J. M. B. Hume. 1989. Simple closing midwater trawl for small boats. N. Amer. J. of Fish. Management. 9:372-377.

Greenbank J. 2002. Jones Lake (Wahleach) Reservoir: tributary spawner enumeration and drawdown assessment. Vancouver: White Pine Environmental Resources Ltd. 18 p. Prepared for BC Hydro, Power Supply Environment.

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

Harwood, J.E., R.A. van Steenderen and A.L. Kuehn. 1969. A rapid method for orthophosphate analysis at high concentrations in water. Water Res. 3: 417-423.

Healey, F.P. 1985. Interacting effects of light and nutrient limitation on the growth rate of *Synechococcus linearis* (Cyanophyceae). J. Phycol. 21: 134-146.

Hecky, R.E. and P. Kilham. 1988. Nutrient limitation of phytoplankton in freshwater and marine environments: A review of recent evidence on the effects of enrichment. Limnol. Oceanogr. 33(4, part 2): 796-822.

Inglis, S.D. 1995. Wahleach reservoir fertilization experiment: Year 2 pre-fertilization assessment. Draft contract report prepared for B.C. Ministry of Environment, Lands and Parks. Surrey, B.C. 60 p plus appendices.

Irvine JR, J.F.T Morris and L.M Cobb. 1993. Area-under-the-curve salmon escapement estimation manual. Can. Tech. Rep. Fish. Aquat. Sci. 1932: 1-84.

Johnston N.T., M.D. Stamford, K.I. Ashley and K. Tsumura, 1999. Responses of rainbow trout (Oncorhynchus mykiss) and their prey to fertilization of an oligotrophic montane lake. Can. J. Fish. Aquatic. Sci. 56:1011-1025

Langeland, A. and H. Reinertsen. 1982. Interactions between phytoplankton and zooplankton in a fertilised lake. Holarctic Ecology. 5: 253-272.

Larkin, G.A., G.A. Wilson, K.I. Ashley, P.A. Slaney, R.W. Land, S. Biancolin and P. Davidson. 1999. Development of a Premier Northern River Fishery: Mesilinka River, The Fourth Year of Fertilization (1997). British Columbia Ministry of Environment, Lands and Parks, Fisheries Branch. Fisheries Project Report No. RD 70.

Leibold, M.A. 1989. Resource edibility and the effects of predators and productivity on the outcome of trophic interactions. Am. Nat. 134(6): 922-949.

Lund J.G., C. Kipling and E.D. LeCren. 1958. The inverted microscope method of estimating algal numbers and the statistical basis of estimations by counting. *Hydrobiologia* 11: 143-170.

McCauley, E. 1984. The estimation of the abundance and biomass of zooplankton in samples. *in:* Downing, J.D. and F. H. Rigler (Eds) A Manual on Methods for the Assessment of Secondary Productivity in Fresh Waters – 2nd Ed., Blackwell Scientific Publications, London.

McPhail, J.D. and R. Carveth. 1993. Field key to the freshwater fishes of British Columbia. Fish Museum, Department of Zoology, University of British Columbia.

Menzel, D.W. and N. Corwin. 1965. The measurement of total phosphorus in seawater based on liberation of organically bound fractions by persulfate oxidation. Limnol. Oceanogr. 10: 280-282.

Murphy, J.A. and J.P. Riley. 1962. A modified single solution method for the determination of inorganic phosphate in natural waters. Anal. Chim. Acta. 27: 31-36.

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

Perrin, C.J. 1997. Fertilization and monitoring of Wahleach Reservoir in 1996. Report prepared by Limnotek Research and Development Inc. for B.C. Hydro. 72p.

Perrin, C.J. and S. Harris. 2006. Trophic status of Elsie Lake Reservoir, 2005. Report prepared by Limnotek Research and Development Inc. and Hupacasath First Nation for Bridge Coastal Restoration Program. 50p.

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

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

Pennak, R.W. 1989. Fresh-Water Invertebrates of the United States: Protozoa to Mollusca. 3rd Ed., John Wiley and Sons, New York, 628p.

Pick, F.R. and D.R.S. Lean. 1987. The role of macronutrients (C, N, P) in controlling cyanobacteria dominance in temperate lakes. New Zealand Journal of Marine and Freshwater Research, Vol. 21:425-434

Pieters, R., L.C. Thompson, L. Vidmanic, S. Harris, J. Stockner, H. Andrusak, M. Young, K. Ashley, B. Lindsay, G. Lawrence, K. Hall, A. Eskooch, D. Sebastian, G. Scholten and P.E. Woodruff. 2003. Arrow Reservoir fertilization experiment, year 2 (2000/2001) report. RD 87, Fisheries Branch, Ministry of Water, Lands and Air Protection, Province of British Columbia.

Redfield, A.C. (1934) On the proportions of organic derivatives in sea water and their relation to the composition of plankton. *In:* Daniel, R.J. Ed., James Johnstone Memorial Volume, pp. 176-192, University Press of Liverpool.

Redfish Consulting Ltd. 1999. Performance evaluation of six Britsh Columbia kokanee spawning channels. Unpubl. Contractor report prepared for the Ministry of Fisheries, Province of British Columbia, Victoria, BC.

Rhee, G.-Y. and I.J. Gotham. 1980. Optimum N:P ratios and coexistence of planktonic algae. J. Phycol. 16:486-489.

Rigler, F.H. 1968. Further observations inconsistent with the hypothesis that the molybdenum blue method measures orthophosphate in lakewater. Limnol. Oceanogr. 13: 7-13.

Sandercock, G.A. and G.G.E Scudder. 1996. Key to the Species of Freshwater Calanoid Copepods of British Columbia. Department of Zoology, UBC Vancouver, BC.

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

Schindler, D.W. 1977. Evolution of phosphorus limitation in lakes. Science. 195: 260-262.

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

Stainton, M.P., M.J. Chapel and F.A. Armstrong. 1977. The chemical analysis of freshwater. 2nd. ed. Fish. Environ. Can. Misc. Spec. Publ. 25.

Scholz AT, White RJ, Koehler VA, Horton SA. 1992. Measurment of thyroxine concentration as an indicator of the critical period for imprinting in kokanee salmon (): Implications for operating Lake Roosevelt kokanee hatcheries. Cheney: Upper Columbia United Tribes Fisheries Research Center, Eastern Washington University. 96 p. Prepared for U.S. Department of Energy.

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

Stockner, J.G and K.I. Ashley. 2003 Salmon Nutrients: Closing the Circle. Pages 3-15 *in* J.G. Stockner, editor. Nutrients in salmonid ecosystems: Sustaining production and biodiversity. American Fisheries Society Symposium. Volume 34.

Stockner, J.G. and E.A. MacIsaac. 1996. The British Columbia lake enrichment program: Two decades of habitat enhancement for sockeye salmon. Regulated Rivers: Research and Management, Vol 12. 547-561.

Stockner J.G. and K.G. Porter. 1988. Microbial food webs in freshwater planktonic ecosystems, pp 71-84, In: Carpenter S.R. (Ed), Complex interactions in lake communities, Springer Verlag, New York, NY

Stockner, J.G., and K.S. Shortreed. 1988. Responses of *Anabaena* and *Synechococcus* to manipulation of nitrogen:phosphorus ratios in a lake fertilization experiment. Limno. Oceanogr., 33, 1348-1361.

Stockner, J.G., and K.S. Shortreed. 1989. Algal picoplankton production and contribution to food webs in oligotrophic British Columbia lakes. Hydrobiologia, 173, 151-166.

Stumm, W. and J.J. Morgan. 1981. Aquatic Chemistry: 2nd Edition. Wiley and Sons, New York. 780p.

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

Utermohl, H. 1958. Zur Vervollkommnung der quantitativen Phytoplankton methodik. Int. Verein. theor. angew. Limnologie, Mitteilungen No. 9.

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

Yeatman, H.C. 1959. Cyclopoida. pp. 795-861, In: W.T. Edmondson [Ed.], Fresh-Water Biology, Johns Wiley and Sons, New York.

Ward, B.R., and P.A. Slaney. 1988. Life history and smolt-to-adult survival of Keogh River steelhead trout (*Salmo gairdneri*) and the relationship to smolt size. Can. J. Fish. Aquat. Sci. 45:1110-1122.

Watson, S., and J. Kalff. 1981. Relationships between nanoplankton and lake trophic status. Can. J. Fish. Aquat. Sci. 38:960-967.

Wetzel, R.G. 2001. Limnology, lake and river eco-systems. 3rd edition. Academic Press, San Diego, CA.

Wilson, G., R. Land, K. Ashley, T. Berhout, F. Pick, M. McCusker, G. Scholten and D. Sebastian. 2000. MS. The Alouette Fertilization Experiment: Year two (1999) report, The first summer of fertilization. Fisheries Science Section. RD85.

Wilson, G., K. Ashley, M. McCusker, R. Land, J. Stockner, G. Scholten, P. Woodruff and D. Sebastian. 2003. MS. The Alouette Fertilization Experiment: Year 1998-2002, Final Report. Fisheries Science Section. RD99.

Wilson, M.S. 1959. Calanoida. pp. 738-794, *in:* W.T. Edmondson Ed., Fresh-water Biology, Johns Wiley and Sons, New York.

Wood, E.D., F.A.J. Armstrong and F.A. Richards. 1967. Determination of nitrate in seawater by cadmium-copper reduction to nitrite. J. Mar. Biol. Ass. U.K. 47**:** 23-31.

Appendix 1. Phytoplankton species and biovolume (B) estimates for Wahleach Reservoir.

Bacillariophytes *diatoms*	**B**	**Chryso-Cryptophyte** *flagellates*	**B**	**Chlorophytes**	**B**	**Chlorophytes**	**B**
Diploneis sp.	250	Bitrichia sp.	200	Actinastrum hantschii	125	Quadrigula	250
Fragilaria acus	100	Chilomonas sp.	500	Arthrodesmus sp.	500	Scenedesmus sp	60
Fragilaria angustissima	150	Chromulina sp1	20	Aulomonas sp.	50	Sphaerocystis sp.	250
Fragilaria sp.	250	Chroomonas acuta	150	Ankistrodesmus sp.	80	Spondylosium sp.	250
Fragilaria ulna	1000	Chryptomonas sp.	500	Chlorella	20	Staurastrum sp.	1000
Achnanthes sp.	80	Chrysidiastrum	250	Clamydocapsa sp.	1000	Staurodesmus sp.	1000
Asterionella formosa var1	100	Chrysochromulina sp.	75	Closterium	300	Tetraedron	50
Asterionella formosa var2	120	Chrysoikos sp.	75	Closteriopsis	150	Ulothrix	700
Cocconeis sp.	200	Dinobryon sp1	150	Coccomyxa sp.	150	Volvox	4000
Cyclotella bodanica	500	Dinobryon sp2	200	Coelastrum sp.	500	Willea sp.	750
Aulicoseira granulate	250	Isthmochloron	200	Cosmarium sp.	500	Xanthidium	700
Cyclotella comta	350	Kephyrion sp.	50	Crucigenia sp.	200		
Gomphonema sp.	750	Mallomonas sp1	500	Crucigeniella apiculata	700	**Dinophytes** ***Dinoflagellates***	
Ceratoneis sp.	350	Mallomonas sp2	700	Dichtyosphaerium	900	Ceratium sp.	5000
Cyclotella stelligera	150	Ochromonas sp.	250	Elakatothrix sp3	250	Gymnodinium sp1	500
Cyclotella sp	150	Pseudokephrion sp.	100	Euglena	2500	Gymnodinium sp2	1500
Cyclotella glomerata	50	Pseudopedinella sp.	150	Eudorina elegans	500	Peridinium sp2	350
Cymbella sp. (large)	500	Rhodomonas sp.	100	Franceia ovalis	350	Peridinium sp1	700
Cymbella sp.	250	Small microflagellates	15	Gleotila sp	75		
Fragilaria construens	80	Stenokalyx	75	Golenkinia radiate	250	**Cyanophytes** ***Cyanobacteria***	
Fragilaria crotonensis	120	Synura	700	Gonium	500	Anabaena sp	300
Fragilaria capucina	100	Tetraedriella patiens	120	Kirchneriella sp.	50	Anabaena circinalis	900
Aulicoseira italica	200			Langerheimia	30	Aphanothecae sp.	100
Eunotia sp.	250			Micractinium pusillum	125	Aphanizomenon sp.	1500
Diatoma sp.	150			Monoraphidium	200	Anabaaena akinetes	15
Aulicoseira distans	350			Nephrocytium	350	Merismopedia sp.	20
Aulicoseira sp.	350			Oocystis sp.	500	Oscillatoria sp2	20
Gyrosigma	150			Pandorina sp.	1500	Oscillatoria limnetica	35
Navicula sp.	500			Paulschultzia sp.	100	Synechococcus sp. (<2 um)	5
Nitzschia sp.	200			Pediastrum sp.	1000	Synechocystis	1
Pinnularia sp.	2000			Planctonema sp.	350	Lyngbya sp.	500
Pleurosigma sp.	700			Planctosphaeria	1000	Microcystis sp.	500
Rhizosolenia sp.	50						
Stephanodiscus hantschii	500						
Stephanodiscus sp.	1500						
Suriella	500						
Tabellaria fenestrate	500						
Tabellaria flocculosa	500						

Appendix 2. Mean phytoplankton density and biomass by phytoplankton classes in Wahleach Reservoir in 2004-2005. Shaded columns indicate fertilized years**.**

Abundance by Class (cells ·ml^{-1})	Mean of Stn 1 and Stn 4 2004	2005	2006
Bacillariophyceae (diatoms)	856.6	914.9	1656.4
Chryso- & Cryptophyceae (flagellates)	973.1	774.6	1471.9
Dinophyceae (dinoflagellates)	133.5	92.9	95.3
Chlorophyceae	106.4	152.1	207.8
Cyanophyceae	435.9	389.4	338.6
GRAND TOTAL	2505.5	2323.9	3769.9
% Bacillariophytes	0.34	0.4	0.34
% Chryso- & Cryptophytes	0.39	0.3	0.47
% Dinophytes	0.05	0.0	0.03
% Chlorophytes	0.04	0.1	0.05
% Cyanophytes	0.17	0.2	0.11

Biomass by Class (mm3 ·L^{-1})	Mean of Stn 1 and Stn 2 2004	2005	2006
Bacillariophytes	0.24	0.25	0.59
Chryso- & Cryptophytes	0.13	0.11	0.17
Dinophytes	0.11	0.08	0.06
Chlorophytes	0.04	0.04	0.10
Cyanophytes	0.01	0.07	0.01
GRAND TOTAL			
% Bacillariophtes	0.45	0.45	0.40
% Chryso- & Cryptophytes	0.25	0.21	0.37
% Dinophytes	0.21	0.15	0.11
% Chlorophytes	0.07	0.08	0.10
% Cyanophytes	0.02	0.12	0.02