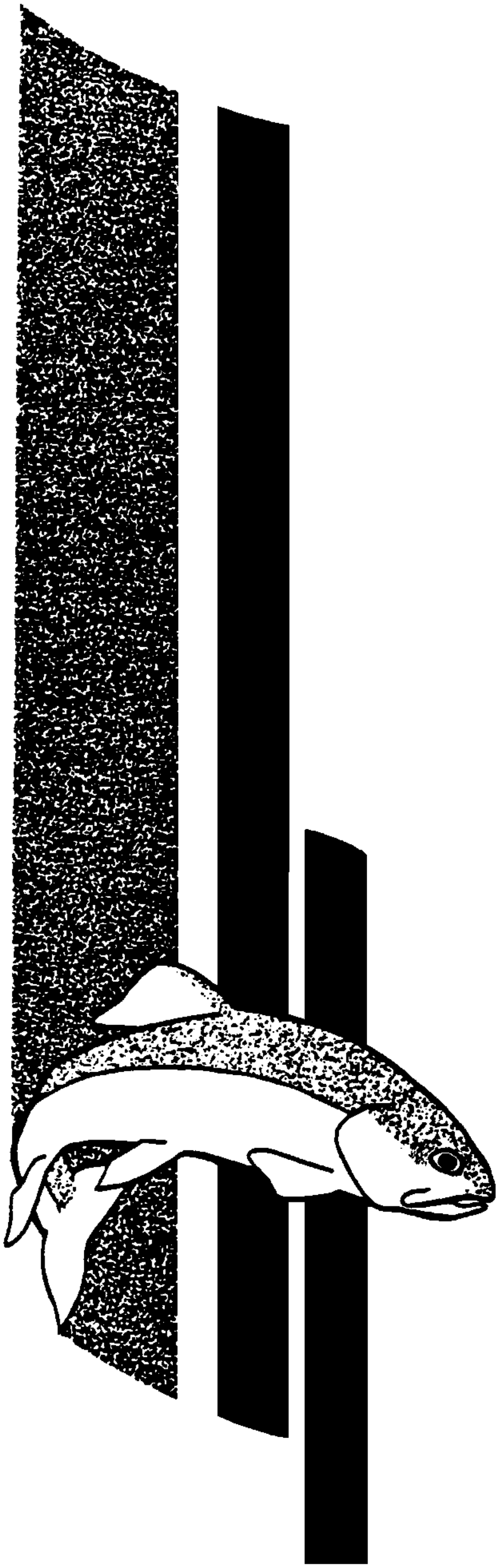

THE ALOUETTE RESERVOIR NUTRIENT RESTORATION PROGRAM, 2003-2008

by

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Executive Summary

Alouette Reservoir has been fertilized since 1999 with the goal of restoring reservoir productivity and enhancing the sport fishery. Dam construction has led to elimination of marine derived nutrients, large water level fluctuations, and an altered hydraulic regime that, collectively, have exacerbated naturally low reservoir productivity. A suite of physical, chemical and biological parameters were measured to examine the ecosystem response to fertilization from April through to October. This report summarizes results of the monitoring program for 2003-2008, with emphasis on the 2008 field season.

As in previous years, the reservoir was fertilized over a 20 week period between April and September with agricultural grade liquid ammonium polyphosphate (10-34-0: N-P_2O_5-K_2O; % by weight) and liquid urea-ammonium nitrate (28-0-0: N-P_2O_5-K_2O; % by weight). The areal loading rates in 2008 were 204 mg-phosphorus/m^2 and areal nitrogen loading rates were 1520 mg-nitrogen/m^2 with a resulting mean N:P ratio of 7.5. Areal loading rates for 2003-2007 ranged from 160-204 mg-phosphorus/m^2 and from 921-1,451 mg-nitrogen/m^2 resulting in the N:P ratio increasing from 5.1 in 2003, to 6.7 in 2004 and 2005, to 7.1 in 2006 and 2007.

The seasonal cycle of thermal stratification was typical of temperate systems. Warming of the water column was slightly delayed in 2008 as the spring was unseasonably cool. Thermal stratification developed in May and was well established by August and early September and then destratified with almost complete mixing of the water column evident by October. On average, the north basin was ~1.5°C warmer than the south basin and the mixed layer depth in both basins was approximately 6 meters. Orthograde oxygen profiles, indicative of low productivity, were observed during all years despite the addition of fertilizer. Secchi disk depth, a generalized method used to estimate phytoplankton populations and water clarity was 6.0 m in 2008, slightly less than mean values of 6.6 m for 2003-2008.

Water chemistry results indicate that the reservoir has continued to respond to nutrient additions as illustrated by elevated TP, TN and chlorophyll and despite these elevated metrics, the reservoir has remained oligotrophic. Soluble reactive phosphorus concentrations in 2003-2008 were often at detection levels, suggesting rapid uptake and assimilated by the phytoplankton assemblage. In 2006 and 2008, nitrogen limitation was generally not observed whereas in 2007, chronic nitrogen limitation was found despite similar fertilizer loading strategies from 2006-2008. Clearly other factors besides fertilizer additions in part control the ecosystem response.

The phytoplankton community in 2008 was extremely favorable for kokanee growth. Nanoflagellates (2.0-20.0 µm) accounted for ~73% of the biovolume, which are considered necessary for optimal growth of key zooplankton species such as *Daphnia sp.,* the preferred kokanee food source. This extremely high contribution of flagellates was the highest level recorded during 2003-2008. Phytoplankton cell densities were 5,480 ± 5644 cells/ml in 2008 and phytoplankton biovolume was 0.35 ± 0.40 mm^3/ml. It is not surprising that considerable interannual variability was observed in the phytoplankton community from 2003-2008 considering a differing loading strategy and variable nutrient export. The mean 2003-2008 cell densities of 5,259 cells/ml and biovolume of 0.25 mm^3/ml were 45% and 72% above pre-fertilization values respectively.

Similar to the phytoplankton community, the zooplankton community was extremely favorable for kokanee growth. Zooplankton densities and biomass reached record highs of 15.50 individuals/L and 96.78 µg/L respectively with an extremely healthy contribution by *Daphnia* sp of 2.4 individuals/L and 60.7 µg/L. Prior to fertilization *Daphnia* were largely absent from the zooplankton community. Total zooplankton abundances of 8.04 individuals/L and biovolume of 42.5 µg/L for 2003-2008 were well above pre-fertilization levels with an average 9 fold increase in density and nearly a 14 fold increase in zooplankton biomass.

The 2008 hydroacoustic survey estimated ~372,000 fish compared to ~45,000 in the pre-fertilization year, an approximate 8 fold increase. In an effort to determine species composition, pelagic gillnets were set in concert with the hydroacoustic survey. The results clearly showed that at >10 m depth, kokanee represented 95% of the total catch with pikeminnow, rainbow and cutthroat comprising the remaining 5%.

Kokanee are of particular importance because they are the keystone species in the reservoir. As well, they are an important component of the sport fishery and may be vital to the restoration of sockeye salmon in the watershed. In 2008, the mean length of gillnet caught kokanee (primarily 2+ and 3+) was 272 mm and mean weight was 292 g compared to 223 mm and 127 g for the pre-fertilization period, representing a 22% increase in length and a 129% increase in weight. Condition factor was also at a record high at 1.67 for 2+ kokanee and 1.44 for 3+ fish. A linear mixed model demonstrated that the length of 3-year-old kokanee has increased significantly with fertilization ($p=0.039$). It is noteworthy that the models' results were substantially improved by the inclusion of annual phosphorus loading levels ($p=0.011$).

The comprehensive monitoring program suggests the Alouette Reservoir pelagic community continues to respond to fertilization. There is a strong linkage between fertilizer loading and community response as demonstrated by modelling. This supports the hypothesis of the Alouette Reservoir Nutrient Restoration Program that supplemental nutrient additions have increased reservoir productivity by being incorporated into the food chain.

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1. Introduction

Hydro developments in British Columbia during the 1950s to the 1970s have been greatly beneficial in supplying the province with relatively inexpensive electricity. A consequence of these projects has been the formation of large reservoirs that usually are quite unproductive and comparable to many interior oligotrophic large lakes or ultra-oligotrophic coastal lakes (Stockner and Shortreed 1985; Stockner 2003). Over the last four decades both the federal and provincial fisheries agencies have adopted nutrient addition strategies to restore and or enhance a number of these unproductive lakes and reservoirs. Most of these experiments involve additions of phosphorus and nitrogen during the growing season. The Alouette Reservoir Nutrient Restoration Project draws on nearly 40 years experience of lake and stream fertilization efforts in British Columbia (Stockner 1981, Stockner and MacIsaac 1996, Stockner and Ashley 2003). This project addresses some of the ecological consequences of the Alouette-Stave-Ruskin hydroelectric system and was initiated as part of the Stave Falls Disposition Order.

Funding is provided by BC Hydro and the project is implemented in partnership with the Ministry of Environment. Personnel, scientific equipment and scientific guidance are provided by MOE and in-kind support is provided by the Ministry of the Attorney General (Alouette River Correctional Unit). Project goals are to: 1) compensate for the potential increase in entrainment and turbine mortality due to the new Stave Falls Power Plant Replacement Project and 2) enhance the Alouette Reservoir sport fishery and 3) enhance the productivity of Stave Reservoir in the vicinity of the Alouette Powerhouse. The first five years of the project, 1998-2002, constituted the experimental phase, necessary to determine if the goals were achievable with fertilization. Initial results have been documented by Wilson et al. (2000), Harris et al. (2007) and given the success observed to date, fertilization has become an annual activity.

Under the terms of the Disposition Order, nutrient restoration is scheduled for 70 years until 2068. The annual monitoring program includes all trophic level responses to nutrient additions. One year of baseline data was collected in 1998 prior to the initiation of nutrient additions in 1999 when only the north basin was fertilized. Whole reservoir fertilization has been conducted during the growing season from 2000 to 2008.

From a scientific perspective the monitoring will greatly add to the science of ecosystem restoration. There is a growing amount of technical information being accumulated on large lake and reservoir restoration projects such as Kootenay Lake fertilization (Ashley et al. 1997a; Schindler et al. 2007a) and the Arrow Lakes Reservoir fertilization (Schindler et al. 2007b). Results from this program will add to this knowledge base and assist BC Hydro and the MOE in their large scale reservoir restoration efforts.

This report presents data from 2008 and compares it with trends observed from the 2003-2007 data. The expectation is that fertilization through nutrient transport up the food web should enhance phytoplankton and zooplankton productivity leading to higher than pre-fertilization fish biomass, particularly kokanee (*Oncorhynchus nerka).*

2. Background

From 1925 to 1928, the forerunner to BC Hydro, the BC Electric Company, built the Alouette Dam across the South Alouette River at the downstream end of the original two Alouette lakes. Subsequent increase in water level joined the two lakes and flooded portions of the South Alouette River and tributaries. Most of the reservoir outflow was diverted from its natural outflow to the Alouette River to a subsurface tunnel connected to Stave Reservoir at the north end. This diversion likely resulted in annual net export of phytoplankton, zooplankton and fish out of the Alouette Reservoir into Stave Reservoir.

Dam construction had a direct effect on nutrients and productivity. The reservoir acts as a nutrient sink, increasing sedimentation rates and reducing productivity of the littoral areas that are subject to large environmental changes with reservoir drawdown (Friedl and Wuest 2001, Stockner and Ashley 2003). The combination of these factors has resulted in a reservoir with unnaturally low productivity, and little ability to support the historical abundance of fish, a process recently termed “cultural oligotrophication” (Stockner et al. 2000).

In addition, the dam prevented the returns of sockeye (*O. nerka*), chinook (*O. tshawytscha*), coho (*O. kisutch*), chum (*O. keta*), and pink (*O. gorbuscha*) salmon, as well as steelhead (*O. mykiss*), and cutthroat trout (*O. clarki*) to their spawning habitats above the dam, resulting in localized extinction. These salmon acted as natural ‘fertilizer’ in these lakes, streams, and rivers; their carcasses ensuring a continuous nutrient supply for both the anadromous and resident fish populations in the watershed, as has been documented in similar systems (Larkin and Slaney 1996, Cedarholm et al. 1999). With migration blocked, this natural nutrient load to the reservoir was eliminated.

Details of the natural history of the reservoir area, historical salmon escapement to the system and the reservoir’s management history can be found in Wilson et al. (2003).

3. Study Site

Alouette Reservoir is a moderately large reservoir, 1,666 ha at full pool, located in the Coast Mountains at 49°17´N, 122°29´W, about 16 km northeast of Maple Ridge, in a steep-sided glacial trench. The reservoir is comprised of two basins joined by a narrow section approximately 9 km upstream from the dam (Figure 1). The west shore and part of the southeast shore of the south basin are within Golden Ears Provincial Park.

Approximately 16 permanent tributaries flow into the reservoir (MELP, 1980), including the major tributaries Gold Creek, Moyer Creek (both 3rd order streams), and the upstream portion of the South Alouette River (4th order stream). The reservoir shoreline is generally steep, with narrow littoral areas often composed of sand, gravel and boulders. The widest littoral areas are the alluvial fans at the mouths of the larger tributaries and at the south end adjacent to the dam (Figure 1).

Elevations of the Alouette Reservoir range between 125.51 m (full pool), above which water flows over the crest of the dam spillway, and the minimum elevation of 114 m, based on licensed storage, providing 147 x 10^6 m^3 of active storage volume (Table 1). The normal minimum operating level is 116 m due to turbidity problems with the low level outlet flows when the reservoir level drops below 116 m (BC Hydro, 1996). A spring surface release occurs from April 15th to June 14th. The reservoir elevation is kept above 122.5 m from June 15th to Labour Day (Sept 5th) for recreational purposes. The new water use plan allows for a short shoulder season where the reservoir elevation will be at 121.25 until September 15.

Table 1 Alouette Reservoir morphometric data.

	original lakes	full pool	min. operating level	north basin	south basin
surface elevation (m)	113	125.51	116	123[a]	123[a]
area (ha)	1,410	1,666	1,494	491	1,131
total volume (m^3 x 10^6)	-	1,306	1,151	-	-
active volume (m^3 x 10^6)	-	147	0	-	-
length, max (km)	-	-	17[b]	6.7	10.0
width, max (km)	-	-	1.6[b]	1.2	1.6
width, mean (km)	-	0.95	0.87	0.73	1.13
depth, max (m)	-	152	141	149	138
depth, mean (m)	-	78.4	77.2	-	-
shoreline (km)	-	-	37.5[b]	-	-

Source: Burrard Power Company (1923), BCF (1980), BC Hydro Survey and Photogrammetry Dept.
[a] average summer elevation [b] from BCF map at reservoir elevation of approx. 117 m.

Winters are generally mild and wet, and summers are mild and dry (Hare and Thomas 1979). The heavy winter rainfalls in the Coast Mountains create large winter snowpacks (Cannings and Cannings 1996). Due to the moderating influence of the ocean, temperatures along the southern coast of B.C. seldom fall below freezing in the winter or exceed 25°C during the summer.

Logging and forest fires in 1926 and 1931 removed most of the old-growth forest from the Alouette drainage basin (Driver and Spurgeon 1998) and the second growth forest consists of Douglas fir, western hemlock, western red cedar, lodgepole pine (*Pinus contorta*) and red alder. Due to flooding, submerged and partially-submerged stumps, deadheads and standing trees are found along most of the near shore regions.

Fish species in the reservoir include the following species: Rainbow trout (*Oncorhynchus mykiss*), Cutthroat trout (*O. clarki*), kokanee salmon (*O. nerka)*, Lake trout (*Salvelinus namaycush)*, Bull trout (*S. confluentus*), Redside shiner (*Richardsonius balteatus*), Peamouth chub (*Mylocheilus caurinus*), Northern pikeminnow (*Ptychocheilus oregonensis*), Large scale Sucker (*Catastomus macrocheilus*), Lake chub (*Couesius plumbeus*), Threespine stickleback (*Gasterosteus aculeatus*) and unidentified species of Sculpins. Earlier studies had identified Dolly Varden (S*alvelinus alpinus malma*) in the reservoir, but these were conducted before Cavender (1978) proposed that Dolly Varden be separated into two species, Dolly Varden (*Salvelinus malma*) and bull trout (S*alvelinus confluentus*). Haas and McPhail (1991), who developed methods to distinguish between the two species in the Northwest, identified the species in the main Alouette tributary of Gold Creek as bull trout. A historical record of fish stocking in Alouette Reservoir is provided in Appendix A.

4. Methods

4.1 Fertilizer Additions

The reservoir is fertilized with inorganic phosphorus and nitrogen using blends of agricultural grade liquid ammonium polyphosphate (10-34-0: N-P_2O_5-K_2O; % by weight) and urea-ammonium nitrate (28-0-0: N-P_2O_5-K_2O; % by weight). In 2008, 19.6 MT of 10-34-0 and 76.1 MT of 28-0-0 were added to Alouette Reservoir (Table 2). The annual phosphorus loading rate was 204 $mg \cdot P/m^2$ and the annual nitrogen loading rate was 1520 $mg \cdot N/m^2$, which was the same phosphorus loading rate utilized in 2006 and 2007. Perrin et al. (2006) recommend at least 200 $mg \cdot P/m^2$ for the production of the *Daphnia* sp., which are crucial for sustaining kokanee. This loading rate falls within the range applied to other oligotrophic lakes (102–164 $mg \cdot P/m^2$ by Langeland and Reinertsen (1982), 27-100 $mg \cdot P/m^2$ by Clarke et al. (1997), 100–600 $mg \cdot P/m^2$ 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).

The fertilizer blends were mixed by the distributor and delivered in bulk to the tank farm throughout the fertilization period. The tank farm, with a holding capacity of 40,000 liters, is located at BC Correction's Bell-Cor net pen facility on the east shore of the lake (Figure 1). Fertilizer applications occur once a week for twenty weeks between the end of April - September. Fertilizer was transferred from the tank farm to a temporary holding tank located on the landing craft by a crew from BC Corrections (inmates and guards). The north basin fertilizer application zone is located between the Corrections Facility and the north basin sample site, and the south basin zone from approximately 300 m north of the boat launch to the south basin site (Figure 1). The fertilizer boat travels at 15-20 km per hour (determined using a GPS system) while following a sinuous course through the application zone. Fertilizer is pumped from the boat with a battery powered bilge-pump (rated 757 L/hr) through a 2.5 cm I.D. hose into the prop-wash. Rapid mixing of the fertilizer at the surface is necessary to prevent sinking out in the epilimnion, since the fertilizer has a specific gravity approximately 1.4 times greater than water. Good mixing is also achieved by varying the flow rate of the fertilizer and the boat speed. Water is added to the fertilizer when additions are < 200 liters to ensure coverage of the entire fertilization zone. Average application rates in 2008 were 28 L/minute, and ranged from 10 to 40 L/minute with the occasional peak of 90 L/minute.

The fertilizer blends, timing of the additions, and the amounts added to each basin were intended to mimic the natural spring phosphorus loadings to the lakes, compensate for biological uptake of nitrogen, and maintain a nitrogen to phosphorus (N:P) ratio for optimum growth of edible algae. The weekly phosphorus loading increased progressively from 6 mg-P/m^2 at the end of April to 19.5 mg-P/m^2 in late May and then decreased to 4.2 mg-P/m^2 in September (Figure 2). Weekly nitrogen additions were approximately 4 mg-N/m^2 in the spring and increased in mid-summer to 117 mg-N/m^2, then decreased to 65 g-N/m^2 in early fall (Figure 3). The annual amount of N loaded to the reservoir has increased in recent years to reflect rising concerns around N-limitation.

Table 2 Annual fertilizer additions to the Alouette Reservoir, 2003-2008.

Year Dates	Basin	Fertilizer added		Phosphorus		Nitrogen	
		10-34-0 (mt)	28-0-0 (mt)	(kg)	(mg/m^2)	(kg)	(mg/m^2)
2003 (Apr 22 – Sept 1)	north	5.9	14.0	882	180	4,521	921
	south	13.7	32.4	2,031	180	10,425	921
	total	19.6	46.4	2,913	360	14,946	1,842
2004 (Apr 22 – Sept 1)	north	5.3	16.9	785	160	5,272	1,074
	south	12.2	39.0	1,809	160	12,144	1,074
	total	17.5	55.9	2,594	320	17,416	2,148
2005 (Apr 24- Sept 4)	north	4.3	17.0	785	160	5,276	1,075
	south	9.9	39.1	1,809	160	12,154	1,075
	total	14.2	56.0	2,594	320	17,430	2,150
2006 (May 8- Sept 11)	north	6.7	23.0	1,002	204	7,124	1451
	south	15.5	53.1	2,307	204	16,535	1451
	total	22.3	76.1	3,309	408	23,535	2,902
2007 (May 8- Sept 04	north	6.7	23.0	1,002	204	7,124	1451
	south	15.5	53.1	2,307	204	16,535	1451
	total	22.3	76.1	3,309	408	23,535	2,902
2008 (April 28- Sept 08)	north	6.7	24.2	1,002	204	7,464	1520
	south	15.5	55.9	2,307	204	17,192	1520
	total	22.3	80.1	3,309	408	24,656	3040

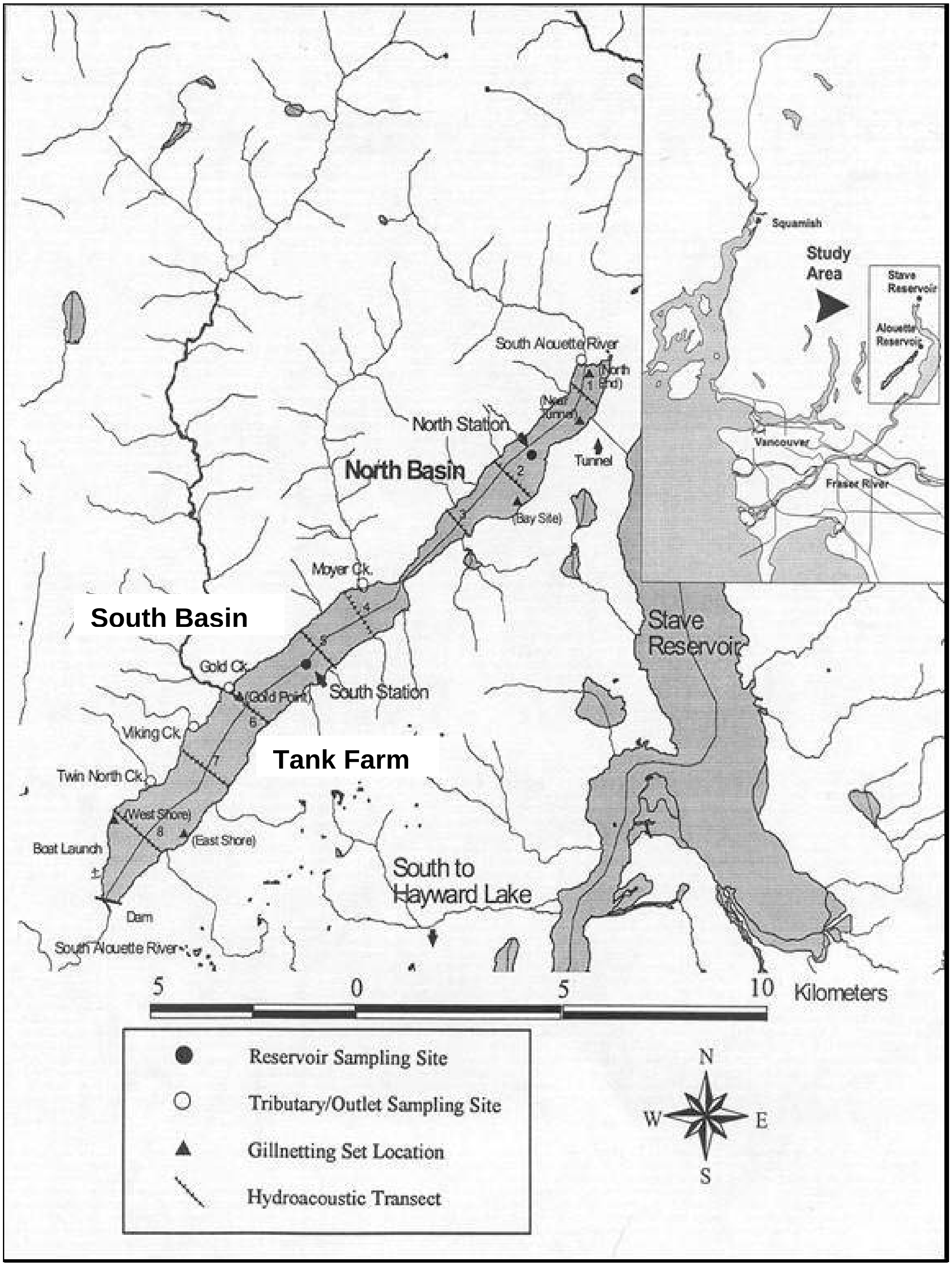

Figure 1 Map of Alouette Reservoir showing sample sites.

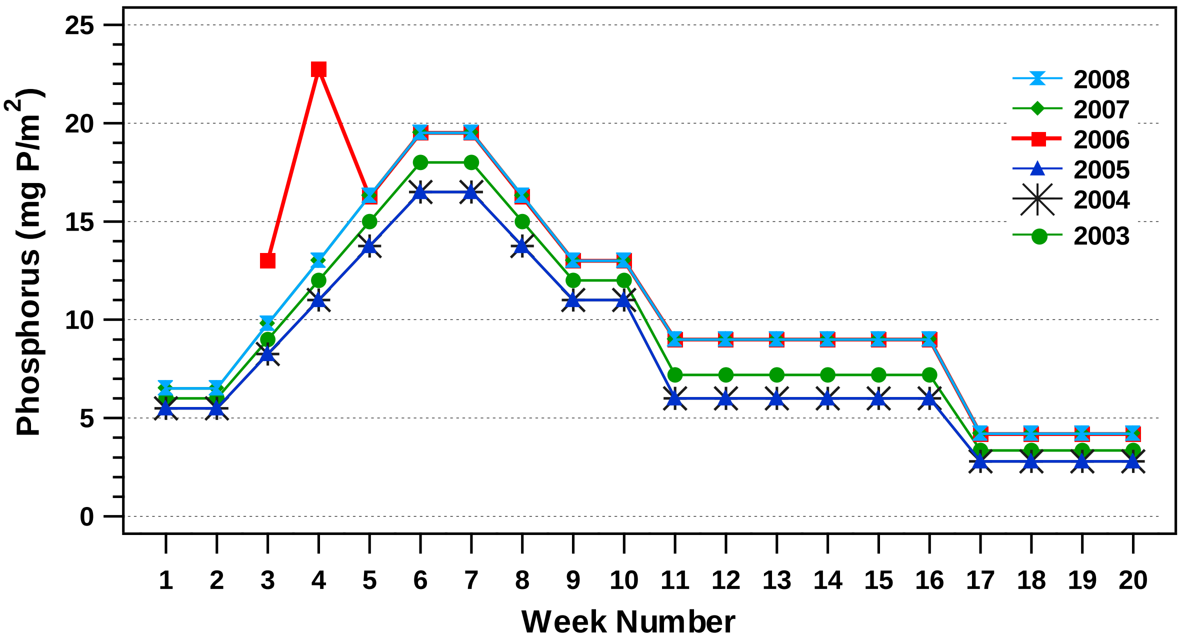

Figure 2 Areal phosphorus loading rates to Alouette Reservoir, 2003-08 in the north and south basins.

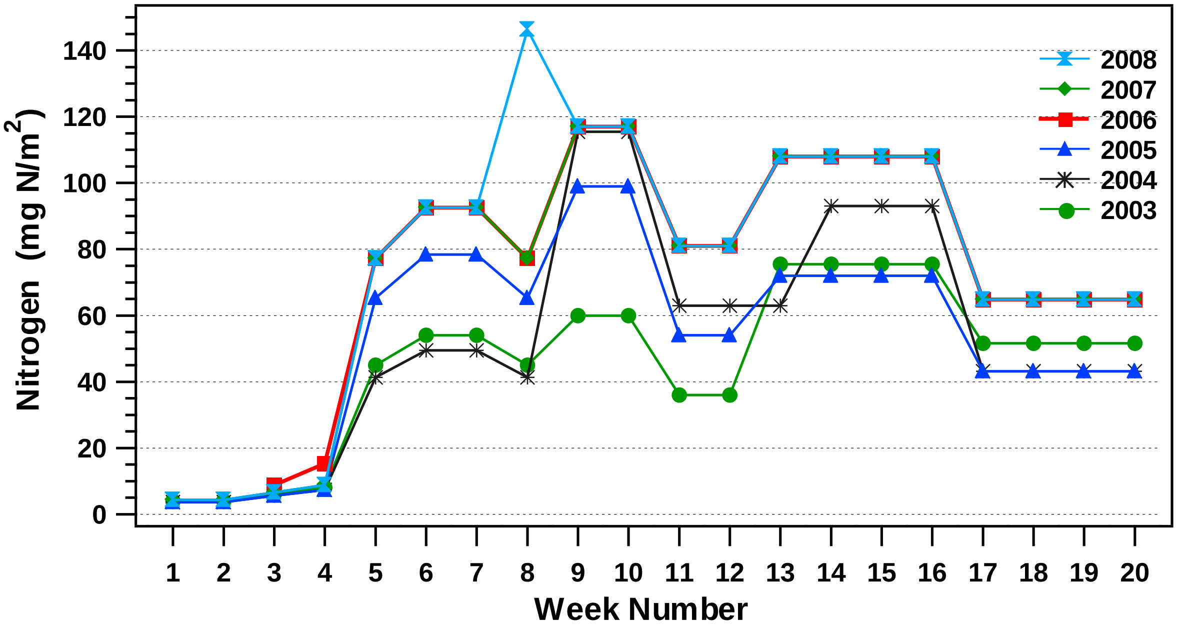

Figure 3 Areal nitrogen loading rates to Alouette Reservoir 2003-08 in the north and south basins.

The 2008 program was aimed at maintaining the annual N:P ratio (weight:weight) of the added fertilizer at 7.5, which was slightly higher than the N:P ratio of 7.1 used in 2006 and 2007. The resulting N:P ratio of the fertilizer is precisely controlled, and increased steadily from 0.67 in April to 15.0 in September (Figure 4). In 2008, the N:P ratios were increased starting in week 5 of the nutrient restoration experiment to compensate for strong nitrogen drawdown that usually begins at the end of June and early July. N:P ratios are conservative because high N:P ratios are associated with blooms of large filamentous diatoms, which are unpalatable to zooplankton and are considered nutrient sinks (Stockner and Hyatt 1984; Stockner and Shortreed 1988).

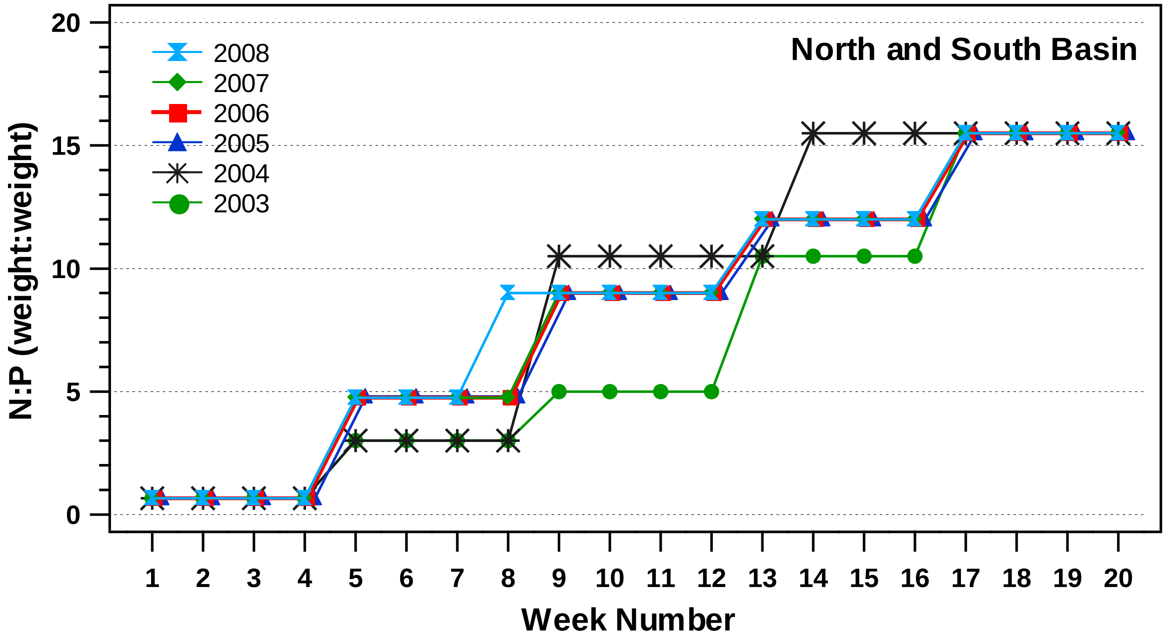

Figure 4 Areal nitrogen:phosphorus ratios (weight:weight) to Alouette Reservoir 2003-08 in the north and south basins.

4.2 Sample Sites

One monitoring site was selected in the north basin (N 49° 22.400 W 122° 20.535; EMS ID#E270283) and one in the south basin (N 49° 19.610 W 122° 25.424; EMS ID#E254169) (Figure 1). The sites were located at maximum depths and near the middle of each basin.

4.3 Climate

Temperature and precipitation data were provided by BC Hydro from a weather station near the Alouette Reservoir dam. The mean of maximum and minimum temperatures for each day were calculated and reported as monthly means. Precipitation is reported as monthly averages.

4.4 Reservoir Operations

Reservoir operations data were provided for 1984-2008 by BC Hydro. Average daily inflow to the Alouette Reservoir, outflow via the low level outlet to the South Alouette River, outflow via the spillway to the South Alouette River, discharge via the crest gate of the Alouette Dam to the South Alouette River, discharge to Stave Reservoir, and day end elevations are reported. Epilimnetic volume and the volume of water from the surface of the reservoir to the thermocline were averaged for May to October to determine the annual volume.

4.5 Physical and Chemical samples

Vertical profiles of dissolved oxygen (mg/L) and temperature (ºC) were taken *in situ* at 1 m intervals with an YSI 550A meter, air-calibrated on site. Water transparency was measured with a standard 20-cm Secchi disk depth on the shady side of the boat without a viewing chamber.

Three water samples were collected: at 1 m and 80 m with a Van Dorn water sampler and from the epilimnion with tygon tubing. The samples were immediately stored in the dark and on ice until delivery to the laboratory. Samples were collected for pH, TP (total phosphorus), TDP (total dissolved phosphorus), SRP, (soluble reactive phosphorus), TN (total nitrogen), nitrate + nitrite-nitrogen (NO_3 + NO_2-N) and occasionally for silicic acid. The dissolved fractions were field filtered through a 0.45 µm sterile Sartarous filter. Analysis was completed by Maxxam (nee Philips Science Center) Laboratory, Burnaby, BC. 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). TDP included orthophosphate, polyphosphates and organic phosphates (Strumm and Morgan 1981) and SRP included the orthophosphate ion and acid-labile P compounds (Harwood et al. 1969) and may overestimate biologically available P (Rigler 1968, Bothwell 1989).

Chl *a* samples were collected from the epilimnion and analyzed by *in vitro* fluorometry (Yentsch and Menzel, 1963). It is important to correct for phaopigment concentrations which may equal or exceed functional pigment. Water samples (0.15-0.75 L) were filtered using parallel filtration onto 47-mm diameter 0.45 μm cellulose acetate filters using a vacuum pressure differential of <100 mm of Hg. Samples were stored at -20^{o}C prior to analysis in 5 ml of 90% acetone and stored in the dark for 20-24 h. The fluorescence of the acetone extract was measured before and after the addition of three drops of 10% HCl in a Turner Designs™ Model 10-AU fluorometer calibrated with a solution of commercially available Chl *a*. Calculations for Chl *a* were made using the equations of Parsons et al. (1984). The average phytoplankton biomass of the euphotic zone was determined by calculating the mean of all sampling depths. Areal biomass (mg/m^2) was calculated by vertically integration of all depths according to procedures of Ichimura et al. (1980)

4.6 Phosphorus Budget

Natural inputs and exports of phosphorus may indicate trophic state but may also impact ecosystem response to fertilizer addition. Calculation of the phosphorus budget may aid our understanding of the systems response and may help explain year-to-year variation in reservoir biology. Loading and export values for TP were calculated for the April-September period.

Estimates of nutrient loading from the tributary streams are currently not undertaken so mean nutrient concentrations from the tributaries for 1998-2002 were used for calculation of loading values for 2003-2008. Nutrient concentrations below the detection limit were assigned a value of half the detection limit. Ungauged inflows were estimated as 54% of the total B.C. Hydro inflow values (Wilson et al*.* 2003). Daily nutrient concentrations in the ungauged inflow were estimated from a five year average of all nutrient concentrations measured in the South Alouette River and Moyer and Gold creeks. The concentrations from Viking and Twin North creeks were excluded because these tributaries flow from the only developed area of the watershed, whereas most of the ungauged inflow is assumed to originate from recently undisturbed areas.

Daily export values were calculated from the daily average outflow values to the South Alouette River and discharge to Stave Reservoir. Nutrient concentrations in the discharge to Stave Reservoir were assumed to be the same as those recorded in the north basin epilimnetic (composite) water samples and concentrations in the outflow to the South Alouette were assumed to be the same as those recorded in the south basin epilimnetic (composite) water samples. These values were extrapolated from nutrient concentrations in monthly water samples over the days between sample collections and summed to obtain annual values.

Loading and export values were calculated for the April-September period, which covers approximately 31% of the total annual inflow, because water chemistry data and stream discharge values were only available for this period. Winter loading values was assumed to be inconsequential, as Alouette functions similarly to a run-of-the-river reservoir during winter and early spring when thermally destratified (Wilson et al. 2003). During April-September, however, outflow is at its lowest and the reservoir stratifies and acts more like a lake, with considerably longer water residence time.

Calculation of the nitrogen budget is on file.

4.7 Phytoplankton Enumeration

A depth integrated sample of the epilimnion was collected in glass amber bottles, preserved with acid-Lugol's solution, and stored in a cool and dark location until analysis. 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 small nanoflagellate (2.0-20.0 μm) 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 biovolume estimates for Alouette Reservoir appears in Appendix B.

4.8 Zooplankton

Duplicate macrozooplankton samples were collected from 0-20 m 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 net was raised at a speed of ~0.5 m/sec. 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 and cladoceran fecundity (data on file). Samples were re-suspended in tap water filtered through a 74 µm mesh and sub-sampled using a four-chambered Folsom-type plankton splitter. Splits were placed in gridded plastic petri dishes and stained with Rose Bengal to facilitate viewing with a Wild M3B dissecting microscope (at up to 400X magnification). 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. *Daphnia* spp. was not identified to species for density counts. Zooplankton species were identified with reference to taxonomic keys (Sandercock and Scudder 1996, Pennak 1989, Wilson 1959, Brooks 1959).

4.9 Fish Populations

Monitoring the fish population response to nutrient restoration utilized a combination of floating and sinking gillnets to determine species composition, presence/absence, size-at-age, relative biomass estimates and catch per unit effort data. This information is then combined with acoustic and trawl survey data to establish trend information on the key fish populations.

All near shore gillnetting has been conducted during late September or early October except in 1998 when the project started and gillnetting was delayed until November. Gillnetting generally has taken place before temperature destratification and water temperatures usually have ranged from 17°C to 20°C except for 1998 and 2002 when gillnetting was conducted in water ~10°C. Nets are set overnight (from approximately 16:00-10:00 h) at each of six sites in the reservoir, three in each of the north and south basins (Figure 1). At each site, two nets were set: a floating 'experimental' net composed of six different standard mesh sizes (31, 41, 64, 76, 79, and 100 mm) each in 3.0 m panels, and one sinking net with 15.2 m (50 ft) panels of identical mesh sizes. Two sizes of floating 'experimental nets' are used; the shallow experimental nets (XS) are 2.4 m (8 ft) deep and the deep experimental nets (XD) are 6.1 m (20 ft) deep. Two panels of experimental net are set at each location: XS-XD is set at the North End, Bay, Gold and West shore site and XD-XD is set at the Tunnel and East shore site. All sinking nets used for near shore gillnetting are 2.4 m deep and 91.4 m in length (or 8 ft x 300 ft). Nets are extended perpendicular from the shore; floaters from shoreline and sinking nets from approximately the 6 m depth contour. Total area of nets set each year has been 3746 m^2 except in 2004 when only 2811 m^2 was fished owing to damaged nets. Fish numbers caught and their biomass for 2004 were adjusted to reflect the lesser amount of nets used.

The annual gillnetting program has been standardized using the same nets, same soak times (~18 hours) and amount of net therefore "net sets" referred to herein represent the sum of all netting results for that year. CPUE was calculated on the basis of the amount of net (m^2) fished; area of net fished was adjusted if number of nets varied as was the case in 2004. Due to the small sample size of some species, not all species results are summarized (e.g. lake char). In 2008 the standardized gillnetting protocol was conducted during September 17-19th; additional netting in the pelagic area was undertaken October 2-3, 2008. This additional pelagic netting was designed to identify species composition and distribution within this habitat type, therefore the results are reported separately.

Captured fish were identified using the field key of Freshwater Fishes of British Columbia (McPhail and Carveth 1992), with fork length and weight recorded using either an electronic balance, or a spring scale for fish >600 g. Condition factors were calculated as: $W\ (g) \times 10^5 / L\ (mm)^3$.

Scale samples and or otolith samples were taken for select species as well as some stomach contents; maturity stage (immature, maturing, mature, spawning, spent) was visually determined for all kokanee, bull trout, and lake trout, and representative samples of rainbow and cutthroat trout. Scale samples were taken, processed, and read as described in Ward and Slaney (1988). Scales were pressed into acetate and the imprint read under 30x magnifications, with age determined by counting annuli. In some years otoliths were also taken from bull trout, cutthroat trout, lake trout and kokanee for ageing purposes by counting annuli under a microscope at appropriate magnification.

File data was obtained for gillnetting sampling that occurred in 1985-1987. Knight (1987) summarized the 1985 and 1986 data but the 1985 data was very limited, not comparable and therefore was not used in this report.

Hydroacoustic surveys

ALR fish populations have been monitored annually since 1998 by means of hydroacoustic and trawl surveys. The data provides general trends in fish distribution and abundance in the pelagic zone and reflects a cumulative response to reservoir fertilization. A detailed summary of methods for the hydroacoustic and trawl surveys is provided by Harris et al. (2007).

An effort is made to complete the nighttime surveys at times of similar pool elevation (limnetic area) and thermal stratification (Table 3) and in 2008 the surveys were conducted on October 6-7th. The acoustic surveys consist of 8 standard transects, 3 in the northern basin and 5 in the southern basin (Figure 1). Survey data were obtained using a Simrad model EY500 120 KHz split beam system. The Simrad system was calibrated in the field at the beginning of the survey; specifications are found in Appendix E. Prior to 2008, survey data were also collected using a Simrad 70 kHz single beam sounder; this equipment was retired in 2008.

Split beam data was analyzed using Sonar 5 post processing software version 5.9.8 described by Balk and Lindem (2008). Habitat was stratified by 5 m depth layers and then further stratified into relatively homogeneous zones within each basin using density depth contour plots. Stratum areas for each transect, zone and depth layer were derived from reservoir bathymetry and adjusted for pool level at the time of survey (Table 3, Appendix F). Summaries of fish density by transect for fall survey years are presented in Appendix G. As in previous years, Monte Carlo simulations were used to combine all depth and zone strata into a single Maximum Likelihood Population estimate (MLE) with bounds for all fish in pelagic habitat and for the fish >75 mm in pelagic habitat (Appendix H)

Fish size distributions were estimated by the split beam method as described by Simmonds and MacLennan (2005). The fish densities in number/ha for each transect and depth strata were output in 36 1-decibel (dB) size groups from -62 to -26 dB using Sonar 5 software and compiled on a Excel spreadsheet. Each density by transect, depth and size group was then expanded by the estimated area of habitat at depth to develop a size specific population estimate for the reservoir.

Fork lengths of gillnet and trawl caught fish were converted to an acoustic size equivalent using Love's (1977) empirical dorsal aspect relation (Appendix I) and then compared with acoustic size distributions**.** Love's 45 degree aspect relation did not match the acoustic size data to gillnet measured lengths as well as the dorsal aspect equation, so the latter was used. The resulting distributions were used to verify appropriate size cut-off points for separating fry from older fish. The smaller size group (i.e.<75 mm) represented stickleback, age 0 kokanee and redside shiners while the larger size group (i.e. >75mm) represented age 1-3 kokanee, smaller numbers of 1+ redside shiners and cutthroat trout, rainbow trout and northern pikeminnow.

Pelagic gillnetting

Throughout the study it has been assumed that most of the pelagic fish are nerkids based on acoustic surveys on a number of large lakes and reservoirs. There has always been uncertainty surrounding this assumption since Alouette supports such a wide variety of fish including sticklebacks and shiners which are known to be pelagic in some systems such as in Wahleach Reservoir (Perrin et al. 2006). In an effort to expand species composition and vertical distribution data, pelagic gillnet sampling was completed. Pelagic gillnets were set at 2 stations in the north basin and three stations in the south basin at 0, 10, 15 and 20 m on October 2-3rd.

Trawl sampling

As in previous years, the trawl gear consisted of a 20 m long opening and closing 3 m x 7 m beam trawl with graduated stretched mesh sizes of 6 to 92 mm towed at ~0.83 m/s. Trawl net depth was measured with a Notus net sensor system. Target depths for trawling were determined from a preliminary analysis of acoustic data. The sampling strategy was changed in 2008 in order to sample some discrete layers to assist in determining species composition since all previous year's trawl sampling had produced very few age 0+ fish and captured no older fish. On October 7, 2008 two stepped oblique trawls were performed with the intention of capturing a representative sample of age classes and species composition across the entire fish layer. As this method proves challenging to acquire adequate numbers of fish when densities are low, two directed trawls were also carried out at depths targeting specific fish layers, deciphered from hydroacoustic observation. One directed trawl was focused on the upper layer above the thermocline (2-9 m) while the other was at directed lower (8-24 m), but with emphasis on the 8-15m depth.

Table 3 Alouette Reservoir average surface temperatures, pool elevations and limnetic habitat area at time of hydroacoustic surveys, 1998 – 2008.

Year	Survey date	Surface Temp °C	Pool elevation m	Limnetic Habitat [2] ha
1998	September 14	20.7 (Sept. 14)	121.0	1356
1999	October 12	12.7 (Oct. 19)	121.6	1370
2000	September 7	18.0 (Sept. 05)	121.3	1370
2001	November 1	11.9 (Oct. 22)	121.8	1370
2002	November 1	10.0 (Nov. 05)	116.8	1306
2003	October 24	17.0 (Oct. 24)	122.5	1383
2004	October 19	15.0 (Oct. 12)	121.2	1370
2005	October 13	13.7 (Oct. 13)	120.3	1356
2006	July 24[3]	23.4 (July 24)	121.3	1370
2006	October 23	14.1 (Oct. 23)	117.9	1319
2007	October 25	No data	121.2	1370
2008	October 6[4]	14.0 (Oct. 06)	120.3	1356

1. Full Pool elevation 125.51m
2. Limnetic habitat Area: habitat with a depth greater than 20m. Note these areas are slightly different from the habitat areas at depth provided in Appendix H which represents midpoint areas for corresponding 5m depth strata.
3. July 2006 survey was done to assess seasonal variation
4. October 2008 netting conducted in the pelagic habitat

Fish samples were kept on ice until processed the following morning. The species, fork length, weight, stomach content and stage of maturity were recorded; external parasites, internal lesions and general physical condition were noted and recorded if abnormal. Scales were taken for age interpretation when available (fish highly susceptible to net abrasion). When scales were not available, approximate age groups were estimated from combined trawl and gillnet sample length frequency distribution data.

Pelagic biomass estimates

Total fish biomass in the pelagic zone was calculated from acoustic size data. It is important to note that this is different from the total weight of fish in kg caught in the standard set of near shore nets reported as *"near shore biomass".* Some further refinements to estimating pelagic biomass from acoustic size data have been made since previously reported biomass estimates. Pelagic biomass estimates have been re-calculated for all previous years of split beam data using the newer methods. The main difference is that the newer Sonar 5 software enables outputs at a finer scale (i.e. 1 dB compared with 3 dB size bins used previously). Biomass was calculated for the pelagic zone by estimating the total fish abundance for the basin by 1 dB size increments. These numbers were expanded by an average weight equivalent for each 1dB size bin. The weight equivalents were developed by converting size in dB to length equivalents using Love's empirical relation and then applying an empirical length weight relation based on fish captured in Alouette Reservoir. Species included in analyses were kokanee, rainbow trout, cutthroat trout, bull trout, redside shiner, three spine stickleback and lake trout and were obtained from trawling and gillnetting. Combining fish captured from all years produced a more consistent length weight relation than did individual years (reported previously) where catches were sometimes low and some key species were under-represented some years. The larger sample size may account for the improvement. A final change is to report biomass estimates focusing primarily on planktivores, the species such as kokanee that are most likely to respond to fertilization. Two filters were employed to focus on the kokanee community, target size and depth. Excluding fish >45 cm (-32 dB) produced more stable estimates of biomass for the target species, since it was assumed that all kokanee fall below this size cut-off, and a few large predators can change the total biomass significantly. Small numbers of large fish are difficult to detect and enumerate due to extremely low density, but can have a large influence on overall biomass estimates. Secondly, only targets measured below 10 m (10-50 m) were reported on. Species depth stratification information collected in 2008 indicated that kokanee are largely limited to, and are the dominant species of this depth in the pelagic zone. Additionally, many of the larger targets that could influence biomass in the top 0-10 m are likely to be stocked rainbow and cutthroat trout, whose densities are related to stocking rates and angling pressure. Biomass reported here is fish up to 45 cm length located from 10-50 m, and are primarily made up of planktivores.

The genetic composition of the nerkid population in Alouette Reservoir is in doubt, particularly kokanee vs. sockeye that historically migrated upstream of the current dam location (Wilson et al. 2003). For the purpose of this report all nerkids are considered kokanee until research proves otherwise.

Nerkid out-migration monitoring

As part of a separate project undertaken by BC Hydro to assess the feasibility of sockeye re-anadromization into the ALR, a study is on-going to determine the possible migration success of nerkid populations from the Alouette Reservoir. Out-migration monitoring from the Alouette Dam was conducted using rotary screw traps located downstream in the South Alouette River to capture fish displaced from the reservoir under controlled spill conditions. Estimates were derived using mark recapture methods (Mathews and Bocking 2008). The out-migrant estimates are used in this report in conjunction with estimates from acoustic surveys to ascertain the annual in-lake nerkid population.

Kokanee Analysis: Size at age and growth

Linear mixed models

A good indicator of how fertilization influences trophic productivity is fish growth. The effect of fertilization on kokanee growth was tested using linear mixed-effects (LME) models (Pinheiro and Bates 2000; Venables and Dichmont 2004). For the first model, the response variable was the length of individual 3-year-old kokanee[1]. The predictor variable was Era (pre-fertilization and post-fertilization), which was modeled as a fixed effect. In order to account for inter-annual variation in length-at-age due to causes other than fertilization, year was included in the model as a random effect. Pre-fertilization kokanee size-at-age data included 1986, 1987 and 1998 while post fertilization data included 1999 to 2008.

For the second model, the addition of fertilizer was analyzed for its effect on kokanee size at age. The response variable was length of individual 3-year-old kokanee. The predictor variable was phosphorus loading (P) modeled as a fixed effect with inter-annual variation (year) in length-at-age, due to causes other than fertilization, included as a random effect. These analyses were performed using R 2.5.0 (R Development Core Team 2007).

von Bertalanffy growth model

Growth trajectories were estimated using the von Bertalanffy growth function (VBGF) from kokanee caught in gillnets from individual years for the pre and post fertilization periods. It is acknowledged that due to selectivity of gillnetting, younger kokanee ages (1+ and 2+) were under represented in some sample years. Growth analysis required some reconstruction of size of younger age groups (ages 1+) necessary to fit growth curves for individual years. For years 1986-87, ages were assigned from length specific regressions, back calculated aging and length frequency analysis. In addition, limited trawl and hydroacoustic data was also used to determine assigned length-at-age cut-offs. No age 0 kokanee were used in the analysis, however, the trawl/hydroacoustic information indicated age kokanee fry (age 0+) were <75 mm in length for any one year.

An overall VBGF was fitted to kokanee (all ages) data pooled from pre-fertilization and post-fertilization data. This model assumes that all age-groups have experienced the same growth environments over their past lifespan and doesn’t account for the variability in cohort specific rates or year to year changes in growth conditions experienced in ALU

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[1] Reference to age 3 kokanee and age 3+ kokanee both indicate fish that have grown through four summers

in past years due to other factors (i.e. inter or intra-specific competition or environmental). This analysis was performed using R 2.5.0 (R Development Core Team 2007).

The von Bertalanffy somatic growth curves (Ricker 1975) were calculated from a 3 parameter nonlinear model:

$$L(t)_{age}=L_{\infty}*(1-EXP(-k(Age-t0)))+\varepsilon$$

where:

$L(t)_{age}$= length at age
L_{∞}=is the asymptotic average maximum body size
k=is a growth rate coefficient that determines how quickly the maximum is attained
t0=is the hypothetical age at which the species has zero length
ε=residual error structure about the expected growth line

Analysis of variance (ANOVA) was also performed on condition factor from the length-weight relationship of kokanee, rainbow trout and bull trout caught in gillnets from 1986-87, 1998 and 1999-2008 to determine differences between pre and post fertilization years. This analysis was performed using R 2.5.0 (R Development Core Team 2007).

5. Results

5.1 Climate

The mean daily temperature in 2008 was 9.0°C, which was approximately 1°C cooler than the 1998-2008 long term mean. This was mainly due to cooler temperatures from January to August and the record low temperatures recorded in December 2008 (Figure 5). The 2003-2008 mean annual air temperature was 10°C, just slightly warmer than the 1998-2008 average of 9.8°C (Figure 5). The average temperature during the months of fertilization for 2008 was 14.8°C and the 2003-2008 mean annual temperature was 15.9°C.

Generally, precipitation levels followed the same historical patterns of drier weather during the fertilization period and heavier precipitation throughout the winter and early spring. The mean daily precipitation in 2008 was 5.8 mm, which was the driest year in the 2003-2008 study period. The average precipitation for 2003 to 2008 was 6.4 mm, essentially the same as the long term average of 6.5 mm between the years 1998 and 2008 (Figure 6). The 2007 study year was a relatively high precipitation year with an average of 7.7 mm. The average rainfall during the months of fertilization generally low with the exception of a high rainfall period from mid July to beginning of August in 2008. The mean rainfall during fertilization months was 3.1 mm in 2008 which was slightly higher than 2.8 mm recorded for 2003-2008.

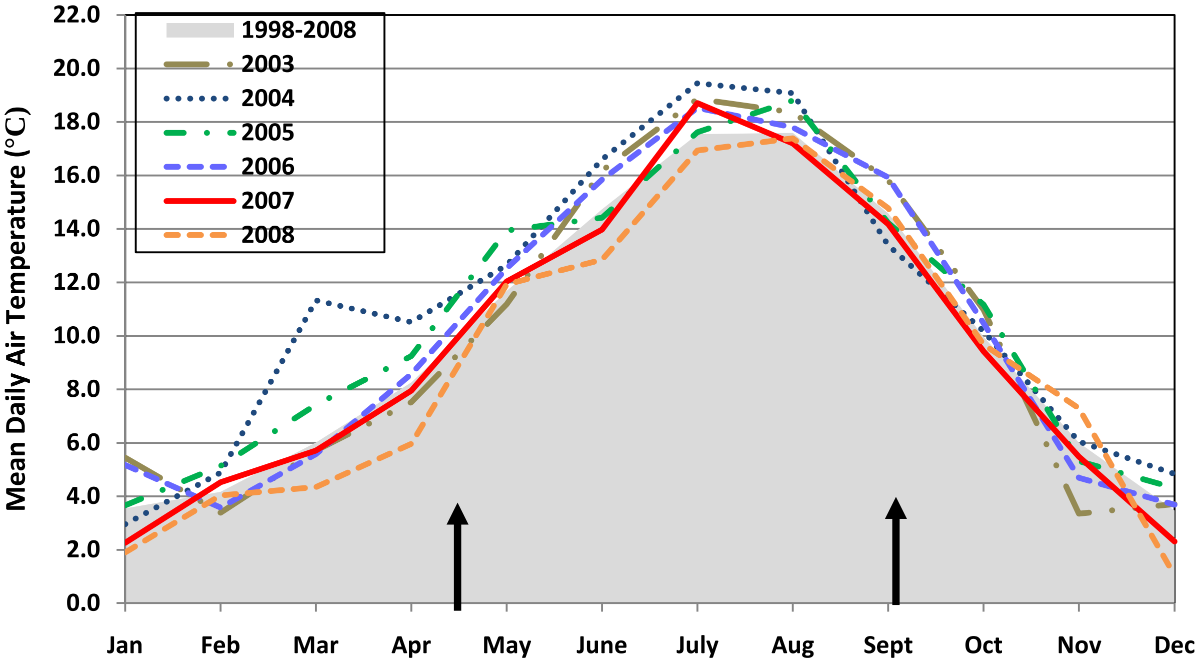

Figure 5 Mean daily air temperatures (ºC) measured at Alouette Reservoir forebay, 2003-2008. Shaded area represents mean air temperature from 1998-2008 and arrows indicate the start and end dates of fertilization.

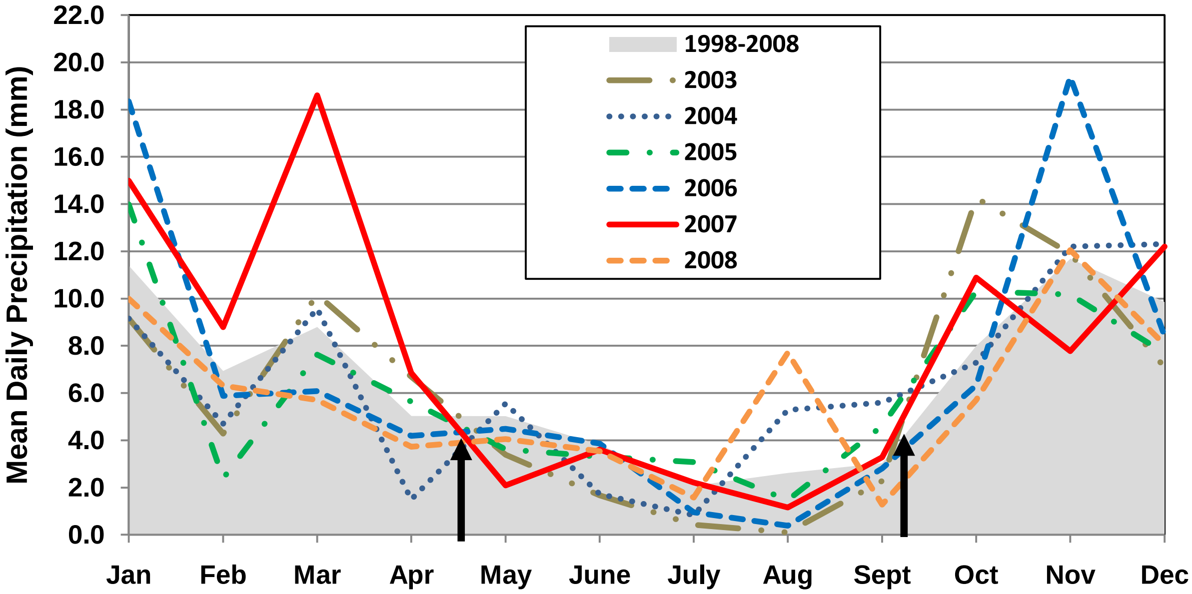

Figure 6 Mean daily precipitation (mm) measured at Alouette Reservoir forebay, 2003-2008. Shaded area represents mean precipitation from 1998-2008 and arrows indicate the start and end dates of fertilization.

5.2 Reservoir Operations

Since inflow is closely related to the precipitation pattern inflow is at its lowest during the time of fertilization and highest during the winter and early spring (Figure 7). Mean daily inflow in 2008 was 20.5 m^3/s which was much higher than the 2003-2008 mean inflow of 12.1 m^3/s. Inflow was generally below average in January to April and above average in May to September 2008. The 2007 study year had an extremely high mean daily inflow of 74.7 m^3/s for the month of March and November 2006 peaked at 68.8 m^3/s.

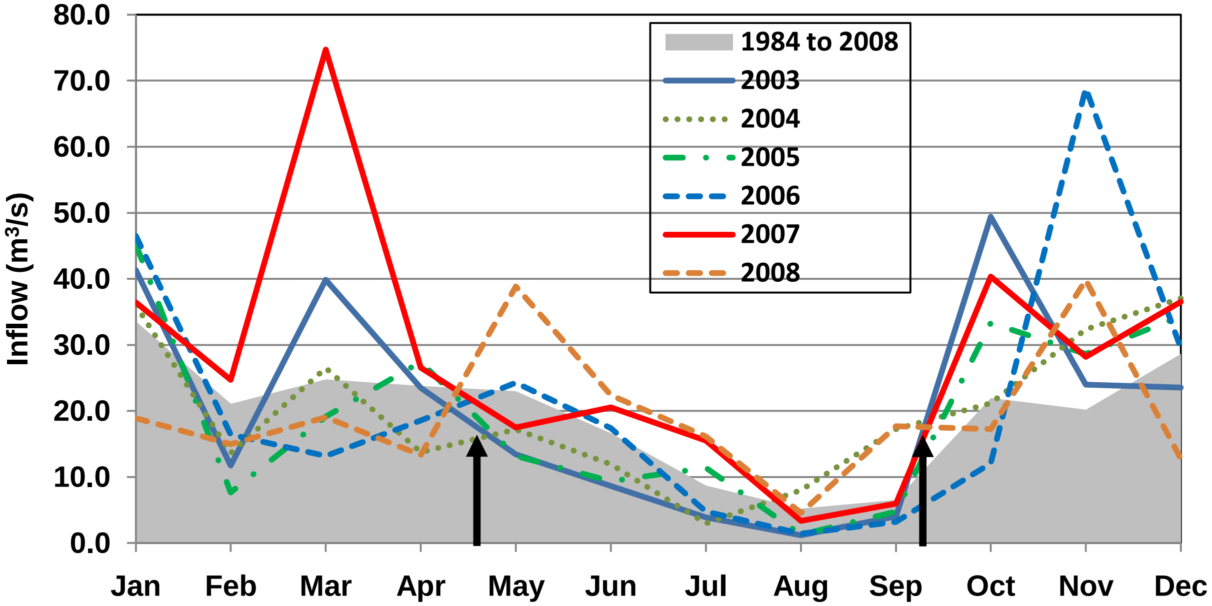

Figure 7 Inflow (m^3/s) of Alouette Reservoir, 2003-2008. Shaded area represents mean inflow from 1984-2008 and arrows indicate the start and end dates of fertilization.

Reservoir elevation in 2008 was generally above the long term mean except during a brief period in February (Figure 8). Throughout the months of fertilization, the reservoir was at an average annual elevation of 123.3 m (GSC) which is consistent with the set minimum recreational levels for the reservoir of 122.25 m from May long weekend to mid-September. Generally the elevation was below average in 2005 and 2006 and the low elevation in spring of 2006 caused a late launch to the fertilization program. The reservoir generally draws down in the fall after recreational elevation requirements have been met. The 1984-2008 average drawdown was 3.5 m and the 2003-2008 period average drawdown was 5.6 m. The minimum reservoir elevations were well above the required 114 m for all years.

The tunnel that connects Alouette Reservoir to Stave Reservoir is open on an irregular basis (Figure 9.) Generally discharge is lowest during the fertilization period and highest from September to March, a period of high inflow to the reservoir. On average, the maximum discharge during the fertilization period is generally ~22 m^3/s but on several occasions in May and July 2007 and in June 2008 the adit gate was open and maximum discharge peaked at 50 m^3/s. In the fall and winter months, the adit gate is opened more frequently, and peak discharges of 50 m^3/s are common. This release from Alouette Reservoir is a controlled attempt to avoid unwanted flooding in the Alouette River. Discharge during the fertilization period could have possible implications on nutrient export to Stave Reservoir and the resulting net phosphorus retention in the reservoir. Tunnel discharge of at least 20 m^3/s occurred for 34 days in 2007 during the fertilization period and in 2008 increased to 84 days. This is considerably higher than ~11 days in 2003 and 24 days in 2004 and may be related to reservoir inflows and the requirements of the new operating plan.

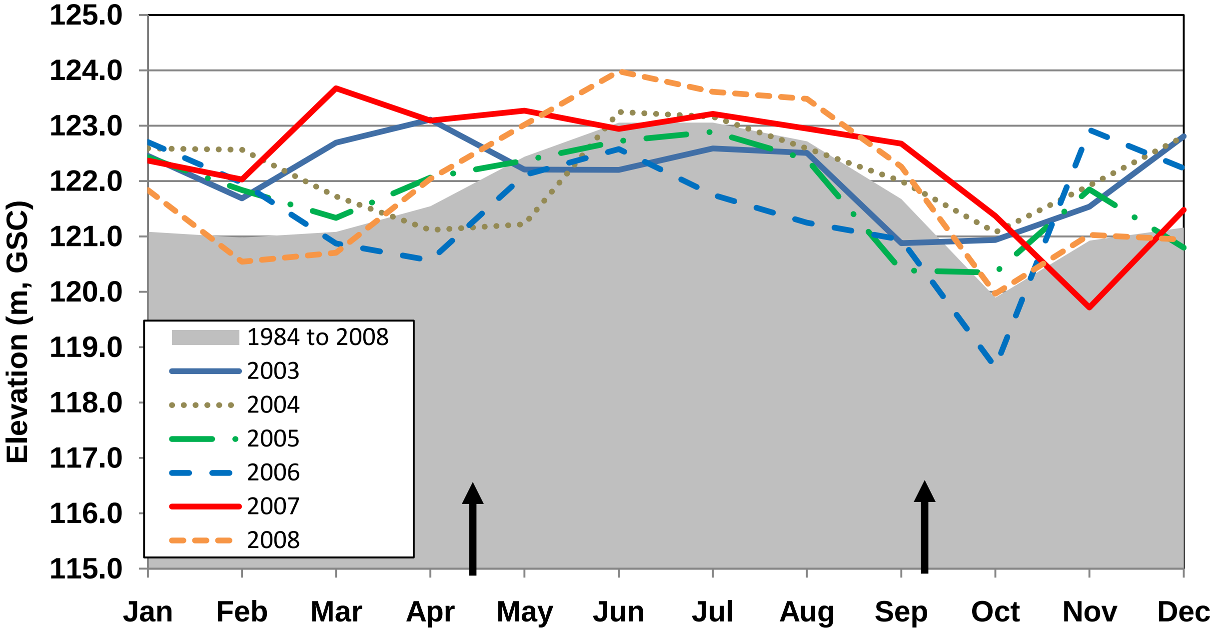

Figure 8 Reservoir surface elevation (m, GSC) of Alouette Reservoir, 2003-2008. Shaded area represents mean elevation from 1984-2008, arrows indicate the start and end dates of fertilization and dashed line indicated the normal minimum operating level.

As of 1996, BC Hydro has regulated minimum flows in the Alouette River in order to maintain acceptable flow for fish and their habitat. The average outflow through the dam from 1996 to 2008 was 2.81 m^3/s (Figure 10). The study period of 2004-2008 had similar mean outflows to the long term average. Outflows in 2004 were 3.61 m^3/s 2.89 m^3/s in 2005, 2.63 m^3/s in 2006, 2.29 m^3/s in 2007 and 2.28 m^3/s in 2008. In 2004 and 2005 outflow through the dam spiked to 35.0 m^3/s in January and February. This regulated discharge would have been in effort to control unwanted flow over the dam in times of increased inflow. Between mid April and June 2007 and 2008, the low level outlet to the river was closed and the spillcrest gate over the dam released in order to allow smolting fish a safe passage to the river while maintaining acceptable flows in the river.

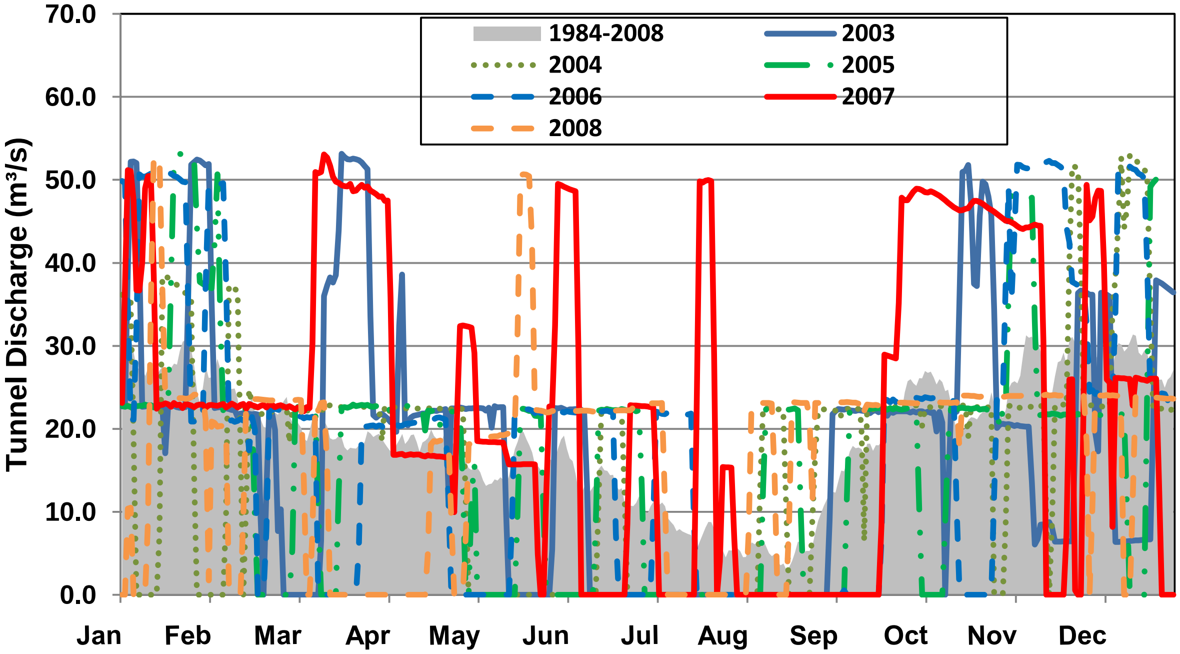

Figure 9 Tunnel discharge to Stave Reservoir, 2003-2008. Shaded area represents the mean discharge from 1984-2008.

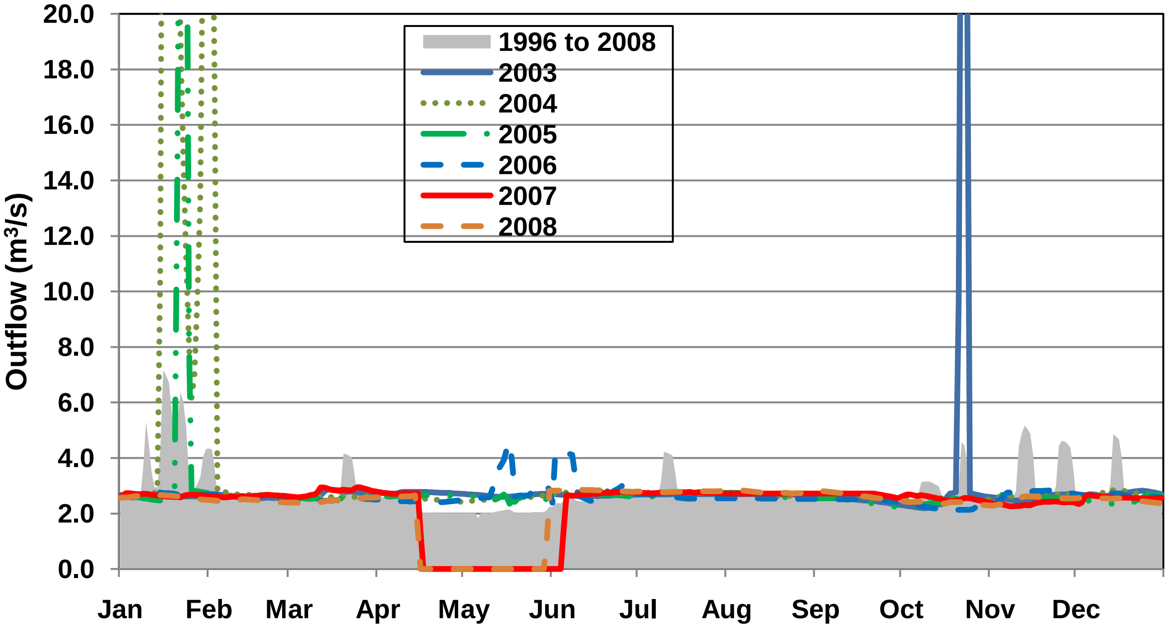

Figure 10 Outflow from the low level outlet to Alouette River, 2003-2008. Shaded area represents mean outflow from 1996-2008.

The residence time in 2008 was 1.84 years, similar to the values for 2006 and 2007 which was slightly lower than the 2004-2008 and the long term mean of 1.90 and 1.96 years respectively. The epilimnetic residence time for 2008 was the lowest in the last 5 years of the experiment at 0.71 years or 259 days, nearly 57 days shorter than the 1984-2008 long term mean.

Table 4 Residence time and epilimnetic residence time for Alouette Reservoir, 1998-2008.

Year	Residence Time (years)	Epilimnetic residence Time (years, days)
1998	1.78	0.92, 336
1999	1.39	0.42, 153
2000	2.06	0.56, 204
2001	2.08	0.78, 285
2002	1.78	0.44, 161
2003	1.96	0.94, 343
2004	1.98	1.09, 398
2005	2.01	0.86, 314
2006	1.83	0.80, 292
2007	1.83	0.86, 314
2008	1.84	0.71, 259
Mean (1998-2008)	1.95±0.36	0.87, 316
Mean (2003-2008)	1.90±0.36	0.88, 320

5.3 Physical and Chemical data

Temperature profiles in 2008 indicate that the water column was isothermal at the end of April with water temperatures of ~6°C. This was considerably cooler than observed in previous years, which is generally ~10°C but this varies greatly in relation to weather conditions. Thermal stratification had developed in May and was well established by August when maximum epilimnion temperatures were noted at 23.1°C in the north basin and 21.2°C in the south basin. Surface water stratification was weakening with thermocline deepening in September and although profiles were not completed in October it is likely that complete mixing of the water column had begun (Figure 11). This seasonal pattern of thermal stratification is typical of temperate systems (Wetzel, 2001). On average, the north basin was ~1.5°C warmer than the south basin which was ~1°C higher than in previous years. On average, the mixed layer depth in both basins was approximately 6 meters, approximately 1-2 m shallower than in previous years.

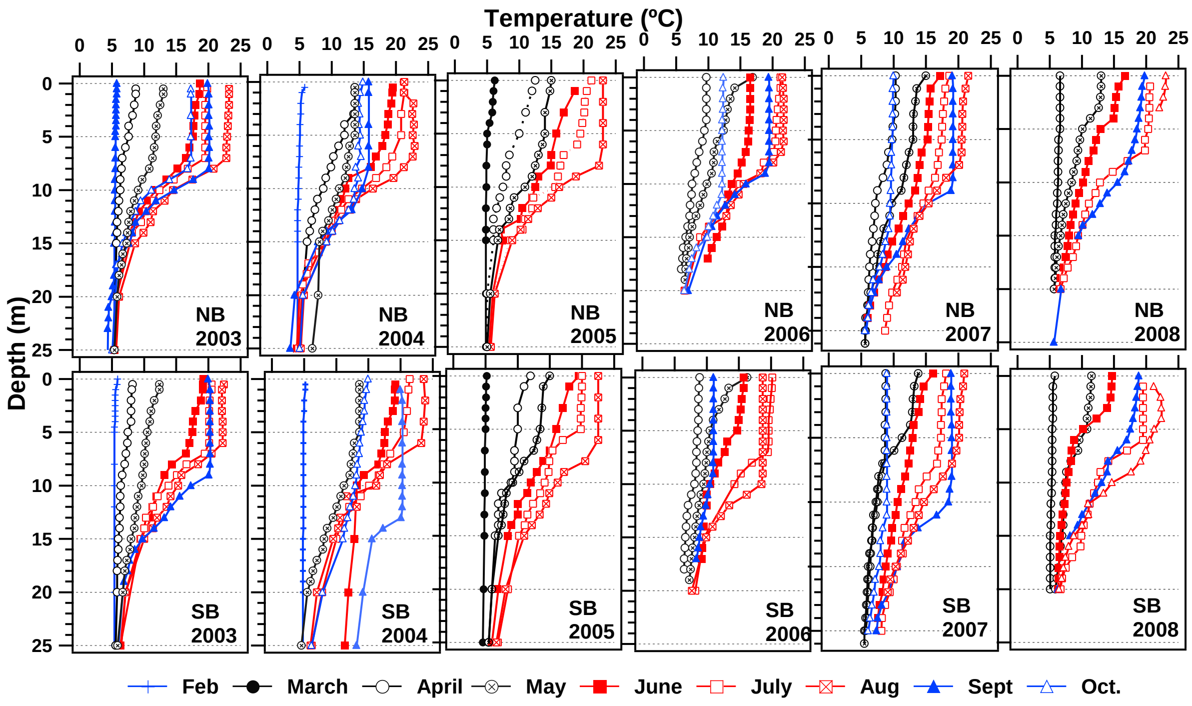

Figure 11 Temperature profiles for the north basin and south basin of Alouette Reservoir, 2003-2008.

In April 2008, the epilimnetic oxygen concentrations were similar from the surface down to 20 m indicative of a well mixed water column (Figure 12). As the epilimnetic water warms in May, the solubility of oxygen decreases and the resulting oxygen profile show slightly elevated oxygen concentrations at depth. This general pattern is clearly visible in the June-August profile and is called an orthograde oxygen profile, which are typical of stratified oligotrophic lakes. Typically dissolved oxygen concentrations between 8-11.5 mg/L are observed in the epilimnion and values are between 10-12.5 mg/L in the hypolimnion (Figure 12). The concentrations at depth show a more uniform vertical profile with little seasonal variability. In general, a hypolimnetic oxygen deficit was not evaluated as profiles did not extend down into the hypolimnion.

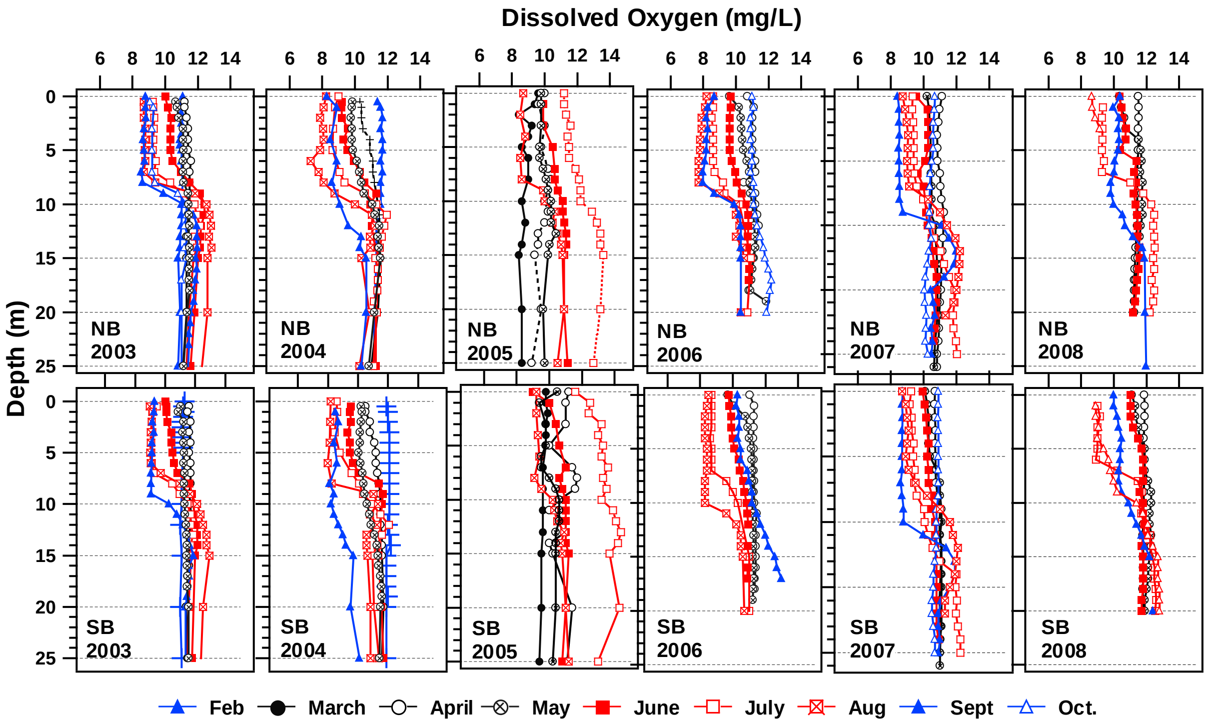

Figure 12 Dissolved oxygen profiles for the north basin and south basin of Alouette Reservoir, 2003-2008.

In 2008, the mean annual secchi depth in the north and south basin was ~6 m (Figure 13 13), approximately half the secchi depth measured before fertilization. The secchi depth in 2008 was similar to the values measured in 2003 and 2004 and deeper than the lowest clarity measured in 2007. The secchi depth ranged from a low of 4 m to a high of 8 m. The 2003-2008 mean for the north basin was 6.7m and for the south basin was 6.2 m which was less than half the values of 12.2 m found in the pre-fertilization year.

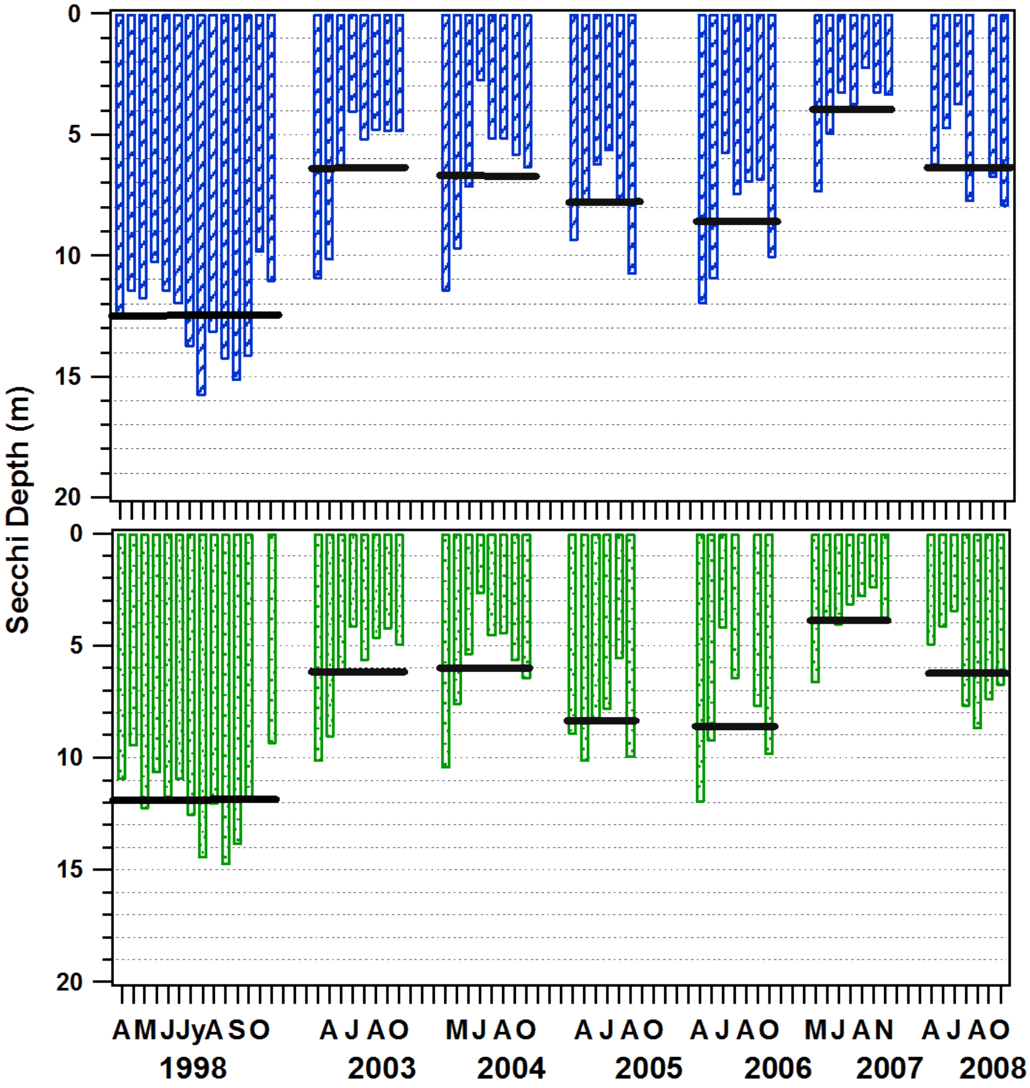

Figure 13 Secchi depths in the north basin and south basin of Alouette Reservoir in 1998 and 2003-2008. Bar indicates mean annual Secchi depth.

Vollenweider (1968) studied the relationship between lake productivity to total phosphorus and found in general, TP concentrations below 5 µg/L are indicative of ultraoligotrophic productivity and TP between 5-10 µg/L are related to oligo-mesotrophic productivity. The mean TP in 2008 was 5.1 ±2.6 µg/L, which falls at the lower end of the oligo-mesotrophic productivity range. The 2008 values were approximately 78% higher than pre-fertilization levels of 2.8 ±1.5 µg/L, clearly showing that the reservoir is responding to nutrient additions. The 2003-2008 mean was 4.1 ±2.6 µg/L indicative of ultraoligotrophic lake productivity (Figure 14).

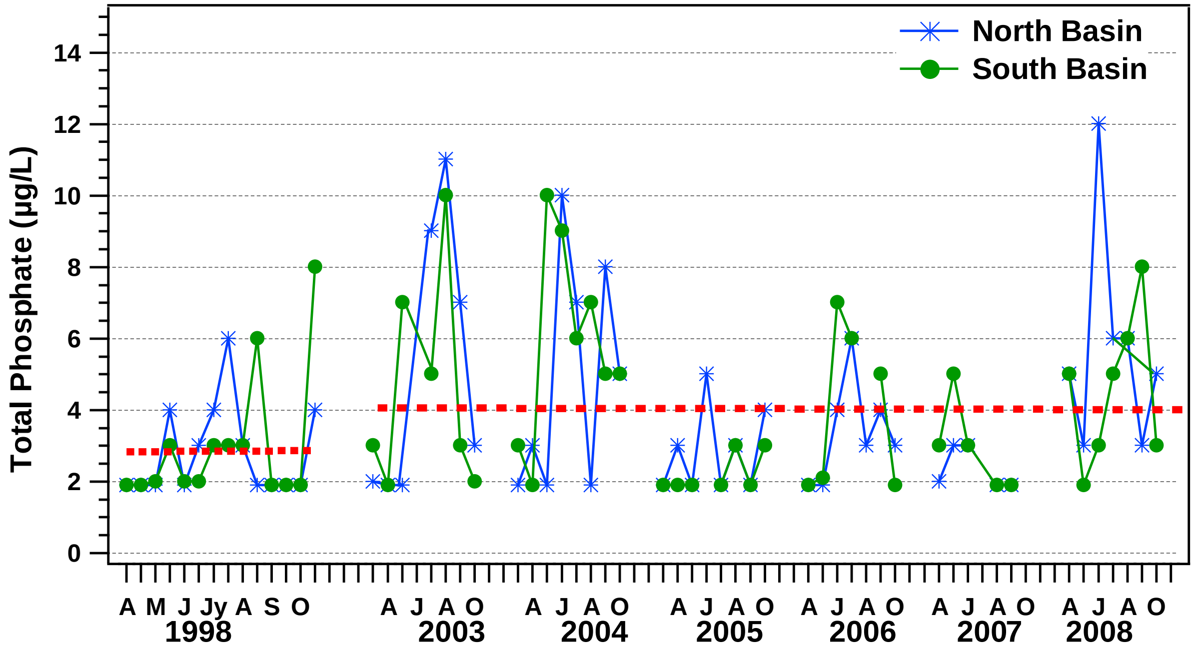

Figure 14 Epilimnetic total phosphorus concentrations in the north and south basin of Alouette Reservoir, 1998 and 2003-2008. Red dashed line indicates mean values for 1998 and for 2003-2008.

The orthophosphate ion is the chemical form that is readily available to phytoplankton. In 2008, mean soluble reactive phosphorous concentrations were 1.82 ±1.1 µg/L, ranging from detection limits to 4 µg/L (Figure 15). It is important to note that there are several months where concentrations were at detection limits despite weekly addition of fertilizer suggesting there was rapid uptake and assimilation of nutrient by phytoplankton. The 2003-2008 mean was 2.7 ±1.0 µg/L, which is higher than pre-fertilization concentrations and higher than the values measured in 2008.

Mean epilimnetic concentrations of TN were low and ranged from 159.3 ±30.5 µg/L in 2008 (Figure 16), which is extremely low and indicative of ultraoligotrophic conditions (Wetzel 2001). The annual average epilimnetic total nitrogen (TN) concentrations in 2003-2008 was 164.0 ±39.3 µg/L are similar to 168 µg/L the concentration measured prior to fertilization (Wilson et al. 2002). The seasonal cycle of TN were highest in the spring, progressively decreased in the summer and increased again in the fall.

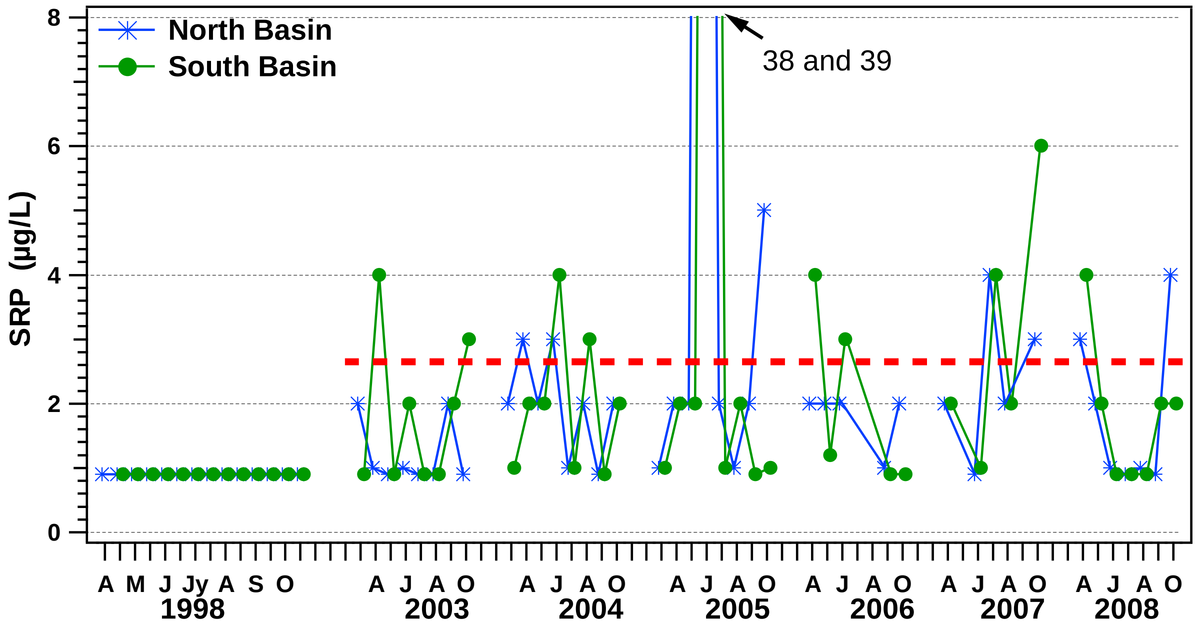

Figure 15 Epilimnetic SRP concentrations in the north and south basin of Alouette Reservoir, 1998 and 2003-2008. Red dashed line indicates mean values for 2003-2008. Values for 1998 are for 0-20 composite sample and for 2003-2008 are for 1 m sample.

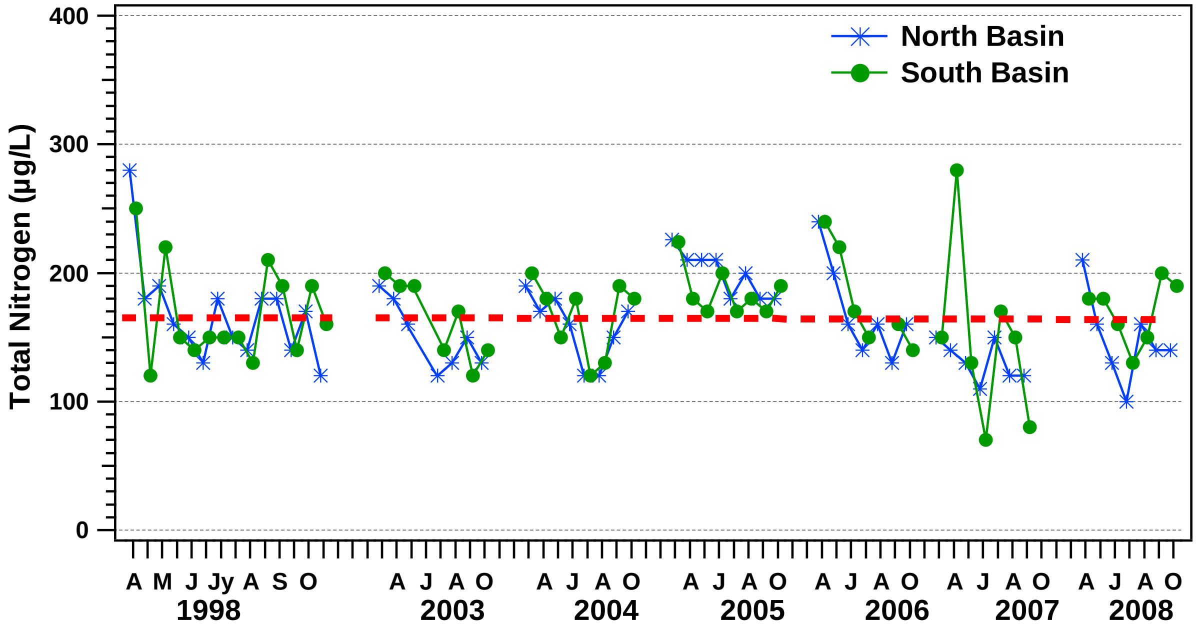

Figure 16 Epilimnetic TN concentrations in the north and south basin of Alouette Reservoir, 1998 and 2003-2008. Red dashed line indicates mean values for 2003-2008. Values for 1998 are for 0-20 composite sample and for 2003-2008 are for 1 m sample.

Nitrate-N (NO_3+NO_2-N) is an important form of dissolved nitrogen supporting algal growth (Wetzel 2001). The mean epilimnetic nitrate concentrations in 2008 were 79.5 ±44.3 μg/L. The high measure of variance reflects the strong biological utilization of nitrate and highlights the dynamic nature of nitrate in Alouette Reservoir (Figure 17). Early spring nitrate concentrations were ~130 μg/L, well above limiting concentrations of 20 μg/L which were maintained for all months except for July when nitrate concentration dipped below to 8 μg/L (Figure 17). The 2003-2008 mean was 72.6 ±50.5 μg/L which are similar to the concentrations observed in 2008. It is important to highlight the relatively high concentrations measured in 2005 and the absence of nitrogen limitation in this study year. It is also significant to note that despite identical loading strategies in 2006 and 2007, severe and sustained nitrogen limitation was observed in 2007 while in 2006 concentrations were sufficient for growth.

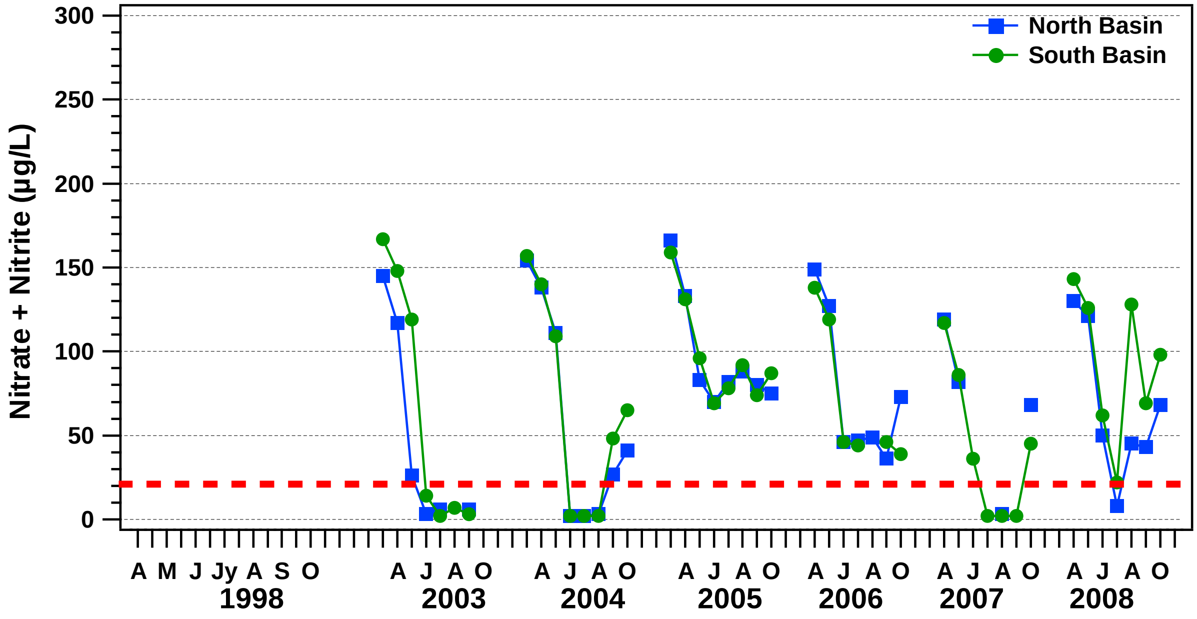

Figure 17 Nitrate + nitrite concentrations of 1 m sample in the north basin and south basin of Alouette Reservoir, 2003-2006. Discrete sample was not collected in 1998. Red dashed line indicates concentration considering limiting to phytoplankton growth.

In 2008, chlorophyll concentrations were moderately low at 2.20 ±1.94 μg/L and 1.67 ±1.44 μg/L in the north and south basin respectively, approximately 3 fold higher than pre-fertilization values of 0.67 ±0.44 μg/L (Figure 18). These concentrations are indicative of oligotrophic systems (0.3-3.0 $\mu g \cdot L^{-1}$ Wetzel, 2001) suggesting efficient transfer of carbon up the food chain. A substantial drop in chlorophyll concentrations was observed in July and August which coincides with the emergence of *Daphnia* sp (Figure 24), which suggests tight coupling of the trophic levels.

Chlorophyll *a* concentrations in 2003-2008 of 1.85 ±1.26 µg/L (2006 data is not available) were well above the pre-fertilization means. On average, chlorophyll levels are nearly 2 fold higher in fertilization years. The extremely high values measured in 2007 coincide with a large cyanophytes bloom of *Oscillatoria* sp, which is an inedible species that accumulates in the water column, likely with negligible grazing pressure. The high chlorophyll concentrations in 2004 and 2007 lead to the decreased water clarity as shown in Figure 13.

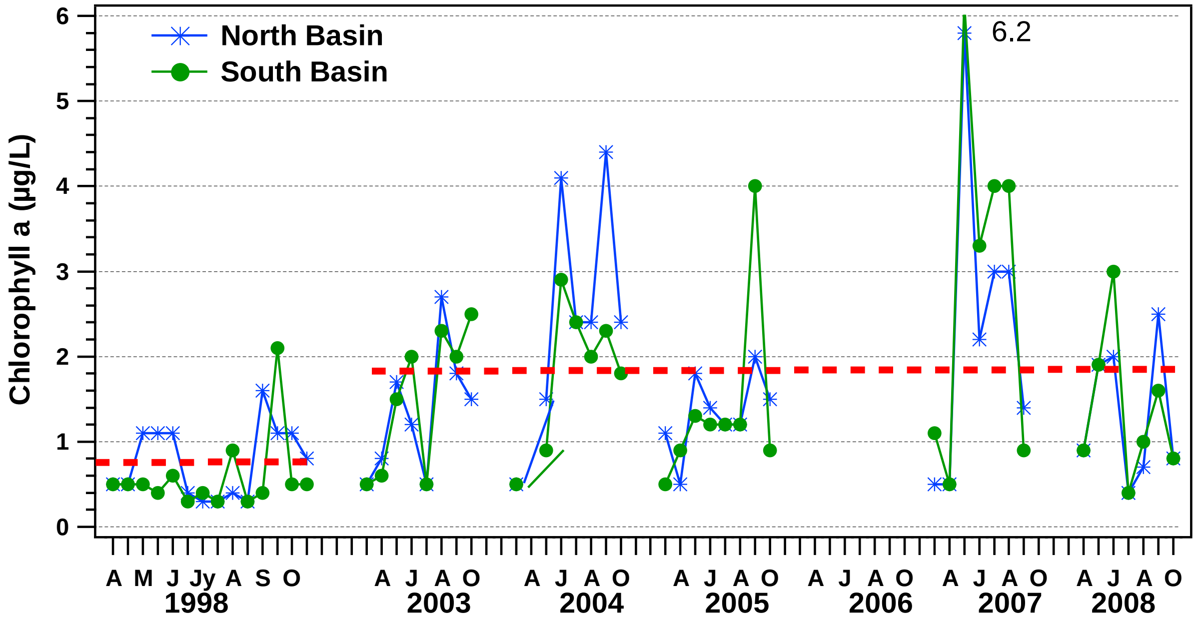

Figure 18 Epilimnetic chlorophyll *a* concentration in the north basin and south basin of Alouette Reservoir, 2003-2008. Red dashed line indicates mean concentration for 1998 and for 2003-2008.

5.4 Phosphorus Budget

In 2008 the phosphorus load from the watershed was 546 kg-P, accounting for 14% of the total phosphorous budget (Table 6). The FFSBC net pen project was not in operation in 2008, therefore the phosphorus input from that source was zero. Loading from atmospheric sources were taken from Wilson et al. (2003), and are considered minor contributors to the total nutrient budget. It is estimated that phosphorus from the fertilizer accounted for 85% of the total phosphorus budget with the addition of 3,309 kg-P.

Estimated annual loss of phosphorus via the tunnel consistently accounts for the greatest output of phosphorus from the reservoir. Phosphorus export through the tunnel was relatively high in 2008 at 1,318 kg-P, which was nearly 3 fold higher than the 2003-2007 mean of 478 kg-P (Table 6). Phosphorus export through the dam low level outlet was an order of magnitude lower at 157 kg-P, which is 1.3 fold higher than the 2003-2007 mean of 119 kg-P. The spill of nutrient rich surface water accounted for an additional export of 57 kg-P, which was just 5% of the total phosphorous export due the short nature of the spill period.

The proportion of total phosphorus exported relative to total phosphorus input was high in 2008 at 39%, which was similar to the value calculated in 1998 and lower than the highest value calculated in 1999 and 2000 (Squires et al. 2009).

Table 5 Source of seasonal (Apr.-Sept.) phosphorus load and discharge for Alouette Reservoir in 1998-2008.

Source	Phosphorus (kg)						
	1998	2003	2004	2005	2006	2007	2008
Input							
Watershed	185	289	361	352	358	488	546
Netpens	409	266	232	226	184	0	0
Atmosphere	49	49	49	49	49	49	49
Fertilizer	0	2,913	2,594	2,594	3,309	3,309	3,309
Total Input	**643**	**3,517**	**3,236**	**3,221**	**3,900**	**3,846**	**3,904**
Output							
Tunnel	179	204	529	295	547	818	1318
Outlet	91	135	171	41	120	129	157
Crest Gate	-	-	-	7	45	54	57
Total Discharge	**270**	**340**	**701**	**343**	**712**	**1001**	**1532**
Net P- Retention	**373**	**3,177**	**2,536**	**2,885**	**3,233**	**2,899**	**2,429**

Source	% of Total P Input & Discharge						
	1998	2003	2004	2005	2006	2007	2008
Input							
Watershed	29%	8%	11%	11%	9%	13%	14%
Netpens	64%	8%	7%	7%	5%	0%	0%
Atmosphere	8%	1%	2%	2%	1%	1%	1%
Fertilizer	0%	83%	80%	81%	85%	86%	85%
Output							
Tunnel	66%	60%	76%	88%	82%	86%	89%
Outlet	34%	40%	24%	12%	18%	14%	11%
Crest Gate	-	-	-	2%	6%	5%	4%
Total Discharge/Total Input	**42%**	**10%**	**22%**	**11%**	**18%**	**26%**	**39%**

5.5 Phytoplankton

In 2008, phytoplankton cell densities and biovolume were higher in the north basin than in the south basin (Figure 19); cell densities were 5,721 ± 5,624 cells/ml and 5,239 ±5,664 cells/ml respectively. The cell densities in both basins were extremely low in April and May at 454 and 534 cells/ml in the north basin and 191 and 460 in the south basin which were actually lower than cell densities measured in pre-fertilization years. Low water temperatures of ~6ºC and the lack of water stratification may partially explain the low April densities as sampling likely occurred before conditions were favorable for phytoplankton growth. This does not explain the low values in May when thermal stratification was developing and normal temperatures were observed. These extremely low densities account for the high standard deviation of the means (Appendix C). Cell densities ranged from 354 - 14,394 cells/ml in the north basin and 191 - 15,292 cells/ml in the south basin and densities peaked in June in the north basin and in July in the south basin. Phytoplankton biovolume in the north basin was 0.41 ± 0.53 mm^3/ml compared to 0.28 ± 0.26 mm^3/ml in the south basin (Figure 19) and peaked in June at both basin.

With the exception of the two low fertilization years (2005 and 2006), the phytoplankton densities and biovolume have been consistently higher during the treatment years relative to the pre-fertilization year. On average the cell densities increased 45% from 3,611 cells/ml in 1998 to 5,221 cells/ml for 2003-2008 and densities increased nearly 72% from 0.15 mm^3/ml to 0.25 mm^3/ml for 2003-2008 (Appendix C).

The time series also illustrates the considerable variability in the response of the phytoplankton community with the highest levels observed in 2007, a year of chronic nitrogen limitation, and the lowest levels were observed in 2005 (Figure 19). The phytoplankton densities and biomass in 2005 were the lowest recorded in the 8 year time series and were likely linked to successive seasons of low phosphorus loading in the reservoir highlighting the importance of maintaining critical levels of phosphorus. From 2006-2008 the fertilizer treatment strategy was relatively consistent but the phytoplankton densities increased nearly 4 fold from 2,425 cells/ml in 2006 to 11,814 cells/ml in 2007 and then subsequently decreased to ~5,000 cells/ml in 2008. Clearly other factors beside fertilizer loading are impacting the response of the phytoplankton community which highlights the importance of multi-year datasets, the importance of ancillary information and of maintaining a consistent strategy in order to enable biologists to determine the dynamics of the ecosystem response.

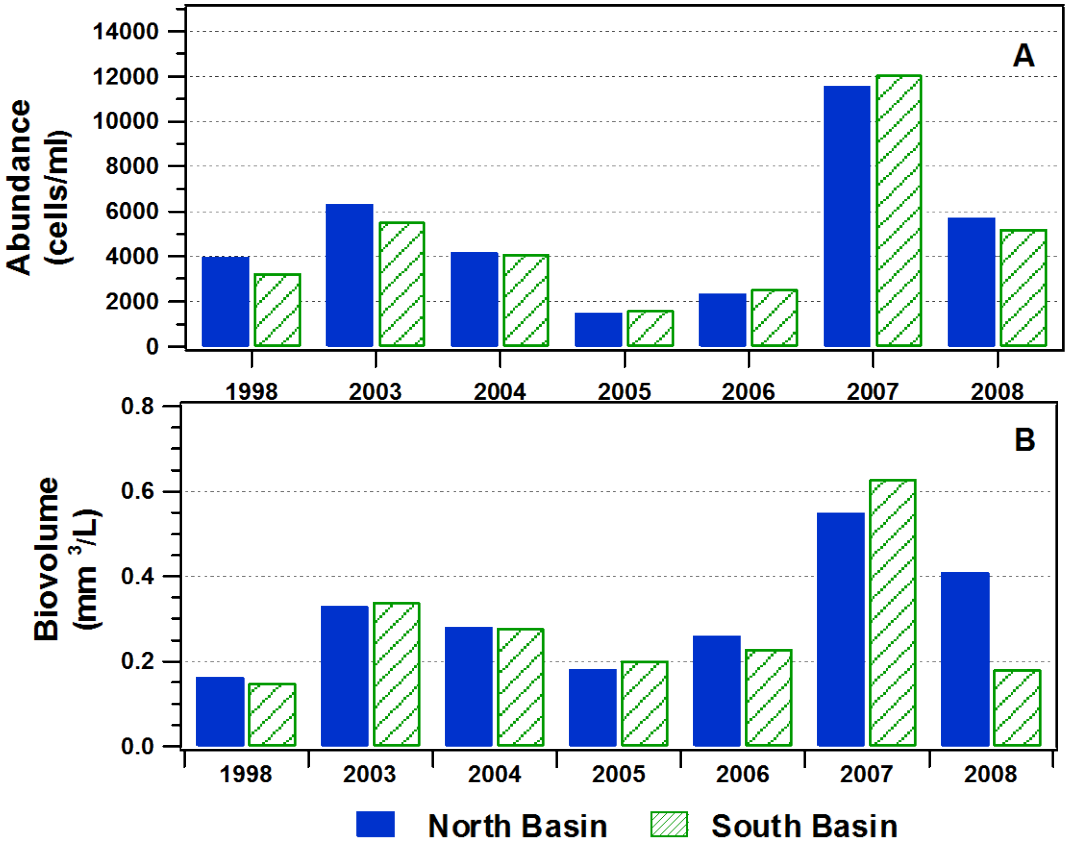

Figure 19 Annual mean abundance (panel A) biovolume (panel B) of the phytoplankton community in Alouette Reservoir, 1998-2008.

Phytoplankton species assemblages of the two basins were very similar in 2008 where Cyanophytes were numerically dominant followed closely by Chrysophytes and Cryptophytes (nanoflagellates), with minor contributions by diatoms (Bacillariophytes), green algae (Chlorophytes), and dinoflagellates (Pyrrhophytes) (Figure 20). In terms of biovolume, Chrysophytes and Cryptophytes accounted for 73% the phytoplankton community followed by Cyanobacteria, large celled dinoflagellates (Pyrrhophytes), Chlorophytes and finally diatoms (Bacillariophytes) (Figure 20). A total of 41 species of phytoplankton were identified in Alouette Reservoir during 2008 (Appendix B).

Figure 20 illustrates quite clearly that in 2008 cyanobacteria numerically dominated the phytoplankton assemblage, accounting for ~43% of the total abundance largely due to a large bloom in June and July of *Oscillatoria*, an unbranched filamentous nonheterocystous cyanophyte. *Oscillatoria* sp. are large microplankton size cells (>20 µm) which are not readily consumed by the zooplankter *Daphnia* sp., and are considered carbon sinks. Large blooms of *Oscillatoria* have been observed in previous years of the fertilization experiment (Wilson et al. 2003). *Synechococcus* sp. was commonly observed in low abundances except in July in the south basin when densities of 2,606 cells/ml were observed.

The predominance of cyanophytes in 2008 was followed closely by Chrysophytes and Chryptophytes that accounted for 44% of the cell densities and 73% of the biovolume. There was a great diversity of nanoflagellates ranging in size from 2-20 μm, and the most common genera were *Chromulina* sp., *Chrysochromulina* sp., *Chroomonas* sp. *Ochromonas* sp and various unidentified small flagellates. Nanoplankton is the size class most easily grazed by herbivorous zooplankton and the high contribution of this size class should lead to efficient transfer to carbon up the foodchain. Chyrso and Chryptophytes peaked in June at 8,829 cells/ml and 0.41 mm^3/L and remained relatively high for July and August accounting for between 65 and 78% of the total cell densities.

In 2008, chlorophytes, dinoflagellates and diatoms combined accounted for less than 4% of cell densities and less than 12% of biovolume which is considerably lower than observed in earlier years (Figure 20). From 2003-2008, these three groups accounted for 9.5% of total cell densities and 45% of the biovolume. This decrease in relative abundance is due to the large bloom of cyanophytes and chryto and chrysophytes rather than an abrupt decrease in absolute numbers of these three groups. Chlorophytes, also commonly known as green algae, accounted for <1% and ~3% of the total abundances and total biomass in the reservoir, respectively. The Chlorophyte community was composed of a mixed assemblage of genera that included *Ankistodesmus* sp., *Chorella* sp, *Clamydocapsa sp., Elakatothrix* sp. and *Scenedesmus* sp. A minor contribution was made by the Pyrrhorphyta, or the dinoflagellates which accounted for <1% of the cell densities and because of their relative large size they accounted for nearly 6% of the biovolume. *Gymnodinium,* a naked dinoflagellate was predominantly found and less commonly an armored dinoflagellate, *Peridinium* was observed. Diatoms were generally absent from the phytoplankton community with the exception of a small community of *Fragilaria acus, Fragilaria capucina and Cyclotella stelligerra* during June and September. Collectively diatoms only accounted for <2% of total abundances and 3% of total biovolume.

Generally the seasonal peak is observed in June or July except in 2005 when no major peaks or blooms were observed, likely due to low fertilization levels. From 2003-2008, the relative contribution of the 5 major phytoplankton classes is similar to the breakdown observed in 2008 with Cyanbacteria and Chryptophytes and Chysophytes accounting for the majority of the phytoplankton community. While 2008 was an exceptional year for Chrysophyte and Chryptophyte biovolume as shown in Figure 20 the relative importance of this group has remained consistent. The most obvious exception was the extremely high contribution of diatoms in 2007 which accounted for ~40% of the biomass in both basins. This bloom was largely composed of *Tabellaria* sp. a large inedible diatom.

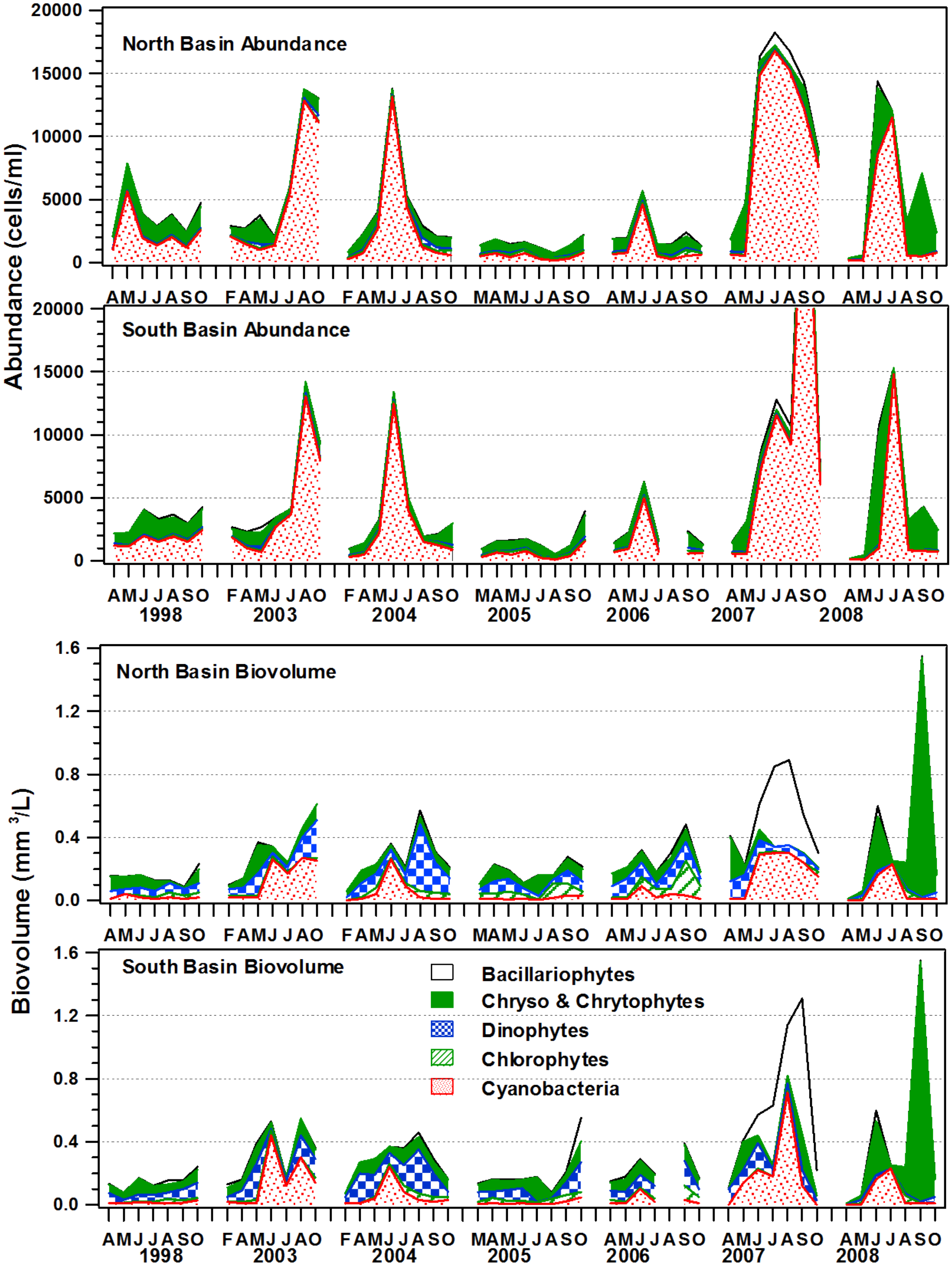

Figure 20 Mean seasonal densities and biomass of the major phytoplankton classes in the north & south basins of Alouette Reservoir, 1998 (pre-fertilization year) and 2003-2008 (fertilization years).

5.6 Zooplankton

In 2008, 7 cladocerans and 3 calanoid copepod species were identified in Alouette Reservoir (Table 6). *Daphnia rosea* (Sars), *Holopedium gibberum* (Zaddach), *Eubosmina longispina* (Leydig) and *Leptodora kindtii* (Focke) were commonly observed as were the following copepods, *D. bicuspidatus thomasi*, *Skistodiaptomus oregonensis* (Lillj.) and *Epischura nevadensis* (Lillj.)

Over the 2003-2008 study period, sixteen cladocerans were identified but 9 of these species were rarely observed and the copepod, *Leptodiaptomus ashlandi* (Marsh) was only found in 2007 in one sample. Two cladocerans, *D. rosea* and *E. longispina* were predominant during the study period *as was the copepod, D. bicuspidatus thomasi*.

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Table 6 List of zooplankton species identified in Alouette Lake, 2003-2008.

	2003	2004	2005	2006	2007	2008
Cladocera						
Daphnia rosea	+	+	+	+	+	+
Eubosmina longispina	+	+	+	+	+	+
Holopedium gibberum	+	+	+	+	+	+
Leptodora kindtii	+	+	+	+	+	+
Alonella nana	+	+			+	+
Scapholeberis mucronata		+			+	+
Polyphemus pediculus			+			+
Diaphanosoma brachiurum				+	+	
Chydorus sphaericus	+	+			+	
Alona sp.	+	+				
Scapholeberis sp.	+		+			
Sida crystallina		+			+	
Alonella sp.			+			
Ceriodaphnia reticulata		+				
Chydorus sp.			+			
Daphnia galeata mendotae			+			
Copepoda						
Diacyclops bicuspidatus thomasi	+	+	+	+	+	+
Epischura nevadensis	+	+	+	+	+	+
Skistodiaptomus oregonensis	+	+	+	+	+	+
Leptodiaptomus ashlandi					+	
Total Number of Species	11	13	12	8	13	10

In 2008, the zooplankton densities and biomass reached record highs of 15.50 individuals/L and 96.78 µg/L respectively. During the 2003-2008 time period, densities increased almost five fold, from 3.83 individuals/L in 2003 to 15.50 individuals/L in 2008. A sharp decrease was observed in 2007 to 7.32 individuals/L followed by an equally sharp increase in 2008 to 15.50 individuals/L (Figure 21). Zooplankton biomass also increased dramatically from 2003 to 2006, where biomass increased nearly 5 fold from 18.41 µg/L in 2003 to 89.88 µg/L in 2006. However, in 2007, a sharp biomass decrease to 14.92 µg/L occurred followed by a significant increase in 2008 of 96.78 µg/L. With the exception of the 2007 season, the annual trends of biomass seem to closely track the phosphorus loading in the reservoir (Figure 21), which is similar to the response shown for phytoplankton abundances and biovolume. In most years there appears to be a possible link between phosphorus loading from fertilizer and zooplankton productivity.

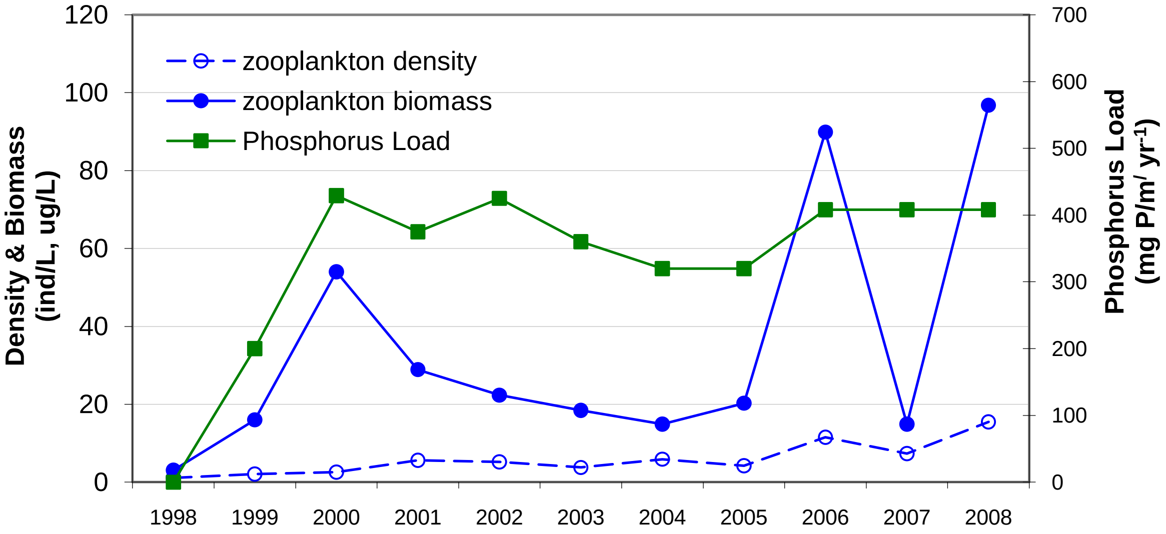

Figure 21 Seasonal average zooplankton density and biomass and phosphorous load in Alouette Reservoir, 1998-2008.

While the zooplankton community in both basins increased relative to pre-fertilization values (Figure 22), the mean response of the north basin was stronger than the mean response observed in the south basin. On average, zooplankton density increased 10 fold in the north basin compared to a 6 fold increase in the south basin, while for biomass the north basin increased nearly 22 fold and the south basin increased 10 fold. Seasonal average total zooplankton density and biomass are shown in Appendix D.

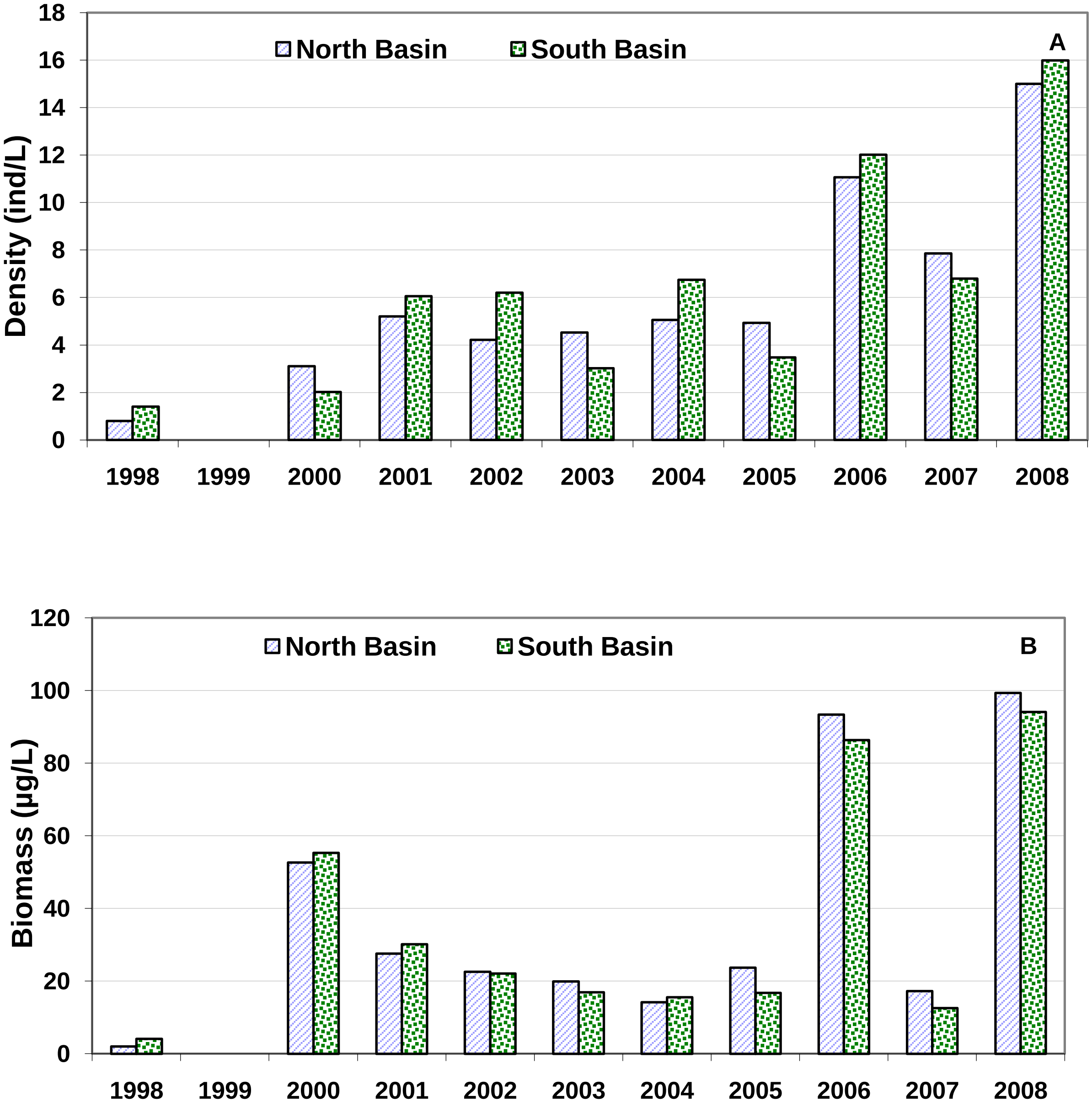

Figure 22 Zooplankton density (panel A) and biomass (panel B) in the north basin and south basin of Alouette Reservoir, 1998-2008.

In 2008, copepods and other cladocerans (excluding *Daphia* sp.) represented 85% of total zooplankton density (Figure 23) while *Daphnia* sp accounted for just 15%. From 2003-2008, copepods and other cladocerans accounted for 77% to ~99% of densities while *Daphnia* sp ranged from a low of 0.05% to a high of 23%. In 2004, *Daphnia* were largely absent while in 2005 *Daphnia* sp. reappeared and peaked in 2006 at 2.59 individuals/L.

In 2008, copepods and other cladocerans (excluding *Daphia* sp.) represented 37% of total zooplankton biomass (Figure 23) and due to their large size, *Daphnia* sp. accounted for nearly 63% of the biomass. From 2003-2008, copepods and other cladocerans accounted for 35% to ~99% of zooplankton biomass, while *Daphnia* sp accounted for 0.21% to 65% of the biomass during the same time period (Figure 23). The most striking feature was the reappearance of *Daphnia* in 2005, which accounted 56% of the total zooplankton biomass in the whole reservoir. *Daphnia* biomass increased again in 2006, accounting for ~65% of the zooplankton biomass, then in 2007 decreased to only 3%, and in 2008 increased again to ~63%. It is important to note, that *Daphnia* were absent from the zooplankton community in 1998, prior to nutrient restoration.

Total zooplankton abundance and biomass are well above pre-fertilization levels. The strongest zooplankton response to fertilizer additions was in 2008 with a near 14 fold increase in density and nearly a 32 fold increase in zooplankton biomass relative to 1998. Although all groups increased relative to pre-fertilization years, the appearance of *Daphnia*, a large cladoceran zooplankter, largely accounts for the dramatic increase in biomass (Figure 23).

Numbers of Copepoda have shown considerable interannual variability where the numbers increased in 2004, decreased in 2005 and increased again in 2006, 2007 and 2008 (Appendix D). In 2003 and 2004, the numbers of Copepoda ranged between 0.7 individuals/L and 10.78 individuals/L consisting of *Epischura nevadensis* and *D. bicuspidatus thomasi.* Although numerous, *D. bicuspidatus thomasi* are considered too small and are too fast for optimal transfer of carbon to higher trophic levels (Hyatt et al. 2004). In 2004, 2006, 2007 and 2008 an early season bloom of copepods was observed, consisting of between 6.23-10.78 individuals/L averaged for the whole lake. Copepod biomass in 2002 and 2005 was 3.13 µg/L while in 2004, 2006, 2007 and 2008 it was 8.67, 11.78, 9.16 and 14.02 µg/L, respectively.

Numbers of “Other” Cladocerans in the north and south basin were low in 2003 and 2004, showed little seasonal variability and lacked any major seasonal peaks. Other Cladocerans were composed primarily of *Eubosmina,* averaging ~3 individuals/L in both basins. In 2005, the numbers of Other Cladocera increased in the north basin due to a peak of *Eubosmina* in June with 18.04 individuals/L, while in the south basin the magnitude of the peak was lower, with 9.12 individuals/L. In 2006, a small *Eubosmina* bloom appeared in mid-summer and peak numbers appeared in October with 14.33 individuals/L and 9.46 individuals/L in north and south basin, respectively. Similar to the previous year, in 2007 Other Cladocerans also have two peaks during the sampling season. The first one occurred in early summer, but only in north basin with 7.24 individuals/L when *Eubosmina* was the most numerous. The second one appeared in September in both basins averaging 8.59 and 6.60 individuals/L in north and south basin, respectively. In 2008, the number of Other Cladocera increased in the north basin due to a peak of *Eubosmina* in July with 18.86 individuals/L, while in the south basin the magnitude of the peak was almost three fold higher than in the north basin, with 53.67 individuals/L On average, other cladoceran density increased approximately 3.5 fold to ~7 individuals/L in 2008 relative to 2007 (Figure 24).   In terms of biomass, other cladoceran biomass of 13.06 and 19.69 µg L^{-1} in 2003 and 2006, was at the higher level than during 2004, 2005 and 2007 when it was 5-6 µg/L. Biomass of other cladocerans achieved the highest level in 2008 with the average biomass of 22.03 µg/L.

Numbers of *Daphnia* have also shown considerable interannual variability in Alouette Reservoir. In 2003 and 2004 *Daphnia* numbers were low, and were a minor component of the zooplankton assemblage, averaging <0.05 individuals/L (Figure 24). The numbers of *Daphnia* rebounded in 2005 and reached a peak in July with 3.79 individuals/L in the north basin and 2.09 individuals/L in the south basin. In 2006 the numbers of *Daphnia* increased again, when midsummer numbers peaked at 9.88 individuals/L and 13.17 individuals/L in north and south basin respectively. *Daphnia* were present in samples during the entire season in 2005 and 2006, and they accounted for the highest proportion of the zooplankton community from July to October. In 2007 their density was relatively low averaging 0.03 and 0.02 individuals/L in north and south basin respectively. In 2008 *Daphnia* first appeared in the north basin in June, and peaked in July with 8.77 individuals/L. In the south basin *Daphnia* first appeared with 9.33 individuals/L. In terms of biomass, *Daphnia* biomass was relatively low in 2003 and 2004, averaging less than 1.5 µg/L. In 2005, *Daphnia* biomass increased to 11.29 µg/L and in 2006 increased nearly 5 fold to 58.41 µg/L. However, in 2007 *Daphnia* biomass decreased again, averaging only 0.52 µg/L in both north and south basin. *Daphnia* biomass increased significantly in 2008 in both the north and the south basin, averaging 64.17 and 57.28 µg/L respectively. The highest total zooplankton biomass during all study years was found in the south basin with 347.84 µg/L in August 2008, when *Daphnia* accounted for 51% of total biomass with 178.29 µg/L (Figure 24).

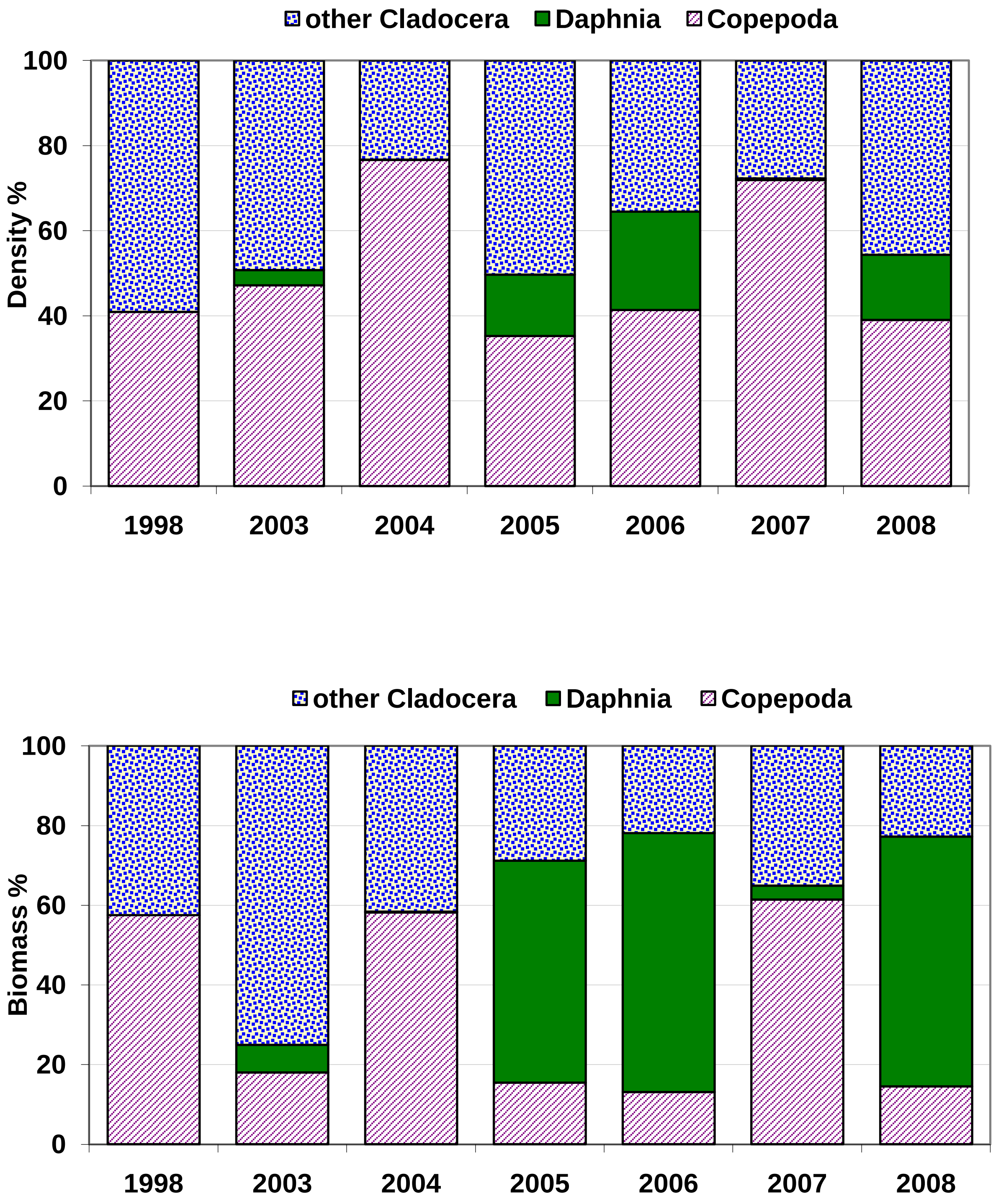

Figure 23 Relative contribution of each group to zooplankton density and biomass in Alouette Reservoir, 1998 and 2003-2008.

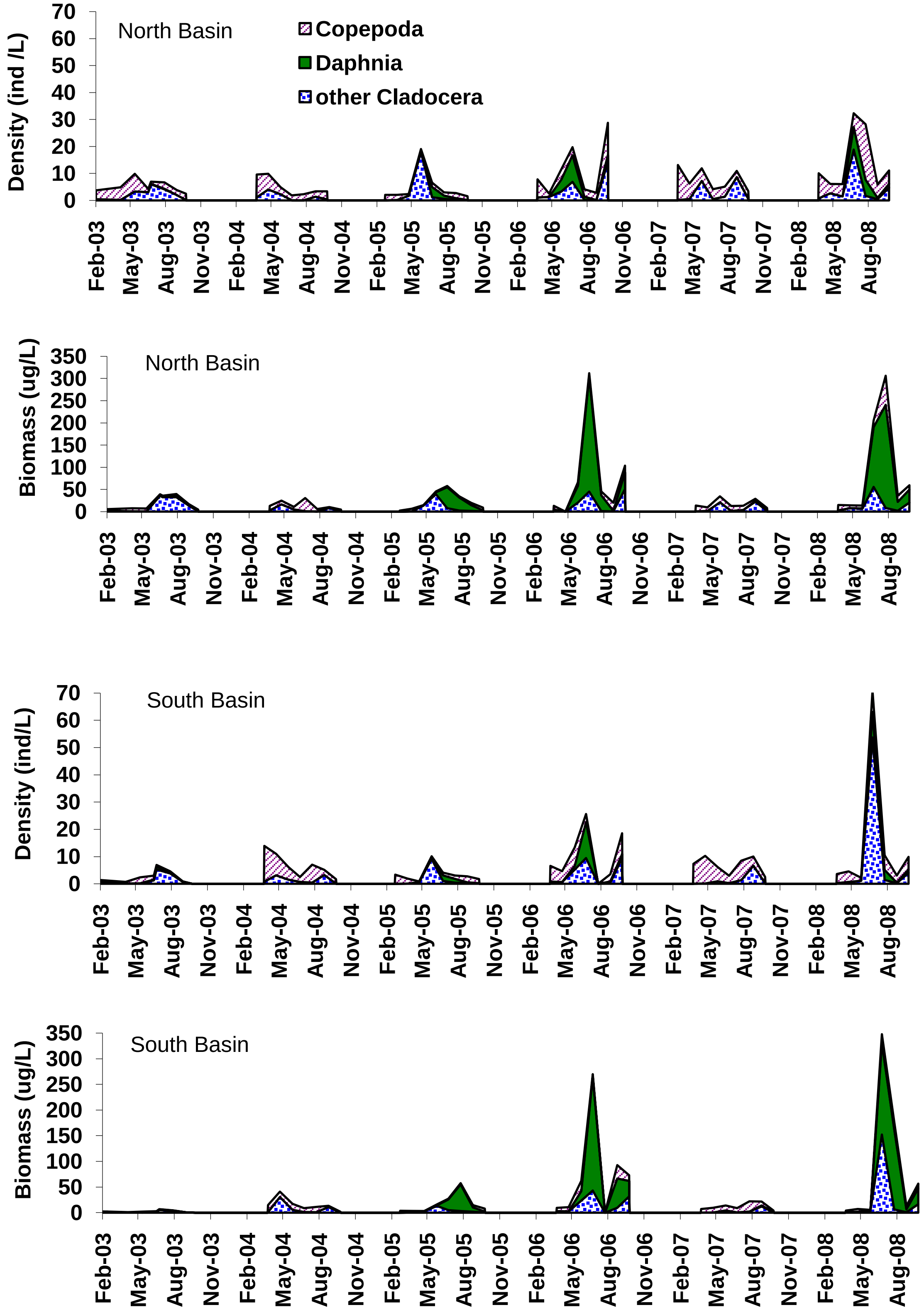

Figure 24 Zooplankton density and biomass by major groups (Copepoda, *Daphnia* and Other Cladocera) in Alouette Reservoir, 2003-2008.

5.7 Fish Populations

5.7 a Species Composition of near shore gillnetting

Northern pikeminnow, redside shiners and suckers (*Catostomus spp*. combined) represented 86% of the total gillnet catch in 2008 with pikeminnows the dominate catch at 43% (Figure 25). Kokanee and peamouth comprised 7% and 3% respectively of the total catch. All salmonids combined comprised 11% of the total catch but no lake char were captured and <1% were bull trout. Overall, the non-salmonid composition accounted for 89% of the total catch compared to the salmonid composition of 11%. This composition is similar to 2007 when the non salmonid component was 87%, far higher than the 53% level in 1998 (Figure 25).

5.7 b Gillnet total catch, biomass and CPUE of near shore gillnetting

Rainbow trout and cutthroat trout are stocked annually in the reservoir therefore were excluded from analysis of the gillnet trend data due to the variable rates of annual stocking that make year-to-year comparisons impossible (Figure 26a; Appendix A). An analysis of the stocking rates demonstrates a direct relationship (r^2=0.60) to total catches, biomass and CPUE, thus confounding the effects of fertilization on the reservoir fish populations (Figure 26b).

A total of 1,256 fish (all species) were capture in the standardized gillnets in 2008, considerably higher than the 780 caught in 2007 (Table 7). Trends in relative gillnet catches that are assumed to reflect abundance of all species (except redside shiners and cottids) have been monitored since 1998. The 2008 kokanee catch was much higher than in 2007 whereas the other salmonids were about the same (Table 8). Catches of redside shiners and northern pikeminnow increased substantially in 2008 compared to 2007 whereas peamouth chub numbers were far less in 2008 compared to 2007 (Table 8).

Biomass of all species caught in gillnets in 2008 totaled 167 kg, slightly higher than in 2007 (Table 7). Of the salmonids, excluding rainbow trout and cutthroat trout, kokanee and bull trout combined for only a total of 17% of the total biomass, up slightly compared to 2007 (Figure 27). Kokanee biomass in 2008 increased for the first time since 2000 (Figure 28a). Non-salmonids dominated the biomass at 77% of the total in gillnet catches in 2008 (Figure 27). Pikeminnow biomass increased substantially in 2008 while sucker biomass actually decreased and peamouth remained the same (Figure 28b). Northern pikeminnows and sucker sp. have comprised >60% of all the biomass in virtually all sample years of near shore netting.

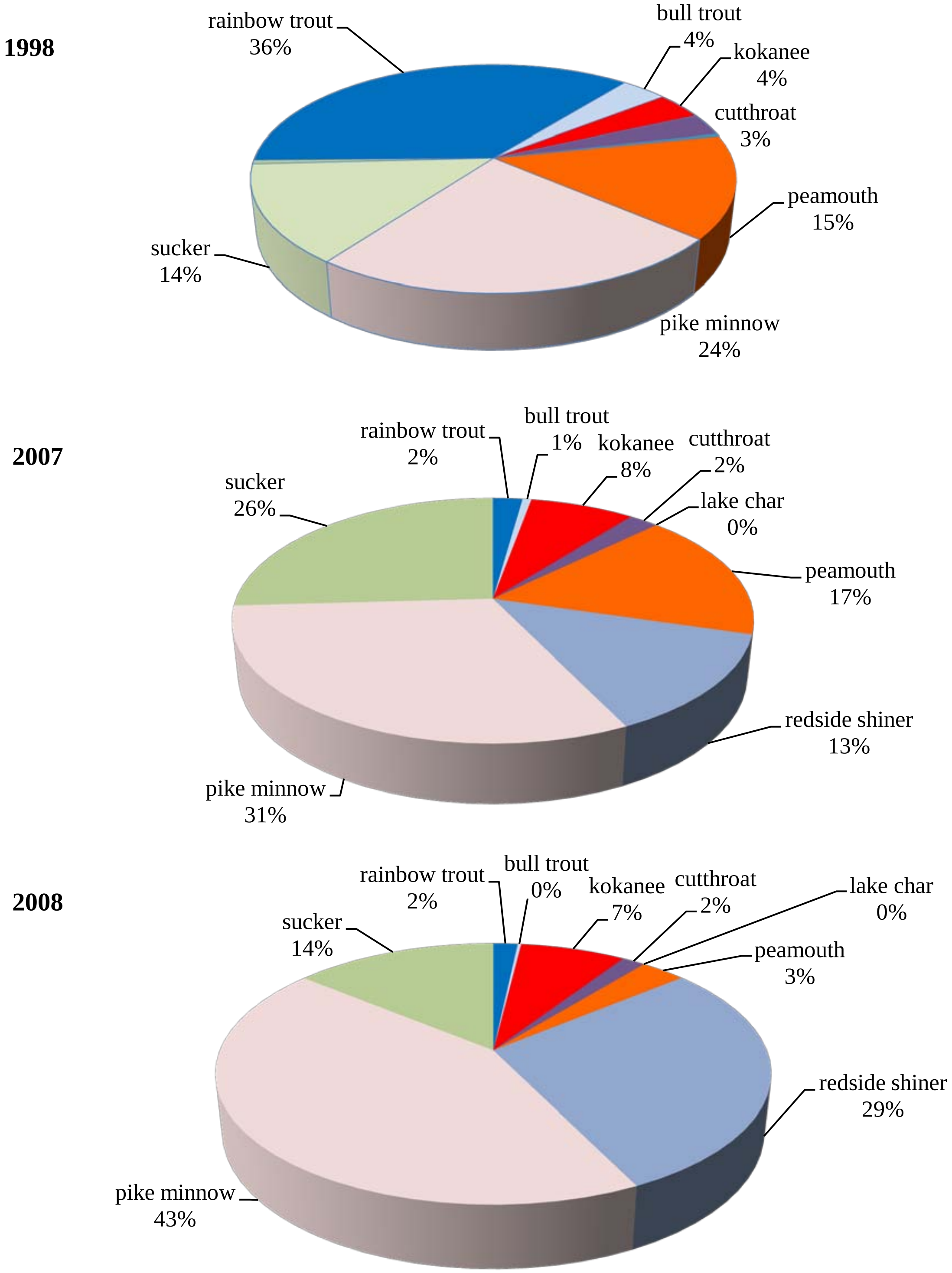

Figure 25 Percent fish species composition of gillnet set catches from Alouette Reservoir in 1998, 2007 and 2008.

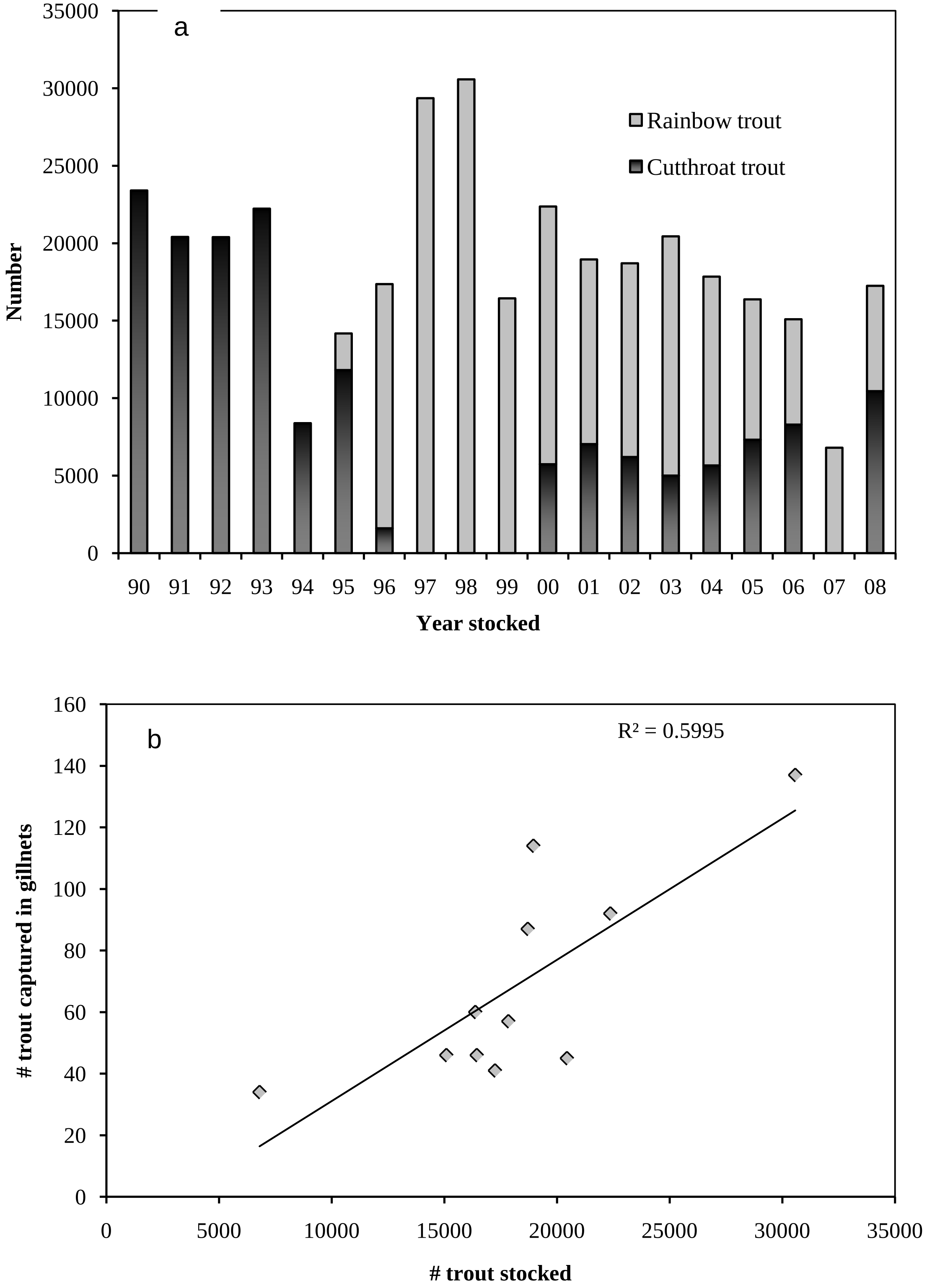

Figure 26 Number of trout stocked into Alouette Reservoir 1998-2008 (a) and relationship between trout number of stocked and number of trout captured in the fall net sets (b), 1998-2008.

Overall, CPUE for all species increased to 2.01 fish/m^2 of net in 2008, nearly double the 2007 rate of 1.25 fish/m^2 (Table 7). This higher catch rate was similar to those determined in the early 2000s, and the same general pattern is evident in the acoustic abundance trend. Standardized CPUE estimates were also calculated for individual species based on the number caught/m^2 of net fished. Similar to total catch, individual species CPUE estimates provide an index that is assumed to be proportional to population abundance, although for pelagic species such as kokanee and bull trout this relationship is likely less apparent. For the salmonids, the 2008 catch rate for kokanee increased whereas the bull trout catch rate was the lowest recorded in eleven years of record (Figure 29a). Although numbers caught in any one year have been low the downward trend for bull trout is unexpected. Non-salmonid catch rates increased for pikeminnow while 2008 sucker and especially peamouth catch rates declined (Figure 29b). Assuming these rates are proportional to reservoir population abundance it appears that pikeminnow track kokanee reasonably well with two peaks: one at the onset of fertilization and a second peak possibly forming in 2008. The sucker population appears to be relatively stable whereas the peamouth population has slowly been trending downward since 2003.

Table 7 Total number of fish, biomass and CPUE (fish/m^2/net) caught annually during fall gillnetting in Alouette Reservoir, 1998-2008 (Lake trout not included in biomass).

Year	# of Fish	Biomass (kg)	CPUE (#fish/m^2/net)
1998	633	158	0.88
1999	752	121	1.22
2000	1,137	207	1.84
2001	1,371	198	2.2
2002	1,023	141	1.74
2003	1,599	205	2.48
2004	1,049	137	2.94
2005	608	114	0.98
2006	833	108	1.08
2007	780	138	1.25
2008	1,256	167	2.01

Table 8 Numbers of all fish species caught in gillnets in Alouette Reservoir, 1998-2008.

Species	1998	1999	2000	2001	2002	2003	2004*	2005	2006	2007	2008
rainbow trout	198	35	24	54	17	19	26	35	16	17	21
bull trout	20	9	13	17	18	34	23	15	10	5	3
kokanee	21	51	167	109	123	77	95	90	50	61	91
cutthroat	17	11	30	59	70	26	44	25	28	17	20
lake char	2	1	1	0	2	1	0	0	1	0	0
peamouth	80	62	102	252	237	442	274	125	98	132	39
redside shiner	1	171	223	352	145	168	431	61	25	103	360
pikeminnow	131	294	445	385	372	674	270	158	278	244	540
sucker	77	123	131	128	46	98	203	105	165	202	175
sculpin	3	6	15	15	16	10	11	0	5	0	7
Grand Total	550	763	1151	1371	1046	1549	1376	614	676	781	1256
Salmonid species	258	107	235	239	230	157	188	165	105	100	135
Non-salmonid species	292	656	916	1132	816	1392	1189	449	571	681	1121

* 2004 adjusted upward 25% see Harris et al. 2008

Note: small differences exist in 2003-2006 reports. All fish assumed to be gillnet caught in data base where no description of methods exists

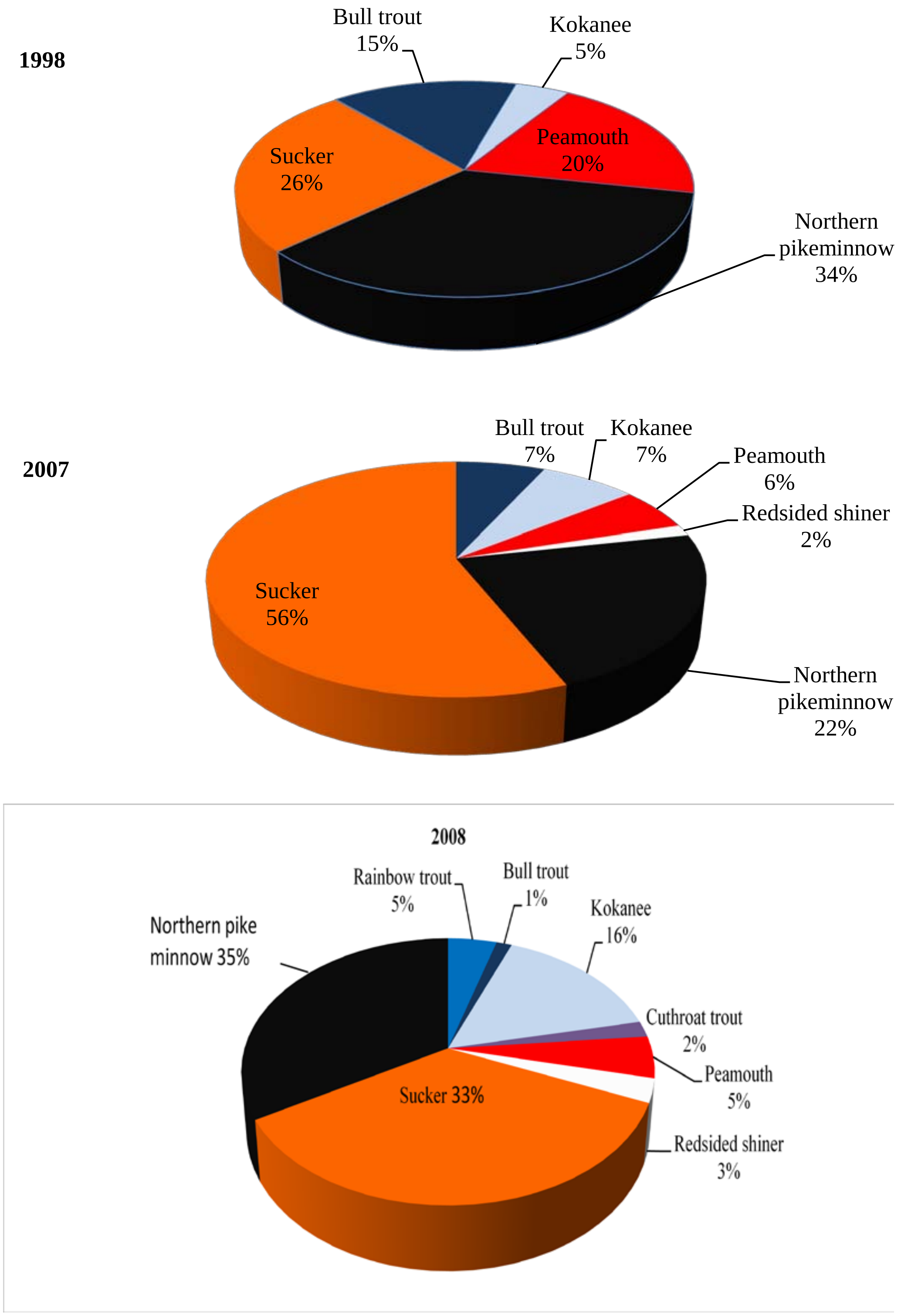

Figure 27 Biomass of fish species (%) from gillnet catches in Alouette Reservoir 1998, 2007 & 2008.

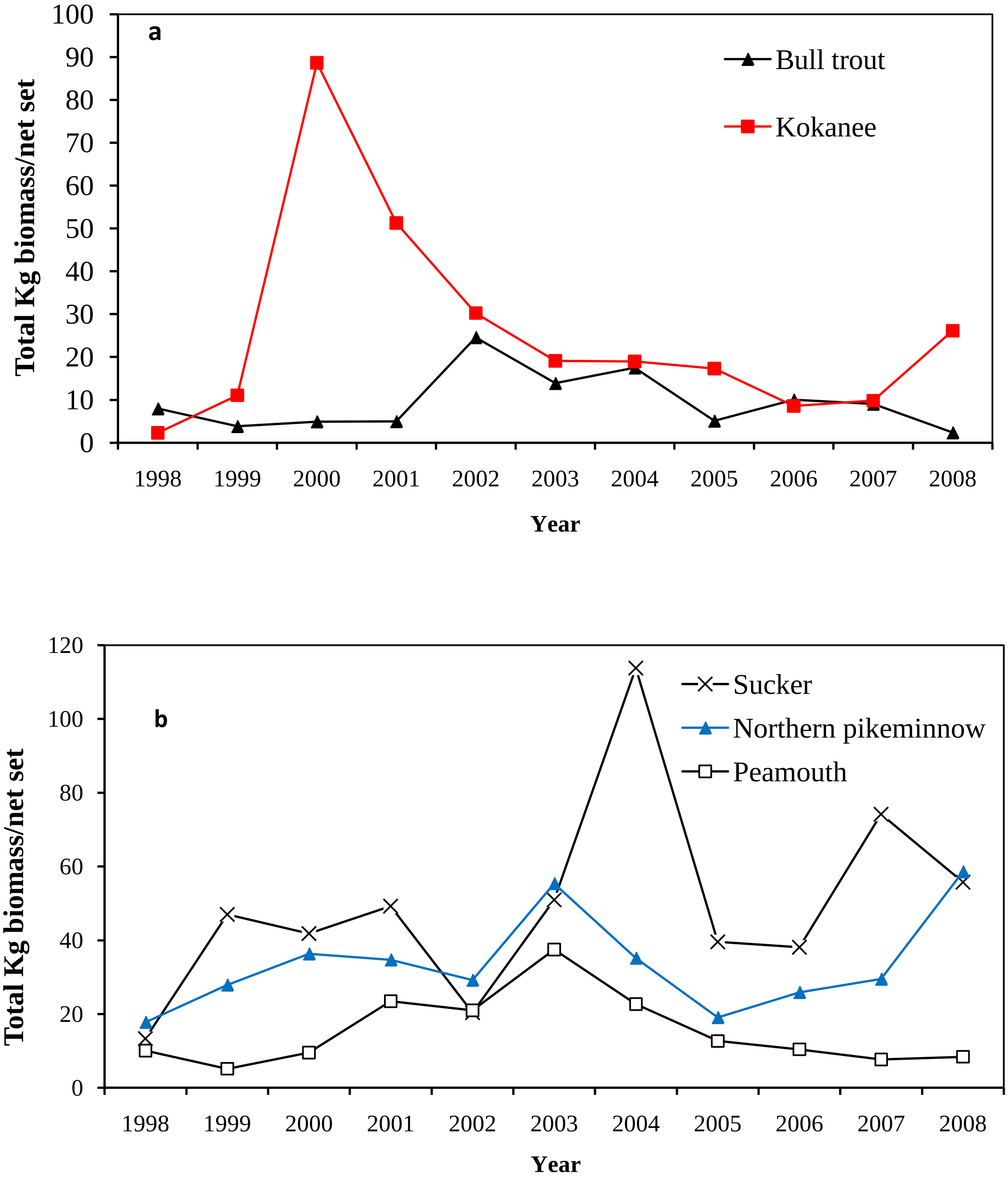

Figure 28 Total biomass of a) salmonid and b) non salmonid species caught annually in Alouette Reservoir using standard gillnet sets 1998-2008.

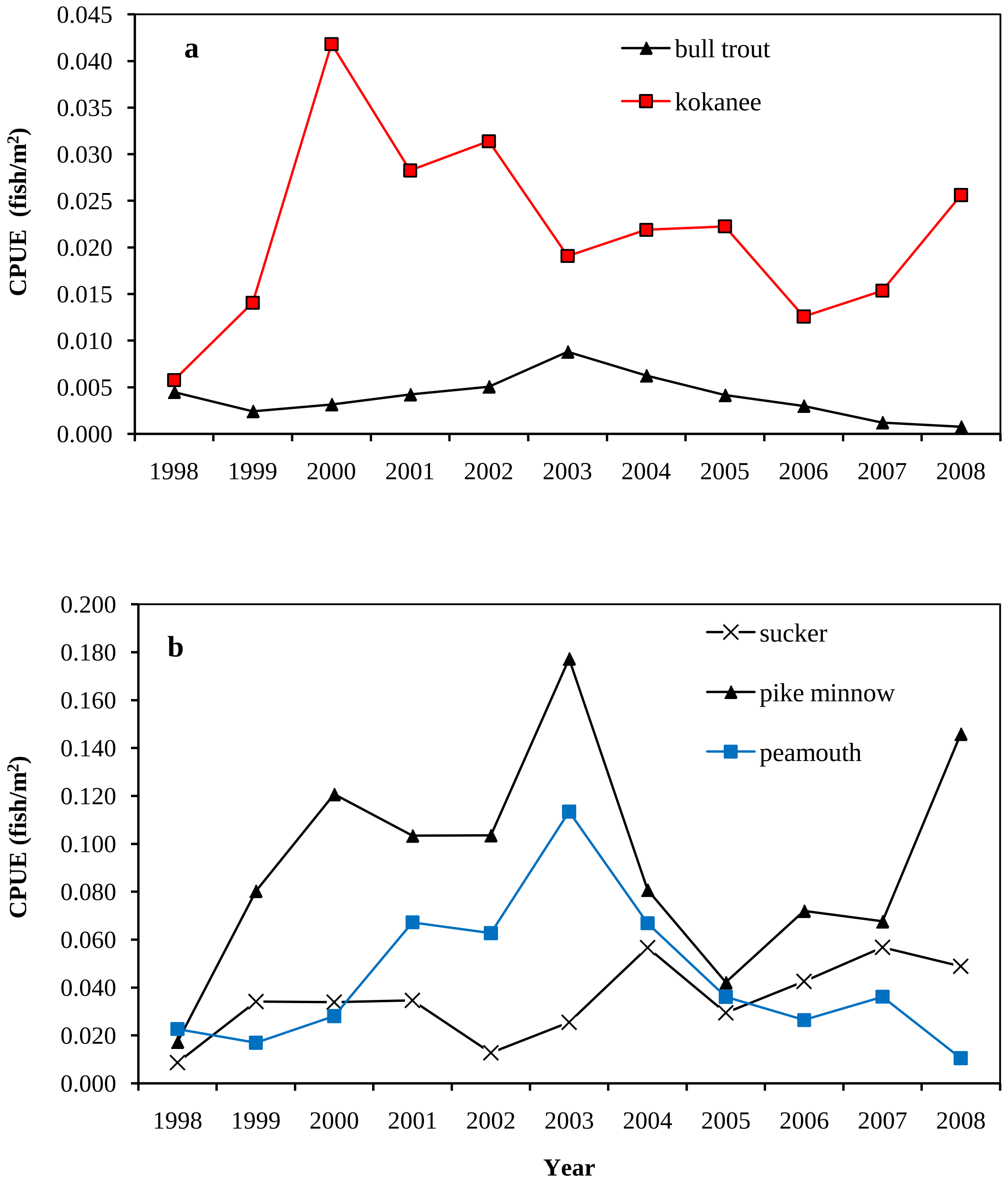

Figure 29 CPUE of a) salmonid and b) non salmonid species caught annually in Alouette Reservoir using standard gillnet sets 1998-2008. Note difference in scale of Y axis between the two graphs.

5.7 c Hydroacoustic and trawl surveys

The 2008 acoustic survey results indicated that longitudinal fish densities were highly variable in their distribution across both basins (Figure 30). Highest densities were recorded at transects 4 and 8 which are at opposite ends of the south basin while the lowest density was in transect 7 (see Figure 1 for transect locations). As in past years, 2008 average fish densities were significantly higher in the south basin compared to the north basin (Table 9, Figure 30). Transect 8 has often supported the highest densities across the period of study, which was again the case in 2008. Closer examination of the fish distribution data shown in Figure 31 was achieved by separating fry and non-fry sized fish using a 75 mm (-47dB) cut-off. Fry densities ranged from 60-360 fish/ha while non-fry sized fish were less variable at 25-60 fish/ha. Basin averages show little variation for non-fry sized fish whereas there were nearly twice the numbers of fry sized fish in the south basin compared to the north basin (Figure 31, right hand side of graph). It is evident that reservoir fish densities increased dramatically commencing in 2001 (Table 9).

Depth distribution of all fish at the time of the acoustic survey is illustrated for the two size groups in Figure 32. The temperature profile at that time is also displayed to emphasize the organization of fish by size through the temperature profile. Most fry sized fish (<75 mm) were above 10 m depth, where the temperature range is ~13-15°C. At the same time, a smaller portion of the fry sized fish and virtually all fish >75 mm were oriented at or below the thermocline (and below 10 m deep) where the temperature ranges from ~5-13°C. Assuming this distribution is in response to temperature preference, a likely organization of species for fry sized fish would include a redside shiner dominated upper (>13°C) layer, with the area at or below the thermocline (<10 m) being dominated by primarily kokanee fry and some stickleback. This distribution is supported by the results from directed trawl sampling as demonstrated later in this report (Table 12 and Figure 37). As for larger fish (>75 mm), species specific temperature preferences would suggest a distribution consisting of the warmer surface layer (0-10 m) being dominated by non-salmonids, and containing a few kokanee, rainbow, and cutthroat. Kokanee, having a preference for temperatures below 13°C would likely dominate pelagic areas at or below the thermocline (>10 m), with a few non-salmonids and other salmonids present. This assumption is in agreement with pelagic gillnet results for 2008 as later described by Table 10 and Figure 36.

Table 9 Average fish densities (fish/ha) by basin for Alouette Reservoir, from 70 kHz single beam data 1998-2001; split beam 2002-2008.

	North Basin			South Basin		
	Avg.	min.	max.	Avg.	min.	max.
1998	33	22	39	61	32	94
1999	33	25	40	50	7	164
2000	36	8	74	79	37	142
2001	42	16	89	228	112	484
2002	120	98	142	292	206	439
2003	254	243	266	251	83	475
2004	269	212	319	267	228	341
2005	195	159	224	231	207	268
2006	175	149	217	256	211	301
2007	105	66	161	156	103	224
2008	195	157	241	290	87	412

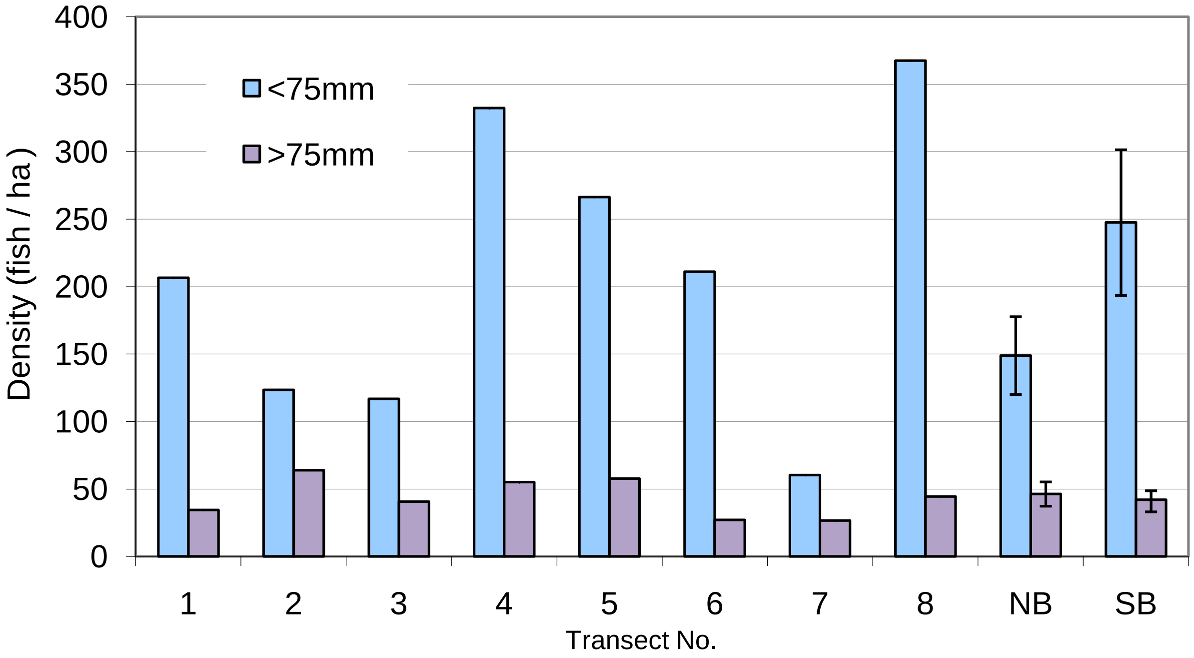

Figure 30 Longitudinal density distribution of all fish species in the pelagic habitat from night time 120kHz split beam acoustic survey data, October 2008. NB = North Basin (transects 1-3) average density with 95% confidence limits, SB = South Basin (transects 4-8) average density with 95% confidence limits.

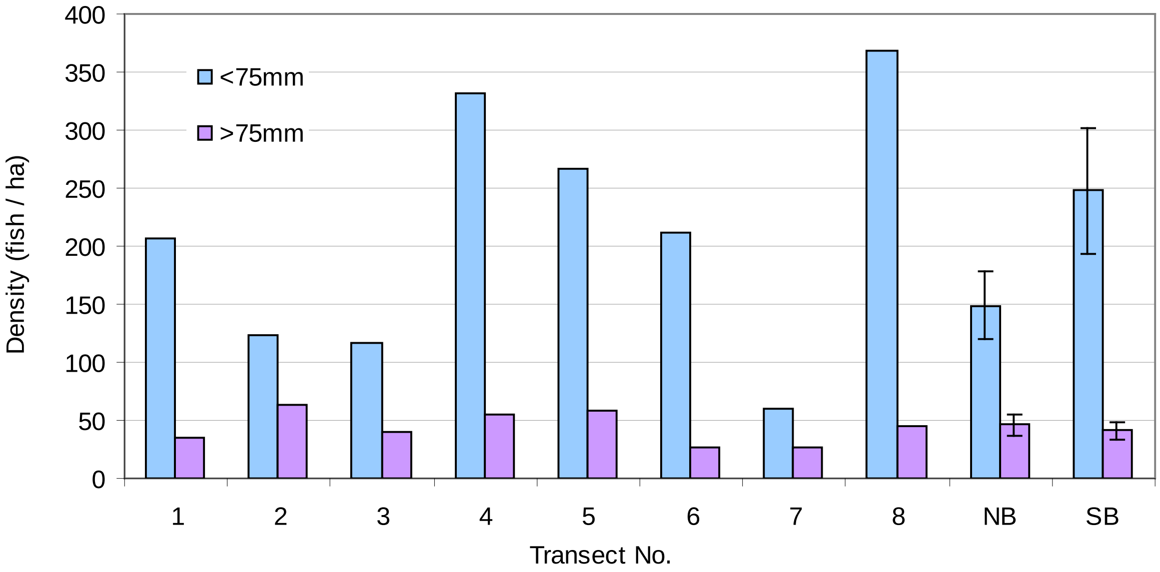

Figure 31 Longitudinal density distribution of all fish species in pelagic habitat in two size groups, <75mm and >75mm and basin averages, from night time 120kHz split beam acoustic survey data, October 2008. NB = North Basin (transects 1-3) average density with 95% confidence limits; SB = South Basin (transects 4-8) average density with 95% confidence limits.

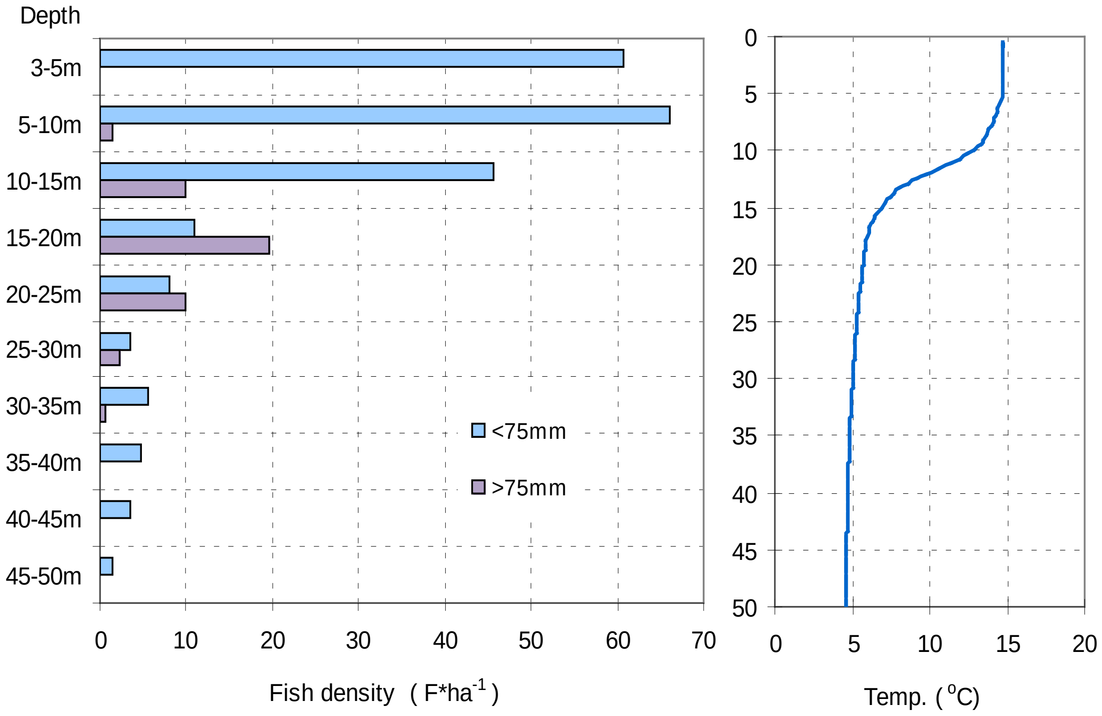

Figure 32 Average fish density at depth for two size groups of fish, <75 mm and fish >75 mm and average temperature at depth from night time 120kHz split beam acoustic survey data and temperature profile data, October 2008.

Fish abundance and biomass

Prior to fertilization limnetic abundance estimates of all fish were <100,000, but since 2000 total numbers of fish determined by either a single or split beam echosounder have increased ~4 fold (Figure 33; Appendix H). The 2008 estimate of 371,800 is the highest estimate for the period of study, followed closely by the previous peak abundance period that occurred during 2002-2004 (Figure 33). The depressed abundance estimate for 2007 illustrated in Figure 33 coincides with a large out-migration of juvenile kokanee (Matthews and Bocking 2009). The maximum likelihood abundance estimate (MLE) for fish >75 mm that inhabit the pelagic habitat increased slightly in 2008 over 2007 (Figure 34). However, the large fish MLE population trend has remained relatively stable from 2005-2008 following the initial surge in trophic level responses to fertilization that occurred beginning in 2000-2001. Fish abundance <75 mm show a similar trend but with greater variation; a substantial decline was evident in 2007 followed by a greater than two fold increase in 2008 (Figure 34). It should be noted that the 2001-2008 data are from the 120 kHz split beam sounder re-analyzed with Sonar 5, hence the numbers may vary somewhat from earlier reports.

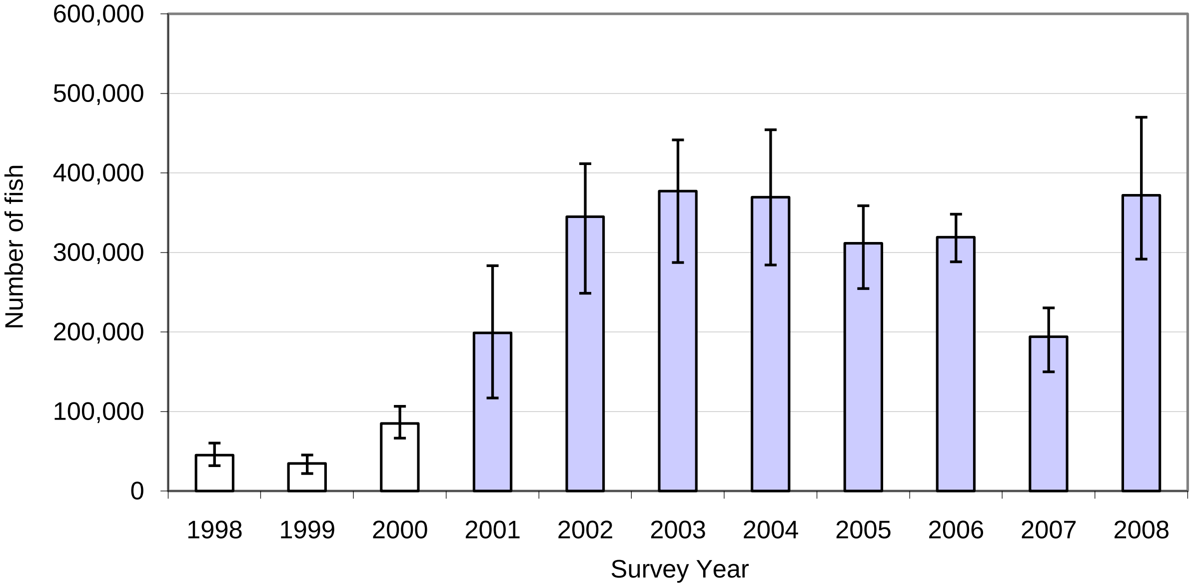

Figure 33 Abundance estimates with bounds for fall pelagic fish populations from acoustic surveys 1998 – 2008. Error bars denote 95% confidence limits on maximum likelihood estimates. Data are from single beam data for 1998 - 2000 and split beam data 2001 -2008.

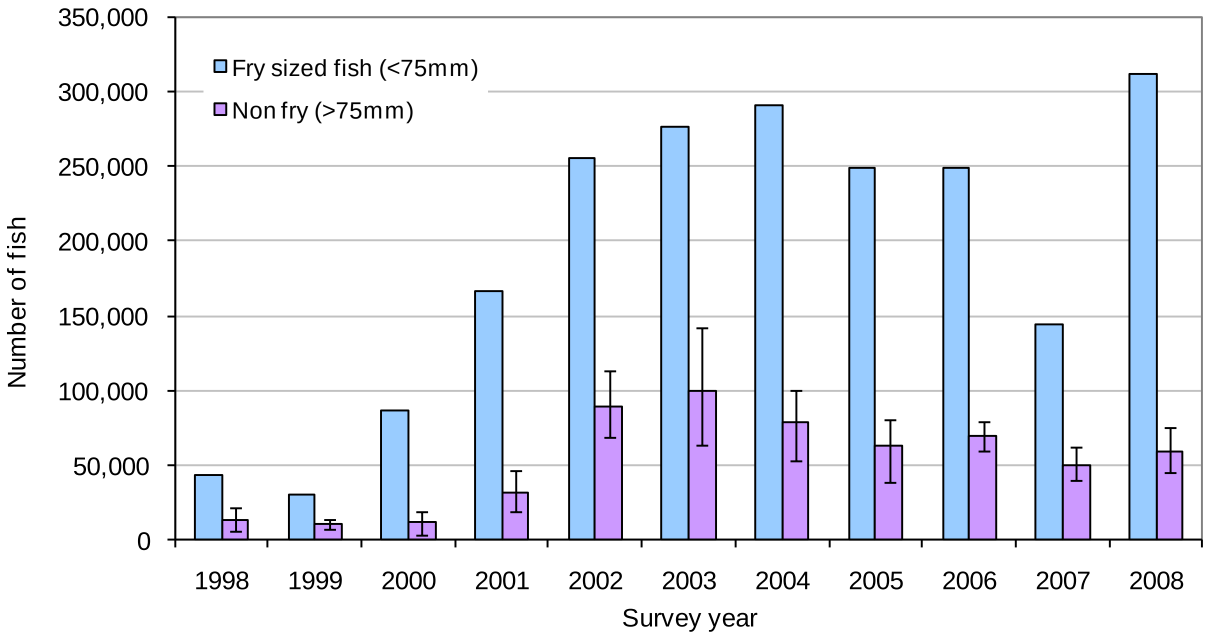

Figure 34 Trends in abundance of fry sized fish and larger sized fish in Alouette Reservoir based on fall acoustic surveys 1998-2008. Fry estimates represent the difference between fish >75 mm and total fish abundance estimates. Error bars denote 95% confidence limits on maximum likelihood estimates. Data are from single beam data for 1998 - 2000 and split beam data 2001 -2008.

An estimation of total biomass in the pelagic zone (10-50 m) was obtained using mean weights of all gillnet or trawl caught fish (excluding lake char) and applying these weights to the acoustic estimates of total numbers. Limnetic biomass, an important determinant of nutrient addition, was estimated at 8.3 kg/ha in 2008, more than double the 2.9 kg/ha calculated for 2007 (Figure 35). The 2008 estimate reverses a downward trend that commenced after 2003 and bottomed out in 2007. The biomass trend across the study period shows some variability, particularly evident in the dramatic increases in 2003 and 2008. It is assumed that while the overall trend is well described by this biomass estimation method, there may be some imprecision occurring on any given year due to the sensitivity of the method to hydroacoustic calibration. Future refinements to both species composition and the biomass calculation methodology, particularly the assignment of average weight per acoustic decibel bin, should improve the reliability of these estimates.

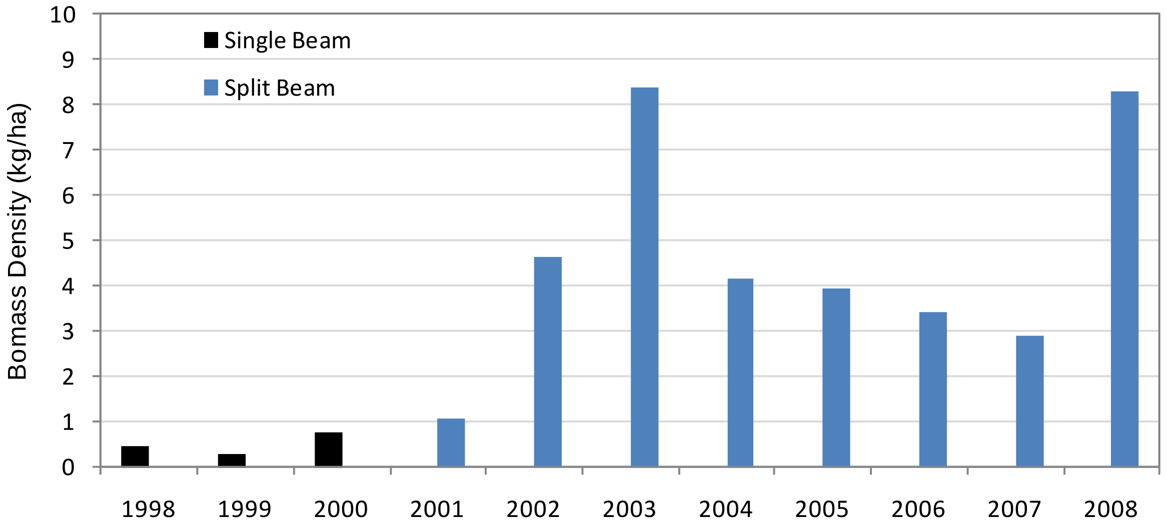

Figure 35 Trend in biomass density (kg/ha) in the pelagic habitat of Alouette Reservoir 1998-2008 based on hydroacoustic surveys. Estimates are based on fish populations with acoustic target strengths <-32 dB (<450 mm) located between 10-50 m depth.

5.7 d Pelagic gillnetting and trawl survey

Slightly more than half (54%) of all fish caught in the pelagic gillnets were located in the surface waters (~0-3 m). Redside shiners, northern pikeminnows, rainbow and cutthroat trout comprised virtually all the numbers with very few kokanee (Figure 36; Table 10 & 12). The near shore surface nets, discussed elsewhere in this report, captured primarily trout and northern pikeminnow while only 11% of the total catch in the shallow littoral nets were kokanee. Within the near shore nets most of the kokanee (89%) were caught in the sinking nets at > 3 m depth. The pelagic zone (>10 m) catch was almost entirely the sole domain of kokanee (Figure 36; Table 10 & 12).

The trawl catch is not directly comparable with the gillnet catch owing to the variable depth fished and differences in size selectivity between the two methods. Despite these differences, the trawl sampling also demonstrated that kokanee were captured at the deeper depths while the majority of the shiners and other species were caught closer to the surface (Table 11 & 12; Figure 37). The minimum size captured by gillnets was ~ 75 mm thus threespine sticklebacks most likely were not vulnerable to gillnets, but were vulnerable to the small mesh size of the trawl net. Similarly, the larger fish such as pikeminnow, chub, and rainbow were either at the immediate surface or in densities too low to detect with the trawl net.

Table 10 Number of fish caught in pelagic gillnets set at various depths in Alouette Reservoir, October 7, 2008.

Net depth	Kokanee	N. pike minnow	Peamouth chub	Reside shiner	Suckers sp.	Rainbow Cutthroat	Total
0 m	5	58	2	73	1	21	160
10 m	54	3	0	0	0	3	60
15 m	44	1	0	0	0	0	45
20 m	32	0	0	0	0	0	32
Total	**135**	**62**	**2**	**73**	**1**	**24**	**297**

Table 11 Number of fish caught by directed and oblique trawl net in the pelagic zone of Alouette Reservoir October 7, 2008.

trawl depth	trawl type	Kokanee	N. pike minnow	Peamouth chub	Reside shiner	Three spine stickleback	Rainbow cutthroat	Total
2-9 m	directed	1	0	0	19	1	0	21
5-27 m	oblique	4	0	0	3	2	0	9
5-26 m	oblique	4	0	0	1	0	0	5
8-24 m	directed	14	0	0	5	9	0	28
Totals		**23**	**0**	**0**	**28**	**12**	**0**	**63**

* one sculpin caught in 2-9 m depth trawl

Table 12 Summary of species occurrence by depth from gillnet sets and directed trawling 1998 – 2008.

Year	**1999 - 2008 Near Shore gillnets**			**2008 Pelagic gillnets**			**2008 Trawl**		
Species	Floating	Sinking	N	Surface	>10 m	N	Surface	>10 m	N
TROUT	86%	14%	559	87.5%	12.5%	24	-	-	0
NSC	59%	41%	3200	94%	6%	62	-	-	0
RSC	33%	67%	1184	100%	0%	73	79%	21%	28
TSB	-	-	0	-	-	0	10%	90%	12
KO	11%	89%	886	4%	96%	134	7%	93%	23

Note: near shore sinking gillnets were set perpendicular to the shore line and sinking nets started at or below 6m contour

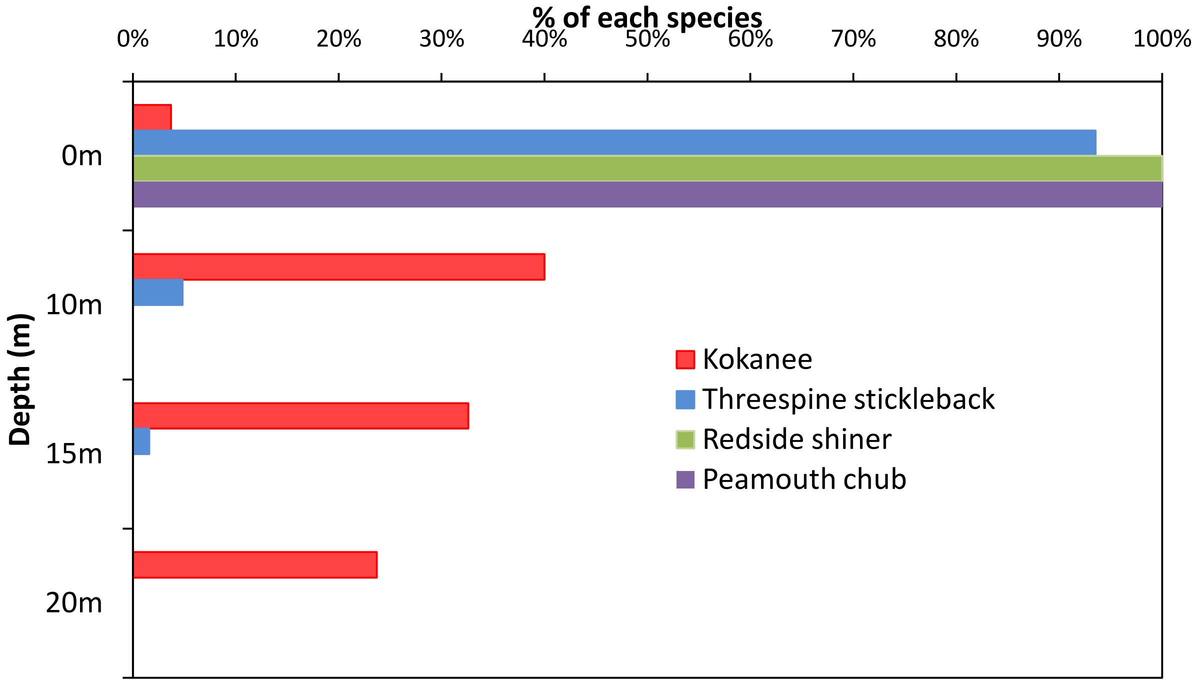

Figure 36 Percent of select species captured in gillnets at each depth interval set in the open waters of Alouette Reservoir October 2-3, 2008. Nets were set at 0 m, 10 m, 15 m and 20 m depths.

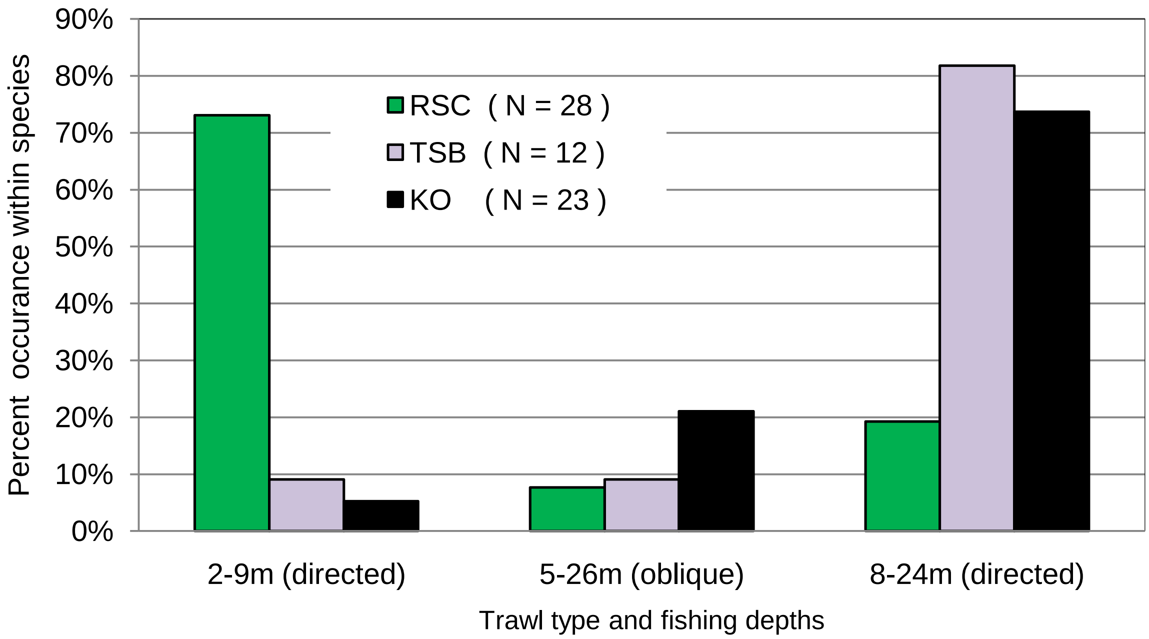

Figure 37 Percent occurrence of each species caught in trawls in 2008.

Figure 38 illustrates the length frequency distributions of fish species captured in the limnetic net sets combined with those trawl captured fish in 2008. The “fry” (<75 mm) were comprised of redside shiners, stickleback and kokanee whereas those >75 mm were predominately kokanee followed by redside shiners and northern pikeminnow and trout. i.e. virtually no sticklebacks. Figure 39 displays the same data with the species converted to acoustic scale to illustrate how each species “fits” under the acoustic curve. Redside shiners were the smallest group in the <75 mm category, sticklebacks were intermediate size and kokanee were the largest.

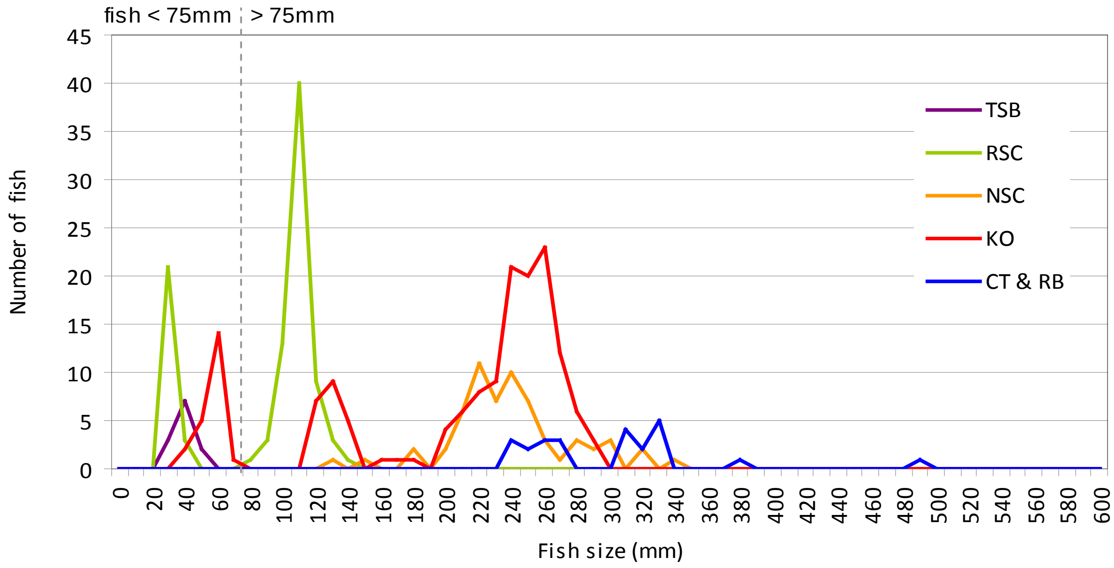

Figure 38 Length frequency of combined trawl and pelagic gillnet samples, October 2008.

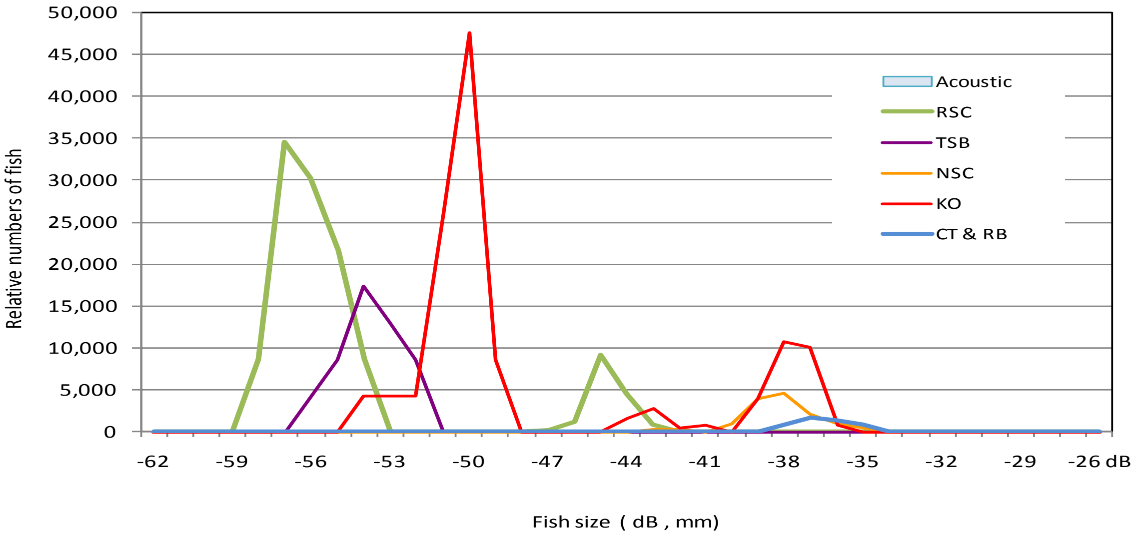

Figure 39 Acoustic length equivalents of trawl and pelagic gill net samples scaled to the acoustic population size frequency, showing occurrence and relative species size peaks within the 2008 120 kHz split beam dB population.

5.7 e Nerkid out-migration

In 2008, an estimated 8,247 nerkids migrated from the Alouette Reservoir compared to far greater numbers of 62,923 in 2007 (Table 13**;** Mathews and Bocking 2009). The 2008 mean length of these nerkids was 71.2 mm significantly less than 81.4 mm in 2007. 87% of these migrants were <100 mm. Of particular interest is that the screw traps caught very few stickleback, peamouth chub, redside shiners or northern pike minnows (Appendix C, Mathews and Bocking 2009). i.e. < 200 of any of these other species compared to 3,224 nerkids (Table 13).

Table 13 Mark recapture estimates for nerkids out-migrating from ALU 2005-2007, using rotary screw trap located in South Alouette River. (data from Mathews and Bocking 2009).

Year	Total catch	Estimate	95% confidence intervals
2005	3,310	7,900	na
2006	1,757	5,064	na
2007	7,787	62,923	48,436 - 77,410
2008	3,224	8,257	na

5.7 f Kokanee

The fish species of particular interest with respect to the Alouette Reservoir fertilization program are kokanee. They are a good indicator species to comprehensively monitor the effects of nutrient additions since they are a pelagic planktivore. Kokanee in Arrow Lakes Reservoir and Kootenay Lake responded rapidly to lake fertilization (Ashley et al. 1997; Schindler et al. 2007a; Schindler et al. 2007b). In addition, kokanee are easily caught by gillnetting and can be tracked through hydroacoustic and trawl surveys.

During the near shore gillnetting survey a total of 54 kokanee were caught on September 8, 2008. Mean length and weight of gillnet captured kokanee was 272 ±19.7 mm and 292 ±44.5 g, respectively (Figure 41; Table 14). Mean length increased as did mean weights for the 2008 sample especially compared to the 2007 sample (Table 14). Mean weight was particularly impressive, the highest value since 2001. Age of captured fish was predominately age 3+ with lesser numbers of age 2+ and a few age 4+ (Table 15).

Table 14 Average length, weight and standard deviation (SD) of kokanee samples collected from near shore gillnetting 1986-1987 and 1998-2008.

Year	n	Length (mm)	SD	Weight (g)	SD
1986	56	222	13.1	121	19.6
1987	69	226	27.7	150	45.4
1998	18	221	9.1	111	23.5
1999	47	253	23.8	221	44.1
2000	35	331	49.6	511	100.6
2001	79	305	80.4	435	241.9
2002	121	267	40.2	250	93.0
2003	77	267	34.4	248	77.6
2004	73	255	20.7	200	37.7
2005	88	234	59.5	191	112.5
2006	47	274	25.2	182	53.9
2007	60	245	25.3	163	40.8
2008	54	272	19.7	292	44.5

Table 15 Sample size (n), by age class, of kokanee caught in on-shore gillnets in Alouette Reservoir from 1998 to 2008.

Year	1+	2+	3+	4+	5+
1998	-	4	14	-	-
1999	1	1	22	23	-
2000	1	1	15	15	3
2001	21	14	40	4	-
2002	11	93	18	-	-
2003	3	33	41	-	-
2004	1	6	66	-	-
2005	28	6	52	2	-
2006	-	14	18	15	-
2007	-	30	30	-	-
2008	-	13	35	6	-

*Note: some differences in sample size exist from previous years summary 1998-2006 in Harris et al. 2008

Mean size of the age 2+ fish in 2008 was considerably larger than equivalent age fish from the previous five years (Table 16). Size of age 3+ in 2008 was considerably larger than the 2007 sample but similar to the previous four years. Of particular interest was the condition of the 2008 kokanee. Condition factors of both ages 2 and 3+ were vastly improved from the poor condition calculated for the 2006 and 2007 samples; in fact, the condition factors in 2008 approximated the highest values yet recorded (Table 16). Note: it has been recognized that there may be an issue with differentiation of age 2+ and 3+ kokanee in 2007. Based on similar length and standard deviation of the samples it is likely that all fish in 2007 were a single age group and most likely age 2+ based on size and compared with all previous years.

Table 16 Mean fork length and standard deviation (FL, SD) and condition factor and standard deviation (K, SD) of age 2+ and 3+ kokanee caught in gillnets in 1986-1987 and 1998 -2008.

	Age 2+					Age 3+				
Year	**n**	**FL**	**SD**	**K**	**SD**	**n**	**FL**	**SD**	**K**	**SD**
1986	49	220	12	1.11	0.10	7	239	2.2	1.04	0.13
1987	28	207	31	1.25	0.10	40	242	4.3	1.23	0.10
1998	4	215	10	0.94	0.20	14	223	8.6	1.05	0.14
1999	1	162		1.37		22	254	8.5	1.34	0.08
2000	1	282		1.45		15	343	13.0	1.33	0.10
2001	14	316	26			40	362	12.8	1.29	0.08
2002	93	268	14	1.24	0.07	18	321	12.4	1.23	0.09
2003	33	251	15	1.25	0.11	41	290	11.7	1.24	0.09
2004	6	237	37	1.14	0.07	66	257	18.3	1.18	0.11
2005	6	249	14	1.25	0.09	52	274	17.1	1.36	0.55
2006	14	253	20	0.87	0.25	18	278	24.5	0.97	0.48
2007	30	243	27	1.22	0.78	30	247	23.4	1.06	0.10
2008	13	267	21	1.67	0.49	35	273	20.6	1.44	0.43

Standard near shore gillnet kokanee catch vs. pelagic gillnet catch

There were some notable differences in the kokanee size composition of the standardized near shore gillnet catch in mid September compared to the pelagic net sets of October 2008. The pelagic catch included a number of small fish (113-210 mm) that were determined as age 1+ whereas none of these same sized fish were caught in mid the near shore netting in September (Figure 40). The near shore sample also contained a much higher percentage of older fish thus explaining why the mean size in the onshore netting in September was actually larger (272 mm) than the pelagic netting in October (220 mm). It is possible that by early October some of the older fish had moved on-shore for staging prior to spawning.

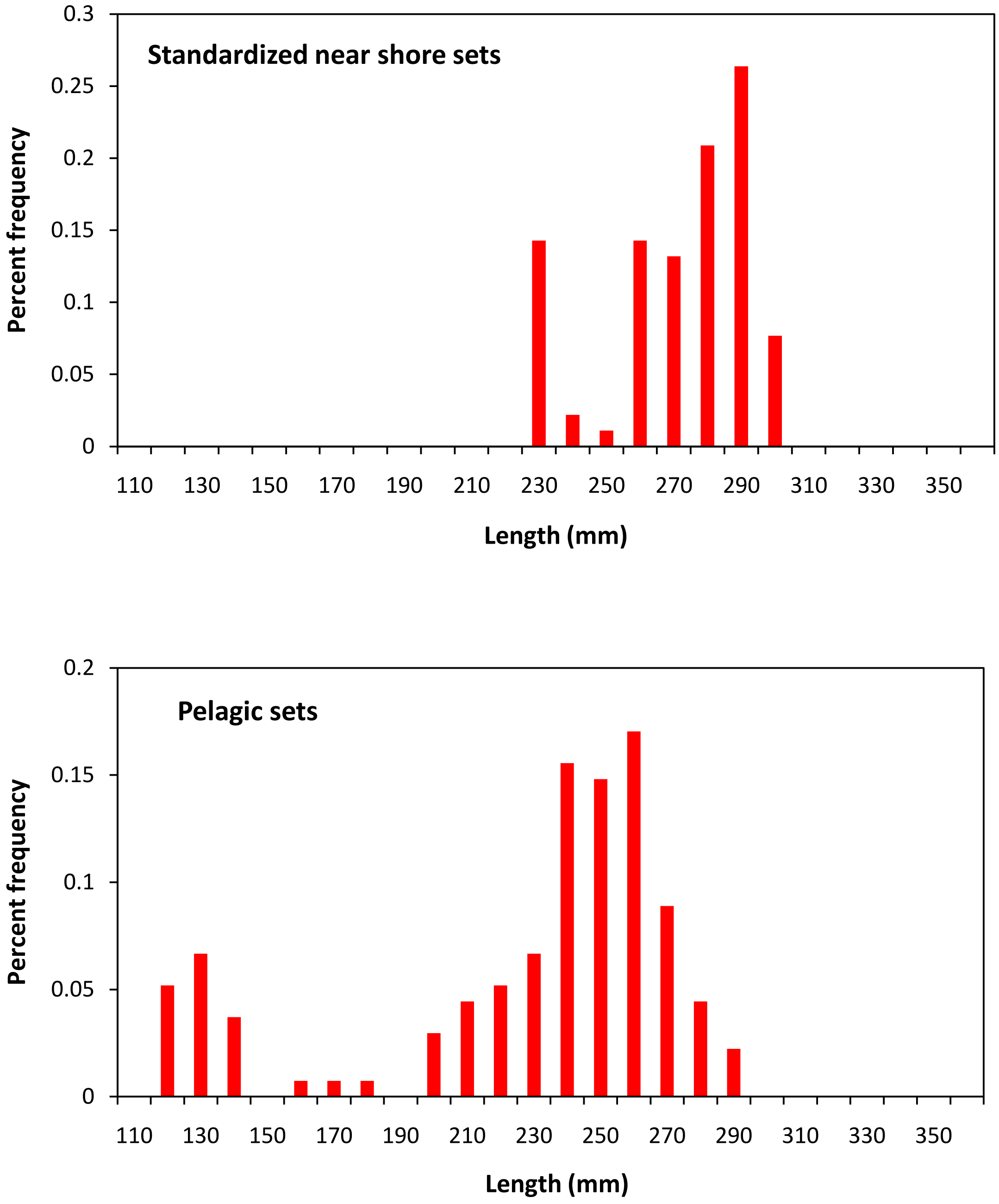

Figure 40 Percent length frequency of kokanee captured in the standardized near shore net sets during September 17-19, 2008 vs. those captured in the pelagic net sets October 3, 2008.

Analysis of Size at Age and Growth of Kokanee

Analysis of the length of 3+ year-old kokanee using a linear mixed-effects (LME) model, with era (pre vs. post) designed as a fixed effect and year as a random effect explaining variation in length, demonstrates a significant (p=0.039) increase post fertilization compared to pre-fertilization (Figure 41). Furthermore, the model improves substantially (p=0.011) with the inclusion of nutrient input (phosphorus) as a fixed effect, indicating a considerable amount of variation in length-at-age for 3+ kokanee is explained by the addition of phosphorus.

In addition, fitting a simple time-invariant von Bertalanffy growth function (VBGF) to kokanee length-at-age data during the pre- and post fertilization years also demonstrated significant differences (p<0.05) between the two era's (Figure 42). In the absence of real data, ages were reconstructed, assuming that age 1+ kokanee were between 75-155 mm based on a combination of length specific regressions, back calculated aging and length frequency analysis. Although parameters (L_{∞}, K) in the model were highly correlated, combined post fertilized years data demonstrated a significantly larger average maximum asymptotic length (L_{∞}) compared to years prior to fertilization. However, it should noted, that this model only represents average growth curves and do not account for cohort specific growth or year to year changes in growth conditions experienced in ALR due to other factors.

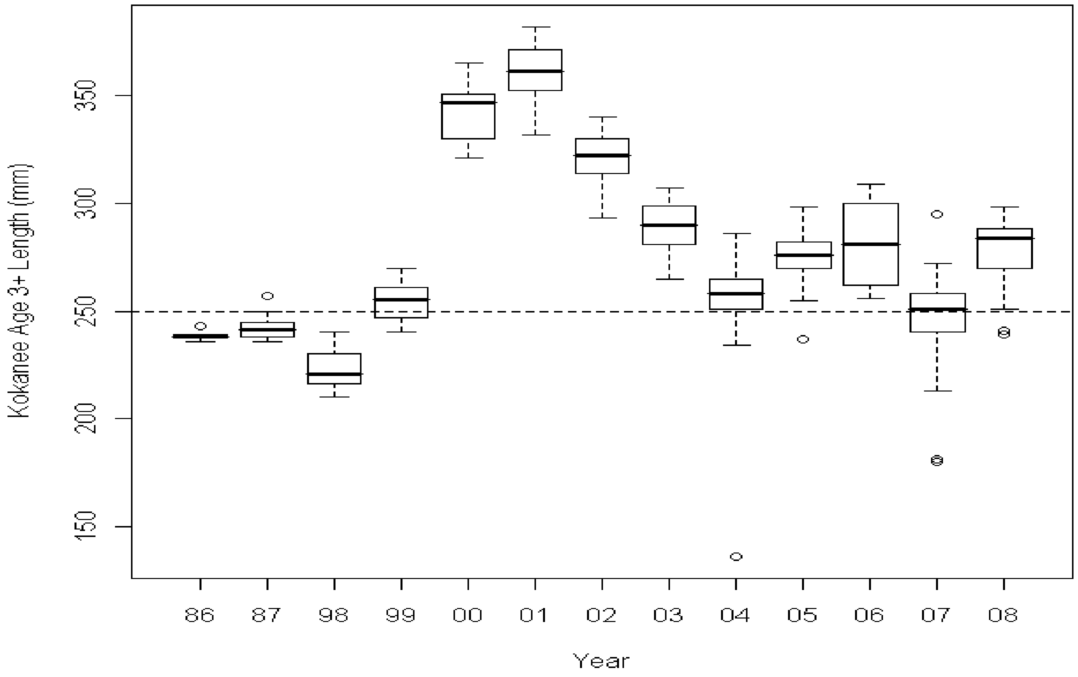

Figure 41 Box plots of length at age of 3+ kokanee caught by gillnets in Alouette Reservoir from 1986-1987 and 1998-2008.

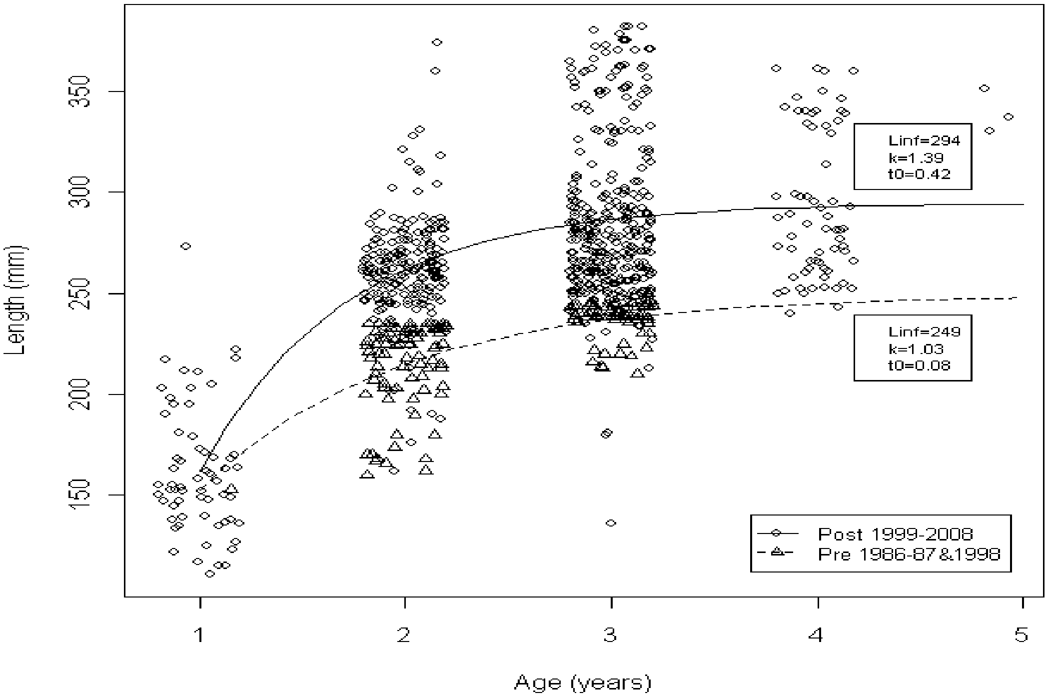

Figure 42 Fitted VBGF for gillnet captured kokanee prior to and after fertilization. Data includes reconstructed kokanee length at age data for 1+ kokanee in 1986 and 1987.

5.7 g Bull Trout

Only three bull trout were captured in standardized near shore gillnets in 2008, the lowest catch in ten years of record. Mean length and weight of gillnet captured bull trout was 408 ±22 mm and 791 ±96 g, respectively (Table 17). Bull trout have not been captured in large numbers in any other sample year but those that were caught were quite healthy in appearance and their condition factors have been moderately high, averaging 1.11 (Table 17). Although sample size was small, estimates for biomass and CPUE from gillnetting both suggest a declining trend since 2002-03 (Figure 28a, Figure 29a).

5.7 h Lake Trout

No lake trout were captured in gillnetting in 2008. A detailed summary of trends in lake trout from 1986-1987 and 1998-2006 can be found in Harris et al. (2008).

Table 17 Bull trout statistics from gillnet sampling from 1986-87, 1998 to 2008.

Year	n	Length (mm)	SD	Weight (g)	SD	CF	SD
1986-87	9	346	-	998	-	-	-
1998	21	335	70	487	276	1.18	0.22
1999	18	334	42	427	145	1.10	0.07
2000	13	284	98	380	356	1.17	0.13
2001	17	278	73	293	219	1.11	0.09
2002	18	360	61	556	240	1.11	0.08
2003	31	387	116	806	876	1.08	0.14
2004	18	400	79	772	356	1.09	0.09
2005	15	413	111	934	538	1.12	0.71
2006	10	430	94	960	636	1.06	0.31
2007	5	538	104	1810	960	1.07	0.08
2008	3	408	22	791	96	1.16	0.09

5.7 i Rainbow Trout

The stocking rate for marked triploid rainbow trout remained the same as the two previous years at 6,800 trout (Appendix A). These catchable size fish, each weighing ~ 243-322 g, were reared at the Fraser Valley Hatchery. Average weight of stocked rainbow trout has been steadily increasing during the last four years (Appendix A).

A total of 21 rainbow trout, the majority of which were of hatchery origin, were captured in the standard gillnets in 2008. Mean length and weight of gillnet captured rainbow trout was 318 ±24 mm and 360 ±80 g, respectively (Table 18). These trout were much larger and weighed more than any previous years captures although weight at release was slightly heavier than previous years. Aging indicated that the majority of these fish were 2+ and 3+ year old fish. An additional nine rainbows were captured in the October pelagic net sets and they had a mean size of 305 mm and mean weight of 329 g. Condition factor indicated an improvement over the previous two years that were some of lowest recorded in twelve years. Rainbow trout biomass and CPUE is highly dependent on the annual stocking rate (Figure 26); the trout biomass in 2008 was only 5% of the total of all fish captured. After two years of poor condition, the condition factor of the rainbows caught in 2008 improved to K= 1.1 (Table 18).

Table 18 Rainbow trout statistics from gillnet sampling from 1986 and 1998-2008.

Year	n	Length (mm)	SD	Weight (g)	SD	CF	SD
1986	5	249	101	292	264	0.87	0.49
1998	233	262	23	169	58	0.95	0.50
1999	35	259	38	212	98	1.16	0.11
2000	24	300	17	314	60	1.10	0.27
2001	54	302	32	314	84	1.16	0.36
2002	17	284	46	258	95	1.06	0.07
2003	19	286	26	259	66	1.09	0.10
2004	21	254	31	151	27	0.94	0.23
2005	32	294	25	280	48	1.13	0.31
2006	25	301	37	241	85	0.87	0.22
2007	17	279	20	200	40	0.91	0.08
2008	21	318	24	360	80	1.10	0.06

5.7 j Cutthroat Trout

A total of 20 cutthroat trout, mostly of hatchery origin, were captured in near shore gillnetting in 2008. A total of 10,450 3n fish were released weighing only about 50 g. Mean length and weight of gillnet captured cutthroat trout was 229 ±68 mm and 160 ± 130 g, respectively (Table 19). Of eighteen trout aged by scale analysis, 8 were age 1+ and 10 were age 2+. Similar to the rainbow trout cutthroat condition improved slightly in 2008 exceeding 1.0 for the first time in four years. Within the reservoir cutthroat trout only represented 2% of the gillnet biomass in 2008.

Table 19 Cutthroat statistics from near shore gillnet sampling from 1986-1987 and 1998-2008.

Year	n	Length (mm)	SD	Weight (g)	SD	CF	SD
1986	11	331	77	366	276	0.84	0.42
1987	1	265	-	185	-	0.99	-
1998	21	310	90	394	434	0.93	0.18
1999	11	255	63	210	142	1.09	0.09
2000	30	256	43	177	76	0.99	0.10
2001	60	262	52	201	109	1.17	0.81
2002	70	278	58	236	177	0.97	0.10
2003	26	272	78	260	255	1.14	0.61
2004	41	278	65	219	135	0.92	0.13
2005	25	254	60	195	166	1.00	0.47
2006	28	251	54	132	123	0.70	0.29
2007	17	236	62	149	103	0.96	0.12
2008	17	229	68	160	130	1.05	0.07

The pelagic gillnet sets in October yielded a relatively high number of cutthroat trout (n=15) and their mean size was 290 mm and mean weight was 326 g. Two much larger cutthroat sized 378 and 487 mm captured during this set account for the larger size and weight of the October sample compared to the September sample.

5.7 k Non-salmonid biological characteristics from gillnetting

Similar to the salmonid monitoring, gillnet catches are also used to monitor the effects of fertilization on non-salmonid reservoir fish populations. An extensive summary of non-salmonid trends can be found in Harris et al. (2008).

A less than desired outcome of fertilization of Alouette Reservoir, but hardly surprising, has been the tremendous response by the non-salmonid fish populations that in 2008 accounted for 77% of the total gillnet biomass. Northern pikeminnow, redside shiners, suckers (*Catostomus spp*. combined) and peamouth, were by far the dominant species caught with northern pikeminnows the most abundant (Table 20). Numbers of peamouth captured have actually been decreasing since 2003 but pikeminnow and suckers have been trending upwards since the inception of fertilization (Table 20). Pikeminnow biomass increased substantially in 2008, peamouth biomass remained constant for the fourth consecutive year while sucker biomass decreased slightly compared to 2007 (Figure 28b). The CPUE in 2008 decreased for both peamouth and sucker while northern pikeminnow CPUE increased considerably (Figure 29b). All three species condition factors were well above 1.0 indicative of good growing conditions in the reservoir.

Table 20 Statistics of peamouth, northern pikeminnow and sucker (*Catostomus spp*. combined) caught in near shore gillnets sets 1998-2008.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Peamouth											
Sample size (n)	80	62	102	251	237	442	210	125	98	132	39
Length (mm)	195	170	171	182	182	179	182	195	216	149	218
Weight (g)	127	83	94	96	89	85	86	109	109	58	221
CF	1.28	1.25	1.29	1.39	1.28	1.29	1.26	1.42	0.97	1.34	1.73
Biomass (kg)	10.1	5.2	9.6	23.5	21.0	37.5	18.2	12.7	10.3	7.5	8.4
Northern pikeminnow											
Sample size (n)	141	293	447	385	372	674	303	163	279	244	528
Length (mm)	239	172	182	187	184	187	195	200	209	209	187
Weight (g)	217	94	82	91	82	82	106	119	97	121	108
CF	1.12	9.51	1.14	1.10	1.07	1.09	1.09	1.20	0.95	1.12	1.21
Biomass (kg)	30.6	27.7	36.3	34.7	29.2	55.4	19.7	19.1	25.7	29.0	58.6
Sucker											
Sample size (n)	79	123	131	128	45	98	205	107	165	202	174
Length (mm)	326	310	285	298	305	332	309	314	266	286	275
Weight (g)	438	382	346	385	416	520	444	371	231	367	321
CF	1.17	1.14	1.25	1.23	1.23	1.26	1.23	1.22	0.96	1.25	1.23
Biomass (kg)	34.6	47.0	45.4	49.2	18.7	50.9	54.6	34.5	37.7	70.5	55.8

6. Discussion

A combination of naturally low productivity typical of coastal British Columbia systems (Northcote and Larkin 1956; Stockner and Shortreed 1985) and formation of a reservoir for hydroelectric generation largely explains why Alouette Reservoir is considered ultra-oligotrophic. This low productive state was further exacerbated by elimination of marine derived nutrients from salmon that historically used this system for spawning and rearing. Wilson et al. (2003) describes in detail all the impacts that have occurred to this system over the last century but clearly the largest impact has been hydro development. Despite the low productivity of this reservoir there is interest in improving the freshwater fisheries that it supports because of its close proximity to the largest urban population in BC. Hence in 1998 as a result of the Stave Falls Disposition Order, BC Hydro began funding an experimental fertilization program with the aim of increasing reservoir productivity. Ecosystem restoration through fertilization of Alouette Reservoir, a comparatively small reservoir, provides the opportunity to mitigate and compensate for the unproductive status of this system. This project mimics the experimental fertilization of other systems including Arrow Lakes Reservoir, Kootenay Lake and Wahleach Reservoir that have all proven to be highly successful (Hyatt et al. 2004; Ashley et al. 1997; Schindler et al. 2007a, b; Perrin et al. 2006). Provincial fisheries managers anticipated that one desirable outcome of fertilizing Alouette Reservoir would be improvement to size and number of kokanee thus making them more attractive to recreational fishing.

The fundamental premise of adding nutrients to lakes and reservoirs is that a “bottom up” response will occur resulting in increased biomass production at each trophic level (Wetzel 2001; McQueen et al. 2001; Schindler et al. 2007 a, b) and ultimately the fish populations would benefit from the transfer of nutrients up the food chain. The fertilization program has been managed using an adaptive management strategy and as such the fertilizer loading formula has been refined in response to emerging concerns of nitrogen limitation. At this point, a complete understanding of ecosystem response to fertilization is not entirely known. For example, despite the use of an identical loading formula in 2004 and 2005, chronic nitrogen limitation was observed in 2004 while it was completely absent in 2005. Furthermore, in recent years (2006-2008) the fertilization strategy has remained consistent, while the response has varied with two of the three years having nutrient concentrations sufficient for growth and one of the years (2007) severe and chronic nitrogen limitation was observed. An examination of natural loading, climate regimes or hydrological conditions does not alone explain the differing ecosystem responses and it is very likely a combination of all these factors interact to cause the differing responses.

The differing response between years illustrates the importance of a comprehensive monitoring program for each trophic level to allow for further refinement to the program. Lower trophic level monitoring is accomplished by study of a suite of physical and chemical water properties and phytoplankton and zooplankton communities. Monitoring the response of the fish populations has relied on standard gillnet sets, and acoustic and trawl surveys to provide trend information for most fish species. The combined methodologies required to accurately assess fish populations in a small basin, where there is considerable spatial and temporal overlap in fish distribution, do have their limitations. Due to the relatively small limnetic area (<1400 ha^2), the standard gillnet sets most likely favor capture of near shore, littoral and littoral profundal dwelling fish species while open water species are likely under-represented. Conversely, acoustic surveys are limited in detecting near shore and upper epilimnion (0-5 m) distributions of fish in Alouette Reservoir. Both methods present problems related to size bias selectivity; gillnetting selects for larger individuals (>100 mm) while trawl surveys select for smaller size fish (<100 mm). However, the combined methodologies are used in assessing trends in size, age and growth that is required for analyzing the acoustics data to estimate kokanee numbers and biomass.

As shown for water chemistry, the response of the phytoplankton and zooplankton communities has fluctuated over the course of the time series. The consistent fertilization approach used in 2006-2008 has yielded widely varying results. For example, the relative contribution of edible cryptophytes and chrysophytes accounted for 33% of phytoplankton abundances in 2006, which dropped down to 10% in 2007 and then increased to 44% in 2008. Likewise for zooplankton, the *Daphnia* sp biomass was 58.4 µg/L in 2006, then decreased dramatically to 0.5 µg/L in 2007 and finally increased in 2008 to levels similar to those found in 2006 at 60.7 $\mu g/L^{-+}$. This varied response is not solely controlled by phosphorus since the phosphorus budget has shown net phosphorus retention was similar in 2006 and 2007 and lowest in 2008. The causes and the consequences of this dynamic ecosystem requires further study which may necessitate the combination of field observations with simulation and statistical modeling however a longer time series is required for this modeling approach.

Kokanee are pelagic planktivores that are considered a good indicator species for comprehensively monitoring the effects of nutrient additions to the reservoir. They are also well suited to reservoirs since most reservoirs are drawdown thus dewatering the littoral habitat that results in lower production and availability of benthic organisms (Wetzel 2001). Similar to the response of kokanee to fertilization of Kootenay Lake, Arrow Lakes Reservoir and Wahleach Reservoir (Schindler et al. 2007 a, b; Perrin et al. 2006), Alouette Reservoir kokanee almost immediately grew larger and weighed more. In fact for most fish species, total gillnet catch, biomass and CPUE increased shortly after fertilization began in 1999. Peak salmonid gillnet metrics were recorded in 2000 and 2001 while the non salmonids metrics tended to peak between 2002 and 2004. Salmonid gillnet biomass declined after peaking in 2000 to near pre-fertilization levels in 2007 before a sharp increase was recorded in 2008. Non salmonid gillnet biomass also declined after peaking in 2004 but their biomass level has remained far higher than pre-fertilization. Overall, non salmonid species are dominant in terms of catch and gillnet biomass, especially northern pikeminnows and sucker sp., with kokanee and possibly bull trout being the primary salmonid beneficiaries. Rainbow and cutthroat trout data is of limited value since their catches appear to be strongly influenced by stocking rates that have been variable during the study period. Based on total gillnet caught biomass, it appears that fish populations have benefited from nutrient addition and restoring the system to its former productivity has been successful.

The best metrics for assessing changes in total in-lake abundance of kokanee in other fertilized systems has been data collected from the acoustic and trawl surveys (see

Schindler et al. 2007 a, b). Unfortunately trawling has limited application on Alouette owing to its small size and relative shallow and limited pelagic habitat. Prior to 2008 the acoustic results were difficult to interpret due to the potential of multiple species inhabiting the pelagic zone. In most large lakes, kokanee are the dominant pelagic fish but small acoustic targets previously detected in the upper epilimnion of Alouette Reservoir placed some uncertainty as to species composition. The October 2008 pelagic gillnet and trawl results clearly demonstrated that kokanee were the dominant fish species below about 10 m depth while pikeminnow and redside shiners dominated the very shallow waters (<3 m). It is suspected that the preponderance of surface dwelling non-salmonids caught in the shallow nets in the limnetic area were present due to temperature tolerances considered above optimal for salmonids. However, the results are not completely clear cut since some threespine sticklebacks were caught in the trawl at deep depths. McIntyre et al. (2006) sampled sticklebacks in the pelagic area of Lake Washington and Perrin et al. (2006) in Wahleach Reservoir with the latter study suggesting that such deep dwelling sticklebacks may be trying to avoid predators. These results need to be confirmed with more pelagic net sets and trawling but initially it appears acoustic surveys in the pelagic area (>10 m) can be used for estimating Alouette Reservoir kokanee abundance since few kokanee were detected in the surface waters and primarily kokanee were caught in water >10 m by both trawl and gillnet. In particular, the age 1-3+ kokanee population appears largely definable based on their acoustic size and depth during night-time fall surveys as indicated by the 2008 pelagic netting and trawl data. Future work is required to further verify this assumption, and to determine the proportion of kokanee fry to sticklebacks in the pelagic zone.

As mentioned, kokanee are a species of particular interest since they are known to be especially responsive to fertilization and can provide excellent sport fishing potential if their minimum size can exceed about 220 mm (Redfish Consulting Ltd. 2002). It was particularly encouraging to see the mean size of the 2008 kokanee increase to 272 mm, well beyond the 220 mm minimum size thus making them very attractive to anglers. At least part of the explanation for the impressive size of 2008 mature fish was the large out-migration of juvenile kokanee in the spring of 2007 (Matthews and Bocking, 2009) that likely led to a density growth response by the 2008 fish due lower abundance in 2007.

The initial increased in near shore gillnet abundance and biomass of kokanee in 2000 and 2001 in Alouette Reservoir was followed by three successive years of decline to levels slightly above pre-fertilization levels. During this decline, Alouette kokanee gillnet biomass had fallen to near pre-fertilization conditions. This sampling method, while providing a consistent measure of near shore kokanee habitat use over time, is of limited value in comprehensively describing kokanee status due to their pelagic habitat preference. For this reason, hydroacoustic sampling and acoustic based pelagic biomass estimates provide a more balanced picture of kokanee status in the reservoir. Acoustic data demonstrates a somewhat different trend than near shore gillnetting post-fertilization. Similar to Arrow Lake Reservoir and Kootenay Lake, Alouette kokanee biomass (kg/ha) has remained high, albeit with wide variation, compared to pre-fertilization levels. A necessary assumption is that pelagic biomass, below 10 m, across the study period has been comprised primarily of kokanee, as it was shown to be in

2008. Future refinement of pelagic species composition and target depth analysis should allow for increased precision for estimating the pelagic biomass of kokanee.

Acoustic based kokanee abundance trends point to a population that has remained predominantly stable at numbers well above pre-fertilization level. Due to species composition issues, the total reservoir population is particularly challenging to interpret given the lack of data on small fish proportions some years (eg numerous redside shiners in 2008). The large fish (>75 mm) population is likely a better indicator of kokanee abundance across the study period, given recent species depth distribution data. Once again assuming that this is indicative of all study years, the acoustic abundance trend for kokanee can be described as a substantial rise beginning in 2001 and peaking in 2003, followed by a slight decline, then successive years of relatively stable abundance. The exception to this is the decline in 2007, which although statistically significant for the total reservoir population, was not significant for the large fish population. Increases in 2008 appeared to be in line with the years leading up to 2007.

In overview, the kokanee increased in both abundance and growth following initial fertilization, similar to other nutrient addition projects. As the age 1-3+ kokanee abundance peaked in 2003, the size had already begun to decline providing evidence that a new carrying capacity had been reached. Both abundance and size declined and stabilized at a lower level by 2005 and remained well above pre-fertilization levels. The only exception to the 2005-2008 trend was in 2007 when kokanee numbers and size declined further, likely as combined result of the out-migration of kokanee fry in the spring, and from the severe nitrogen limitation affecting primary productivity. Compared with 2007, there was a similar response in 2008 to initial fertilization as both size and density increased presumably due to decreased competition and better limnological conditions for food production in the reservoir. It is important to acknowledge that although total fish abundance and biomass increased substantially in 2008, the age 1-3+ kokanee response was more modest and represents a return to levels seen in 2005 and 2006.

It is possible the decline in kokanee abundance from the 2003 peak to 2007 was related to fertilizer loading since kokanee abundance has mirrored a decline in phosphorus loads that in turn affected primary and secondary production (Harris et al. 2008). Further evidence is the increase in 2008 in both abundance and size with increases in epilimnetic total phosphorus concentrations (Figures 14, 34 & 35). There are other factors that may limit kokanee in this reservoir. Certainly analysis of the kokanee data is confounded to some extent by the known out-migration over the dam and the unknown displacement through the tunnel to Stave Reservoir. The list of factors that potentially could affect both abundance and biomass of kokanee include: 1) limited spawning habitat 2) variable hydraulic regime of reservoir limiting kokanee survival 3) higher kokanee emigration rates due to reservoir operations 4) poor food quality due to nitrogen limitation in recent years and 5) phosphorus limitation.

It is not often that kokanee are limited by spawning habitat, but the Alouette Reservoir may be an exception in some years. Kokanee in this reservoir do not spawn in the streams and evidence suggests that they are a shore spawning ecotype (Wilson 2003). Even subtle changes in variation in low pool elevation from year to year could have a substantial effect on a particular cohort's survival, similar to that observed on Okanagan Lake (Andrusak et al. 2008). The low pool elevation of Alouette Reservoir reaches a minimum in the fall following quick drawdown after September 15. Average annual drawdown is ~3 m, measured as surface elevation. Thereafter, the reservoir is generally recharged quickly by late fall and winter rains and elevations then fluctuate throughout the winter. If shore spawning occurs before reservoir drawdown then egg stranding and mortality may occur. A study is currently underway to assess the impact of reservoir operations on kokanee recruitment, particularly analysis of age structure over a 10 year period.

Some evidence suggests that kokanee in Alouette Reservoir may be deep water shore spawners (Wilson 2003). Similar deep water spawning has been recorded by Andrusak and Morris (2005) for North and East Barriere lakes and Anderson Lake (Morris MOE biologist Kamloops BC pers. comm.). Typically, these fish spawn in late fall or early winter in hypolimnetic waters (~3-4 °C). To be successful in pelagic spawning, survival must be highly dependent upon utilizing groundwater upwelling areas which provide sufficient accumulated thermal units (ATU's) to allow for normal egg development and emergence. It is quite possible that the extent of groundwater sources in the Alouette are very limited therefore imposing limitations and or wide variation on annual kokanee fry production. This may be one plausible explanation for why kokanee numbers have been potentially limited in recent years despite continued nutrient additions. Evaluation of depth of shore spawning and timing needs to be investigated.

The hydraulic regime that increases flows from the Alouette Dam via the dam and tunnel could account for recent kokanee abundance limitation in the reservoir, as a result of increased emigration rates. As part of a separate project undertaken by BC Hydro, a study is on-going to determine the out-migration success of nerkid populations from the Alouette Reservoir (Mathews and Bocking 2009). Results to date indicate that substantial numbers of nerkids can potentially out-migrate under certain deliberate discharge conditions; however, overall only a few thousand fish moved out in three of the four years of investigations. Certainly the 2008 acoustic estimates suggest that out-migrants from the south end don't have a substantial impact on kokanee abundance. The acoustic population rebounded in line with the previous years following the estimated out migration of ~63,000 kokanee in 2007, by far the highest emigration estimate compared to the previous two years. No account has been made of how many fish might out-migrate through the tunnel from the north basin into Stave Lake. One interesting outcome of the out-migration has been the return of sockeye salmon to the base of the dam (Mathews and Bocking 2009).

The limnology data summarized in this report indicates seasonal changes in the N: P ratio with N limitations at times that often cause production of undesirable or inedible forms of phytoplankton. This in turn affects the quality of food for macrozooplanktors such as *Daphnia sp*. that kokanee prefer to consume. It has been hypothesized that poor phytoplankton production accounts for lower survival of Okanagan Lake kokanee (Andrusak et al. 2008) and may be a contributing factor in lower kokanee production in

Alouette Reservoir during 2004-2007. Interestingly there was minimal N limitation during 2008 and the zooplankton density and biomass was the highest level recorded since fertilization began. *Daphnia* biomass was also at a record high level supporting the notion that nutrient imbalance may have been one reason for the kokanee decline after 2003.

Analysis of kokanee growth indicates that there has been a significant increase of length-at-age of 3+ kokanee in the post-fertilization era compared to pre-fertilization era (p=0.039) and with the inclusion of nutrient input (phosphorus) as a fixed effect, a considerable amount of variation in length for 3+ kokanee is explained by the addition of phosphorus (p=0.011). Moreover, the data suggests that the population is likely regulated by density dependent factors within the reservoir at least during some years during the enrichment period as evidenced by the decline in size at age with increasing abundance, similar to that observed in Kootenay Lake and Arrow Reservoir (Schindler et al. 2007 a, b). Age structure from gillnetting provides some indirect evidence of a shift to early maturing fish (2+ and 3+) under high growth rates and low density in the early years after initial fertilization. However, more recently, there is evidence that as the in-lake abundance increased the age structure shifted back towards older age classes (3+ and 4+), likely a result of increased competition.

Although kokanee capacity has not yet been determined for Alouette, the data suggests that it might be reasonable to expect kokanee biomass in the order of 4-8 kg**/**ha with continued nutrient enrichment. Based on Kootenay and Arrow long term averages, the spawner biomass in Alouette may be estimated at ~25% of fall biomass or 1-2 kg**/**ha. With an average pelagic area of 1356 ha and average size of age 3+ fish at 4-5 fish**/**kg, the reservoir should produce an annual spawning run of 5,400 to 13,500 kokanee. Refinement of the acoustic and trawl data through better identification of pelagic species composition via gillnetting took place in 2008 and this work bears repeating in an effort to quantify the size and age structure of the kokanee population.

Bull trout abundance in Alouette Reservoir appears to be very low (Wilson et al. 2003; Harris et al. 2008). Despite their low abundance, they are still considered a good metric for monitoring the effects of fertilization at the upper trophic level due to their highly piscivorous nature. These top predators would be expected to take advantage of increasing numbers of prey due to fertilization provided that spawning and rearing is not limited at this time. Initial evaluation of bull trout spawning in 2008 revealed little information although a few spawners were observed in Gold Creek (Ladell and McCubbing 2009). Bull trout have not responded to fertilization as might be expected since their primary prey (kokanee) has increased several fold. It may well be that population size prior to fertilization was naturally low hence the reason annual gillnetting has yielded very small numbers. These top predators are late maturing therefore it may take much longer for them to display increased growth and abundance. Another factor influencing the bull trout gillnet trend could be their response to varying kokanee near shore behavior. If the kokanee tend to be off shore during the near shore gillnet sampling on any given year, the bull trout would then be less likely to be caught by gillnet. Assumedly the bull trout are spatially associated with their primary prey.

In summary, an increase in abundance and biomass of many fish species supports the notion that nutrient addition is providing a bottom up benefit while restoring the productivity of this reservoir to its former potential. This is most apparent in the kokanee population where an increase in growth and abundance is highly evident in the post fertilization era. However, the decline in gillnet based salmonid indices through the mid 2000s, with an apparent reversal in 2008, reinforces the need to closely monitor all trophic levels to gain a better understanding what factors regulate the fish populations in Alouette Reservoir. Reducing some of this uncertainty can best be accomplished through more intensive monitoring of the in-lake numbers through the acoustic surveys and pelagic gillnetting. Also, there is a need to better understand the requirements for shore spawning kokanee in the reservoir and factors that regulate the population. Despite recent declines, in-lake abundance and biomass particularly in 2008 for kokanee were still well above pre-fertilization levels.

7. Recommendations

1. Continue with nitrogen and phosphorus fertilization of the north and south basins. The target nutrient load should be maintained at least 200 mg P/m^2/yr, the level targeted in 1999.

2. To maximize kokanee production, nutrient levels in the reservoir need to be monitored twice a month during June and July to enable rapid adjusments to N:P ratios as required.

3. As increased angler satisfaction is one goal of the fertilization experiment, a creel survey should be conducted on Alouette in 2010.

4. Continue annual acoustics and trawl surveys. Continue to experimentally trawl the limnetic area of the reservoir at night to determine with certainty, species composition and relative proportions.

5. Additional pelagic gillnet sets during annual acoustic survey are recommended for mid-lake habitat to determine limnetic species composition.

6. If the priority of ALR fertilization is to improve salmonid production then littoral gillnetting should be reduced to once every 5 years in favor of increased pelagic gillnetting.

7. Determine age of all kokanee for all years, including back calculations.

8. Direct future fisheries assessment work towards determination kokanee spawner location, numbers, size-at-maturity and fecundity.

9. A greater focus on obtaining bull trout biological data and spawner numbers is required.

10. Use of finescale gillnets are recommended to examine the role and number of sticklebacks in the pelagic habitat.

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9. Appendices

Appendix A Alouette Reservoir Fish Stocking History (FV=Fraser Valley)

Date	#	Mean Weight (g)	Stock	Life Stage	Mark
Rainbow					
2008	6,800	259	FV 3N		
2007	6,800	250	FV 3N	Catchable	Adipose
2006	4,700	245.9	FV 3N	Catchable	
2006	2,100	240	FV 3N	Yearling	
2005	7,212	163.5	FV 3N	Catchable	
2005	1,848	335	FV 3N	Catchable	Adipose
2004	12,188	162.1	FV 3N	Catchable	Right Maxillary
2003	8,876	173.8	FV 3N	Catchable	
2003	6,567	163.9	FV 3N	Catchable	Left Maxillary
2002	6,300	177.8	FV 3N	Catchable	
2003	6,204	153.8	FV 3N	Catchable	Right Maxillary
2001	7,720	156.3	FV 3N	Catchable	
2001	4,200	135.2	FV 3N	Catchable	
2000	16,636	180.5	FV 3N	Catchable	
1999	16,441	203.2	FV 3N	Catchable	
1998	30,449	153.9	FV 3N	Catchable	
1998	127	3346.5	FV	Adult	
1997	65	591.7	FV	Catchable	
1997	29,296	171.9	FV	Catchable	
1996	15,762	218	FV	Catchable	
1995	2,354	244.2	FV	Catchable	
1962	19,250	15	Washington	Fingerling	
1962	33,570	30	Washington	Yearling	
1939	100,000	0	Pinantan	Eyed Egg	
1938	50,000	0	Pinantan	Eyed Egg	
Cutthroat Trout					
2008	10450	50.9	Taylor		
2007	-	-	-	-	-
2006	1,346	117.4	Taylor 3N	Catchable	Adipose
2006	6,945	82.6	Taylor 3N	Yearling	Adipose
2005	6,150	134.1	Taylor 3N	Catchable	Right Ventral
2005	1,166	80.1	Taylor 3N	Yearling	Right Ventral
2004	5,655	78.4	Taylor 3N	Yearling	Adipose
2003	5,000	72.9	Taylor	Yearling	Left Ventral
2002	6,200	79	Taylor	Yearling	Adipose
2001	7,033	76.4	Taylor 3N	Yearling	Right Ventral
2000	5,733	90	Taylor 3N	Yearling	
1996	1,599	152.5	Taylor	Catchable	
1995	11,811	141.9	Taylor	Catchable	
1994	8,383	109.8	Taylor	Catchable	
1993	21,231	121.1	Taylor	Catchable	
1993	1,000	333.3	Taylor	Catchable	
1992	20,392	140.4	Taylor	Catchable	
1992	20,405	97.3	Taylor	Catchable	
1991	3,996	14.6	Taylor	Yearling	
1990	23,405	32.3	Taylor	Yearling	

Date	#	Mean Weight (g)	Stock	Life Stage	Mark
Steelhead					
1984	6,224	95.2	Alouette	Smolt	Right Maxillary
1983	1,132	16.7	Alouette	Parr	
1983	15,075	45.4	Alouette	Smolt	
Lake Trout					
1990	2,681	5.9	Bridge	Fingerling	
1969	97,500	15.0	Jasper	Yearling	
1968	3,725	0.0	Jasper	Yearling	
1968	68,800	2.5		Fry	

Appendix B List of phytoplankton species found in Alouette Reservoir, 2008.

Species		NB	SB
Bacillariophyceae (diatoms)			
1	*Achnanthes sp*	x	
2	*Cyclotella comta*	x	
3	*Cyclotella glomerata*		x
4	*Cyclotella stelligera*		x
5	*Fragilaria acus*	x	x
6	*Fragilaria capucina*	x	x
7	*Fragilaria construens*	x	x
8	*Rhizosolenia sp.*		x
9	*Navicula sp.*	x	
10	*Pinnularia sp.*		x
Chryso- & Cryptophyceae (flagellates)			
11	*Chromulina sp1*	x	x
12	*Chrysochromulina sp.*	x	x
13	*Chryptomonas sp.*	x	x
14	*Rhodomonas sp.*	x	x
15	*Chroomonas acuta*	x	x
16	*Pseudokephrion sp.*	x	x
17	*Kephyrion sp.*	x	x
18	*Ochromas sp.*	x	
19	*Dinobryon sp*	x	x
20	*Boda sp.*[a]	x	x
21	*Mallomonas sp2*	x	x
22	*Bitrichia sp.*		x
23	*Small microflagellates*	x	x
Dinophyceae (dinoflagellates)			
24	*Peridinium sp1*	x	
25	*Gymnodinium sp* large		x
26	*Gymnodinium sp* small		x
27	*Gymnodinium sp1*	x	x
Chlorophyceae			
28	*Ankistrodesmus sp.*	x	x
29	*Chlorella*	x	x
30	*Elakatothrix sp3*	x	x
31	*Scenedesmus sp.*	x	x
32	*Cosmarium sp.*		x
33	*Coelastrum sp.*		x
34	*Clamydocapsa sp.*	x	x
Cyanophyceae (blue-greens)			
35	*Synechococcus sp. (<2 um)*	x	x
36	*Synechococcus sp (coccoid)*	x	x
37	*Synechococcus sp (rod)*	x	x
38	*Synechocystis sp.*	x	x
39	*Oscillatoria sp2*	x	x
40	*Rhaphidiopsis sp*	x	x
41	*Chroococcus sp.*		x

Appendix C Phytoplankton abundances and biovolumes

Table C1 Phytoplankton average seasonal (April-October) density and biovolume in the north basin of Alouette Reservoir, 1998-2008 (cells/ml). Shaded areas indicate fertilization years.

		North Basin					
	1998	2003	2004	2005	2006	2007	2008
Abundance (cell/ml)							
Bacillariophytes-diatoms	117	78	109	41	81	463	84
Chryso&Chryptophytes-flagellates	1536	987	777	723	785	1219	2387
Dinophytes dinoflagellates	90	191	201	74	133	115	29
Chlorophytes	54	90	193	156	180	92	40
Cyanophytes	2339	5525	3363	495	1140	9691	3181
GRAND TOTAL	**4,136**	**6869**	**4543**	**1489**	**2318**	**11,567**	**5721**
% Bacillariophytes	3	2	1	2	4	4	2
% Chryso&Chryptophytes	37	37	14	17	34	11	42
% Dinophytes	2	2	3	4	6	1	1
% Chlorophytes	1	1	1	4	8	1	1
% Cyanophytes	57	57	80	72	49	84	56
Biovolume (mm^3/L)							
Bacillariophytes-diatoms	0.01	0.01	0.01	0.01	0.01	0.02	0.01
Chryso&Chryptophytes-flagellates	0.07	0.08	0.05	0.07	0.07	0.06	0.31
Dinophytes-dinoflagellates	0.05	0.10	0.14	0.06	0.09	0.07	0.02
Chlorophytes	0.01	0.01	0.03	0.04	0.07	0.01	0.01
Cyanophytes	0.02	0.17	0.06	0.01	0.03	0.19	0.06
GRAND TOTAL	**0.16**	**0.36**	**0.27**	**0.18**	**0.26**	**0.55**	**0.41**
% Bacillariophyceae	6	2	4	3	4	41	3
% Chryso&Chryptophyceae	44	21	18	37	26	11	76
% Dinophyceae	30	28	47	28	33	13	4
% Chlorophyceae	9	3	9	23	25	1	2
% Cyanophyceae	11	45	21	8	11	34	15

Appendix C continued.

Table C2 Phytoplankton average seasonal (April-October) density and biovolume in the south basin of Alouette Reservoir, 1998 - 2008. Shaded columns represent fertilized years.

	South Basin						
	1998	2003	2004	2005	2006	2007	2008
Abundance (cell/ml)							
Bacillariophytes-diatoms	94	93	74	30.4	68	567	89
Chryso&Chryptophytes-flagellates	1323	865	914	782	814	1179	2413
Dinophytes dinoflagellates	107	142	190	81	118	132	49
Chlorophytes	44	86	169	165	130	59	66
Cyanophytes	1688	4843	3251	597	1423	10133	2628
GRAND TOTAL	**3257**	**6030**	**4602**	**1655**	**2553**	**12061**	**5239**
% Bacillariophytes	3	2	2	2	3	5	2
% Chryso&Chryptophytes	41	14	20	47	31	10	46
% Dinophytes	3	2	4	5	5	1	1
% Chlorophytes	1	1	4	10	5	1	1
% Cyanophytes	52	80	71	36	56	84	50
Biovolume (mm^3/L)							
Bacillariophytes-diatoms	0.01	0.01	0.01	0.01	0.01	0.27	0.01
Chryso&Chryptophytes-flagellates	0.06	0.07	0.08	0.08	0.07	0.09	0.19
Dinophytes-dinoflagellates	0.05	0.10	0.14	0.07	0.08	0.08	0.02
Chlorophytes	0.01	0.01	0.02	0.03	0.03	0	0.01
Cyanophytes	0.01	0.17	0.06	0.06	0.03	0.20	0.06
GRAND TOTAL	**0.15**	**0.36**	**0.31**	**0.23**	**0.23**	**0.63**	**0.28**
% Bacillariophyceae	6	2	3	3	6	42	3
% Chryso&Chryptophyceae	42	19	24	34	32	14	69
% Dinophyceae	36	28	5	28	35	12	8
% Chlorophyceae	7	4	7	11	14	1	4
% Cyanophyceae	10	48	21	24	13	31	16

Appendix D Zooplankton density and biomass

Table D1 Seasonal average zooplankton density in Alouette Lake, 1998-2008. Shaded columns represent fertilized years.

		North Basin						
		1998	2003	2004	2005	2006	2007	2008
Density (#/L)	Copepoda	0.6	2.40	3.70	1.43	4.59	5.11	7.78
	Daphnia	0	0.06	0.00	0.73	2.59	0.03	2.51
	Other Cladocera	0.2	2.07	1.35	2.77	3.89	2.71	4.38
	Total	0.8	4.53	5.05	4.93	11.06	7.86	15.01
	2003-08 mean		**8.07**					
Biomass (µg/L)	Copepoda	0.8	4.33	9.14	3.42	10.93	9.10	19.34
	Daphnia	0	0.40	0.04	12.03	62.03	0.64	64.17
	Other Cladocera	1.19	15.17	5.05	8.30	20.45	7.53	14.75
	TOTAL	2.0	19.9	14.24	23.75	93.41	17.27	99.40
	2003-08 mean		**44.66**					

Table D2 Seasonal average zooplankton density in Alouette Lake, 1998-2008. Shaded columns represent fertilized years.

		South Basin						
		1998	2003	2004	2005	2006	2007	2008
Density (#/L)	Copepoda	1.1	0.86	5.34	1.53	4.96	5.42	4.33
	Daphnia	0	0.24	0.00	0.48	2.74	0.02	2.22
	Other Cladocera	0.30	1.92	1.40	1.46	4.31	1.35	8.77
	Total	1.4	3.02	6.75	3.48	12.02	6.79	15.99
	2003-08 mean		**8.01**					
Biomass (µg/L)	Copepoda	2.7	1.69	8.19	2.85	12.63	9.22	8.70
	Daphnia	<0.01	2.3	0.02	10.54	54.80	0.41	57.28
	Other Cladocera	1.4	12.9	7.34	3.41	18.92	2.95	26.16
	TOTAL	4.1	16.93	15.55	16.80	86.35	12.58	93.14
	2003-08 mean		**40.39**					

Appendix E Equipment and Data Processing Specifications.

Echosounder Specifications :

Description	SIMRAD EY200P-P
transducer	Single beam 70 kHz
nominal beam angle	11.6 degree
pulse width (msec)	0.3
depth of face (m) / deployment	0.75 , tow foil, vertical, mobile
ping rate (p/sec)	2 - 4
time varied gain	40 log r
TVG range (m)	2 to 62.5
data collection threshold	-65dB
Range collected (m)	0 -100
data storage	Sony TCD- PRO II digital tape deck

Description	SIMRAD EY500
transducer	Split beam 120 kHz
nominal beam angle	7.0 degree
depth of face (m) / deployment	0.75 , tow foil, vertical, mobile
pulse width (msec)	1.0
ping rate (p/sec)	2 – 6
time varied gain	20/40 log r
data collection threshold	-70dB
range collected (m)	0 -100
data storage	computer hard disk

Data Processing Specifications:

Description		
70kHz Single Beam		HADAS version 3.98
Interface gain		calibration tone to intersect 2 volts at 50 milliseconds
TS threshold		-62 dB minimum detectable target approximately - 65 dB
Time varied gain		40 log r
Range processed		3 – 50 m (reported)

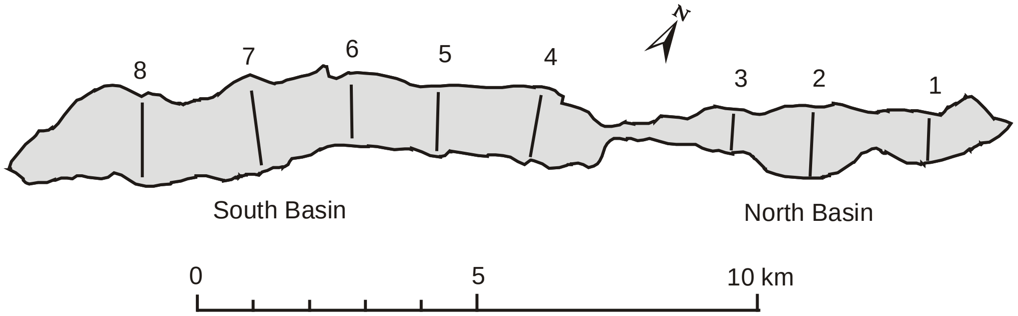
120kHz Split Beam		Sonar5 version 5.9.8
Time varied gain		20/40 log r
TS min threshold (dB)		-70
TS max threshold (dB)		-26
Sv threshold (dB)		-70
Single Echo detector	:SED threshold	-70 dB min, -26 dB max, (reported from -62 to -26dB)
	:Min. echo length	0.60
	:Max echo length	1.60
Fish tracking, per fish	: minimum # echoes	2
	: max ping gap	1
	: max range differential	0.3 m
Range processed		3 – 50 m (reported)

Appendix F Alouette Reservoir Habitat Areas (ha)

Year	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Pool EL	121	121	121.5	121.3	116.8	122.5	121.2	120.3	117.9	121.2	120.3
NB ha											
3	443	443	443	443	428	459	443	438	422	443	438
5	428	428	428	428	407	438	428	422	407	428	422
10	402	402	402	402	381	412	402	396	381	402	396
15	378	378	378	378	369	386	378	376	369	378	376
20	366	366	366	366	356	371	366	364	356	366	364
25	354	354	354	354	344	359	354	352	344	354	352
30	342	342	342	342	332	347	342	339	332	342	339
35	328	328	328	328	313	335	328	325	313	328	325
40	309	309	309	309	294	317	309	306	294	309	306
45	290	290	290	290	275	298	290	287	275	290	287
SB ha											
3	1103	1103	1103	1103	1087	1118	1103	1098	1082	1103	1098
5	1087	1087	1087	1087	1066	1098	1087	1082	1066	1087	1082
10	1061	1061	1061	1061	1040	1072	1061	1056	1040	1061	1056
15	1030	1030	1030	1030	988	1046	1030	1020	988	1030	1020
20	978	978	978	978	936	1000	978	968	936	978	968
25	926	926	926	926	884	948	926	916	884	926	916
30	874	874	874	874	832	896	874	864	832	874	864
35	825	825	825	825	797	844	825	818	797	825	818
40	790	790	790	790	762	804	790	783	762	790	783
45	755	755	755	755	728	769	755	748	728	755	748
Total											
3	1546	1546	1546	1546	1514	1577	1546	1536	1504	1546	1536
5	1514	1514	1514	1514	1472	1536	1514	1504	1472	1514	1504
10	1462	1462	1462	1462	1420	1484	1462	1452	1420	1462	1452
15	1408	1408	1408	1408	1356	1431	1408	1395	1356	1408	1395
20	1344	1344	1344	1344	1292	1370	1344	1331	1292	1344	1331
25	1280	1280	1280	1280	1228	1306	1280	1267	1228	1280	1267
30	1215	1215	1215	1215	1164	1242	1215	1203	1164	1215	1203
35	1153	1153	1153	1153	1110	1178	1153	1142	1110	1153	1142
40	1099	1099	1099	1099	1057	1121	1099	1089	1057	1099	1089
45	1046	1046	1046	1046	1003	1067	1046	1035	1003	1046	1035

Appendix G Transect densities (fish/ha) in Alouette Reservoir, 1998-2008

Survey	Transect density fish / ha								Average basin density	
Year	1	2	3	4	5	6	7	8	NB	SB
1998	39	38	22	56	65	60	94	32	33	61
1999	40	25	33	20	7	49	164	8	33	50
2000	25	8	74	37	85	142	64	65	36	79
2001	89	23	16	112	239	184	121	484	42	228
2002	142	121	98	211	363	242	206	439	120	292
2003		266	243	83	196	294	205	475	254	251
2004	212	275	319	229	341	228	308	228	269	267
2005	203	159	224	211	213	268	207	256	195	231
2006	149	217	159	301	256	211	235	274	175	256
2007	66	161	88	142	224	163	103	146	105	156
2008	241	188	157	387	324	238	87	412	195	290



Alouette Reservoir acoustic survey transect locations 1998 – 2008

Appendix H Maximum Likelihood Estimates (MLE) for all fish >14 mm and fish >75 mm.

	Population of all (fish >14mm)			**Population of non-fry (fish >75mm)**		
	MLE	UB	LB	MLE	UB	LB
1998	45,100	60,210	31,773	13,800	21,434	6,646
1999	34,800	45,200	21,900	11,100	14,087	8,027
2000	85,000	106,445	66,400	11,600	19,461	3620
2001	198,700	283,288	116,905	32,400	46,191	19,306
2002	345,000	411,581	248,617	89,900	113,463	69,464
2003	377,100	441,489	287,275	100,300	141,885	63,325
2004	369,600	454,254	284184	78,900	100,688	52,915
2005	311,500	358,702	254,507	63,300	81,149	39,320
2006	319,000	348,062	288,172	70,100	79,603	60,128
2007	193,900	230,229	149,817	49,700	61,595	39,686
2008	371,800	470,001	291,547	59,900	75,329	44,985

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

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

Aspect 45° : $TS = 18.4 \log_{10} (L) – 1.6 \log_{10} (F) – 61.6$

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

Size class (db)[1]	**Acoustic size range (dB)**		**Fish length range[2] (mm)**		**Fish length range[3] (mm)**	
-29	-29	-26.01	669	960	896	1304
-32	-32	-29.01	466	668	616	895
-35	-35	-33.01	325	465	423	615
-38	-38	-35.01	226	324	291	422
-41	-41	-38.01	158	225	200	290
-44	-44	-41.01	110	157	137	199
-47	-47	-44.01	76	109	94	136
-50	-50	-47.01	53	75	65	93
-53	-53	-50.01	37	52	44	64
-56	-56	-53.01	26	36	31	43
-59	-59	-56.01	18	25	21	30
-62	-62	-59.01	13	17	14	20

1 36 dB range in 12 size classes of 3 dB

2 from Love's (1977) empirical "Dorsal aspect" formula (F = 120 KHz).

3 from Love's (1977) empirical "45° aspect" formula (F = 120 KHz).