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Wahleach Reservoir Fertilization Program

Implementation Year 3 - 4

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WAHLEACH RESERVOIR TROPHIC LEVEL RESPONSES TO FERTILIZATION WITH EMPHASIS ON STATUS OF THE KOKANEE POPULATION

Study Period: 2007 - 2008

Province of British Columbia, Ministry of Environment
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FINAL REPORT

WAHLEACH RESERVOIR TROPHIC LEVEL RESPONSES TO FERTILIZATION WITH EMPHASIS ON STATUS OF THE KOKANEE POPULATION

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Executive Summary

Following a 10+-year period of increased productivity after dam construction in 1953, lake productivity and angler success at Wahleach Reservoir declined. In 1995, a program was begun to restore a productive fishery through fertilization, re-introduction of kokanee, and stocking of sterile cutthroat trout, and to monitor the response of lower trophic levels, fish, and anglers. This report presents new 2007-2008 data, merges 2002-2008 and 1993-2001 data, evaluates key questions about the program objectives, identifies data gaps, evaluates uncertainty in the estimates of fish abundance, and provides recommendations for future monitoring and management of the reservoir.

Annual phosphorus loading has varied from 103–232 mg/m^2, and the ratio of nitrogen to phosphorus has varied from 25 to 9 (by weight). In 2007, phosphorus loading was 149 mg/m^2 and nitrogen loading was 1344 mg/m^2; in 2008, phosphorus loading was 184 mg/m^2 and nitrogen loading was 1592 mg/m^2. Fertilizer, which was added weekly June-October, increased the concentration of total nitrogen and phosphorous in surface waters whereas dissolved nitrogen and phosphorus concentrations decreased. In July-September, when the reservoir was stratified, phytoplankton growth appeared to be nitrogen-limited.

Mean annual phytoplankton abundance peaked in the early years of the project, and since 2000 has been relatively low due to decreased abundance of flagellates and dinoflagellates and cyanobacteria, and modest increase in diatom abundance compared with early years. Mean annual phytoplankton biovolume has been relatively similar among years, because decreases in flagellate and dinoflagellate biovolume have been compensated by modest increase in diatom abundance. Flagellate abundance has tended to peak early in the growing season, whereas diatom abundance has tended to increase over the course of the growing season. In 2008, there was a late summer cyanobacterial bloom. Increases in the rate of annual phosphorus loading corresponded with decreased abundance of flagellates, dinoflagellates, and cyanobacteria, but with no change in chlorophyte abundance and highly variable diatom abundance. Increases in the annual phosphorus loading rate corresponded with increased biovolume of flagellates and dinoflagellates, but relatively low biovolume of chlorophytes and cyanobacteria and highly variable diatom biovolume.

The seasonal dynamics of zooplankton abundance and biomass in Wahleach have varied during fertilization. Zooplankton abundance tended to follow the bell-shaped nutrient loading curve, with biomass peaking early in the growing season and declining by fall. Increases in the annual phosphorus loading rate corresponded with decreases in zooplankton abundance, whereas zooplankton biomass increased as a result of the shift from abundant small copepods to fewer large cladocerans. Overall, increases in cladoceran biomass have corresponded with decreases in the biovolume of edible phytoplankton, and cladoceran biomass has increased since 2006.

Nearshore fall gillnetting indicated that relative abundance of age-1 and older kokanee was highest in the reservoir in 1993 before fertilization, and has fluctuated 33-74% of the maximum since multiple age-classes were re-established in 2000. In contrast, the relative biomass of age-1 and older kokanee was low before fertilization (<15 g /net-h), and highest values have been attained since 2000. The relative biomass of age-1 and older kokanee in 2007-08 was the highest on record (>20 g /net-h). The mean length of age 3 and 4 fish was the largest to date in 2007. Stocking with age-0 kokanee appears to have successfully re-introduced kokanee to Wahleach Reservoir, although population abundance appears to fluctuate considerably from year-to-year.

Stickleback was the most abundant species in the pelagic habitat at all depths in all years of trawl sampling. Since 1993, trawl catches have ranged from 19 to 558 fish /year, kokanee catch has ranged from 0 to 4 fish /year, and in 2008, 3 of 144 fish (2.1%) were kokanee. Trawling has targeted depths where the highest densities of fish were seen with acoustics, thus trawl CPUE is not an unbiased indicator of change in species abundance of small fish.

For 1993-1997, total fish abundance from acoustics increased from 1 million to 6 million, and a large majority of fish was sticklebacks. Coincident with the introduction of cutthroat trout in 1997, total fish abundance decreased from millions to several hundred thousand. In 2007 total abundance was 145,000. It is not clear what cutthroat stocking rate may keep stickleback abundance low without increasing predation on kokanee.

Since re-introduction of kokanee (1997-2004) escapement has been variable, (from 1000 in 2003 to 8000 in 2006), and was relatively low in 2007-08 (3924 and 2494 respectively). The 2008 escapement would have been the result of natural spawning in 2004 plus age-0 stocked in 2004 that spawned at age-4 (a fair number of age-3 kokanee held over in 2007). In 2008, no age-3 or older kokanee were caught in the fall gillnets.

Since reintroduction in 1997, kokanee abundance has increased, but since 2003 abundance appears to have plateaued at a population size lower than before kokanee were extirpated in 1995, and fluctuation in year class abundance appears high. Since fertilization, the relative abundance and biomass of rainbow trout have each decreased, but body size fluctuated within a similar range through baseline and fertilization years.

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1. Introduction and objectives

Following its creation by dam construction in 1953, Wahleach Reservoir supported a productive fishery for kokanee and rainbow trout. As is typical of impoundments (e.g. Ostrofsky & Duthie 1980; Ney 1996; Hall et al. 1999), a 10+-year period of increased productivity was followed by a downturn in productivity (Stockner & Bos 2005; Perrin 1997), and a decrease in angler success (Inglis 1995) possibly due to the combined effects of angling pressure and the illegal introduction of threespine stickleback, which may compete with kokanee. By 1994, the fishery had collapsed, and kokanee were extirpated. Wahleach Reservoir was one of 6 BC hydroelectric projects considered to have excellent potential for increasing recreational angling capacity through enhancement (Hirst 1991). After a 2-year baseline study, a program was begun in 1995 to restore a productive fishery through fertilization, re-introduction of kokanee, and stocking of sterile cutthroat trout to prey on stickleback, a potential kokanee competitor. This ongoing program is part of the Wahleach Water Use Plan and Water License agreement (BC Hydro 2005, 2006, 2008).

It was hoped that fertilization and stocking would establish a self sustaining population of kokanee with fish that were large and abundant enough and to satisfy anglers. It was also hypothesized that nutrient addition and predation on sticklebacks by cutthroat trout could lead to an increase in the size of abundance of rainbow trout through the benthic food web (Perrin et al. 2006). Given the demonstrated success of fertilization in increasing fish yield in lakes and reservoirs (Harris et al. 2007a; Schindler et al. 2006 a, b; Hyatt & Stockner 1985; Stockner & MacIssac 1996; Ashley 1997; Hyatt et al. 2004), this was not an unreasonable expectation. However, fertilization effects can be attenuated in food webs (Brett & Goldman 1997) and lead to variable outcomes (Hyatt & Stockner 1985; Hilborn & Winton 1993; Stockner 1991; Perrin et al. 2006; Squires et al. 2009), so the outcome at Wahleach was not certain. Factors that may affect the transfer of increased production at lower trophic levels up the food web to kokanee include the abundance and density of edible algae, the abundance of density of *Daphnia*, predator-prey interactions, density-dependent responses, and competition among planktivores (Carpenter et al. 1985; McQueen et al. 1989; Beauchamp et at. 1995; Mazumder & Edmundson 2002; Stockner 2005).

It was hypothesized that fertilization would increase the productivity of edible phytoplankton and, in turn, increase the productivity of zooplankton, in particular *Daphnia-sp.* a key forage item for planktivorous fish such as kokanee, as has been observed in other fertilized systems (Thompson 1999; Mazumder & Edmundson 2002). Such increases can produce response in kokanee populations ranging from higher densities of similar sized fish, to similar densities of larger fish, to lower densities of even larger fish (E. Parkinson, BC Ministry of Environment, personal communication). The outcome depends largely on the quantity and quality of juvenile habitat, particularly spawning habitat. If the pre-fertilization spawning habitat is underutilized, higher densities of similar sized fish would be expected. Limited spawning habitat would be expected to produce similar densities of larger fish. More complex interactions such as fouling of spawning habitat or enhancement of predation mortality could produce lower densities and even larger fish, but this is unlikely. In Wahleach, there was potential for fertilization to increase abundance of sticklebacks, a kokanee competitor, with little or no benefit to kokanee (Perrin et al. 2006). Therefore, it was hypothesized that introduction to the reservoir of a piscivore that targeted pelagic and littoral sticklebacks would allow kokanee to benefit from fertilization.

Considering the uncertainties about potential outcomes, a monitoring program was undertaken to measure limnological conditions and fish population status in the reservoir during baseline (1993-1994) and fertilization years (1995-present). Although kokanee re-introduction and enhancement were the primary targets of the fertilization-stocking program, rainbow and cutthroat trout have been important components of the Wahleach sport fishery (Perrin et al. 2006, E. Johnson, BC Ministry of Environment, personal communication) and the fish community, so we have also evaluated their population trends in this report.

The monitoring program was designed to assess the physical (water clarity, temperature, and dissolved oxygen concentration) and chemical (nutrient availability) conditions of the reservoir, and the response of the lower trophic levels (abundance, biomass, and assemblage of phytoplankton and zooplankton) to the nutrient additions. Characteristics of the fish community were monitored with emphasis on kokanee, including abundance, species composition, age, body size, diet, and spawning escapement. Surveys to assess angler success and satisfaction were also conducted at times. These measurements were intended to assess the success of re-introduction of kokanee, fertilization, and cutthroat stocking in establishing a self-sustaining kokanee population attractive to anglers, and to provide data for adjusting fertilization and stocking rates to optimize program success.

We set 6 objectives for the report, as follows: 1) report 2007 and 2008 data; 2) merge the available trophic level data for 2002-2008 with the 1993-2001 food web data that were synthesized by Perrin et al. (2006); 3) as the available data allowed, evaluate key questions (below) about the success of the fertilization and stocking program over the entire 1993-2008 period and consider whether the outcome has changed since Perrin et al.'s (2006) interim assessment through 2001; 4) identify data gaps that prevent evaluation of the key questions; 5) evaluate uncertainty in the estimates of fish abundance at Wahleach; and, 6) provide recommendations for future monitoring and management of the Wahleach program. The status of the fertilization-stocking program at Wahleach was evaluated with respect to the following key questions, which are essentially the same as those asked in 2001 by Perrin et al. (2006):

- Have the nutrient additions increased the availability of edible algae and *Daphnia*?
- Is the kokanee population self sustaining?
- Have the abundance and size of kokanee increased?

- Have angler satisfaction and success increased?
- Has cutthroat trout stocking reduced the abundance of sticklebacks?

2. Study Area

2.1 Background

Prior to impoundment Wahleach Reservoir was a small mountain lake formerly named Jones Lake. Littoral habitat was extensive at Jones Lake, emergent macrophytes, epiphyton and epipelon were abundant, though the lake was nutrient-poor and littoral productivity probably exceeded pelagic productivity (Stockner & Bos 2005). Deemed suitable for game fish, Jones Lake was stocked ca. 1925 with rainbow trout and kokanee eggs (Perrin 1997). When angler satisfaction declined in the thirties (Mottley 1935), the lake was stocked unofficially with 150,000 kokanee (Inglis 1995) and 15,000 rainbow trout (BC Ministry of Environment, Government of BC, Fisheries Inventory Data Query, Appendix A1). By 1940, kokanee were spawning successfully, and gillnets were catching equal numbers of kokanee and rainbow trout (Perrin 1997).

The dam, which was completed in 1953, created a storage reservoir with a spillway, and penstock to a powerhouse. At full pool, reservoir surface area is 30% greater than pre-impoundment area (282 to 410 ha). Mean depth and length each doubled from 6 to 13 m, and 3.3 to 6.1 km, respectively). The dam created a larger, though still relatively shallow, lake with numerous broad sand-gravel beaches strewn with tree stumps (Inglis 1995). Inundation resulted in an increase in phytoplankton and also benthic production (Stockner & Bos 2005) and, in turn, a successful fishery. However, the period of increased production was short-lived, and in 1969 the reservoir was stocked with 50,000 mysids in 1969 (Perrin 1997) to enhance productivity (though the mysids do not appear to have survived). Kokanee spawner counts initially increased, from 1,700 in 1969 to 16,000 in 1980, but in 1995 the abundance of kokanee spawners had decreased to below the limit of detection. The reason for the decline in the kokanee fishery is not known as it coincided with multiple stressors, as follows: 1) introduction of mysids which may compete with kokanee for plankton; 2) increased angler effort as the fishery became better known; 3) increased reservoir age which can lead to decreasing nutrient availability and, in turn, decreased production of phytoplankton and zooplankton; 4) clear-cut logging which resulted in large inputs of terrestrial material , decreased primary productivity, and debris dams at the mouths of some spawning tributaries; 5) substantial spring draw-downs (1975-78) that exposed the littoral zone; and 6) the illegal introduction of threespine sticklebacks (ca. 1990), which may compete with kokanee for zooplankon (Scott and Crossman 1973).

In 2005, BC Hydro developed a Water Use Plan (WUP) to better balance water use and recreational interests in the Wahleach watershed. The WUP included commitments to the fertilization program, reservoir operating constraints, and annual Jones Creek minimum flow targets.

2.2 Location and geography

Wahleach Reservoir is located 20 km southwest of Hope in the southern coastal mountains (Fig. 2-1A) - the first major barrier to moisture-laden air from the west. As a result, precipitation and snowfall are high (Appendices B). The reservoir is formed by a dam across the lake outlet at Jones Creek. Damming flooded 136 ha of surrounding forest.

Watershed area, including the Boulder Creek catchment which was diverted into the reservoir, is 93 km^2 (Fig. 2-1B). Watershed area to lake area is 20, and mean elevation in the catchment is 1220 m. Steep slopes combined with heavy fall rains can cause flash inflows that can lead to spilling (Fig. 2-2) and hillslope failures that result in terrestrial inputs to the reservoir (Inglis 1995).

2.3 Morphometry and hydrology

Impoundment increased the lake elevation by 18 m, and the enlarged surface area mainly represents an increase in shallow water habitat. At full pool the reservoir surface elevation is 641.6 m with a surface area of 412 ha.

The reservoir recharges in the spring-early summer, when demand for power decreases, due to snowmelt, and in fall-winter due to rain (Fig. 2-2 upper). Boulder (via the Boulder Diversion), Flat, and Jones Creek provide a majority of the inflow to the reservoir. Mean annual flow into the reservoir is approximately 6.2cms. As required based on provision of Lower Jones Creek minimum flow requirements, Boulder Creek flows > 0.14 m^3s are diverted to Jones Creek through a diversion structure ~500 m upstream from the reservoir shoreline. Spills in to Jones Creek over the Wahleach Dam spillway may be required in the fall after high when reservoir levels reach > 641.6m, although frespill at Wahleach Dam is an extremely rare event.

2.4 Reservoir operations

Draw-down is through the 4.5 km tunnel and 500 m penstock that connect the reservoir to a power house on the south bank of the Fraser River (Fig.2-1 B). The intake is on the west side of the reservoir at 618.59 m, near the middle of the lake. The reservoir is drawn-down during the winter, when inflows are low. Drawdown is moderate between August and December (Fig. 2-3), and more rapid between December and April. The period of rapid drawdown coincides with trout spawning and kokanee and trout egg development (Fig. 2-3 upper). Pre-WUP mean draw-down was approximately 12 m and maximum draw-down was 17 m- which is large relative to water depth (mean depth = 15 m; maximum = 27 m); the WUP maximum drawdown constraint (since 2005) is 13.6m to 628m. A drawdown of 15 m corresponds with a decrease to 125 ha, and exposes a large area of lake bottom at the north and south ends of the reservoir, and an alluvial fan at mid-lake, with potential to alter benthic productivity, streamflow, and access to spawning tributaries (Perrin 1997). The WUP constraints prevent chronic exposure of shallow substrate, restore some littoral productivity, promote production of benthivorous trout, and provide access to spawning streams at critical time windows (Fig. 2-2 lower) (Perrin & Stables 2001).

2.5 Physical and chemical conditions

Wahleach Reservoir is dimictic (fully mixes in the fall and spring). Thermal stratification occurs between May-June and mid-October, and the reservoir is ice-covered between December and March. In July and August, the water temperature of the epilimnion can reach 19-20 ºC. Hypolimnetic waters are typically oxygen-rich, but may become hypoxic in late summer at >15 m (Inglis 1995). Like many reservoirs and coastal lakes in BC, Wahleach is fast-flushing and oligotrophic (Perrin et al. 2006).

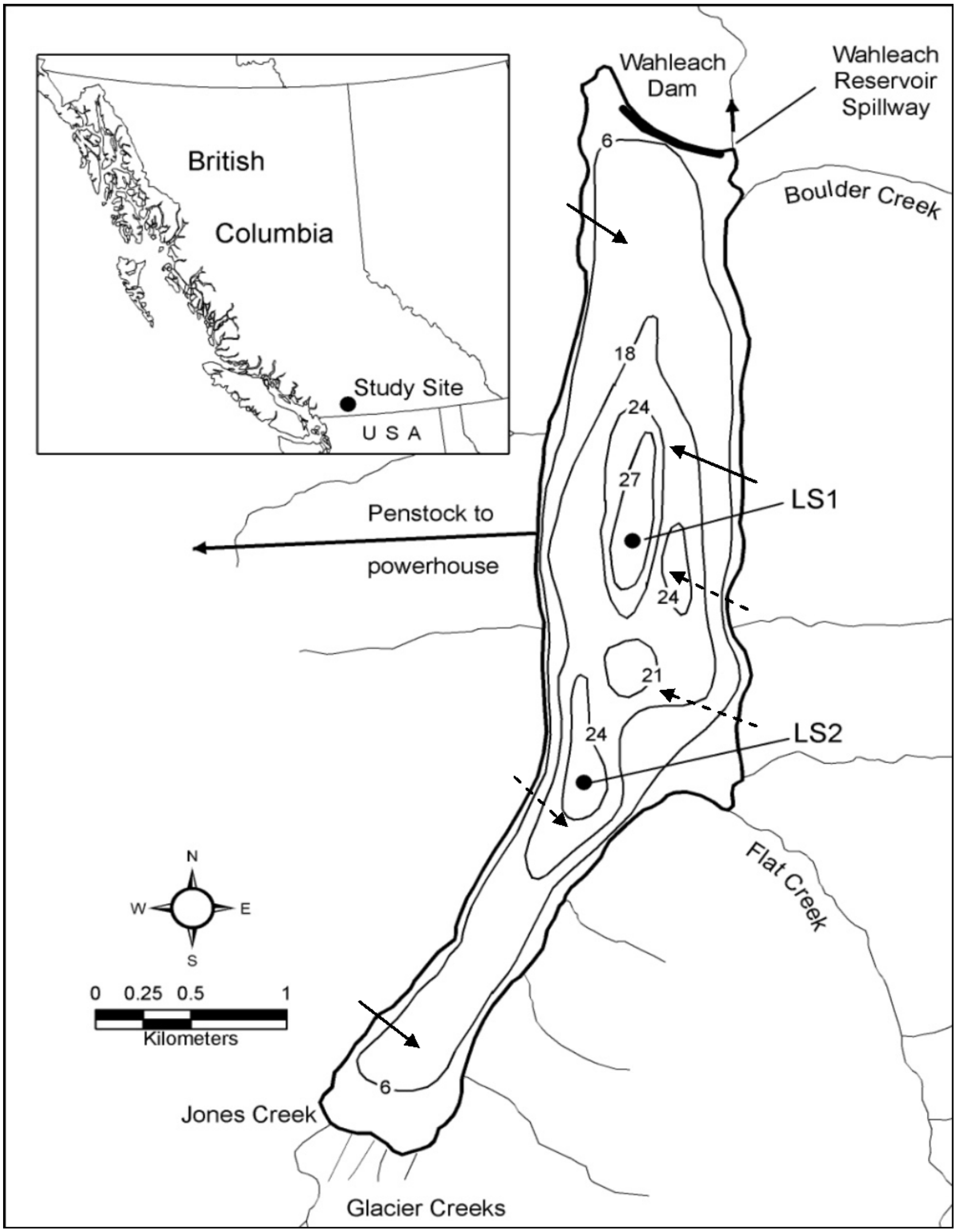

Figure 2-1A Map of Wahleach Reservoir showing sampling stations (N 49^o 22.400 W 122^o 20.535 and N 49^o 19.610 W 122^o 25.424). Note: Map source- BCF (B.C. Fisheries) on file at the Research and Development Section, UBC. Solid arrows indicate sinking net locations and dotted arrows indicate floating net locations. LS2 = north stations; LS2 = south station.

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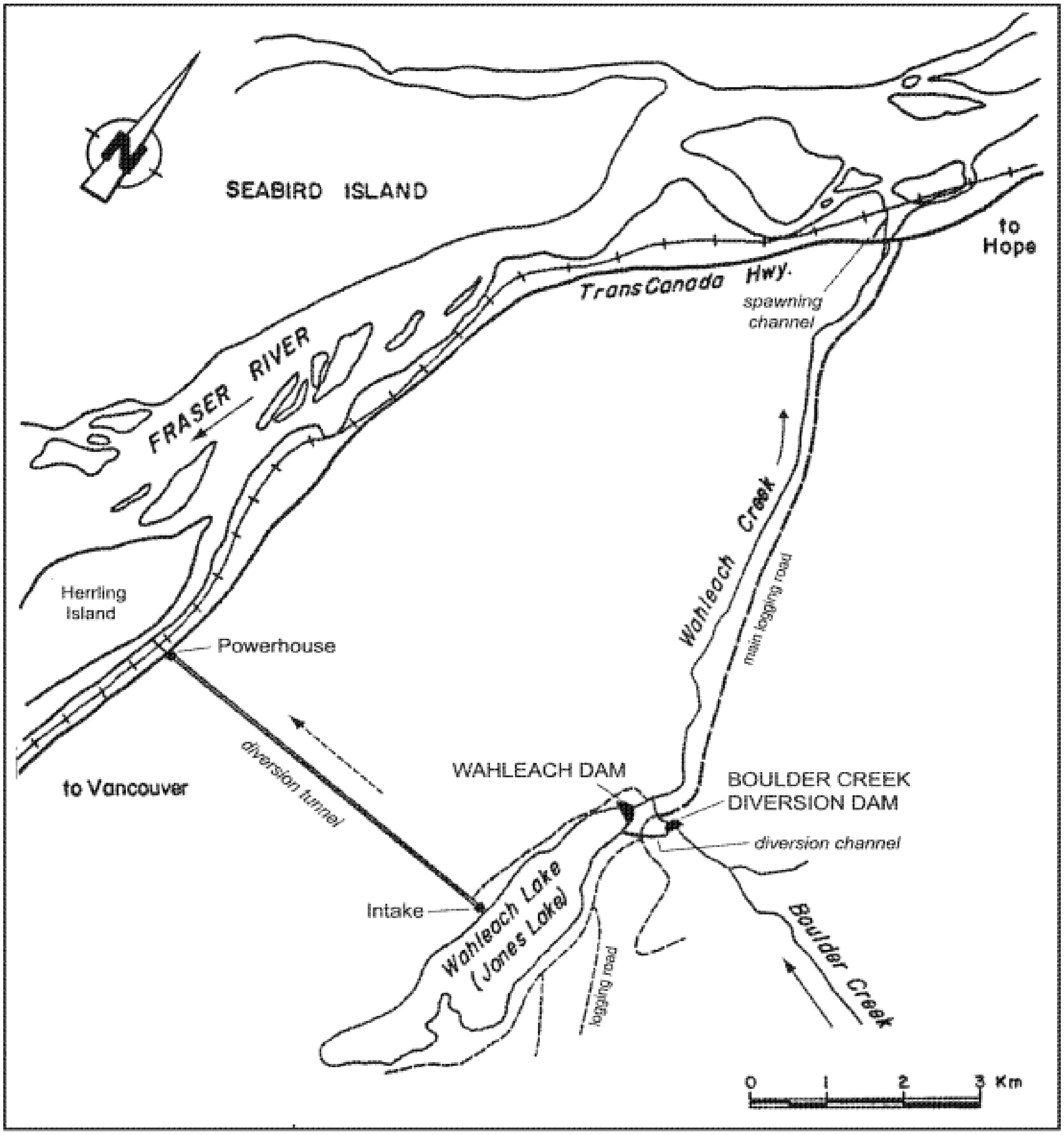


Figure 2-1B

Figure 1. Location and general arrangement of the Wahleach Diversion Project.

Figure taken from Bridge-Coastal Restoration Strategic Plan (2000).

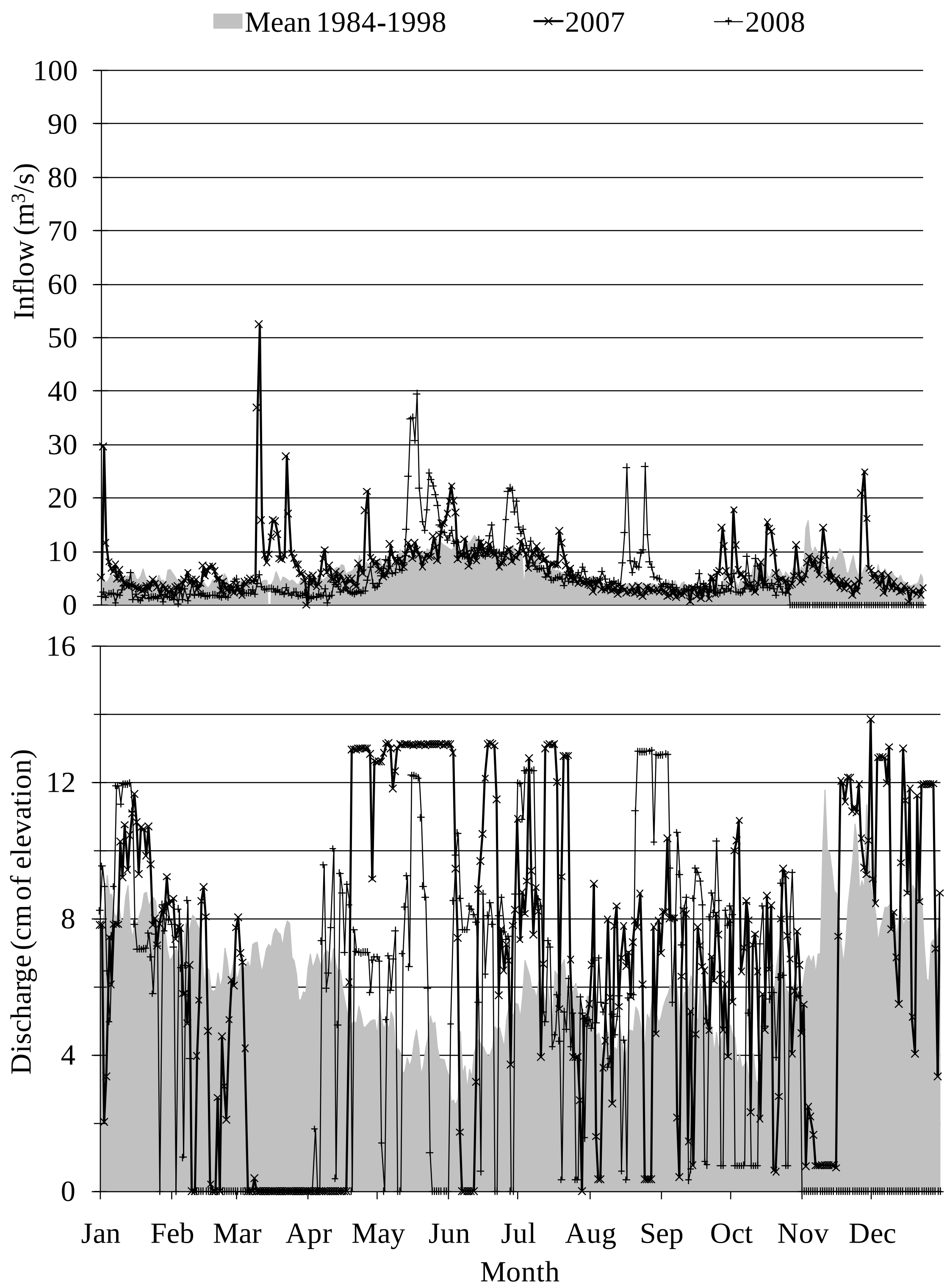


Figure 2-2 Reservoir inflow (upper) and discharges (lower) for Wahleach in 2007-08 and the mean for 1984-1998.

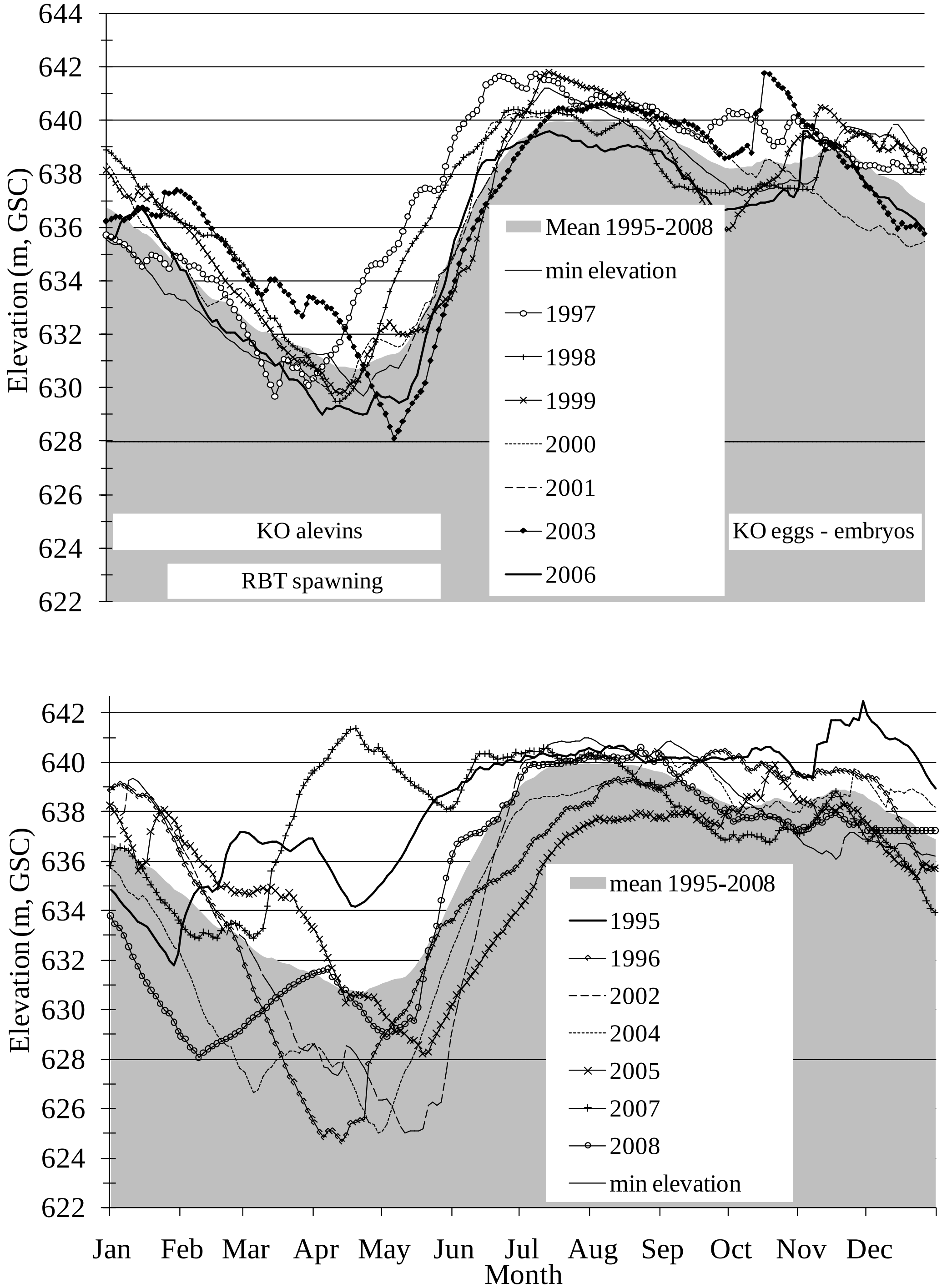


Figure 2-3 Draw-down in Wahleach during typical (upper) and unusual (lower) years. Rainbow trout and kokanee spawning periods are shown in the lower panel. The upper figure shows the timing of key rainbow trout and kokanee life-history stages. KO = kokanee; RBT = rainbow trout; GSC = Geologic Survey of Canada.

3. Methods

3.1 Fertilizer loading

In nutrient poor systems such as Wahleach Reservoir, increased phosphorus loading is expected to increase overall productivity (Downing et al. 1990), and nitrogen is added in concert with phosphorus to avoid nitrogen limitation of phytoplankton growth and proliferation of ungrazeable algae (Ferber et al. 2004; Smith 1982). Among years, annual phosphorus loading has varied from 103–232 mg/m^2 (Fig. 3-1 l upper), and the annual ratio of nitrogen to phosphorus has varied from 25 to 9 (by weight) (2002 loading rate per G. Wilson, BC Ministry of Environment, personal communication). Between 1994 and 2000, phosphorus load was increased, and between 1998 and 2000 the nitrogen load was decreased in response to increased cost. Since 2000, target annual phosphorus load has ranged between 175 and 232 mg/m^2, and target nitrogen load has increased from a low of 882 mg/m^2 to 1770 mg/m^2 (2007-08) in an effort to eliminate the chronic blooms of nitrogen-fixing Cyanobacteria (some of which are inedible and capable of toxin production) with a seasonal maximum nutrient ratio close to 15 to 1. In 2007-08, the target phosphorus load was 204 mg/m^2 and the target nitrogen load was 1770 mg/m^2. In 2007, 149 mg/m^2 phosphorus was added and 1344 mg/m^2 nitrogen was added to the reservoir. Loading was lower than the target in 2007 due to logistical problems which prevented some weekly applications, and because some weekly loads were deferred due to visible algal blooms. In 2008, phosphorus loading was 184 mg/m^2 and nitrogen loading was 1592 mg/m^2. In 2008, loading was less than the target because heavy snow cover delayed start-up by several weeks, and in mid-summer a planned relatively low ratio nitrogen to phosphorus load was replaced with a higher ratio load in an effort to alleviate the apparent nitrogen limitation of phytoplankton growth.

In each year, nutrient additions and nutrient ratios (by weight) have followed a bell-shaped loading curve aimed at increasing production of edible algae between spring and summer (Perrin 1997; Ashley et al. 1997). In 2007-08, target weekly phosphorus loading ranged between about 5 and 18 mg/m^2, weekly nitrogen loading ranged between about 1 and 24 mg/m2 (Fig. 3-1 middle), the nitrogen to phosphorus ratio (by weight) of the fertilizer ranged between about 1 and 16 (Fig. 3-1 lower).

Fertilizer is dispensed from a tank mounted on a jet or motor boat, and discharged into the motor wash to promote mixing.

3.2 In situ measurements

Physical condition (thermal stratification, oxygen availability, and water clarity) and quality of pelagic habitat was assessed monthly from measurements of vertical profiles of dissolved oxygen concentration and temperature, and measurements of Secchi depth at LS1 (north station) and LS2 (south station) (Fig. 2-1A). Water temperature and dissolved oxygen profiles were measured at 1-meter intervals from the surface to 20 m depth using a YSI Model 550A meter. The lower boundary of the epilimnion, or surface warm mixed layer, was determined as the depth at which water temperature change was greater than 1 degree per meter. The depth of the euphotic zone, or the layer of water in which light is sufficient for photosynthesis, was estimated as 2-times the depth of the epilimnion (e.g. Keller et al. 2002). As an index of water clarity, a 20-cm Secchi disk was lowered on the shady side of the boat and Secchi depth transparency was calculated as the average of the depth at which the disk disappeared and the depth at which it reappeared. Secchi depth increases as water clarity increases. Inverse Secchi depth is more closely related to light attenuation, or the interception of light through the water column. Inverse Secchi depth increases with decreases in water clarity and was used to determine the relative importance of chlorophyll concentration to water transparency (Lorenzen 1980). Measurements at LS1 and LS2 were treated as replicates.

3.3 Sample collection

Sampling at stations LS1 & LS2 (Fig. 2-1A) between May and October has been continuous since 1993 (Table 3-1) with relatively minor changes in sample type and collection methods (Table 3-2). To determine nutrient concentrations, discrete water samples were collected at 1 m using a Van Dorn sampler, and a composite sample was collected from the surface to the top of the thermocline (2006-present) or from 0-20 m (1998-2005) using a tube sampler. Water for assessment of chlorophyll concentration, and for measurement of the biomass, density, and species composition of phytoplankton, was taken from the composite sample. Water for analysis of chlorophyll a was stored in a dark bottle for transport to the lab. Replicate phytoplankton samples were stored in glass amber bottles and preserved with acid-Lugol's solution immediately after collection. Duplicate zooplankton samples were collected monthly by vertical haul from 20 m to the surface, using a 157 µm mesh Wisconsin plankton net with a 25 cm opening and 80 µm window at the cod end (1993-95 & 2003-2008), and/or using a Clarke-Bumpus metered tow net (1995-2000), raised at 0.5 m/s. Zooplankton were anesthetized with Club Soda, and preserved with 70% ethanol in the field.

Summaries of the phytoplankton and zooplankton samples collected since 1993 are in Appendix C1 and D1, respectively.

3.4 Nutrient chemistry and analysis

Water chemistry analyses included the following: total phosphorus, total dissolved phosphorus (TDP), soluble reactive phosphorus (SRP) (Menzel & Corwin 1965; Murphy & Riley 1962); total nitrogen (APHA 1995); nitrate + nitrite (NO_{2+3}) (Stainton et al. 1977; Wood et al. 1967); and, silica, and chlorophyll a (after extraction in 90% acetone overnight in the dark at 4°C) (Stainton et al. 1977). Samples for analysis of dissolved nutrients and SRP were filtered in the field (0.45 µm Sartarous filter). Samples for chlorophyll analysis were filtered in the lab under low light, then filters were wrapped in foil and frozen until analysis. All samples for nutrient analysis were stored in the dark on ice and delivered within 24 h to a commercial lab (Maxxam Analytic, Burnaby, BC). Filtered samples were analyzed when possible within 48 h of collection using low-level detection methods. The samples from LS1 and LS2 were treated as replicates.

The analysis of nutrient data includes assessment of the nutrient limitation of algal growth, which is the product of nitrogen and phosphorus concentrations as well as the ratio of nitrogen to phosphorus. We used the atomic ratio of NO_{2+3} to total dissolved phosphorus (TDP) in epilimnetic waters to assess nutrient limitation of phytoplankton growth (J.G. Stockner, personal communication) where NO_{2+3}:TDP < 9 indicates nitrogen deficiency and NO_{2+3}:TDP > 22 indicates phosphorus deficiency (Guildford & Hecky 2000). Nutrient concentrations less than the limit of detection (2 µg/L) were assumed to be equal to one-half of the detection limit. Sufficiency of nutrient supply was assessed using physico-chemical regimes for 2002-2008.

3.5 Chlorophyll analysis

Before 2007, chlorophyll samples were filtered onto cellulose filters and analyzed by a commercial lab (Maxxam Analytic, Burnaby, BC). In 2007, analysis of the cellulose-filtered chlorophyll samples was performed by fluorometric assay in a Ministry of Environment lab. In 2008, chlorophyll samples were filtered onto both cellulose (0.45 µm) and polycarbonate filters (0.4 µm, 0.22, 2.0, and 20 µm) and analyzed fluorometrically in the Ministry lab (some cellulose-filtered samples were also collected for analysis by Maxxam). The comparison of the results of the samples filtered onto cellulose-0.45 µm filters and onto polycarbonate-0.4 µm filters indicated relatively low efficiency of extraction from some of the cellulose filters compared with the polycarbonate filters (extraction from dry filters was better than extraction from wet filters). The chlorophyll results for 2007 correspond with cellulose filters and therefore may be too low. The chlorophyll results reported for 2008 correspond with the polycarbonate filters.

3.6 Phytoplankton enumeration and analysis

At the lab, phytoplankton samples were gently shaken, a sub-sample allowed to settle in a 25 mL chamber for 8 h (Utermohl 1957), then cells were counted by taxa using a Carl Zeiss inverted phase-contrast plankton microscope. Several random fields were examined at low magnification (250x) to count microplankton (20-200 µm) and colonies of diatoms, dinoflagellates, and filamentous blue-greens. A single 10-15 mm transect was examined at high magnification (1560x) to count picoplankton (< 2 µm) and nanoplankton (2 – 20 µm). To achieve suitable accuracy, from 250-300 cells were counted per sample (Lund et al. 1958). Algal cells were identified using Canter-Lund & Lund (1995).

Changes in plankton productivity as a result of nutrient additions were gauged indirectly, from data on standing crop (abundance and biomass) and species assemblage, although standing crop can be decreased by grazing, and grazing can alter species assemblage, such that standing crop and species assemblage may not correspond very well with actual productivity and the availability of edible algae. Previous data reports have reported results for edible versus inedible algae (Inglis 1995; Perrin 1997, based on Sieburth et al. 1978). Because such analysis was not available for more recent data when the report was written, we separated edible from inedible algae based on algal class, where edible = chlorophytes and flagellates; inedible = diatoms and dinoflagellates (too large) and Cyanobacteria (too small). While not strictly correct (some edible and inedible algal species belong to each algal class), the separation is more or less correct for the algal assemblage and the large zooplankton in Wahleach Reservoir, which can ingest nano- to micro-plankton (Perrin 1997).

The phytoplankton response to fertilization was assessed using the following: 1) seasonal abundance and biovolume means for 1993-2008, 2) seasonal dynamics for selected years, as follows: 1994 (baseline); 1996, initial response to fertilization; 2004 and 2006, 10 years into fertilization; and 2007-08, most recent data, and 3) versus the annual rate of phosphorus loading.

Sufficiency of food supply was assessed using data on zooplankton and phytoplankton biomass, abundance, and species assemblages for 1993 to 2008, and the sufficiency of the nutrient supply for the last 6 years was assessed using physico-chemical regimes for 1993-94 (baseline) and 2002-2008, the times for which the most complete data was available.

3.7 Zooplankton enumeration and analysis

At the lab, samples were resuspended in tap water, filtered through 74 µm mesh, subsampled using a Folsom-type plankton splitter, placed in a gridded Petri dish, then stained with Rose Bengal and viewed with a Wild M3B dissecting microscope (up to 400x magnification). From 150-200 of each dominate specie was counted per replicate sample, and the length of 30 organisms was measured for biomass calculations by conversion to dry mass per McCauley (1984). Rare cladocerans and copepods were counted but not identified to species. Identification was per Sandercock and Scudder 1996, Pennak 1989, Wilson 1959, and Brooks 1959. Egg counts and lengths of gravid females were recorded but the data are not reported here.

Cladoceran biomass was used as an indicator of increase in the supply of the large zooplankton preferred by kokanee. Although the largest proportion of cladoceran biomass is comprised of *Daphnia*, which may be preferred by planktivores, other possibly less edible cladocerans such as *Holopedium* also can occur in Wahleach at relatively high abundance and biomass, particularly in the spring and early summer (see blow).

The zooplankton response to fertilization was assessed using the following: 1) seasonal abundance and biomass means for 1993-2008, 2) seasonal dynamics for selected years, as follows: 1994 (baseline); 1996, initial response to fertilization; 2004 and 2006, 10 years into fertilization; and 2007-08, most recent data, and 3) versus the annual rate of phosphorus loading.

3.8 Fish

3.8.1 Minnow trapping

Gee traps baited with salmon roe were used to sample small fish, mainly in the littoral zone, during spring and fall during most years of the study (Table 3-1). Traps were positioned on the lake bottom at 2 metre water depth and fished over night (e.g. Harris et al. 2007b). Most of the traps were set along the western shoreline and at the north and south ends of the reservoir where littoral habitat is relatively abundant. Catch from all traps was pooled to calculate catch per trap-h. In midsummer 2008, baited Gee traps (in triplicate) were positioned at nearshore locations (western shore) with and without stumps, and at two offshore locations at near-surface, mid-water, and deep-water depths to assess littoral (stump versus no stump areas) versus offshore habitat use by stickleback.

Fish captured in minnow traps were identified to species per McPhail & Carveth (1993), enumerated, and weighed. From trap data we computed catch per unit effort (CPUE, fish/trap-h) as an index of small fish abundance. Not all trap data collected over the years was available for this analysis because some archival files were not up to date.

3.8.2 Gillnetting

All gillnets were standard RIC (1997) variable mesh design, as follows: 6 panel, 25-76 mm stretched mesh, 91.2 x 2.4 m total size. In most years of the study, nearshore gillnetting was conducted during one or more seasonal periods (spring, summer, fall, Table 3-1). Typically, during each period 3 floating and 3 sinking gillnets were set perpendicular to shore (Fig. 2-1A) and fished overnight (Table 3-2). These data were used to characterize the fish assemblage in the nearshore zone and to determine size-at-age for each fish species. In October 2000 and 2008, in addition to nearshore sets, gillnets were set over a range of depths in offshore areas (Table 3-2) to characterize the pelagic fish community. Nets set at intermediate depths above bottom were suspended to the desired depth from a float at the end of each panel. Total water depth and GPS coordinates were recorded at the location of each pelagic gillnet.

Fish captured in gillnets were identified to species, enumerated, weighed, and measured in the field. Scales, and otoliths (when scales were unavailable, or for scale-age verification), were taken from all kokanee and from a representative sample of other salmonids. Scales were aged as per Ward & Slaney (1988). Stomach contents from piscivores were qualitatively examined in the field in most years of the study, but stomachs were only collected and analyzed from 1997-2000. The qualitative data, and the 1997-2000 data which was presented in Perrin et al. (2006), are summarized in the report.

Catch per unit effort (catch/net-h) of gillnetted fish was used as index of relative abundance and relative biomass (CPUE x mean weight) of fish species. For midlake gillnetting, analysis was partitioned by sample depth. Fall nearshore sampling was performed most consistently (12 of 16 year) and reflects status at the end of the growing season, so was used to assess year-to-year change in relative abundance and biomass, size-at-age, and species composition. Fall nearshore and pelagic gillnet data were also used to estimate species composition of large fish (>100 mm fork length) in acoustic estimates.

3.8.3 Trawling

Trawling has been conducted in 6 year of the study (Table 3-1). It was always conducted at night, in the deepest part of the reservoir, and immediately following acoustic surveys (Perrin & Stables 2000, 2001; Perrin et al. 2006). Depths where the acoustic surveys indicated fish were most abundant were emphasized (Table 3-2). A small beam-trawl that is effective for capturing age-0 *Oncorhynchus nerka* and stickleback (Hume & MacLellan 2008) was used for sampling in all years. Its specifications were: 12 m length, mouth opening of 2.5 x 2.5 m, stretch mesh size from 5.1 cm at the mouth to 0.3 cm at the cod end) (Perrin et al. 2006). The weighted net was suspended from buoys to the desired depth and towed at 0.6-0.8 m/s for 10 to 40 minutes. Fish caught in the trawl were anesthetized using clove oil and preserved in formalin, except in 2008 when fish were preserved by freezing. Fish were identified to species, enumerated, weighed, and measured. They were used to estimate size of small pelagic fish and to apportion fish <100 mm long in acoustic estimates. Since tows targeted fish layers to supply species information for acoustic surveys, they were not random samples, so trawl CPUE was not computed as an index of relative abundance.

3.8.4 Acoustic surveys

Acoustic surveys focused on kokanee, so all sampling was conducted at night using a down-looking transducer orientation. Surveys were performed in one baseline year (1993), 4 years immediately following reintroduction of kokanee (1997-2000) (Perrin & Stables 2000, 2001; Perrin et al. 2006), and in 2007 (Sebastian & Scholten 2008, Appendix A3) and 2008 (analysis in progress) (Table 3-1). In all years, acoustic surveys were conducted between early October and early November, to include as much of the growing season as possible. Surveys from 1993-2000 used a BioSonics 420 kHz dual-beam or split-beam echo sounder, whereas later surveys used a Simrad 120 kHz split-beam system. Mobile surveys were performed along pre-planned transect lines at a speed of 2m/s or less. In 1997–2000, sampling included nearshore habitat (to approximately 2 m deep) including both ends of the lake, whereas the 2007-08 surveys were primarily limited to pelagic habitat and coverage did not extend as fully to the ends of the lake as the earlier surveys. An additional summer acoustic survey conducted in July 2006 appeared problematic (Harris et al. 2007) and is not described further in this report.

Acoustic data were processed by echo counting at most fish densities encountered in the study, and by echo integration in rare instances when fish could not be resolved individually in dense aggregations (Thorne 1983, MacLennan & Simmonds 1994). Even at the highest fish densities encountered, most fish were seen as individuals because the transducer beam angle was very narrow (about 6 degrees) and many fish were at a relatively shallow depth. In 2007 and 2008, acoustic estimates of fish abundance were apportioned among species based on trawl catch for fish <100 mm, and on and nearshore and pelagic gillnet catch for larger fish. The breakpoint for acoustic targets among size groups >100< mm (about -47 dB) was based on Love's (1977) ±45º acoustic-size relation, which is commonly used for salmonids observed with downward looking acoustics.

Because no trawling was done in 2007, that year's population estimate was apportioned among species using two different approaches. Scholten & Sebastian (2008) used typical values of kokanee-spawners to total-kokanee and kokanee-0 to older-kokanee from other BC lakes to estimate the proportions of kokanee fry and older kokanee in the total acoustic estimate, assuming that these ratios were consistent among years (herein referred as the S&S method, see Scholten & Sebastian 2008 for details). For the second estimate, the 2008 trawl and gillnet catches were applied to the 2007 acoustic estimate of fish abundance, assuming that species, size, and age composition was consistent among years (herein referred to as T&G method). Species apportionment of neither method was depth-stratified, which matched apportionment methods of earlier years (Perrin et al. 2006).

3.8.5 Kokanee response to fertilization

The kokanee response to fertilization was assessed comparing total fish abundance estimates from acoustic surveys and size-at-age from fall nearshore gillnetting, the longest and most consistent data set available for this purpose.

3.8.6 Consumptive pressure of planktivores

Relative consumptive pressure exerted by kokanee and stickleback on their common food resource calculated as effective density by Perrin et al. (2006). Effective density was defined as $N_i \cdot FL_i^2/A$, where N = population size of fish species *i*, FL = mean form length of species i caught in gillnets and trawl, and A is the reservoir surface area. Because of the uncertainty about the kokanee and stickleback composition of the S&S and T&G abundance estimates, the results presented in this report are limited to 1993-2000 data from Perrin et al. (2006).

3.8.7 Spawner habitat and counts

Kokanee

Both before and during enhancement, kokanee spawner counts were conducted weekly or biweekly between September and October (Table 3-1) in Flat, Wahleach (Jones), Boulder, and Glacier Creeks (Fig. 2-1B). Details about surveys conducted since 2001 are provided in Table 3-3. Streams were walked for as long as time permitted, until a barrier to migration was encountered, or until no fish were seen for a reasonable distance upstream (White Pine 2002). Since 1995, daily counts have been scaled up to estimate escapement using the 'area under the curve' method (Irvine et al. 1993). Observer efficiency was assumed to be 90%, and the stream residency to be 10 days (Irvine et al. 1993).

Rainbow trout

Rainbow trout spawner counts were conducted weekly during April and May of 1995 (Inglis May 1995).

Spawning habitat

Access to streams, relative availability of spawning habitat in each tributary, and in-lake spawning habitat were assessed in 1995 (Inglis 1995) and 2002 (White Pine 2002) and the data are summarized here.

3.8.8 Outcomes of fish stocking

Fish were stocked in Wahleach Reservoir for 3 different reasons since the inception of the study in 1993, as follows: 1) most years between 1997 and 2007, sterile age-1 cutthroat trout (1,000-11,000/year, mean = 3,900) were stocked to prey on stickleback and reduce their abundance; 2) between 1997 and 2004, age-0 kokanee (35,000-50,000/year, mean = 48,000) were stocked to re- establish kokanee age-class structure and a naturally reproducing population; and 3) in 1998 and 2002, sterile rainbow trout (2,000-6,000/year) were stocked to enhance the sport fishery. No fish were stocked in 2008. Complete stocking records appear in Appendix A1. We examined the data available from fish sampling during the study period to see if these three objectives were met.

3.8.9 Sport fishery trends

Creel surveys were conducted in 1998, 1999, and 2001, and we present their results which were summarized in Perrin et al. (2006). We also examine potential angler satisfaction by comparing mean size of fish at age to a theoretical angler satisfaction size threshold for low productivity lakes (P. Askey, J.R. Post, and E.A. Parkinson, personal communication). Some additional anecdotal information from conversations with anglers about catch in recent years is also presented.

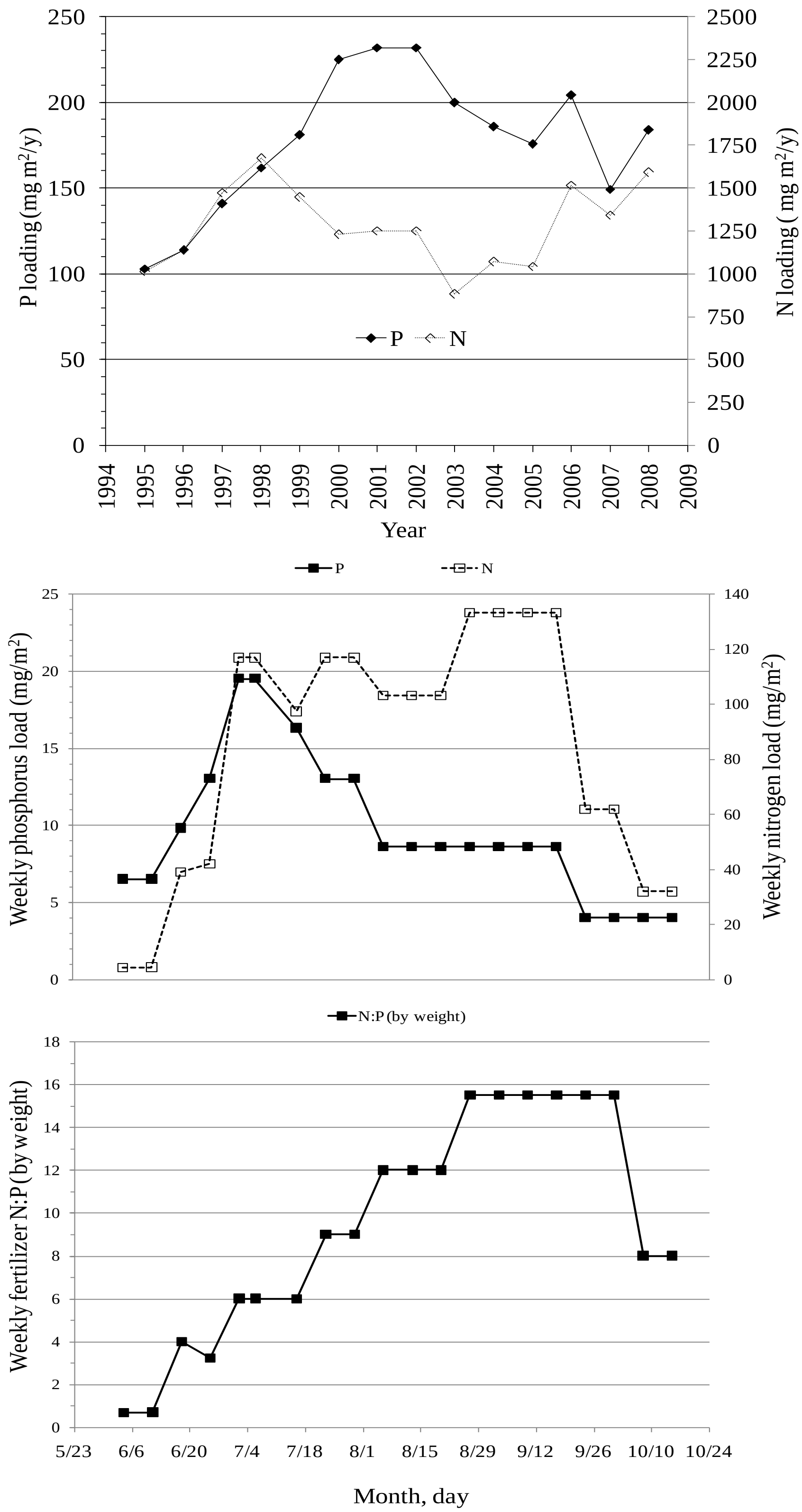


Figure 3-1 Annual nutrient load (upper) 1995-2008 at Wahleach Reservoir. Weekly phosphorus and nitrogen load (middle) and nitrogen to phosphorus ratio (lower) in 2007-08.

Table 3-1 Record of limnological and fish sampling at Wahleach Reservoir, 1993 – 2008.

Category	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Fertilization	-	-	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Limnology sampling	●[1]	●[1]	●[1]	●[1]	●[1]	●[1]	●[1]	●[1]	●[2]	●[2]	●[2]	●[3]	●[3]	●[3]	●[3]	●[3]
<u>Nearshore gillnetting</u>																
spring	-	●[1]	-	-	●[1]	●[1]	●[1]	●[1]	-	-	-	●[3]	●[3]	-	●[3]	●[3]
summer	●[1]	●[1]	●[1]	-	●[1]	-	-	-	-	-	-	-	-	-	-	-
fall	●[1]	●[1]	●[1]	●[1]	●[1]	●[1]	●[1]	●[1]	-	-	●[2]	-	-	●[3]	●[3]	●[3]
Pelagic gillnetting	-	-	-	-	-	-	-	●[1]	-	-	-	-	-	-	-	●
Trawling	●[1]	-	-	-	●[1]	●[1]	●[1]	●[1]	-	-	-	-	-	-	-	●
Acoustic survey	●[1]	-	-	-	●[1]	●[1]	●[1]	●[1]	-	-	-	-	-	●	●	●
Spawner count	●	●	●	-	-	-	-	-	●	-	●	●	●	●	●	●
Gee traps	-	-	-	-	●	●	●	●	-	-	-	●	●	●	●	●

Notes:[1] described in Perrin et al. 2006; [2] no reporting due to lack of funding; [3] described in Harris et al. 2007b; - means no data collected; and shaded = years when sampling was funded by BC Ministry of Environment due absence of Water Use Plan funding.

Table 3-2 Sample type and collection methods at Wahleach Reservoir, 1993-2008. Numbers beneath years refer to references providing descriptions of methods.

<table>
<tr><th></th><th>1993
(1)</th><th>1994-2000
(1,2,3)</th><th>2000</th><th>2001-03
(3)</th><th>2004-05
(4)</th><th>2006-08
(4)</th><th>2008</th></tr>
<tr><td>TRANS</td><td colspan="7">Secchi depth 22-cm black & white disk</td></tr>
<tr><td>PHYTO</td><td colspan="2">Biwk- Int 0-2x SD</td><td rowspan="4"></td><td colspan="2">Mo- Int 0-2x SD</td><td colspan="2">Mo- 1 m, Int epi</td></tr>
<tr><td>ZP</td><td colspan="2">Biwk- Obl CB, 0-20 m
Mo- Vert Wis 150-80 µm, 1 m off B – 0 m</td><td colspan="4">Mo- Vert Wis 157-80 µm, 20-0 m</td></tr>
<tr><td>CHL</td><td colspan="2">Biwk- Int 0-2x SD</td><td colspan="2">Mo- Int 0-2x SD</td><td colspan="2">Mo- Int epi</td></tr>
<tr><td>NUT</td><td>Biwk-1 m, 1 m off B</td><td>Biwk- 1, 20 m</td><td>Until 09-02:
0-20 m, 1 m off B
After 09-02: 1m,
20 m</td><td>Mo- 1, 20 m</td><td colspan="2">Mo- 1 m, Int epi</td></tr>
<tr><td>NS GN</td><td colspan="7">3 floating net sets at 3 m water depth & 3 sinking net sets from shore to 10-15 m water depth</td></tr>
<tr><td>PEL GN</td><td colspan="2"></td><td>2 sets 0-3 m
1 set 18 m</td><td colspan="3"></td><td>2 sets 0-5 m
1 set 5-10 m
2 sets 10-15 m
3 sets 15-20 m</td></tr>
<tr><td>TRAWL</td><td colspan="6">3-6 tows in the deepest part of the Reservoir between 0 and 20 m and targeting fish layers</td><td>1 tow 5-7.5 m
2 tows 10-12/5 m
3 tows at 15-17.5 m</td></tr>
</table>

Notes: *1* Inglis 1995; *2* Perrin et al. 2006; *3* Wilson et al. 2003; *4* Harris et al. 2007b.

2) Plankton type- PHY = phytoplankton; ZP = zooplankton; Zooplankton net type: CB = Clarke-Bumpus; Wis = Wisconsin; 3) Sample type- CHL = chlorophyll a; NUT = nutrient s (total and dissolved phosphorus, nitrite, and nitrate); 4) Frequency- Biwk = biweekly, or every two weeks; Mo = monthly;

5) TRANS = transparency; SD = Secchi Depth (m); 6) Sampling depth- Int= integrated; B = lake bottom; Epi = epilimnion; 7) Angle of net: Vert = vertical; Obl = Oblique; and, 9) NS GN = nearshore gillnet; PEL GN = pelagic gillnet.

Table 3-3 Kokanee spawner counts per creek, # of spawner-count days, and dates of spawner-counts at Wahleach Reservoir, 2001, 2003-2008. '-' = no data. MOE = BC Ministry of Environment. BCIT = British Columbia Institute of Technology.

Year	**2001**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
# days spawner-count	2	3	3	4	5	6	5
Spawner-count dates	17-Sep	19-Sep	17-Sep	7-Sep	20-Sep	3-Oct	13-Sep
	24-Sep	23-Sep	24-Sep	19-Sep	27-Sep	12-Sep	17-Sep
		2-Oct	1-Oct	4-Oct	7-Oct	22-Sep	24-Sep
					11-Oct	26-Sep	1-Oct
					16-Oct	6-Oct	8-Oct
						10-Oct	
Agency	BC Hydro White Pine	BC MOE BCIT	BC MOE BCIT	BC MOE BCIT	BC MOE BCIT	BC MOE BCIT	BC MOE BCIT

4. Results

4.1 Physical and chemical conditions

4.1.1 Temperature, dissolved oxygen, water clarity and chlorophyll

In 1993-94 (pre-fertilization), temperature profiles indicated the epilimnion was 5-10 m in depth (Inglis 1995). In 2007-08, mid-summer depth of the epilimnion was 4-5 m, and deepened to 8 m in the fall (Fig. 4-1). The comparison of mixed layer depth before and after fertilization suggests that the depth of the mixed layer may have been shallower since fertilization than in the baseline years (Fig. 4-2)

Epilimnetic waters in Wahleach are usually oxygen-rich (dissolved oxygen ≥ 8 mg/L) (Fig. 4-3). However, in 2007, an unusual summer oxygen concentration pattern occurred. In late July surface waters contained <6.5 mg/L dissolved oxygen, though the concentration was greater at other times of the year, and in May and August 2007 oxygen concentration peaked below the epilimnion. Again in summer 2008, dissolved oxygen concentration peaked below the epilimnion.

Hypolimnetic waters in Wahleach were typically oxygen-rich during spring and mid-summer. However, during late summer and at depths >15 m fall oxygen concentration can fall to ≤5 mg/L (Fig. 4-3), as occurred in 2008 and in 1993-94 before the reservoir was fertilized (Inglis 1995), which is below the level considered adequate for protection of fish (>6.5 mg/L, CCME 2003).

Between 2002 and 2008, the depth of the warm mixed layer (epilimnion) during the period of strong stratification was 4-5 m (Fig. 4-4), and mid-summer water temperatures were >17°C in the upper 4 to 6 m of the water column. At such times, the warm surface water layer combined with hypoxic bottom waters can reduce the availability of the cool, well-oxygenated pelagic habitat preferred by kokanee (<17º C, DO >4 mg/l) to a narrow depth layer (Berge 2009). There was a short period in 2008 when dissolved oxygen concentration was only slightly above 4 mg/L and temperature was <17º C only between 5 and 17 m (Fig. 4-5), though the frequency of such occurrences is not known.

Secchi depth increases and decreases in response to nutrient additions, although the changes in Secchi depth do not appear to correspond closely with changes in the concentration of chlorophyll *a* (Fig. 4-6 upper). In 1993-94 (pre-fertilization), Secchi depth was, on average, 7 m (Inglis 1995) (Fig. 406 middle). Since fertilization (1995-2008), Secchi depth has ranged between 3.2 m and 5.3 m, and on average, has been 4.2±0.5 m), or about 40% less than during pre-fertilization. Secchi depth was lower in 2007-08, and in 1996, than in all other years. Inverse Secchi depth, an index of light attenuation through the water column, does not appear to increase with increases in chlorophyll *a* concentration suggesting that, in addition to chlorophyll, coloured dissolved organic carbon and/or suspended particulates may also lower water clarity (Fig. 4-6 lower).

Chlorophyll *a* concentrations have ranged between ca. <0.5 µg/L and 12 µg/L since 2002 (Fig. 4-6 upper), and concentrations appear to correspond with the bell-shaped weekly loading curve (Fig. 3-1). Seasonal average chlorophyll concentration has been greater than the baseline concentration (1.9 µg/L) since fertilization with the exception of 2007 when average chlorophyll a concentration was <0.5 µg/L or the lowest on record (logistical problems led to less than target nutrient loading in 2007, see above). Chlorophyll *a* concentration was the highest on record (5.7 µg/L) in 2008, and chlorophyll concentration was the second highest concentration in the first year of fertilization (1995) (Fig. 4-6 lower).

The euphotic zone refers to the layer of water where phytoplankton have sufficient light to fix carbon (photosynthesis) at a rate greater than the re-mineralization of organic matter back to carbon (decomposition). During the summer, and particularly in 2007-08, the depth of the epilimnion has been relatively shallow at Wahleach (possibly due to high light attenuation by terrestrial inputs), and the euphotic zone has extended well below the epilimnion (Fig. 4-2). As a result, phytoplankton may be trapped below the mixed, fertilized layer (epilimnion). Indeed, the dissolved oxygen concentrations peaks at mid-water in summer 2007-08 (Fig. 4-3) may be due to sub-epilimnetic peaks in phytoplankton productivity. Such subepilimnetic peaks in oxygen concentration (mid-August) also occurred in 1994, i.e. before fertilization (Inglis 1995).

In 2008, the chlorophyll *a* measurements were size-fractionated (Fig. 4-7), which can provide information about the size composition of the phytoplankton assemblage. The data for the north and south stations, which differ somewhat, suggest relatively low biomass in the picoplankton size range (0.22-2 µm), and relatively moderate to high algal biomass in the nanoplankton (2- 20 µm) and microplankton (>20 µm) size ranges. Most of the edible algae are Wahleach are in the pico and nano size classes (Perrin 1997)

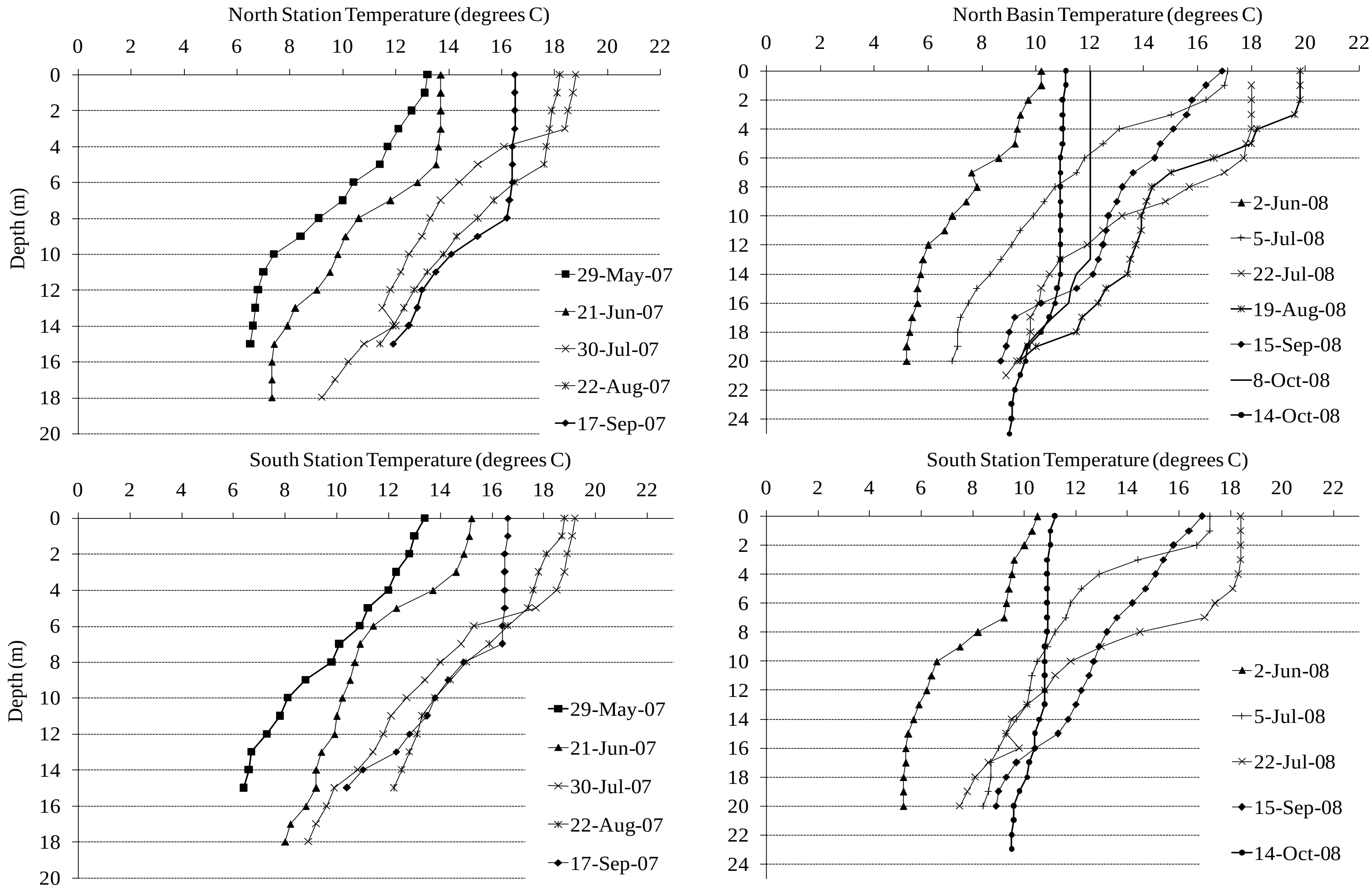


Figure 4-1 Seasonal temperature profiles at Wahleach Reservoir, 2007-08.

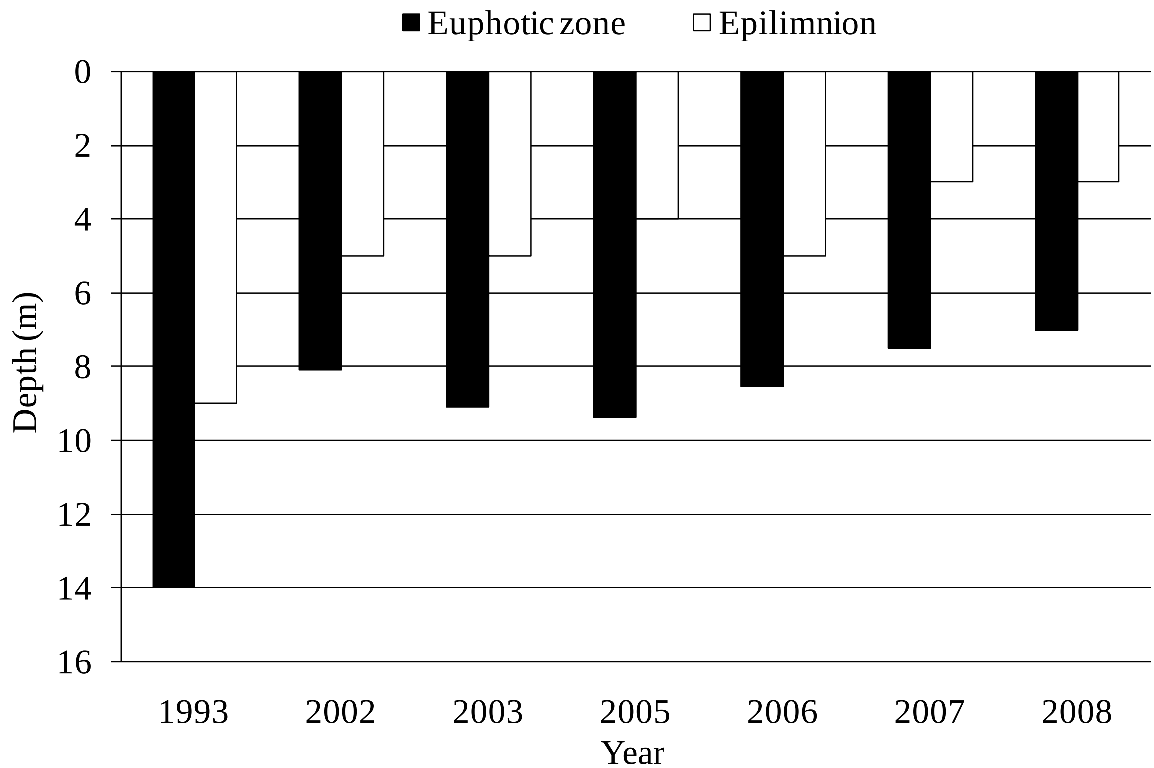


Figure 4-2 Depth of the euphotic zone and epilimnion during the period of strong stratification, 1993-94 and 2002 to 2008 (2-station means).

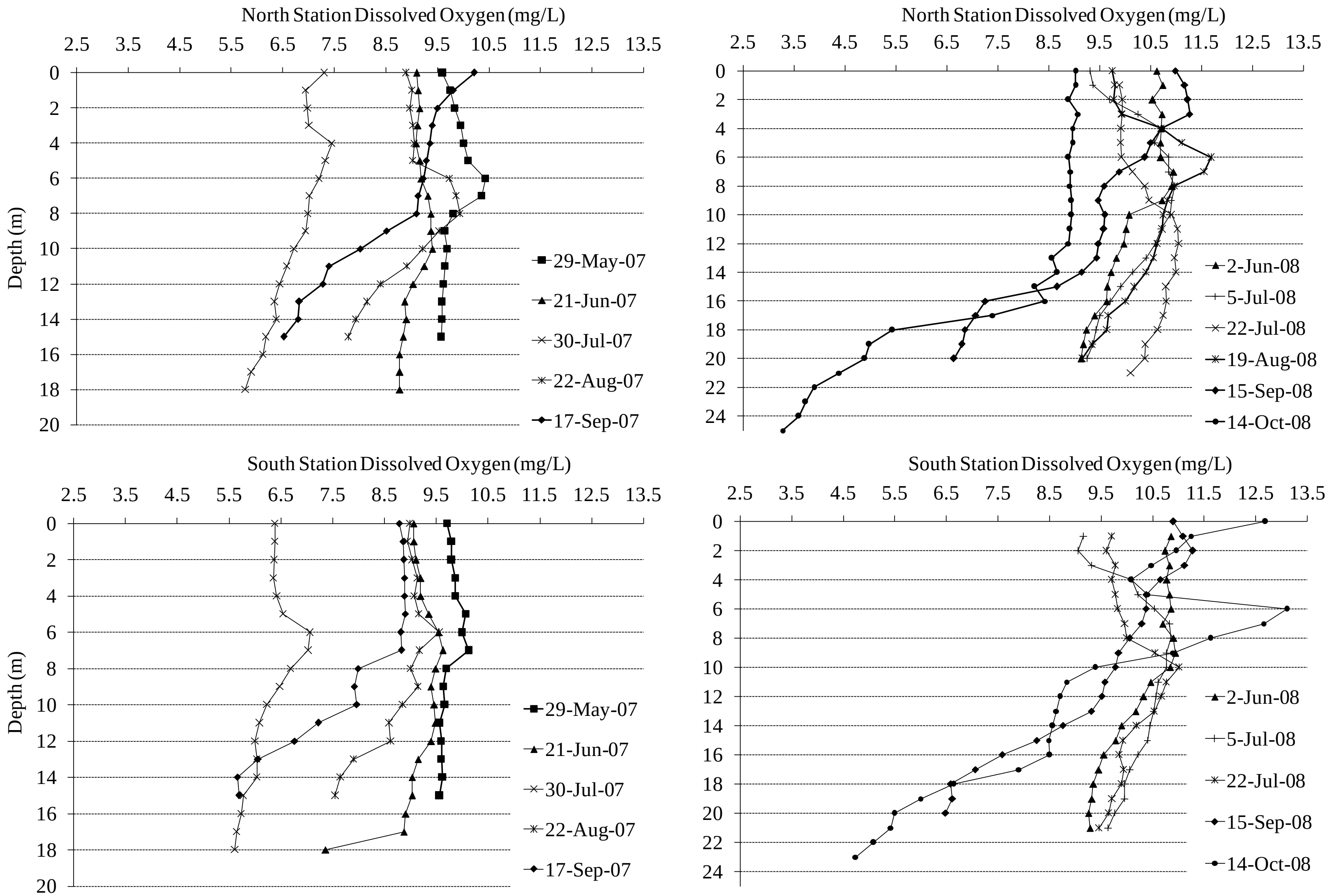


Figure 4-3 Seasonal dissolved oxygen concentration profiles in Wahleach Reservoir, 2007-08.

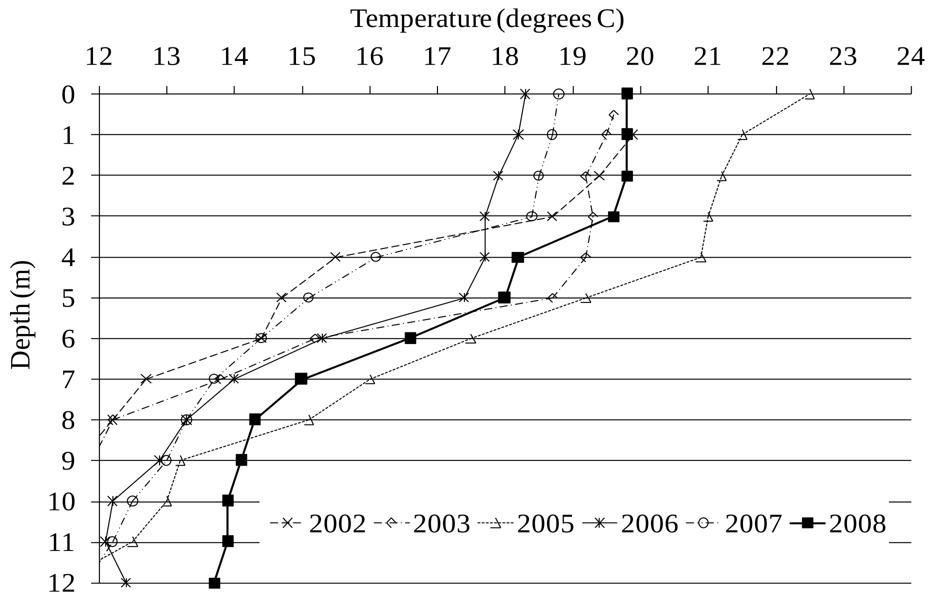


Figure 4-4 Temperature profiles during strong stratification at the north station of Wahleach Reservoir, 2002 – 2008. Profiles were similar at the south station (not shown).

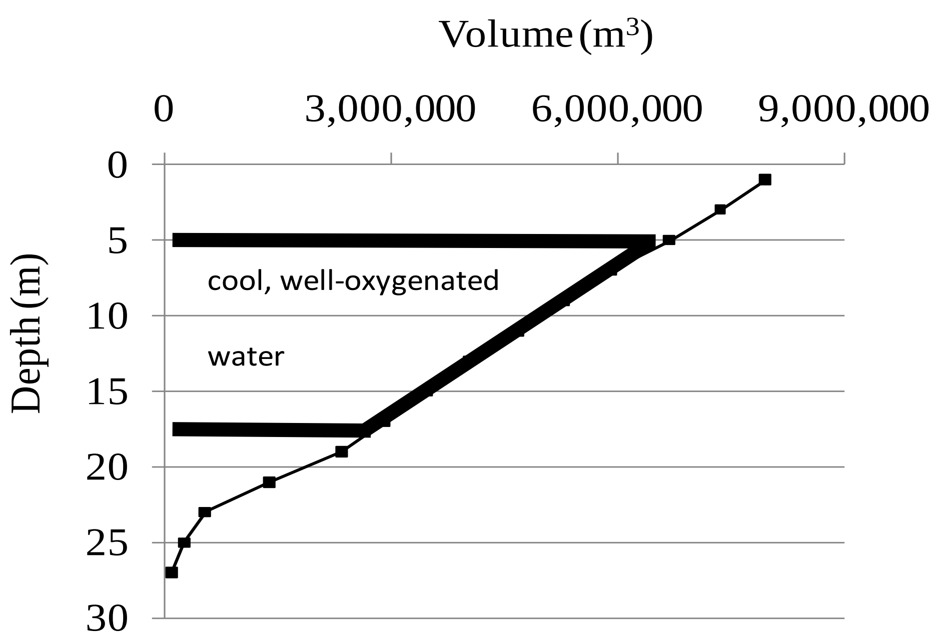


Figure 4-5 Stylized depth-volume relation for Wahleach showing the potential for limited availability of cool (temperature <17 °C), well oxygenated water (dissolved oxygen concentration >6 mg/L) during the period of strong stratification when dissolved oxygen concentrations may fall to a relatively low level.

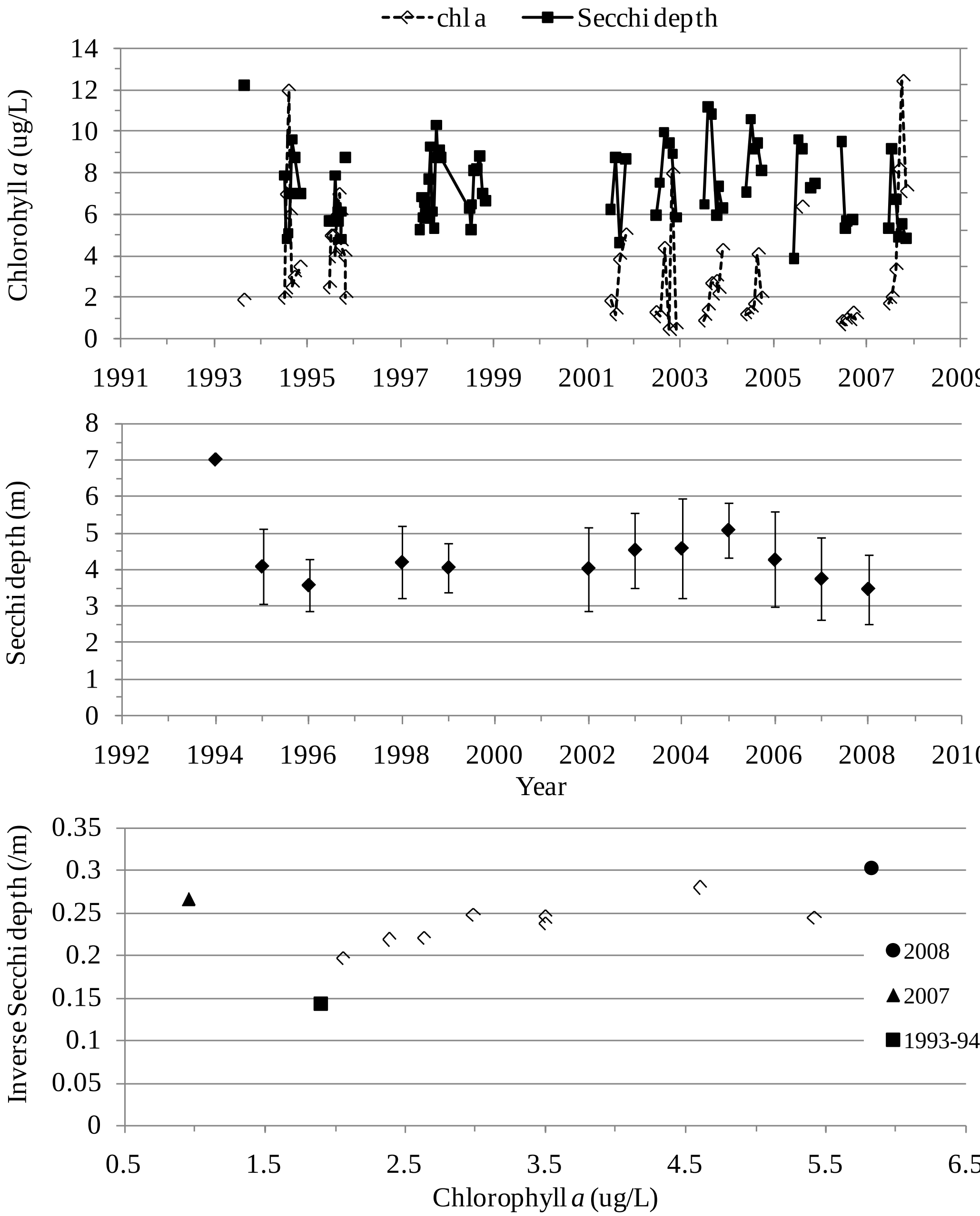


Figure 4-6 Monthly chlorophyll *a* concentration and Secchi depth (2-station means) (upper), seasonal mean Secchi depth ± 1 standard deviation (average of 2-station means) versus year (middle), inverse Secchi depth versus chlorophyll *a* concentration (3.5 µg/L is the average chlorophyll *a* concentration for 1997-1999, Perrin et al. 2006) (lower), at Wahleach Reservoir.

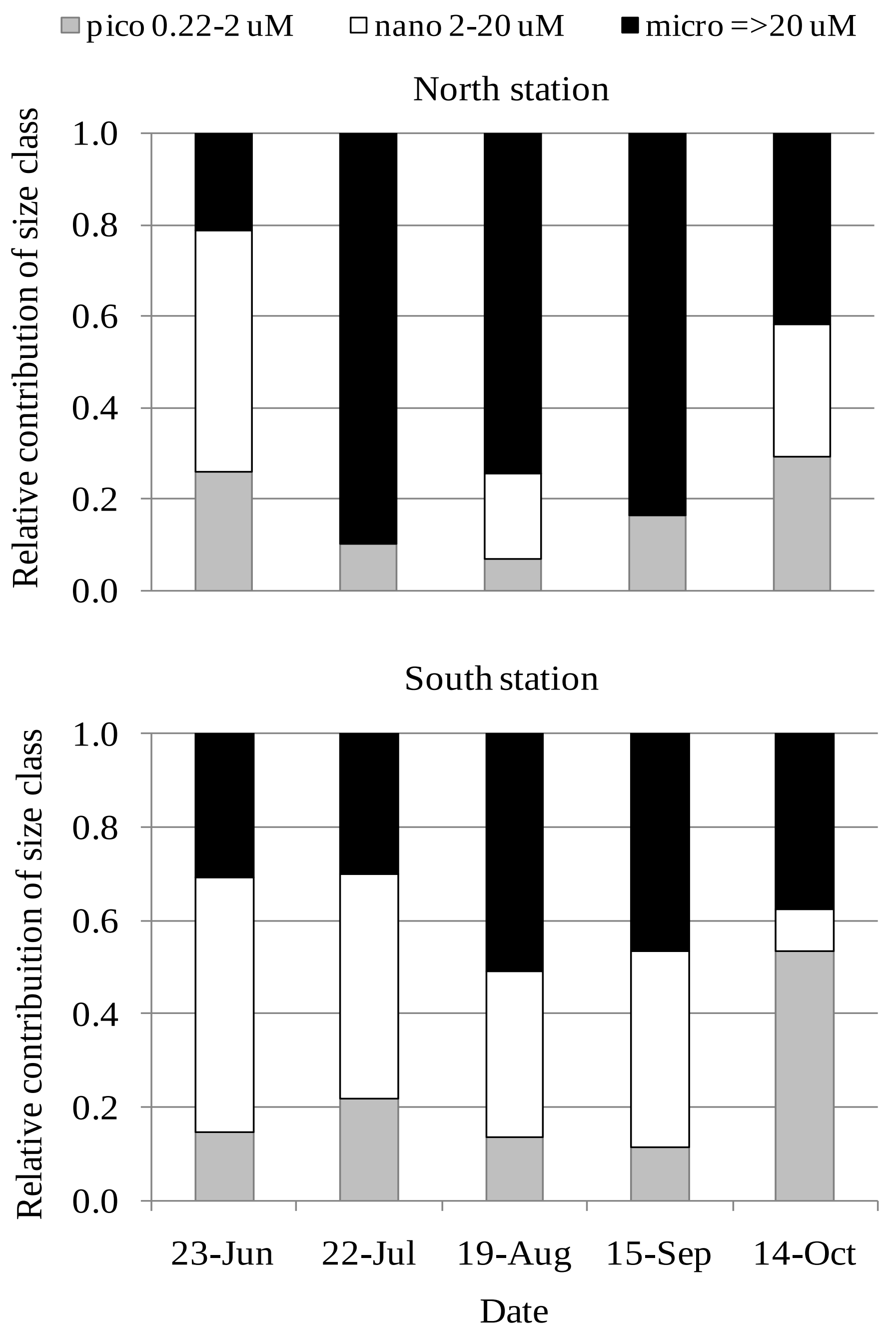


Figure 4-7 Relative contribution of algal size classes to total chlorophyll *a* concentrations at the north and south sampling stations, June to October, 2008.

4.1.2 Nutrients

Total nutrient concentrations represent the sum of what is available plus what has been taken up by phytoplankton. During the period of fertilization, total nitrogen concentration in surface waters has been lower, and total phosphorus concentration has been greater compared to baseline concentrations (1993-94) (Fig. 4-8 upper). In general, the timing of peak total phosphorus concentration in surface waters has corresponded with the peak weekly phosphorus loading rate which occurs mid- to late-summer (Fig. 3-1) (data in 2007 was too sparse to see a pattern). In contrast, total nitrogen concentration in surface waters has been fairly variable, and does not appear to correspond with the seasonal pattern of nutrient loading which peaked in late-August to early September (Fig. 3-1), suggesting processes other than loading, such as nitrogen-fixation, may affect nitrogen concentrations in surface waters (see below).

There was rapid uptake and assimilation of nutrient additions (fertilizer) at Wahleach, as expected in such a low productivity system. As a result of the uptake and assimilation of phosphorus and nutrient additions, total nitrogen and total phosphorous concentrations increased, whereas the availability of unincorporated dissolved nitrogen (NO_{2+3}) and phosphorus (TDP) decreased (Fig. 4-9).

The ratio of NO_{2+3} to TDP in the epilimnion, where a majority of phytoplankton photosynthesis typically occurs, indicated nitrogen limitation of phytoplankton growth in Wahleach during the peak growing season (July to August/September) (Fig. 4-12), when the water column was strongly stratified (Fig. 4-10). In addition to the low ratio of NO_{2+3} to TDP, the relatively greater drawdown of dissolved nitrogen during the summer growing period compared with its drawdown in 1993-94 (Fig. 4-8 upper) corroborates the tendency for nitrogen limitation, as does the occurrence of NO_{2+3} concentrations <20 µg/L (Fig. 4-8 lower) which also signals nitrogen limitation (Wetzel 2001).

The availability of reactive silica can affect the growth of diatoms, which have silica walls. In 1994 (baseline) reactive silica decreased from about 5.5 mg/L in early June to 4.6 mg/L in early October (Inglis 1995). In 2007-08, the concentration of reactive silica was highest (5.5 mg/L) in the spring to decreased to 2.2 mg/L near the end of the growing season, therefore it appears that availability of silica probably does not limit diatom growth in Wahleach. On the other, the minimum concentration of silica in 2007-08 was 50% lower than the minimum concentration observed in 1994 suggesting that silica drawdown may have increased as a result of nutrient additions and increases in diatom production.

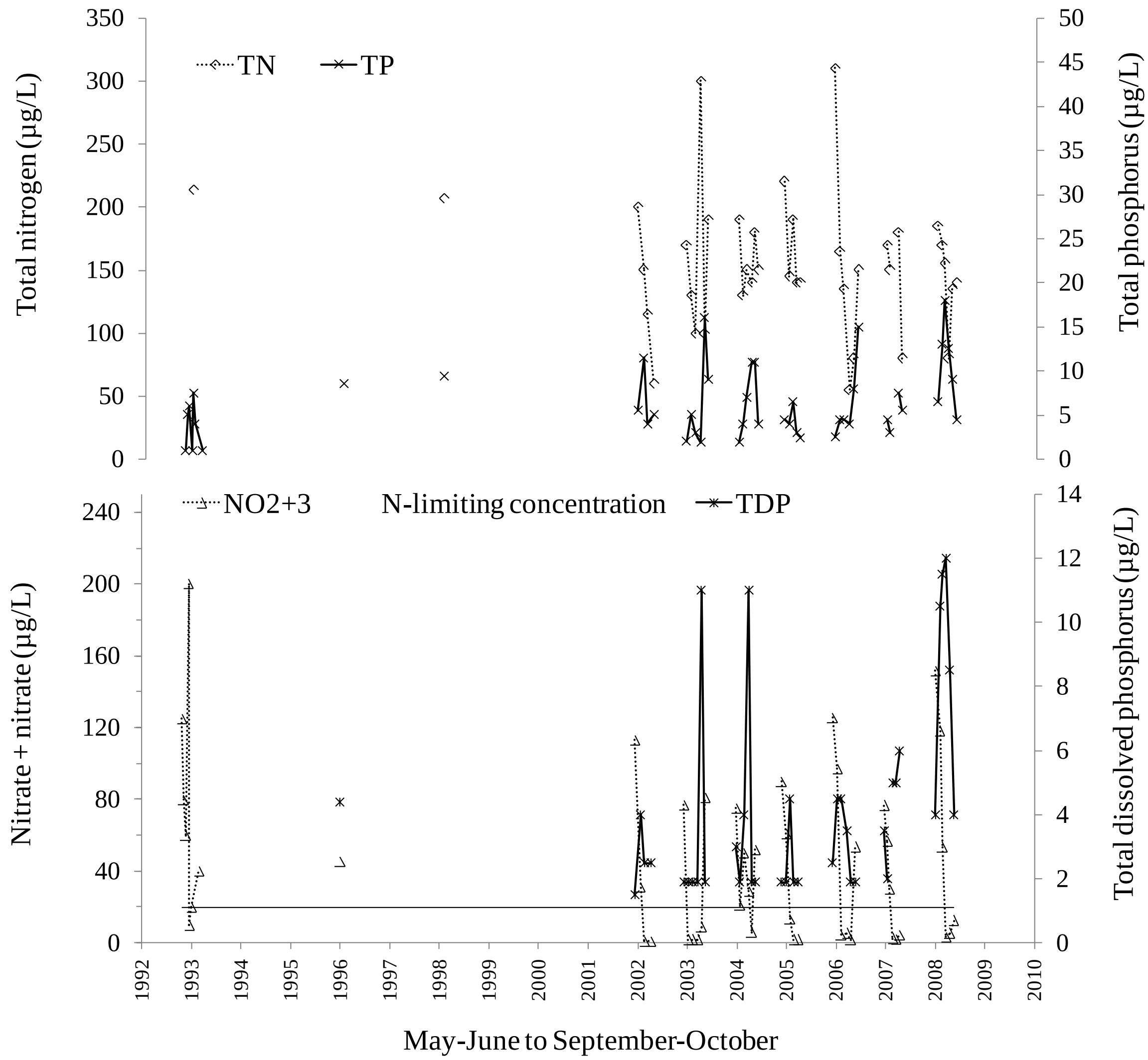


Figure 4-8 Seasonal total nitrogen and total phosphorus concentration dynamics, 1993 (baseline) and 2002 to 2008 (upper), and seasonal dissolved nitrogen (nitrate + nitrite, NO_{2+3}) and total dissolved phosphorus (TDP) concentrations, 1994 (baseline) and 2002 to 2008, in Wahleach Reservoir. The TN value for 1994 and the TN and TP values for 1998 are respectively the mean values for 1993-94 and 1997-99 (Perrin et al. 2006). Nutrient data for 1996 are from Perrin 1997. The TN and NO_{2+3} seasonal dynamics are for 1993 and 1994 respectively (Inglis 1995).

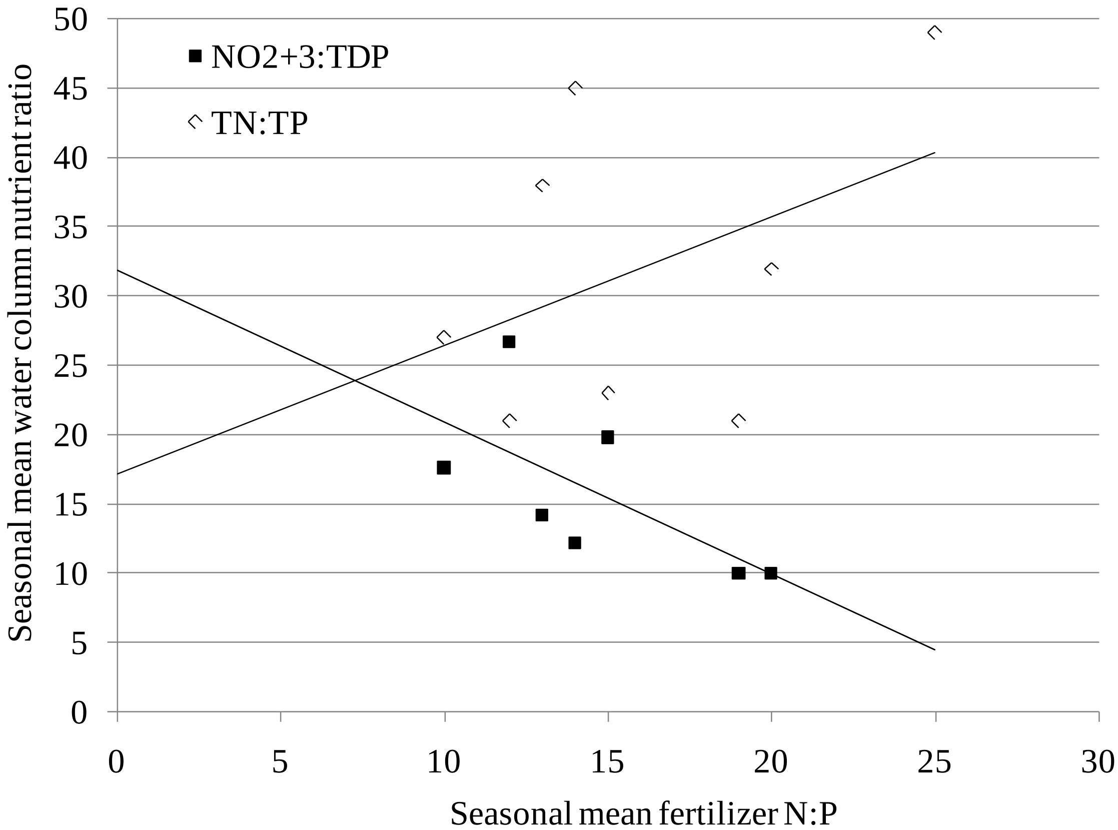


Figure 4-9 Seasonal mean epilimnetic TN:TP and NO_{2+3}:TDP, versus seasonal mean fertilizer N:P (data from 1997-2008 when available).TN = total nitrogen; TP = total phosphorus; TDP = total dissolved phosphorus, for years between 1995 and 2008 when such data was available.

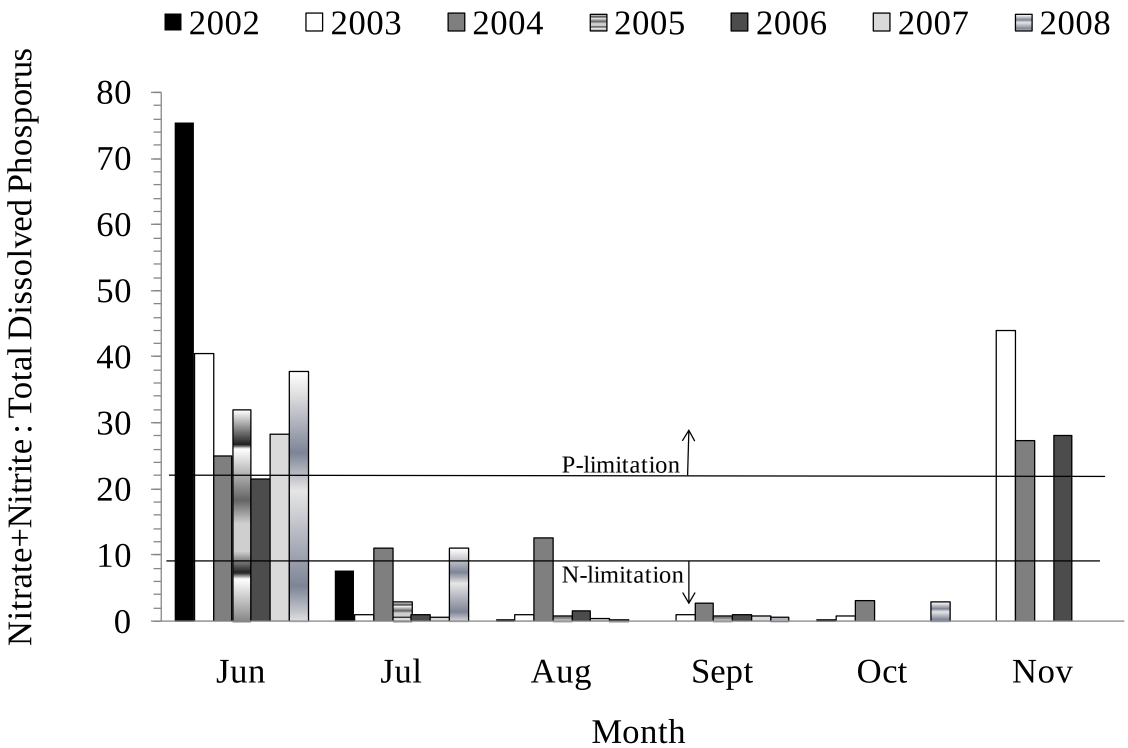


Figure 4-10 Mean monthly epilimnetic NO_{2+3} : TDP by weight, 2002-08. NO_{2+3} = nitrate + nitrite, and TDP = total dissolved phosphorus. Values > 22 indicate phosphorus limitation, and values < 9 indicate nitrogen limitation.

4.2 Phytoplankton

4.2.1 Interannual pattern in phytoplankton abundance and biomass, 1994-2008

Mean phytoplankton abundance peaked in the early years of the project (12,861 cells/mL in 1996), and since 2000 has been relatively low, e.g. 3673 cells/mL in 2007, and 2212 cells/mL in 2008- the lowest abundance on record (Fig. 4-13 upper). The decrease in later years corresponded with decreased abundance of flagellates from a peak of 6448 cells/mL in 1996 to on the order of 1000 cells/mL; decreased dinoflagellate abundance from peak of 1590 cells/mL in 1995, to 388 cells/mL in 2007, and 51 cells/mL in 2008- the lowest abundance on record; and, decreased abundance of cyanobacteria from a peak of ca. 2500 cells/mL in 1996-97, to 600-1000 cells/mL after 2002. In contrast, diatom abundance has increased modestly in later years compared with some earlier years. Mean seasonal phytoplankton biovolume has been more similar among years than mean seasonal abundance (Fig. 4-13), i.e. peak biovolume was 1387 mm^3/m^3 in 1996, and was 1023 mm^3/m^3 in 2007, and 664 mm^3/m^3 in 2008. Biovolume has been relatively similar among years because decreases in flagellate biovolume (peak biovolume of 559 mm^3/m^3

in 1997, 137 mm^3/m^3 in 2007, and 64 mm^3/m^3 in 2008- the lowest biovolume on record) and dinoflagellate biovolume (peak biovolume of 586 mm^3/m^3 in 1995, 258 mm^3/m^3 in 2007, and 45 mm^3/m^3 in 2008- the lowest biovolume on record), which mirror the decreases in their abundance, have been compensated by modest increases in the abundance of large diatoms, which contribute disproportionately to biovolume. The lowest diatom biovolume on record was 35 mm^3/m^3 in 1997, peak diatom biovolume was 585 mm^3/m^3 in 2006, and diatom biovolume was 528 mm^3/m^3 in 2007, and 292 mm^3/m^3 in 2008.

4.2.2 Seasonal dynamics in phytoplankton abundance and biomass, 1994-2008

Although monthly sampling may not fully capture population fluctuations, the seasonal patterns of change in phytoplankton density and biovolume were typical for lakes where physical and chemical conditions change seasonally (Fig. 4-14 & 4-15 respectively). The magnitude of the fluctuations in phytoplankton abundance and biovolume appears to be have been lower during fertilization than in 1994 (baseline year) and 1996 (1 year after fertilization).

Generally, flagellate abundance has peaked early in the growing season, whereas diatom abundance has tended to increase over the course of the growing season (Fig. 4-14). Late summer-autumnal diatom blooms have occurred annually in Wahleach Reservoir both before (1994) and during the period of fertilization. The occurrence and timing of cyanobacterial blooms appear to be less predictable. Such blooms occurred in 2005 and 2008, and may correspond with the fixation of atmospheric nitrogen.

Seasonal biovolume dynamics in 2004 were similar to those in 1994 (pre-fertilization) and somewhat similar to those in 1996 (1 year into fertilization), but in 2006 diatoms and dinoflagellates were more dominant than in baseline years (Fig. 4-15). In June 2007, and more so in 2008, phytoplankton biovolume was sparse and mostly edible flagellates. As summer progressed in 2007-08, flagellate biovolume disappeared, the biovolume of large inedible diatoms increased (e.g. *Tabellaria*, in July and August 2007, and August 2008), and in the fall 2008 there was a bloom of Cyanobacteria (*Anabaena*). The mini-bloom of *Anabaena* in fall 2008 signaled nitrogen limitation in the epilimnion.

4.2.3 Phytoplankton species assemblage

The assemblage of phytoplankton species contributing to abundance and biovolume has not changed substantially during the period of fertilization. The phytoplankton assemblage has been comprised of small picocyanobacteria (*Synechococcus* sp., *Oscillatoria* sp., and in 2008 also *Anabaena* sp.); a few diatoms, for the most part inedible (*Rhizosolenia* sp., *Tabellaria fenestrate*, *Asterionella Formosa* var1, *Cyclotella glomerata* and *stelligera* and *Fragillaria* spp.); a suite of microflagellates in the nanoplankton size range, which has varied somewhat in composition among years but typically has included *Chromulina* spp., *Dinobryon* sp., *Chrysochromulina* sp., Chryptomonas sp., *Rhodamonus* sp., *Chroomonus acuta*, and *Planctosphaeria* sp.); and, a few large dinoflagellates including *Peridinium* spp. and *Gymnodinium* spp. Among the species of phytoplankton, *Synechococcus* and the many of the small microflagellates are considered edible (Perrin 1997).

4.2.4 Phytoplankton versus phosphorus loading, 1994-2008

The abundance of each of flagellates, dinoflagellates, and cyanobacteria has decreased with increases in phosphorus loading (Fig. 4-16 upper). In contrast, the abundance of chlorophytes and diatoms show little or no pattern of change over the annual phosphorus loading rate gradient, i.e. chlorophyte abundance has been relatively low and diatom abundance has been highly variable (not shown). Flagellates and dinoflagellate biovolume also decreased with increased phosphorus loading (Figure 4-16 lower), whereas the biovolume of chlorophytes and cyanobacteria have each remained relatively low, while diatom biovolume has been variable over the phosphorus loading gradient (data not shown).

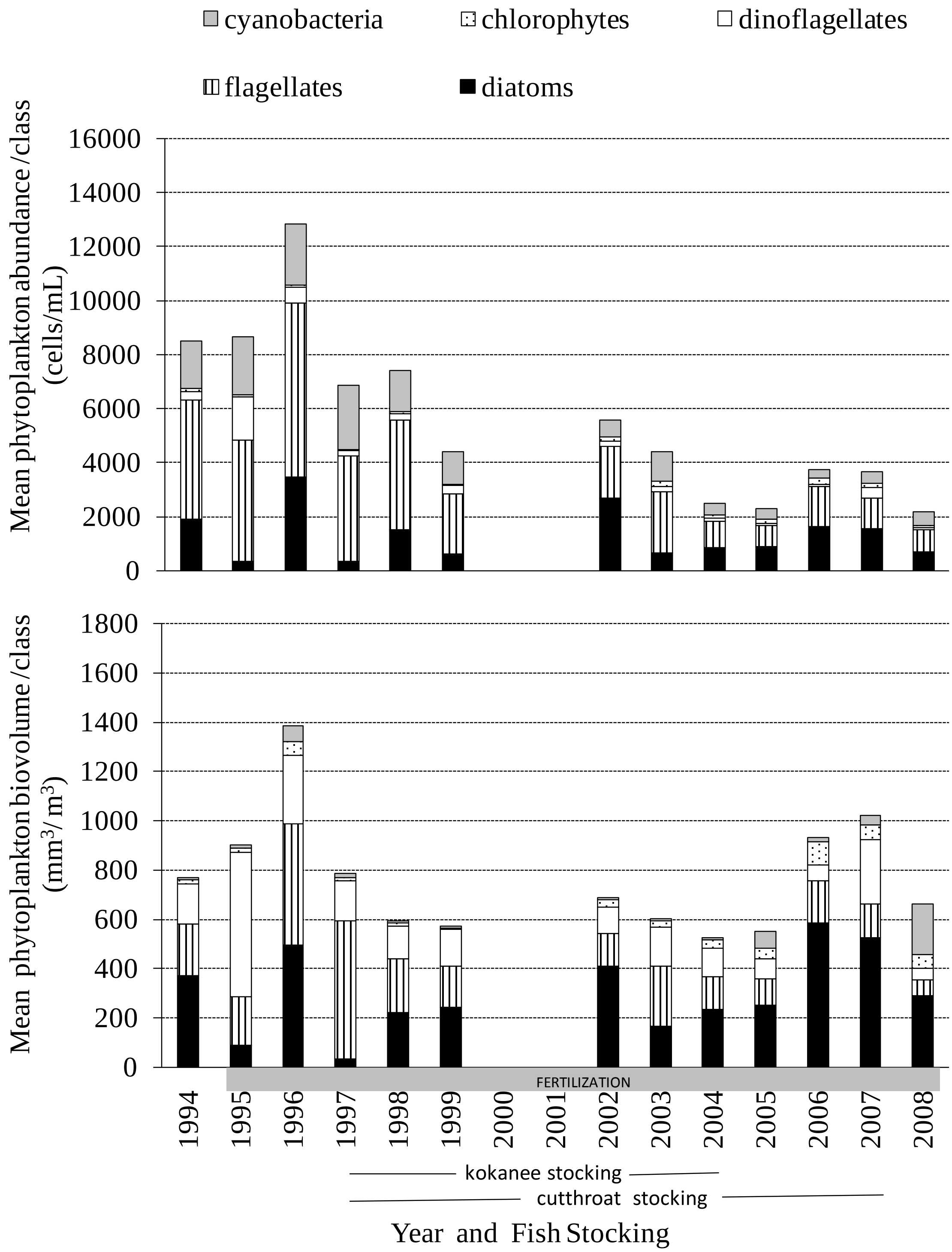


Figure 4-13 Annual pattern of mean seasonal phytoplankton abundance (upper) and biovolume (lower), May-June to October, 1994 (baseline) to 2008. No data available for 2000-01.

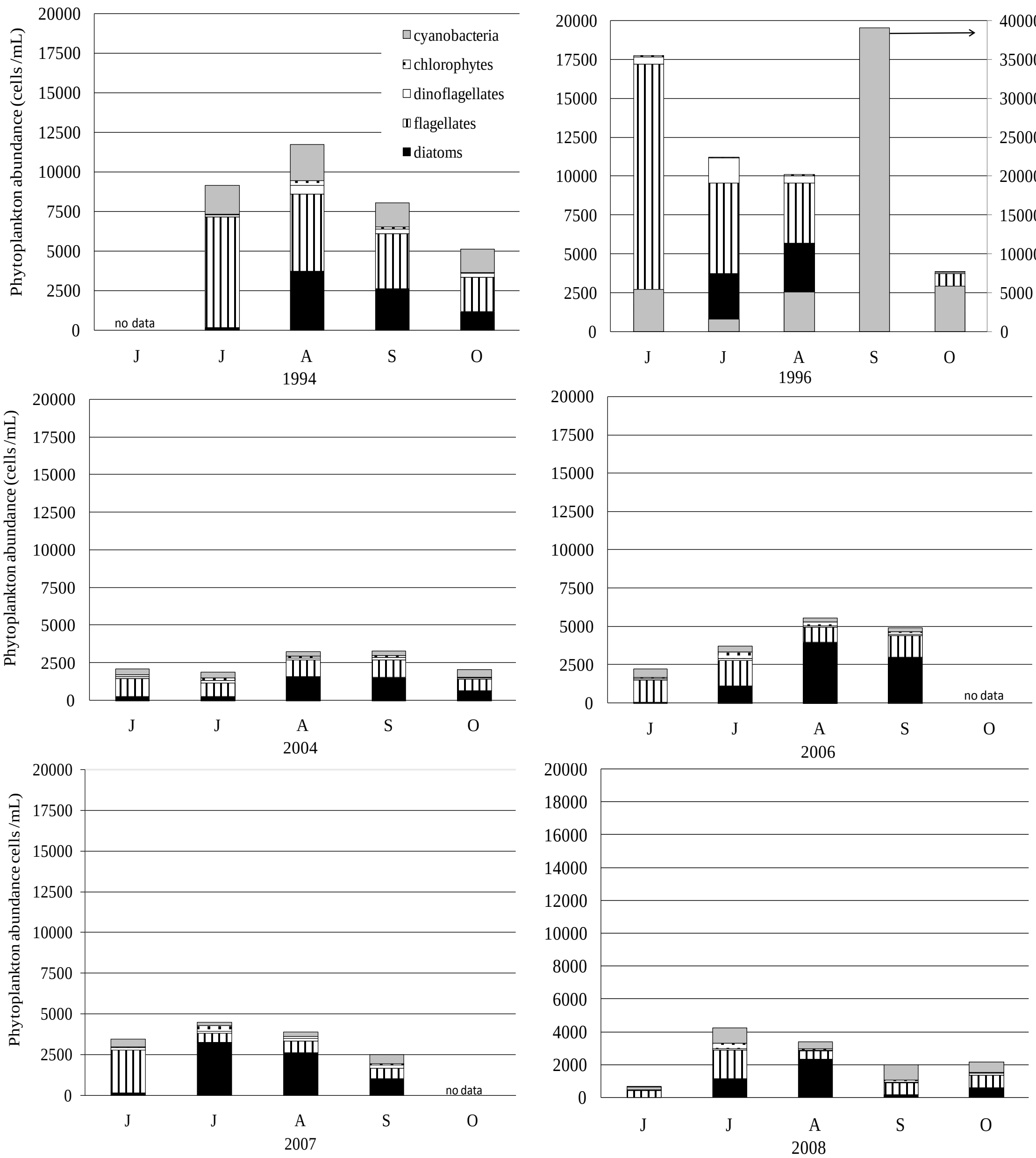


Figure 4-14 Seasonal pattern of phytoplankton abundance per class in 1994 and 1996, 2004 and 2006, and 2007 and 2008.

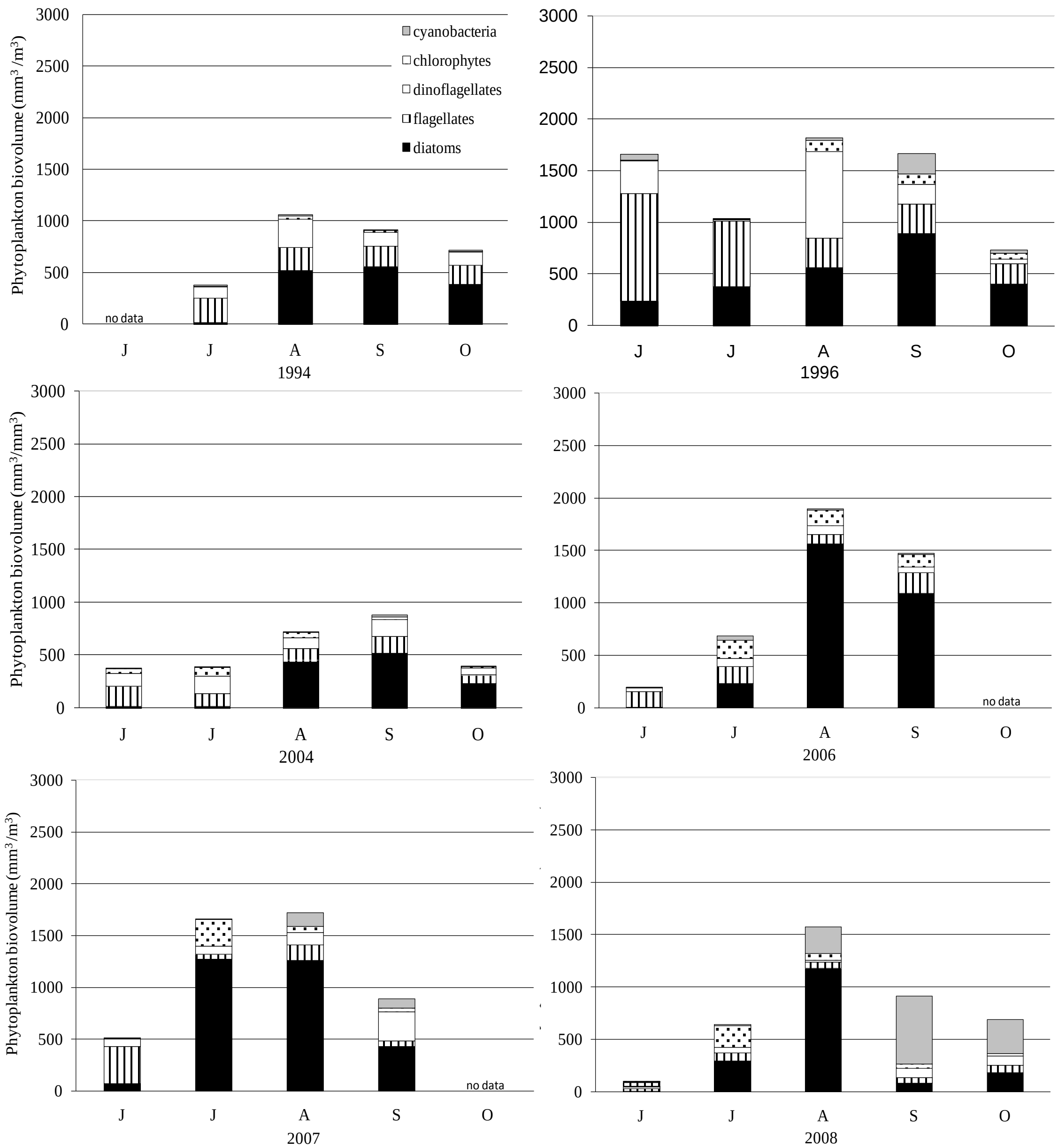
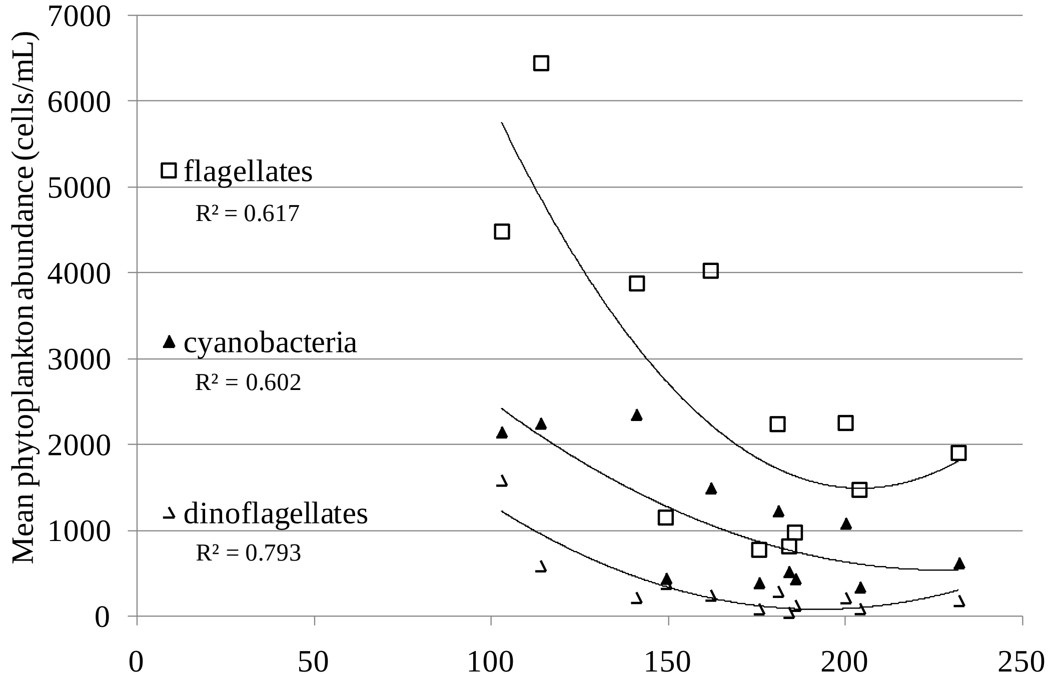


Figure 4-15 Seasonal pattern of mean seasonal phytoplankton biovolume per class in 1994 and 1996, 2004 and 2006, and 2007 and 2008.



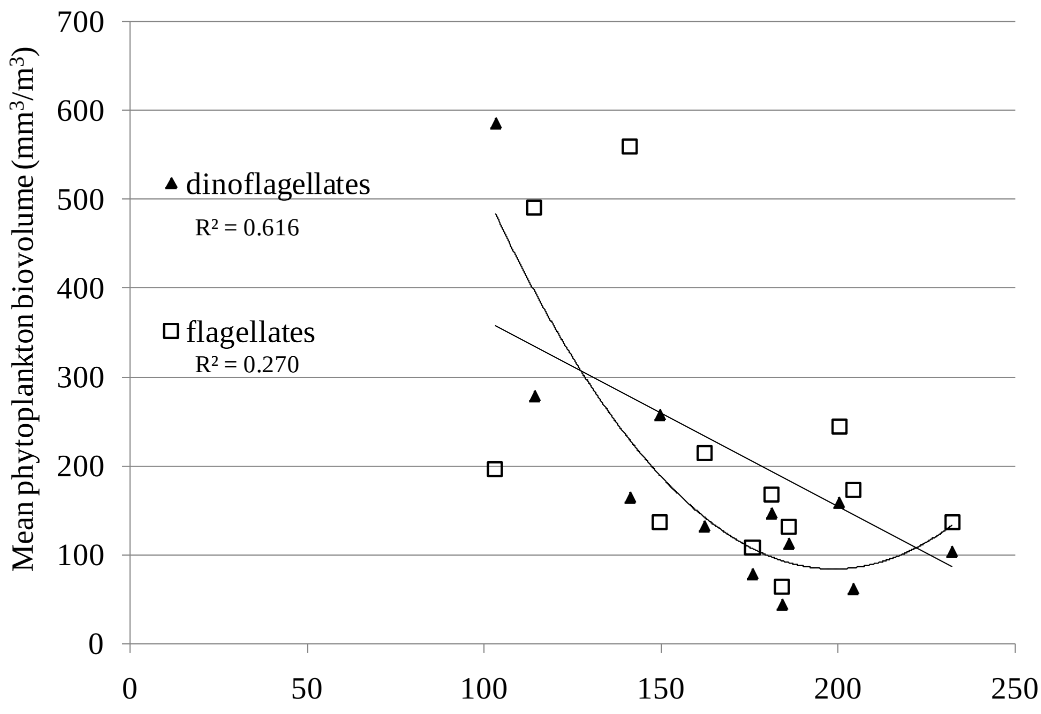


Figure 4-16 Seasonal mean phytoplankton abundance (upper) and biovolume (lower) per algal class versus annual phosphorus loading. Trend lines are linear or polynomial fits.

4.3 Zooplankton

4.3.1 Interannual pattern in zooplankton abundance and biomass and species assemblage, 1994-2008

The abundance and biomass of zooplankton have each been substantially higher during the period of fertilization than in 1993 and 1994 (baseline years) (Fig. 4-17). After fertilization, the zooplankton species assemblage shifted from predominance by the cladoceran *Bosmina longirostris* and the copepod *Cyclops vernalis* to a community dominated by the cladocerans *Holopedium gibberum* and *Daphnia rosea* (Perrin et al. 2006). Although the biomass of small *Bosmina* and copepods initially increased in response to fertilization, the appearance and rapid increase in *Daphnia* biomass (by 100-fold) after 2000, corresponded with substantial decrease in the biomass of all other zooplankton species (Perrin et al. 2006). Although cladoceran abundance was relatively high between 1995 and 2000, and relatively low between 2003 and 2008 (except 2006) (Fig, 4-17 upper), the cladoceran *Daphnia* has continuously dominated zooplankton biomass since 2000 (Fig. 4-17 lower). The cladoceran *Holopedium gibberum* continues to be an important subdominant species at Wahleach. *Holopedium* has appeared in relatively high numbers in the spring but by late summer its abundance and biomass have become negligible whereas *Daphnia* abundance and biomass each have reached peak values.

Among years, copepod abundance peaked in 1996, but since abundance has been relatively low. The low abundance of copepods since 1996 may in part be explained by the annual stocking with kokanee fry between 1997 and 2004.

4.3.2 Seasonal dynamics of zooplankton abundance and biomass, 1994-2008

Zooplankton populations at Wahleach have been dynamic over time, as expected in response to physical conditions, food availability, and grazing by planktivores, though full seasonal dynamics may not have been fully captured by monthly sampling. During the period of fertilization, the seasonal dynamics of zooplankton abundance have varied (Fig. 4-18). In 1996, the increases and decreases in zooplankton abundance (copepods and cladocerans) followed the bell-shaped nutrient loading curve. In later years, zooplankton abundance (almost 100% cladoceran) has peaked early in the growing season and then gradually decreased to minimum abundance in the fall.

The seasonal pattern of zooplankton biomass, which is dominated by cladocerans, also has been variable over the period of fertilization (Fig. 4-19). Generally, biomass peaks have occurred early in the growing season and have declined by fall.

4.3.3 Zooplankton versus phosphorus loading, 1994-2008

Zooplankton abundance has decreased with increases in annual phosphorus loading rate (Fig. 4-20 upper). In contrast, zooplankton biomass has increased with the increases in annual phosphorus loading rate (Fig. 4-20 lower). The inverse correspondence between increases in zooplankton abundance and increases in zooplankton biomass can be explained by the shift from abundant small copepods (e.g. *Cyclops vernalis*) to fewer large cladocerans (e.g. *Daphnia rosea*).

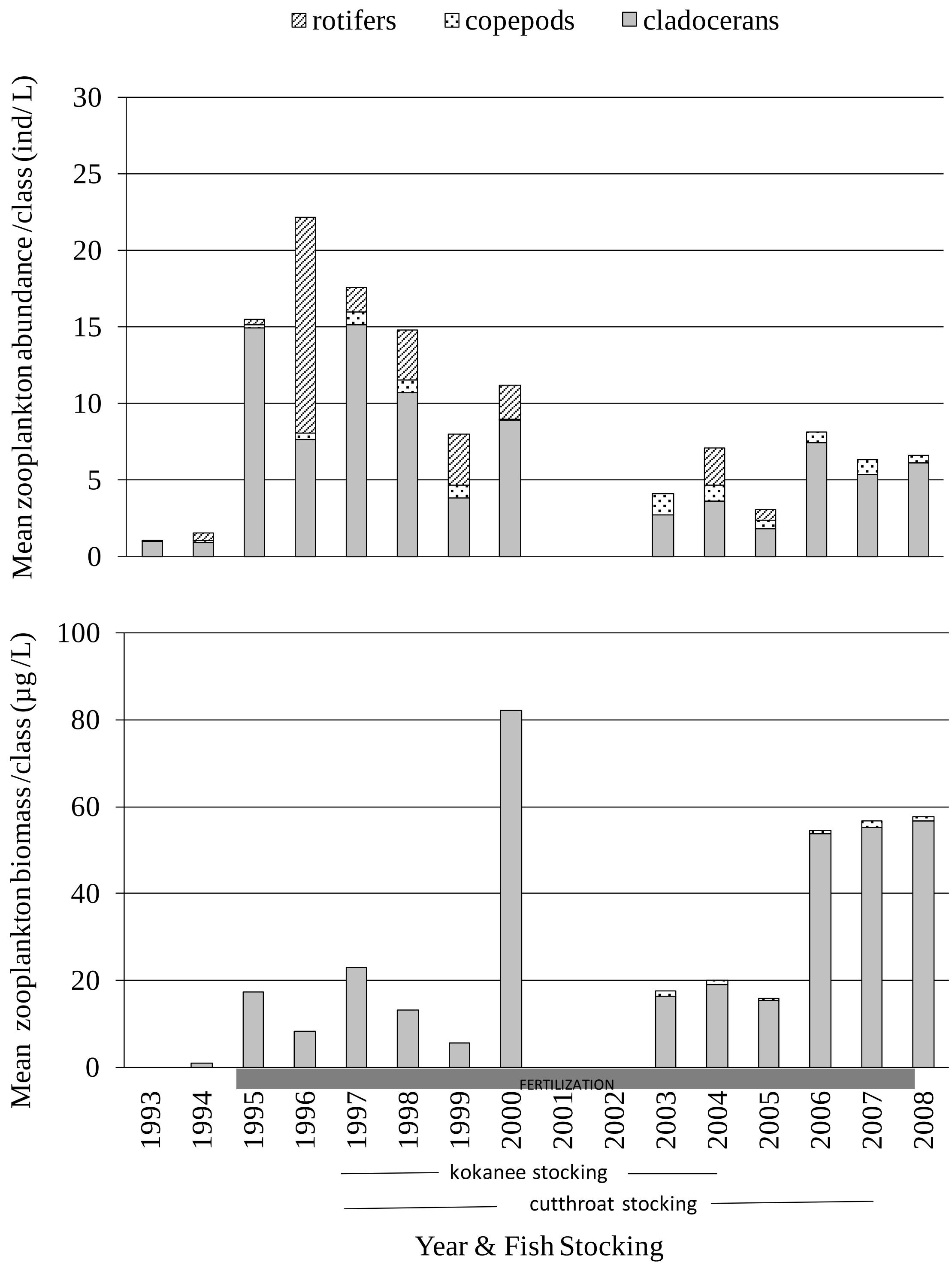


Figure 4-17 Mean seasonal zooplankton abundance (upper panel) and biovolume (lower panel), May-June to October 1994 (baseline) to 2008. No data in 1993, 2001 and 2002.

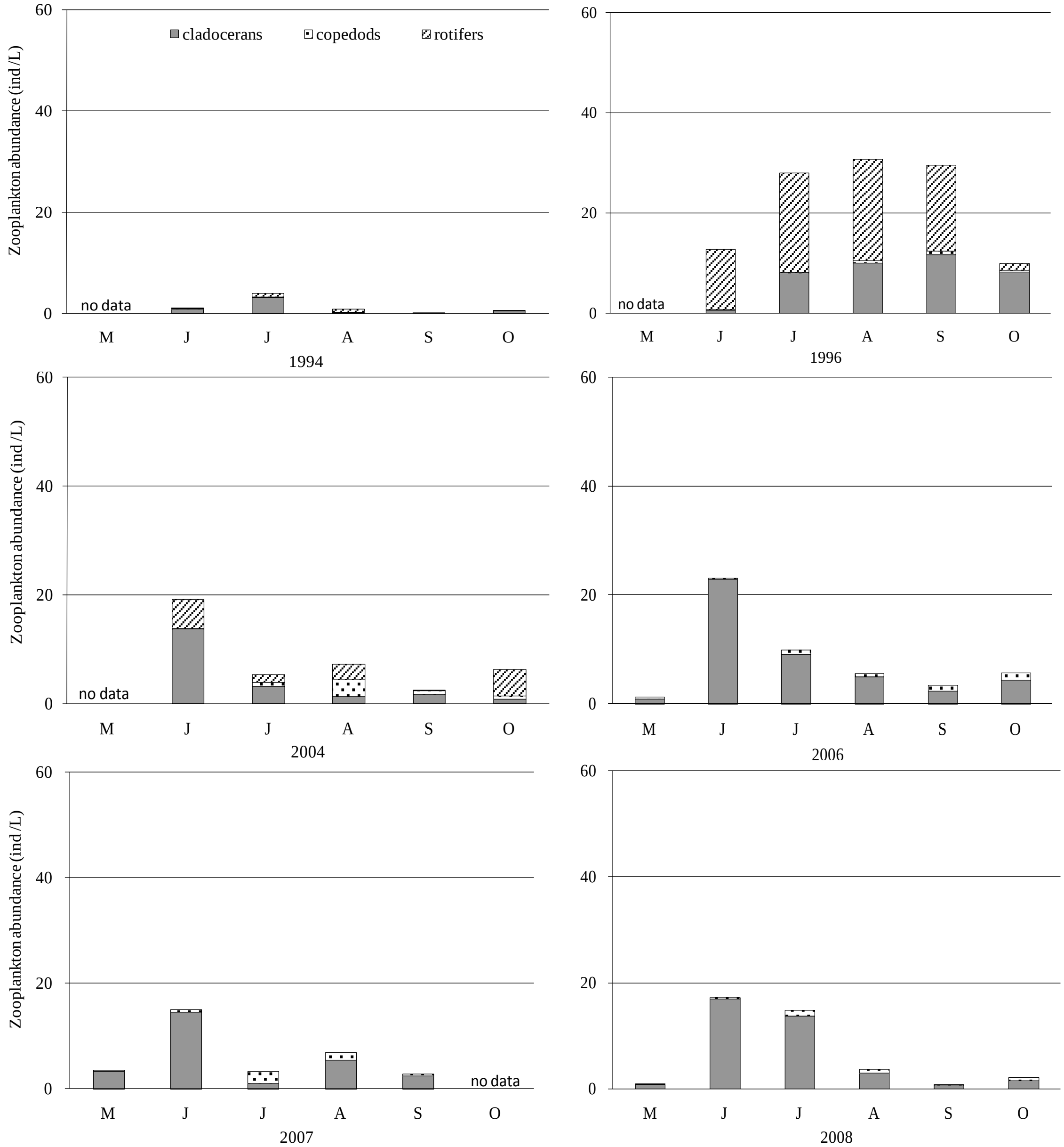


Figure 4-18 Seasonal pattern of zooplankton abundance per class in 1994 and 1996, 2004 and 2006, and 2007 and 2008. No data in 1993, 2001 and 2002.

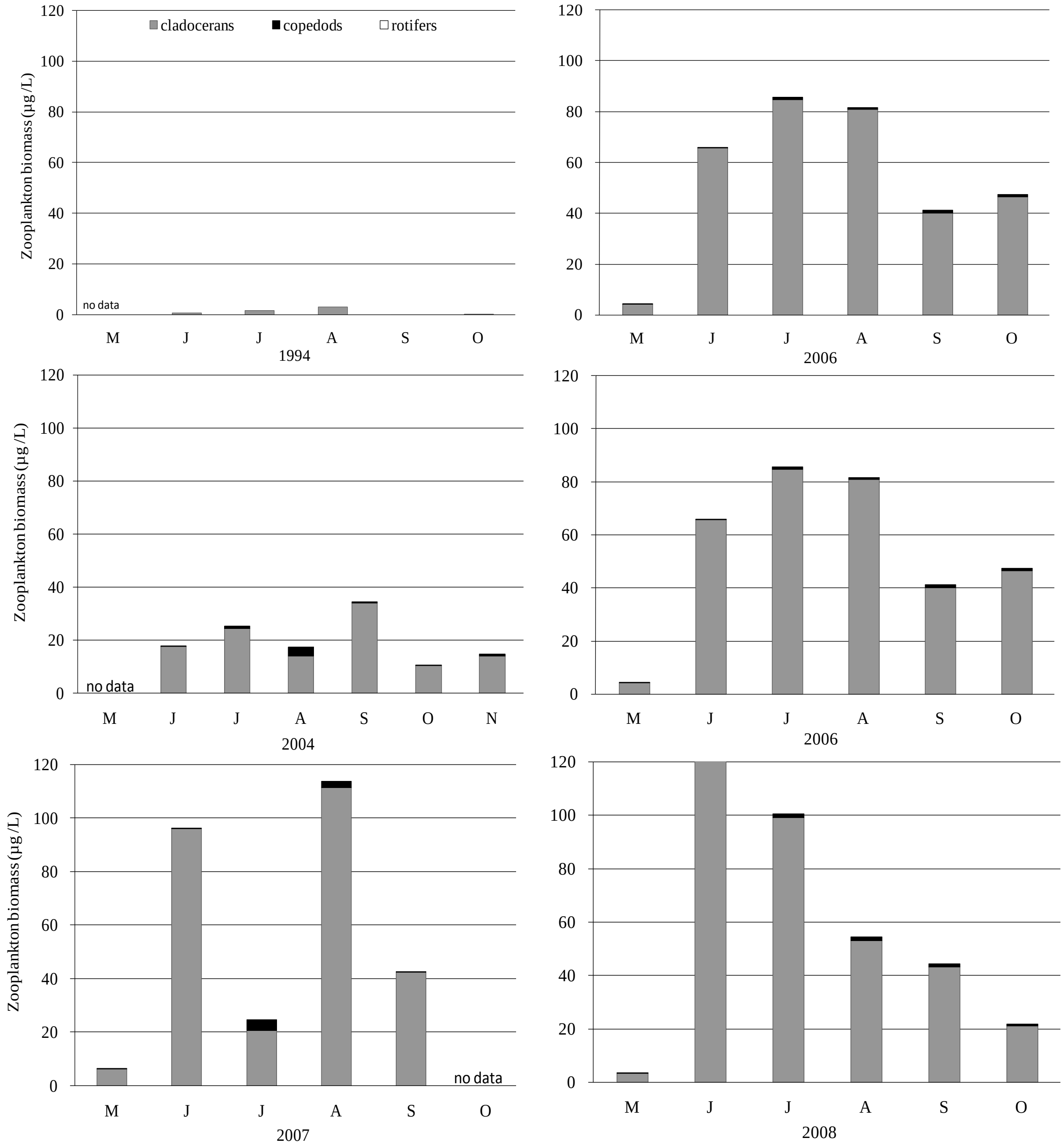


Figure 4-19 Seasonal pattern of zooplankton biomass per class in 1994 and 1996, 2004 and 2006, and 2007 and 2008. No data in 1993, 2001 and 2002.

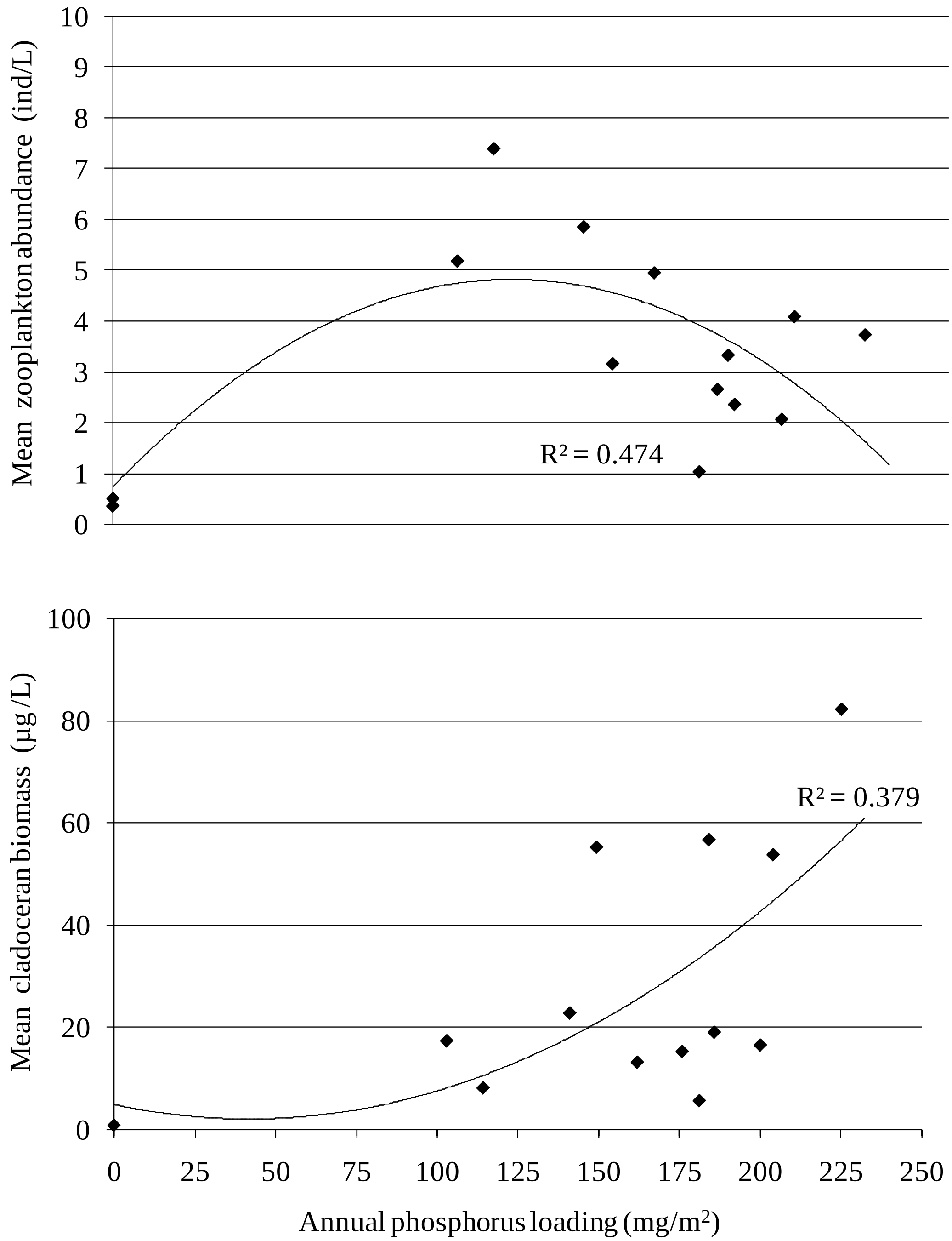


Figure 4-20 Zooplankton abundance versus annual phosphorus loading (upper), and cladoceran biomass versus (lower) versus annual phosphorus loading. Trend lines are polynomial fits.

4.4 Comparison of phytoplankton and zooplankton responses to phosphorus loading

Comparison of the change in the biomass of cladoceran zooplankton and the biovolume of the index of edible phytoplankton among years indicates that increased cladoceran biomass has corresponded with decreased biovolume of edible phytoplankton (Fig. 4-21 upper). Cladoceran biomass was relatively low in the first few years of fertilization and during the period of kokanee stocking (1997 – 2004), but since 2006 cladoceran biomass has been relatively high.

The changes in cladoceran biomass and edible phytoplankton biovolume with increased annual phosphorous loading rate are similar to the trends observed over time but the strength of the relationships with phosphorus loading appear to be stronger than the strength of the relationships with time (Fig. 4-21 lower).

The changes in cladoceran biomass and edible phytoplankton biovolume with increased in annual phosphorous loading rate were similar to the trends over time, but the strength of the relationship between cladoceran biomass and phosphorus loading appears to be stronger than the strength of the relationship between cladoceran biomass and time (Fig. 4-21 lower).

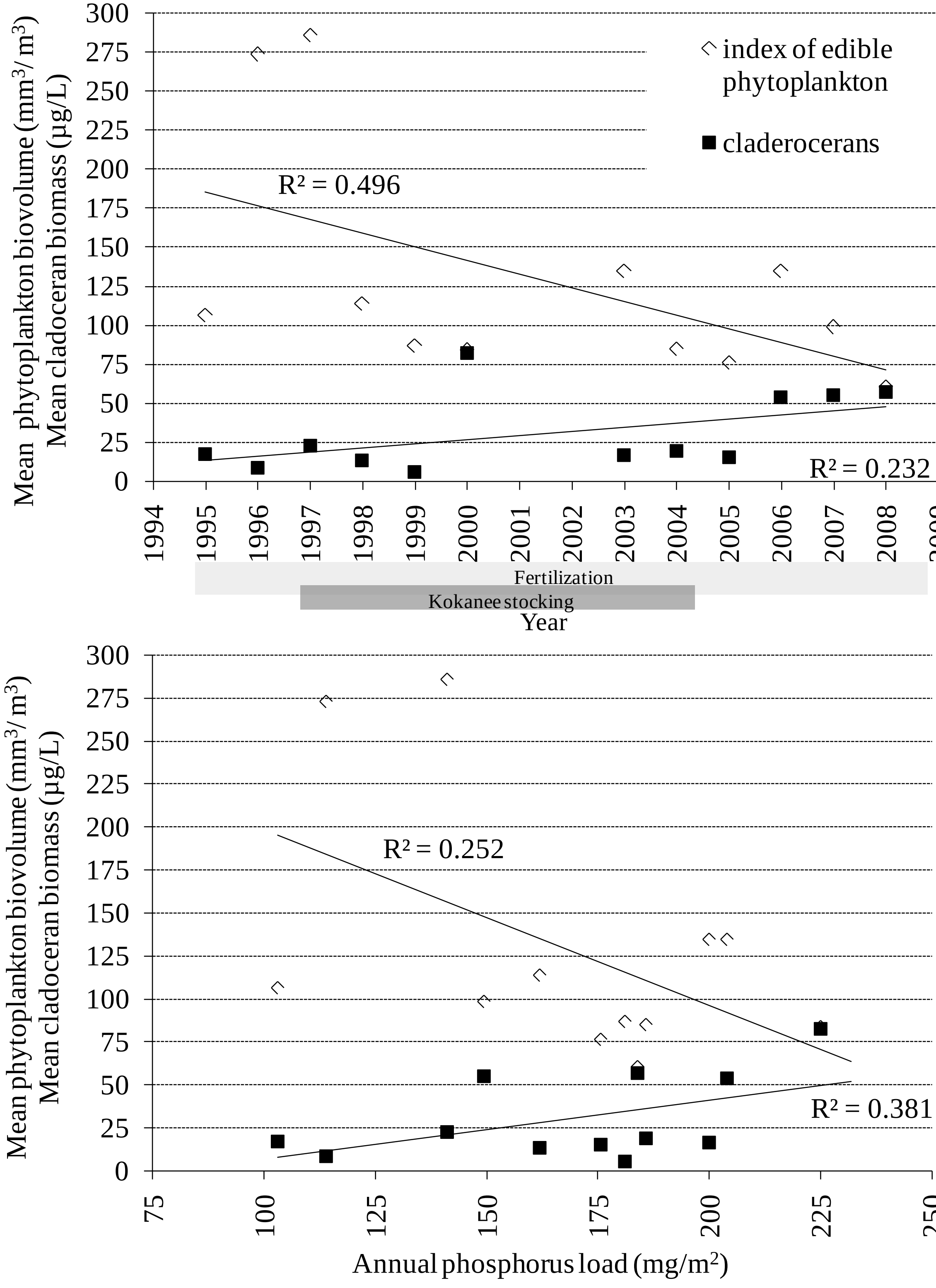


Figure 4-21 Index of availability of edible phytoplankton (sum of Chrysophceae and Cryptophyceae algal classes) and cladoceran biomass (includes *Daphnia*) versus year (upper) and annual phosphorous load (lower).

4.5 Fish

4.5.2 Minnow trapping and gillnetting

4.5.2.1 Minnow trapping

Annual Gee-trap results should be considered qualitative. Sample sizes were small (1-6 traps per sampling period) and were not always documented. Catch rate during spring sampling peaked in 2000 and was moderately high in 1999, 2005, and 2008 (Table 4-1). Fall CPUE was much lower than in the spring, was highest in 1997-1999, and moderately high in 2003. Higher catch rates in the spring may reflect concentration of sticklebacks in the shallows during the spring-summer breeding season.

The results of the 2008 summer gee trap study of stickleback habitat preferences should also be considered qualitative. A number of crayfish were caught in the traps and many traps were baitless upon retrieval, suggesting reduced trap efficiency. The data showed over 10-fold higher CPUE in the littoral habitat at the north end of the lake than at the south end, and equal catch rates in stump and no stump sites at the north end (Table 4-2). No stickleback were caught offshore at any depth, but sample size was small (2 traps per depth) and the traps may not have been set at depths occupied by stickleback.

Table 4-1 Gee trap CPUE (fish/trap-h) in spring and summer in 2 m water at Wahleach, 1997 to 2008. Number of traps is indicated in parenthesis. '-' = no data. * = soak time estimated from mean of all years.

	Fish/trap-h by season	
Year	**Spring**	**Fall**
1997	1.9 (4)	1.4 (-)
1998	4.2 (-)	2.0 (2)
1999	5.6 (-)	2.0 (1)
2000	8.8 (4)*	0.4 (4)
2001	-	-
2002	-	-
2003	-	1.6 (4)
2004	2.0 (4)	-
2005	5.1 (4)	-
2006	-	2.1 (4)
2007	1.9 (4)	0.1 (6)
2008	5.3 (6)	0.2 (6)

Table 4-2 Gee trap CPUE for the summer habitat study, August 18, 2008. Number of traps is indicated in parenthesis. '-' = no data.

	Fish/trap-h by lake section		
Habitat type	**north**	**mid-lake**	**south**
Stumps (2 m)	0.4 (3)	0.05 (3)	0.02 (3)
No Stumps (2m)	0.38 (3)	0 (3)	0.1 (3)
Off-shore- surface, mid-water, bottom	-	0 (6)	-

4.5.2.2 Gillnetting

Kokanee

Gillnetting captured fish >100 mm in length, which included age-1 and older kokanee. Based on nearshore fall gillnetting, relative abundance of age-1 and older kokanee was highest in the reservoir in 1993 (0.26 fish /net-h), before fertilization, and has fluctuated between 33% and 74% of the maximum since multiple age-classes were re-established in 2000 (Fig. 4-22). In contrast, the relative biomass of each of age-1 and older kokanee was low before fertilization (<15 g /net-h), and highest values have been attained since 2000 (Fig. 4-23). The relative biomass of each of age-1 and older kokanee in 2007 and 2008 was the highest on record (>20 g /net-h).

In 1993 (before fertilization), age-2 kokanee were the numerically dominant age-class (Fig. 4-22). Since fertilization, the kokanee population has been dominated by ages 1 and 2, except in 2006 when age-3 was the most abundant group. Most kokanee biomass was from age-1 and age-2 fish, except in 2006 when age-3 dominated (Fig. 4-23). In most years, age-3 kokanee contributed little to numbers or biomass of the gillnet catch because they had left the lake to spawn before sampling took place in mid-October. Age-4 kokanee were only captured gillnets in 2007, in small numbers.

In both years of midlake gillnet sampling (2000 and 2008), kokanee made up about 50% of the catch in midlake gillnets, versus 21-24% in nearshore sets (Fig. 4-24). This difference in proportion between habitats was nearly significant in 2000 (Pearson Chi2=5.7, P=0.057), and highly significant in 2008 (Pearson Chi2=22.8, P<0.0001).

The vertical distribution of kokanee was examined using the same midlake gillnet data. In 2000, when surface and bottom sets were made, kokanee abundance was three fold higher at the surface (0.53 versus 0.18 fish /net-h). In 2008, when midlake gillnets were fished systematically from 0 to 20 m, kokanee were most abundant in the 15-20 m depth range, the deepest range that was fished, where they made up 95% of all fish captured (Fig. 4-25). In 2008, kokanee were also moderately abundant 0-5 m where they made up 28% of the catch. No kokanee were captured 5-10 m in 2008.

Until 2000, age-1 and age-2 kokanee averaged about 125 mm and 175 mm in length. In subsequent years, age-1 fish averaged about 125-210 mm, while the mean size of age-2 fish was about 175-220 mm (Fig. 4-26). Age-3 and 4 kokanee, which were only captured after 2002, averaged about 220-310 mm in length. The mean length of age 3 and 4 fish was the largest to date in 2007.

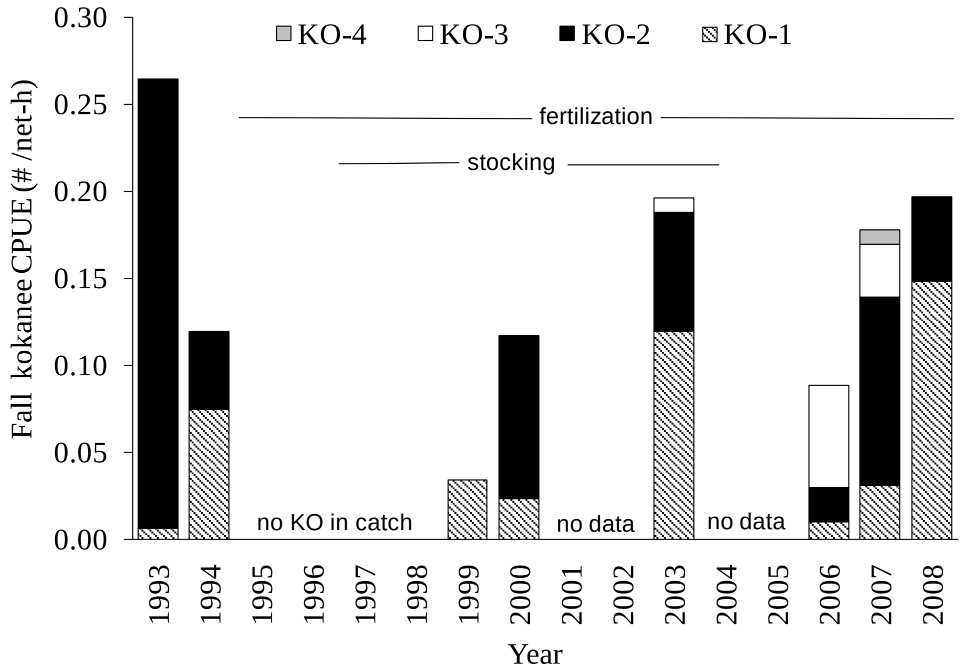


Figure 4-22 Kokanee relative abundance (fish/net-h) and age structure in Wahleach Reservoir, fall 1993-2007, from nearshore gillnetting. KO = kokanee.

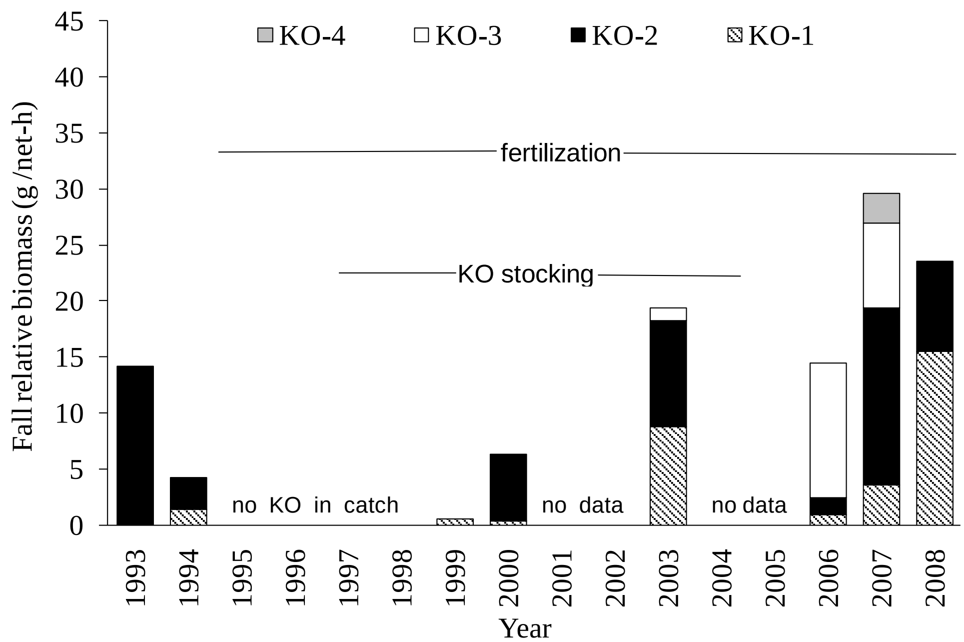


Figure 4-23 Relative biomass of kokanee by age group in Wahleach Reservoir, fall 1993-2007, from nearshore gillnetting. KO = kokanee.

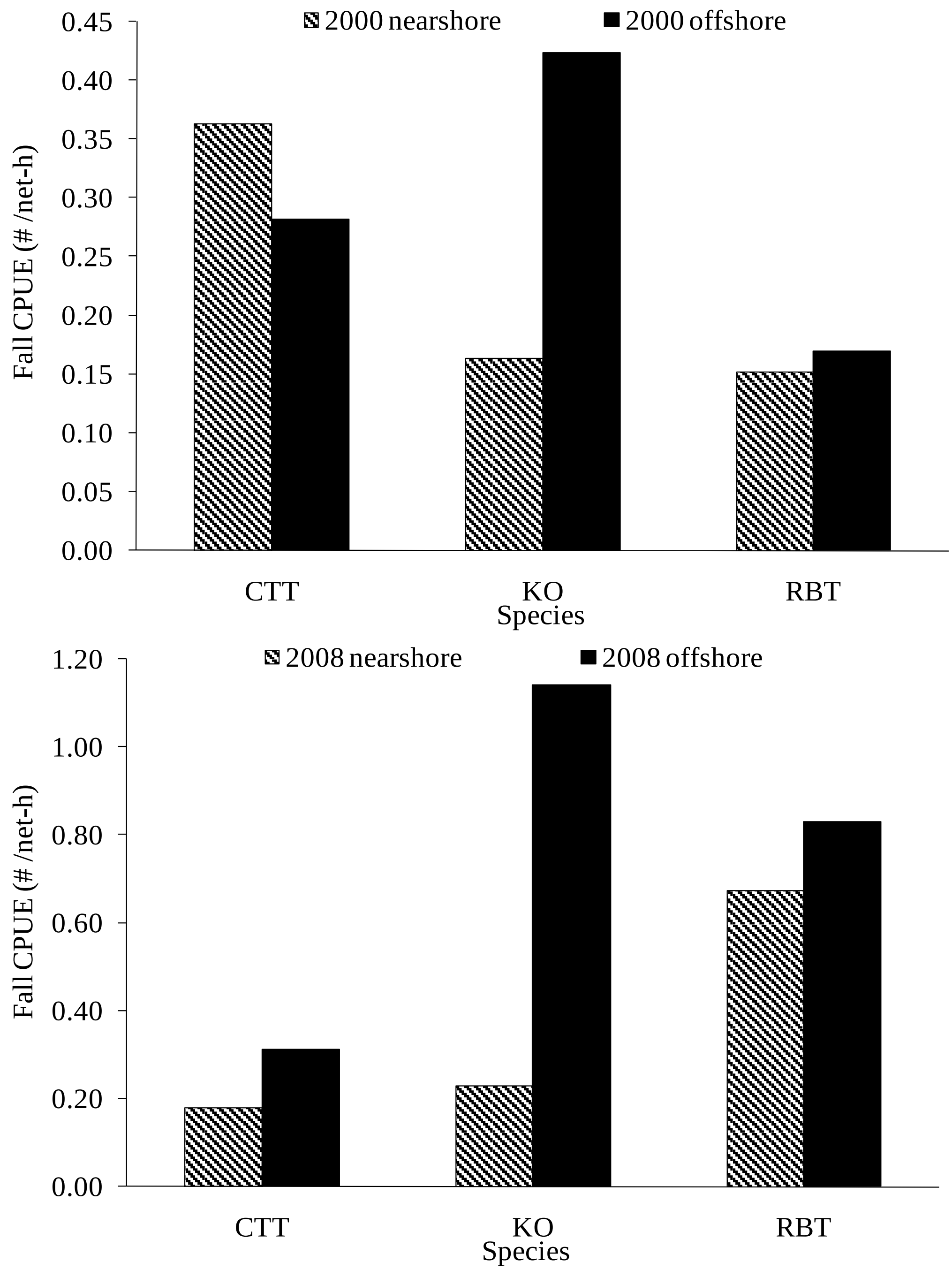


Figure 4-24 Relative abundance (fish/net-h) of kokanee (KO), cutthroat trout (CTT), and rainbow trout (RBT) in nearshore and midlake gillnet catches, fall 2000 (upper) and 2008 (lower).

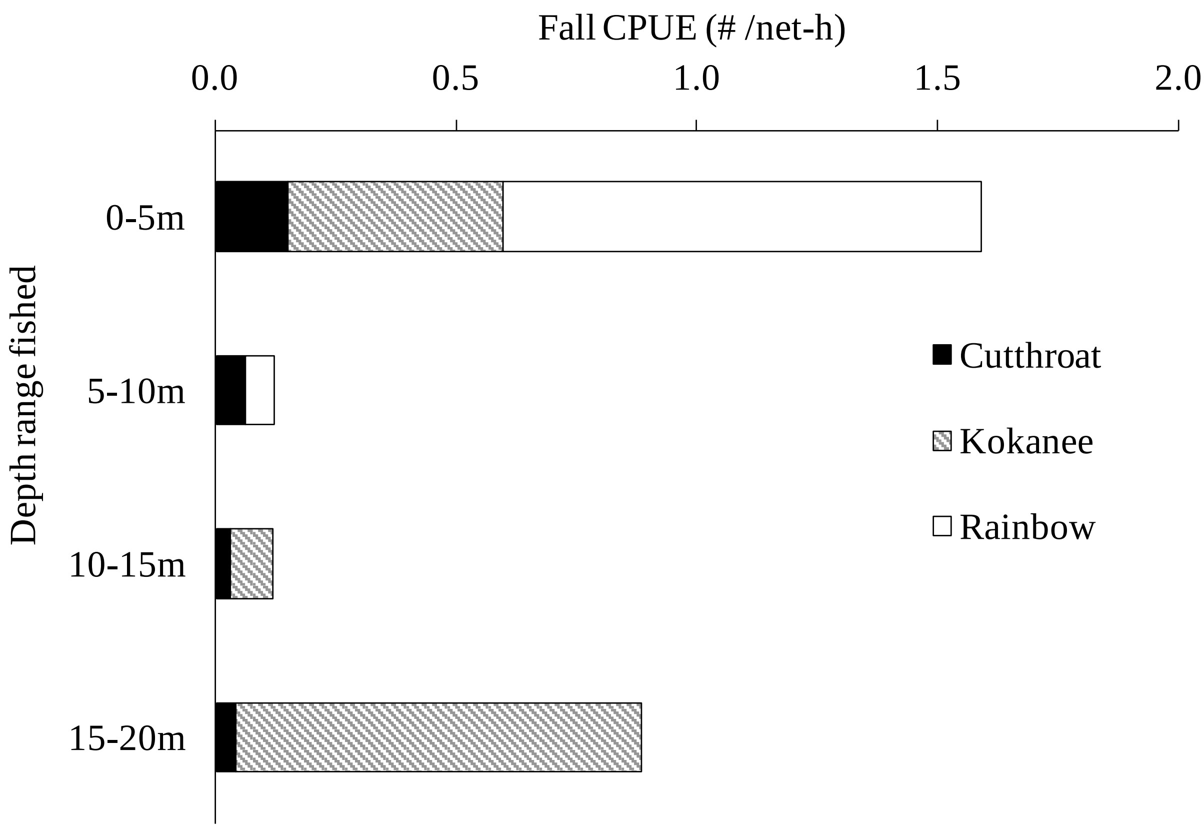


Figure 4-25 Vertical distribution of large fish (>100 mm) in the pelagic zone from midlake gillnet catches, October 2008. CPUE = fish/net-h.

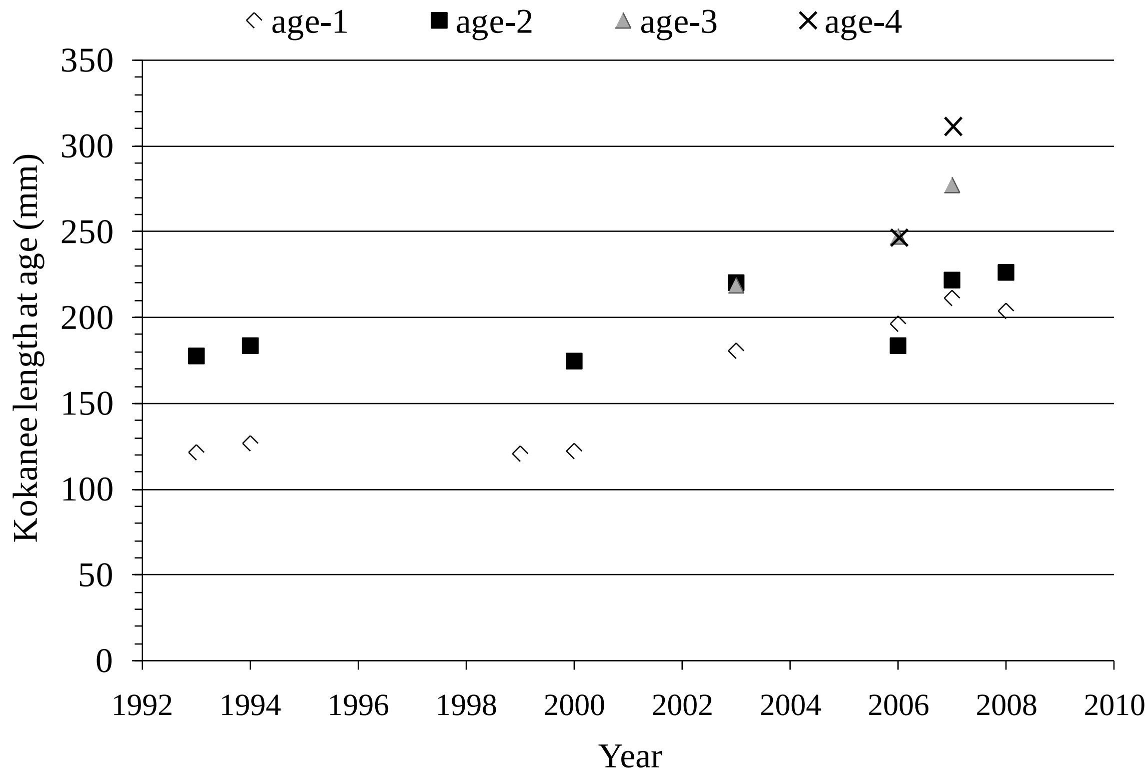


Figure 4-26 Mean length of kokanee age groups captured in fall nearshore gillnets, 1993-2007.

Trout

Rainbow trout

Based on fall gillnet CPUE, in 1993 and 1994 (before fertilization) and in 1995 (the first year of fertilization) age-2 was the most abundant age-class of rainbow trout (Fig. 4-27). Since fertilization, total rainbow abundance in gillnets has been lower and the population has not, for the most part, been dominated by a single age-class. In all years, most rainbow trout biomass was age-2 and older fish (Fig. 4-28). Rainbow relative biomass peaked in 1994-95, was relatively low (<50% of peak biomass) until 2003, and since 2003 has increased to about 60% of peak biomass. The period of relatively low abundance and biomass after 1995 corresponds with the period of fertilization. Additional years of data should help determine if the relative increase in biomass observed in 2003-07 (which corresponds with modest increase in abundance) is indicative of a long-term trend.

In 2000, rainbow trout comprised about the same portion of the catch (20%) in nearshore and midlake sets, whereas in 2008 rainbow made up 62% of the nearshore catch and only 36% of the midlake catch (Fig. 4-24).

The vertical distribution of rainbow trout was examined using the 2000 and 2008 midlake gillnet data (Figure 4-25). In 2000, when surface and bottom sets were made, rainbow trout abundance was two fold higher at the surface (0.20 versus 0.09 fish /net-h). In 2008, when midlake gillnets were fished systematically from 0 to 20 m, rainbow trout were only caught in the uppermost 10 m, and abundance was 16 fold higher 0-5 m compared to 5-10 m.

The mean length of age 2-4 rainbow trout has fluctuated over the years of the study (1993-1997) with no clear difference between pre and post-fertilization periods (Fig. 4-29). Age 2, 3, and 4 fish have averaged 120-220 mm, 180-280 mm, and 260-325 mm, respectively.

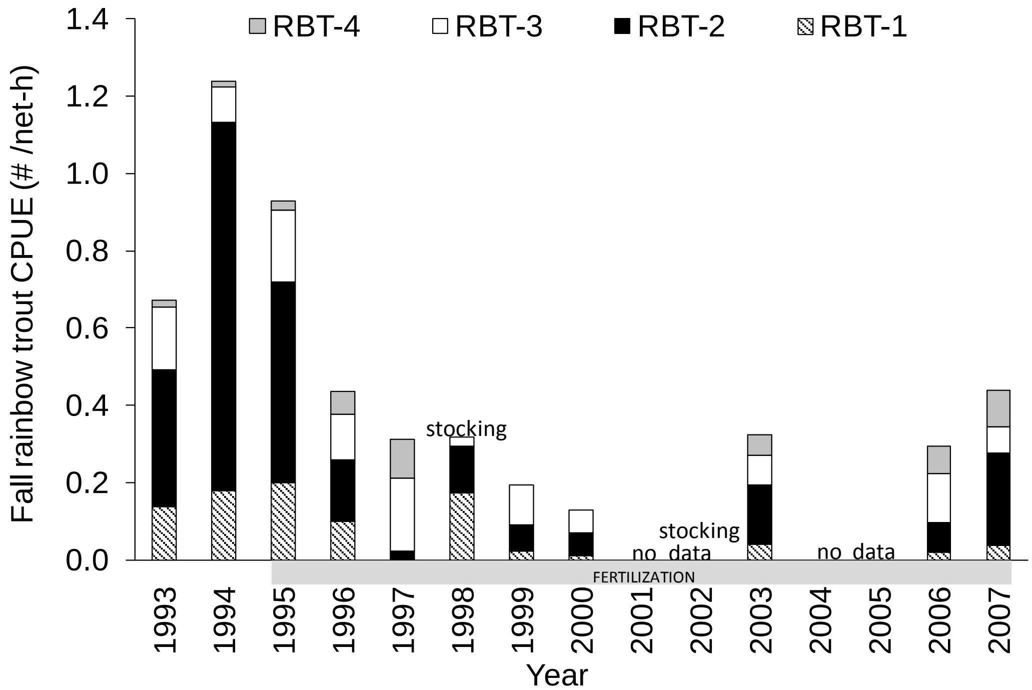


Figure 4-27 Rainbow trout relative abundance (fish/net-h) and age structure in Wahleach Reservoir, fall 1993-2007, from nearshore gillnetting. RBT = rainbow trout.

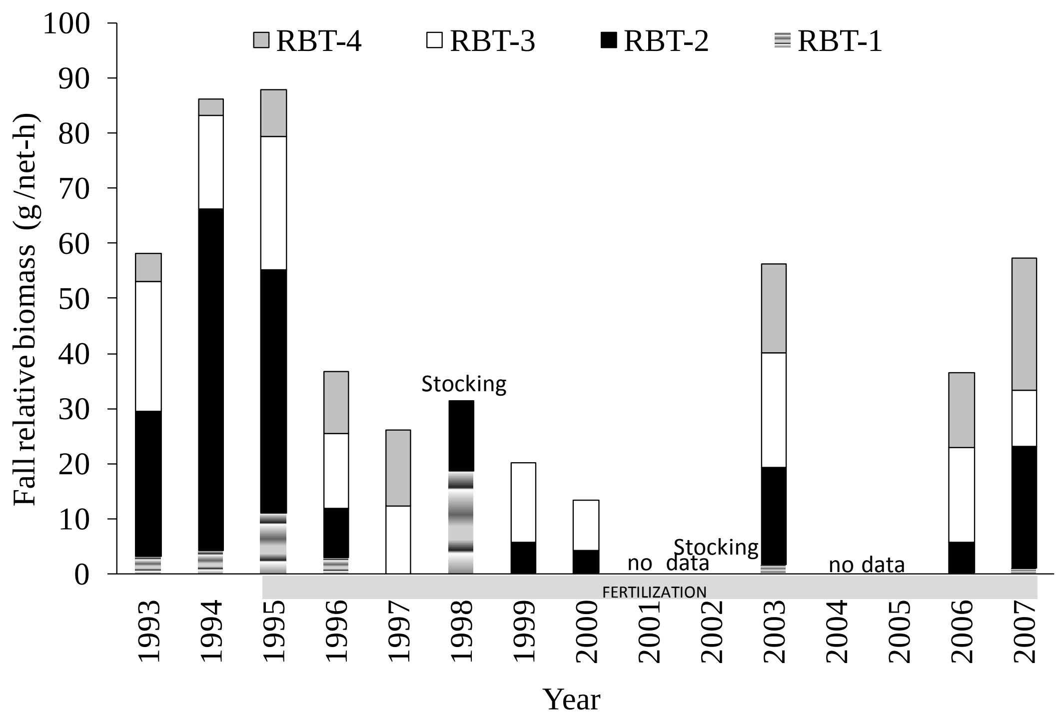


Figure 4-28 Relative biomass of rainbow trout by age group in Wahleach Reservoir, fall 1993-2007, from nearshore gillnetting. RBT = rainbow trout.

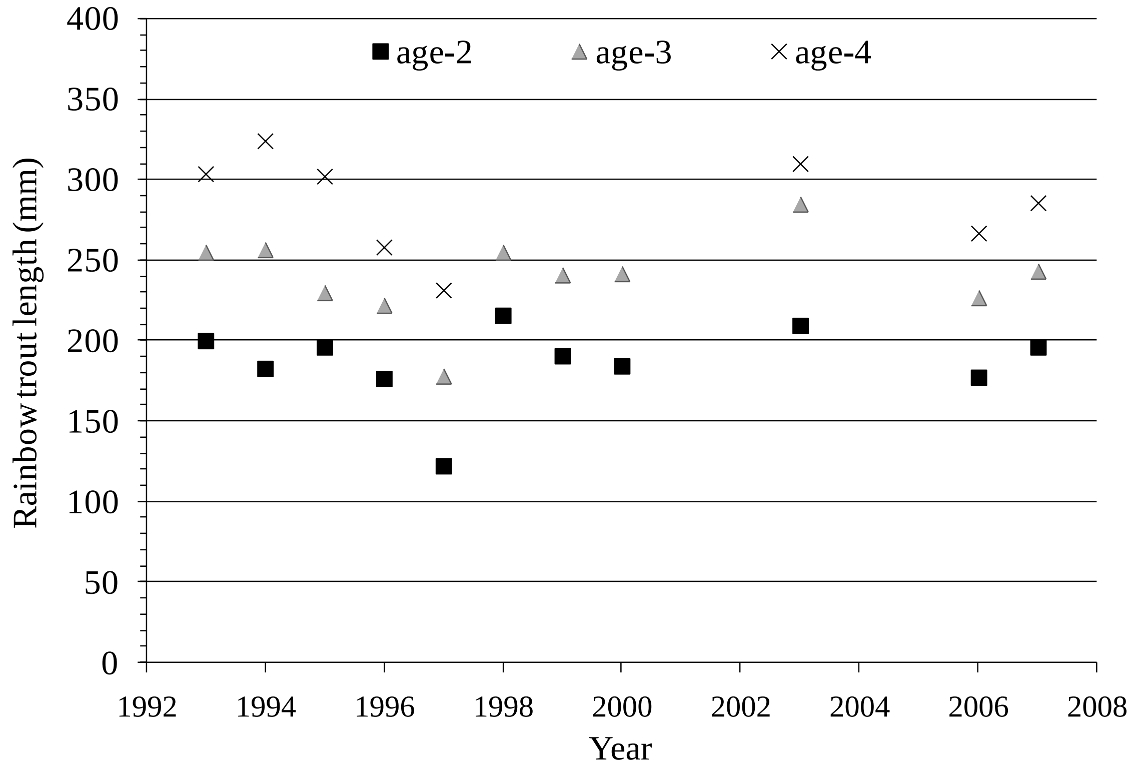


Figure 4-29 Mean length of rainbow trout age groups captured in fall nearshore gillnets, 1993-2007.

Cutthroat trout

Cutthroat trout were introduced to Wahleach Reservoir in 1997. Based on fall CPUE, age-1 cutthroat were the most abundant age-class in 1997-1999 (Fig. 4-30), and thereafter age-2 and age-3 fish have been dominant. Cutthroat relative biomass (g/net-h) increased after introduction in 1997, peaked in 2000, and has since decreased (Fig. 4-31). Although cutthroat trout were stocked in 2007, their abundance in that year was relatively low compared to all previous years. Ages contributing most to cutthroat biomass have varied since they were first introduced. Age-1 fish made large contributions for the first 3 year (1997-1999), but have made up less than 5% of biomass since 1999. Starting in 1999, age-2 and-3 fish made up the largest portion of biomass, except in 2007, when age-4 were relatively important.

In 2000, cutthroat trout comprised a much larger portion of the catch in nearshore sets (53%) than in midlake sets (32%), whereas in 2008 they made up a relatively small proportion of the gillnet catch in both locations (14-17%, Fig. 4-24).

The vertical distribution of cutthroat trout was examined using the 2000 and 2008 midlake gillnet data. In 2000, when surface and bottom sets were made, cutthroat trout CPUE was similar in surface and bottom sets (0.29 versus 0.27 fish /net-h, Fig. 4-25). In 2008, when midlake gillnets were fished systematically from 0 to 20 m, cutthroat trout were caught over the entire range, but abundance was 2.5 times higher at 0-5 m than at any other depth layer.

The mean length of age 2-4 cutthroat trout has declined markedly since they were first introduced to the reservoir in 1997 (Fig. 4-32). The mean size of age-2 fish declined from 385 mm in 1998 to 245 mm in 2003, and was 255 mm in 2007. Age-3 and age-4 fish showed similar decreasing trends in mean size.

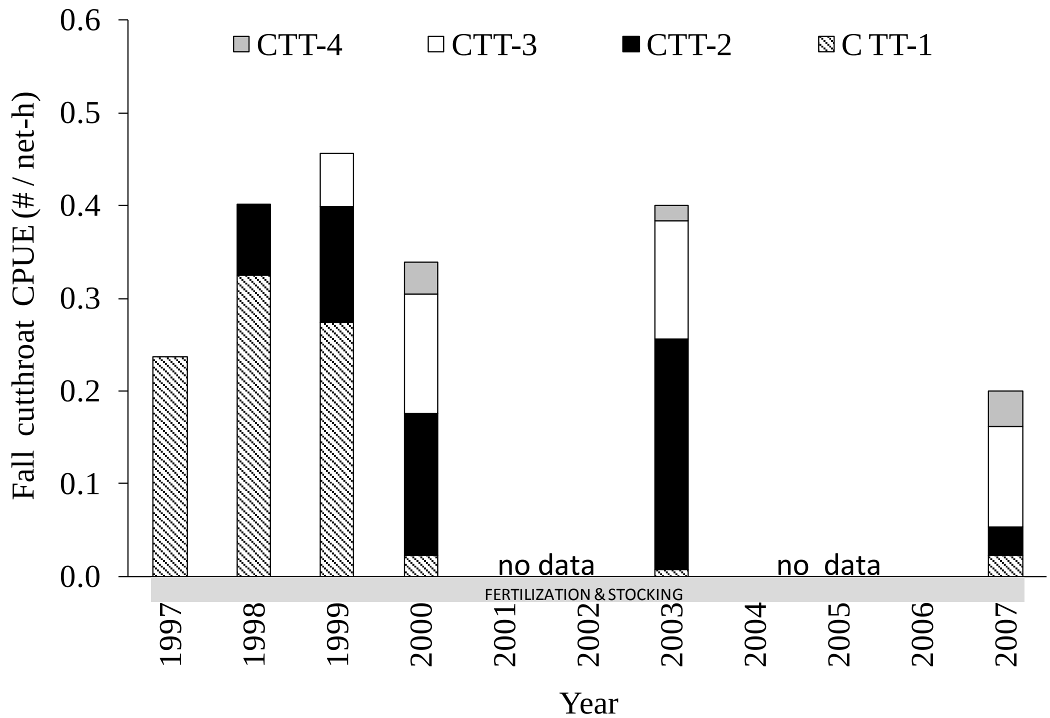


Figure 4-30 Relative abundance (fish/net-h) and age composition of cutthroat trout in Wahleach Reservoir, fall 1993-94 (baseline) to 2007, from nearshore gillnetting. CTT = cutthroat trout.

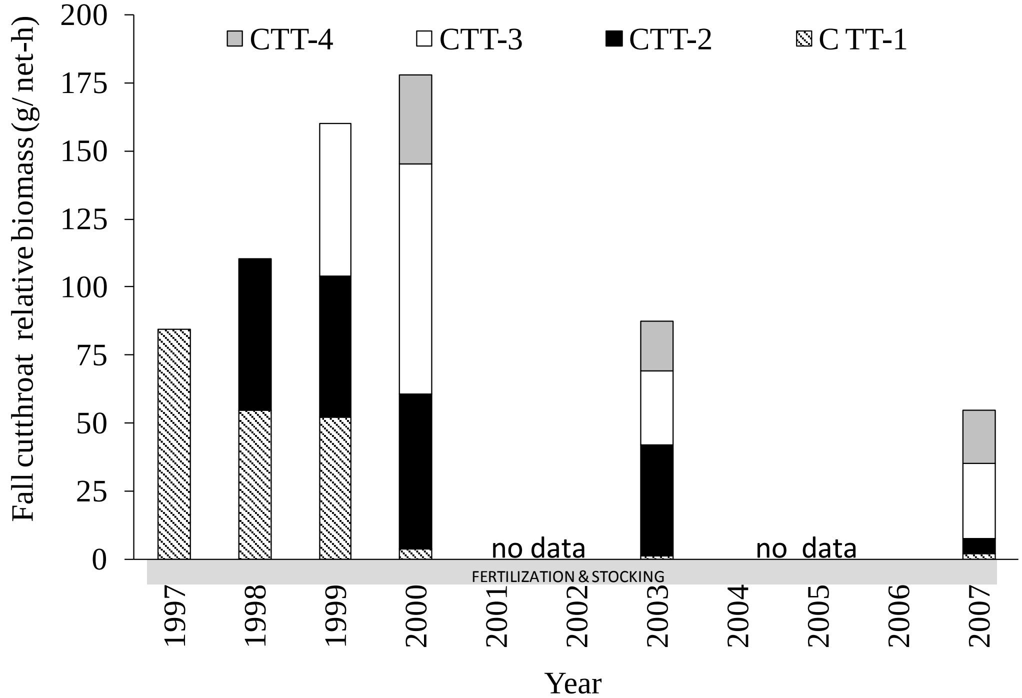


Figure 4-31 Relative biomass (g/net-h) and age composition of cutthroat trout in Wahleach Reservoir, fall 1993-2007, from nearshore gillnetting. CTT = cutthroat trout.

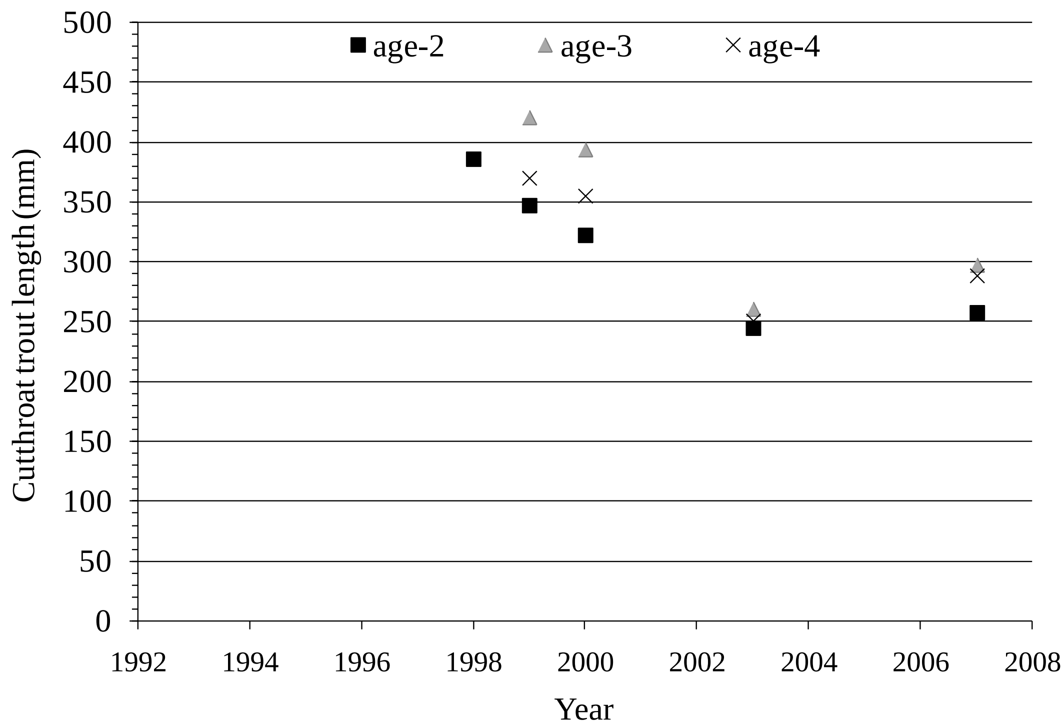


Figure 4-32 Mean length of cutthroat trout age groups captured in fall nearshore gillnetting, 1993-2007.

4.5.3 Trawling and acoustic surveys

4.5.3.1 Trawling

Since 1993, trawl catches have ranged from 19 to 558 fish /year, most of which were threespine stickleback (Table 4-3). The catch of kokanee has ranged from 0 to 4 fish /year, or 0 to 10.5% of the total catch. In 2008, 3 of 144 fish (2.1%) were kokanee. Since trawling has targeted depths where the highest densities of fish were seen with acoustics, rather than sampling depths randomly, trawl CPUE is probably a biased indicator of year-to-year change in individual species abundance.

With one exception (an age-1 kokanee), all fish captured in the trawl were <100 mm in length. In 2008, the mean length of kokanee fry (70 mm) was the smallest of any year, although the difference was probably not significant due to small sample size (Fig 4-33). The mean length of sticklebacks (37 mm) in 2008 was also the smallest to date.

In 2008, total CPUE (total fish /tow) was relatively low nearest the lake surface (3.1 fish /tow) and highest in the 15-17.5 m layer (78.1 fish /tow) - the deepest layer fished (Fig. 4-34). Kokanee were caught only in the deepest layer. This depth distribution of fish (for species combined) was similar to preliminary 2008 acoustic results, which showed highest fish densities at 10-18 m (G. Scholten, BC Ministry of Environment, personal communication).

Stickleback was the most abundant species in the pelagic habitat at all depths in all years of trawl sampling (Table 4-3).

Table 4-3 Catch, effort, and CPUE (fish/tow-hr) from all years of trawling in Wahleach Reservoir. All sampling was at night during October.

Sampling	**# of**	**Total**	**Total catch**			**Mean catch per tow-h**		
Year	**Tows**	**Tow-h**	Kokanee	Stickleback	Total	Kokanee	Stickleback	Total
1993	3	0.75	0	209	209	0.0	278.7	278.7
1997	3	0.67	0	37	37	0.0	55.5	55.5
1998	5	2.60	4	558	562	1.5	214.6	216.2
1999	6	3.35	3	52	55	0.9	15.5	16.4
2000	4	1.62	2	17	19	1.2	10.5	11.8
2008	6	3.00	3	141	144	1.0	47.0	48.0

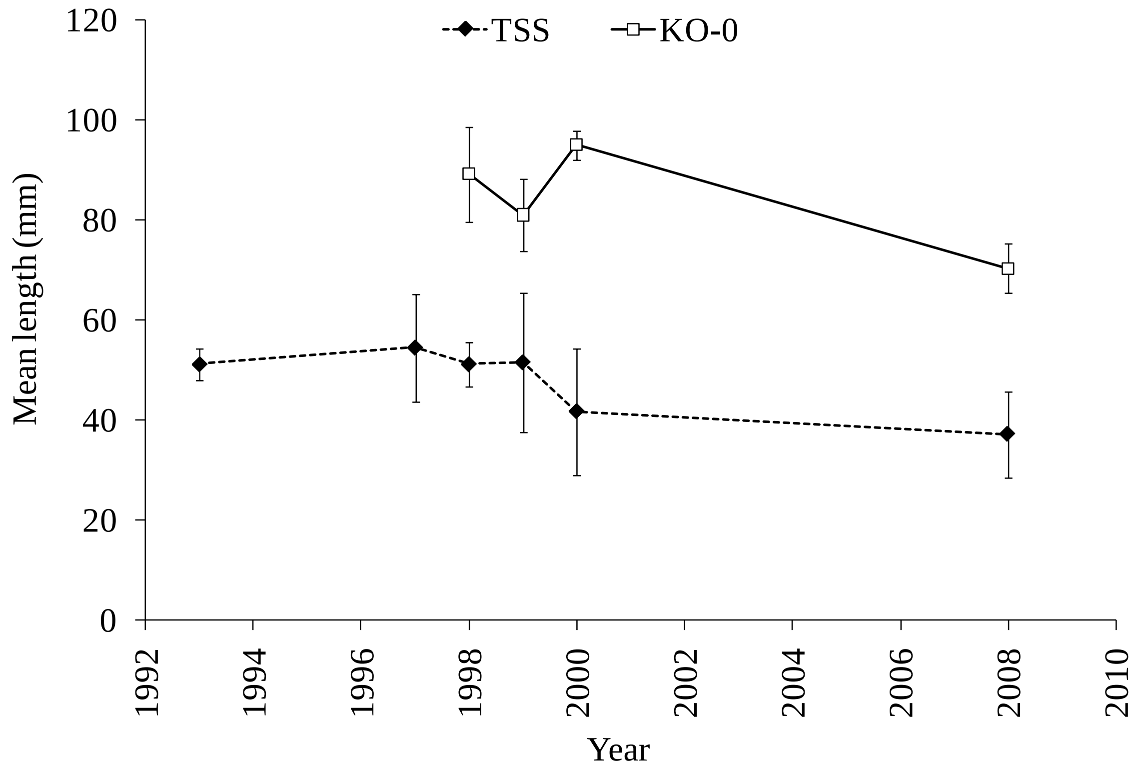


Figure 4-33 Mean length of stickleback (TSB) and kokanee-0 (KO-0) caught in the trawl, 1993-2008).

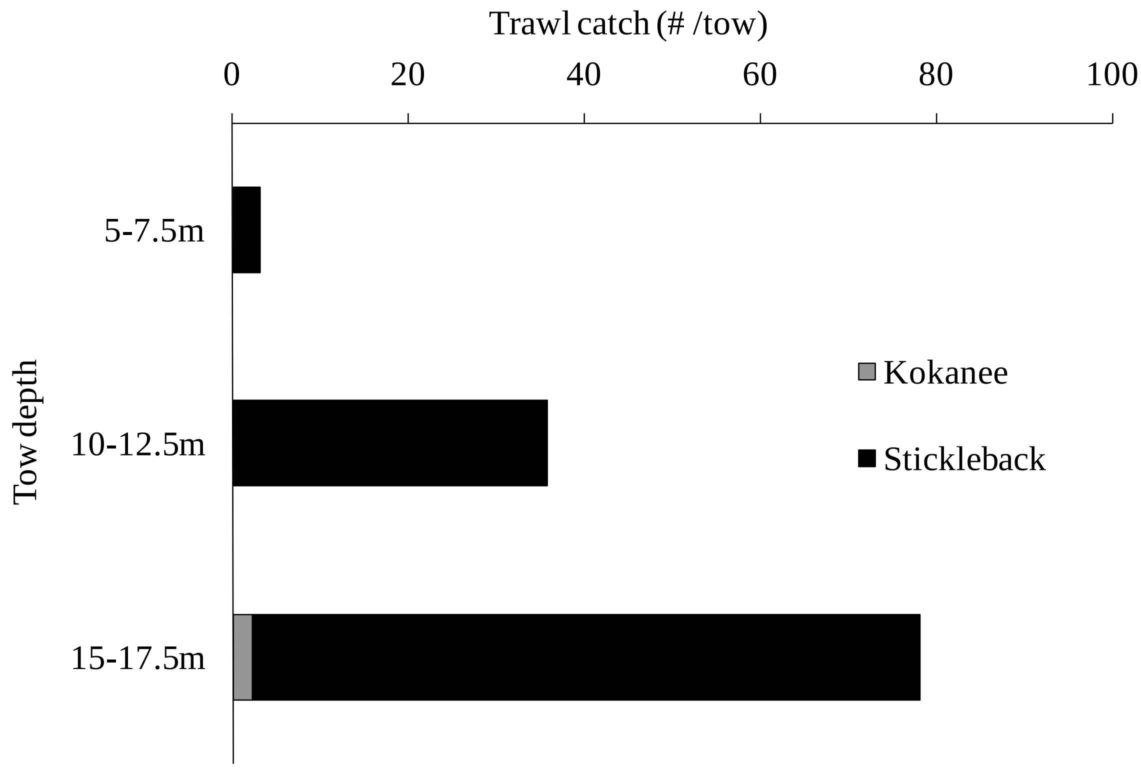


Figure 4-34 Vertical distribution of small fish (<100 mm) in the pelagic zone from trawl catches, October 2008.

4.5.3.2 Acoustic surveys

Total abundance of all species combined

Between 1993 and 1997, total fish abundance estimated from acoustic surveys increased from about 1 million to 6 million fish, and a large majority of fish was sticklebacks (Fig. 4-35, Perrin et al. 2006). Coincident with the introduction of cutthroat trout in 1997, total fish abundance decreased from millions to several hundred thousand. In 2007 total abundance was 145,000 (Scholten and Sebastian 2008)

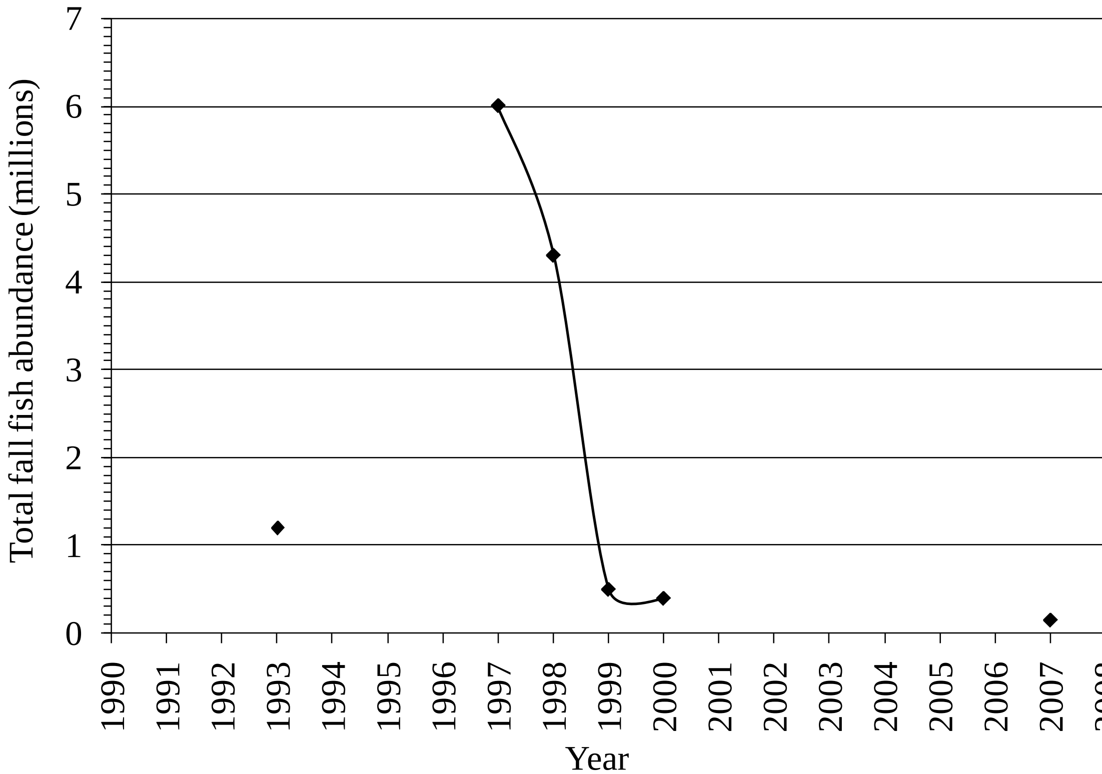


Figure 4-35 Total fish abundance in Wahleach based on acoustics; shallow water was surveyed in all years except 2007, from Perrin et al. 2006.

Abundance by species

Kokanee

Absolute abundance of kokanee of all sizes estimated from acoustic surveys increased from zero in 1997 to 50,400 fish in 2000 (Fig. 4-36; Perrin et al. 2006). In 2007, kokanee abundance was estimated at 60,000 by the S&S method and 4,739 by the T&G method. Kokanee densities were 123/ha in 2000, and 146/ha (S&S) and 12/ha (T&G) in 2007 (both based on a full pool area of 410 ha). The large discrepancy between the two methods of estimating kokanee abundance in 2007 was mainly due to the very different estimates of the species composition of small fish (<100 mm), which were by far the most abundant size fraction in the acoustic estimate (Scholten & Sebastian 2008). The T&G method estimated a low number of kokanee fry (and a large number of sticklebacks) based on less than 3% kokanee in the trawl catch, whereas the S&S method estimated a much higher number of kokanee fry (and a correspondingly lower number of sticklebacks). For reasons described in the discussion we question the accuracy of both estimates due to uncertain species composition, but believe the S&S estimate is closer to actual 2007 kokanee abundance.

Stickleback

From 1997 to 2000, stickleback abundance decreased from 6,046,685 to 350,000 (Fig. 4-36, Perrin et al. 2006). This appears to have been in response to predation by cutthroat trout, which were stocked from 1997-2007 to prey on sticklebacks (Perrin et al. 2006). By 2007, stickleback abundance had decreased further to 75,000 (S&S) or to 137,222 (T&G). Compared to 2000, the S&S estimate represents a 79% decline in stickleback abundance, whereas the T&G estimate is a 61% decline. However, actual abundance in 2007 may have been higher than the estimated abundances because the 2007 acoustic survey only partially sampled the nearshore habitat where sticklebacks were abundant in some previous years (Perrin et al. 2006). Again we question both the T&G and S&S estimates due to uncertainties about species composition (see Discussion).

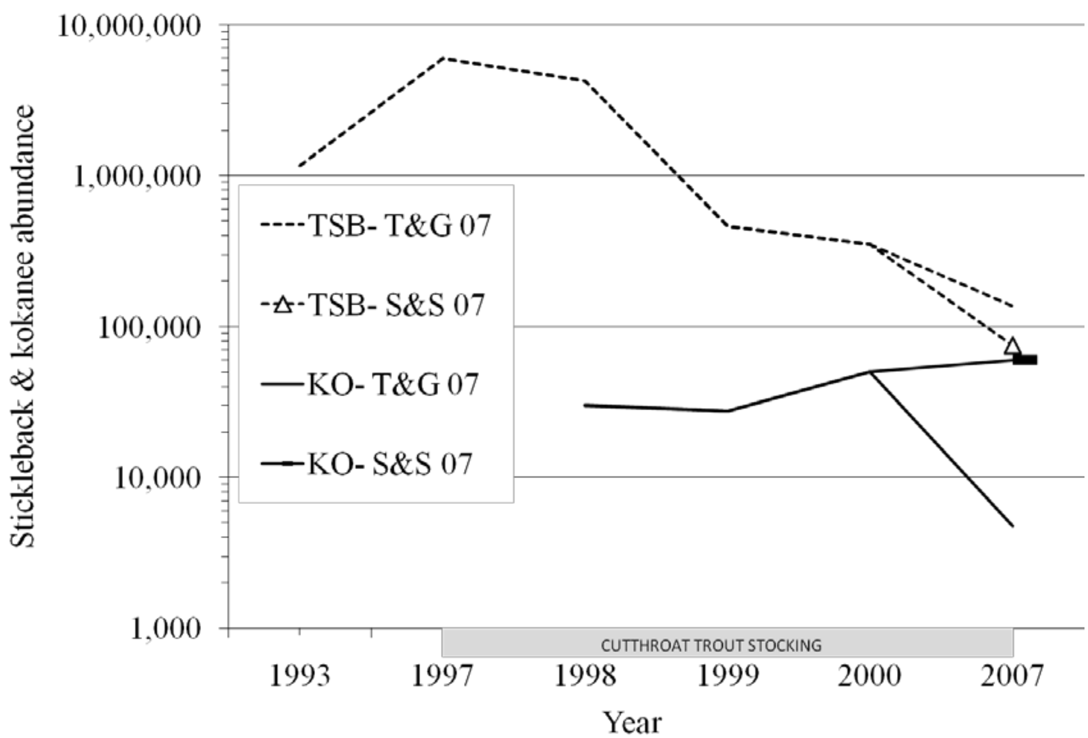


Figure 4-36 Kokanee and stickleback abundance from acoustic surveys, pelagic gillnetting, and trawling. Data for 1993 to 2000 are from Perrin et al. 2006. Estimates for 2007 are based on acoustics without gillnetting or trawling (S&S), and on 2007 acoustics combined with 2008 pelagic and nearshore gillnetting and trawling (T&G).

Trout

The 2007 cutthroat trout abundance estimates from acoustics were 2,500 (S&S) and 800 (T&G) (Fig. 4-37). Both the S&S and T&G estimates for 2007 indicated an appreciable decrease since 2000 when the estimate of cutthroat abundance was 18,084. Similarly, the 2007 rainbow trout abundance estimates (S&S=7,500, T&G=2,639) indicated a decrease in rainbow trout abundance from 10,549 in 2000.

These estimates of trout abundance should be considered with caution. Acoustic surveys of Wahleach were designed to assess kokanee in midwater, and estimates of absolute trout abundance generated from them could contain considerable error in either direction (see Discussion). More reliable estimates of annual trout abundance trends are probably provided by fall gillnetting (see above).

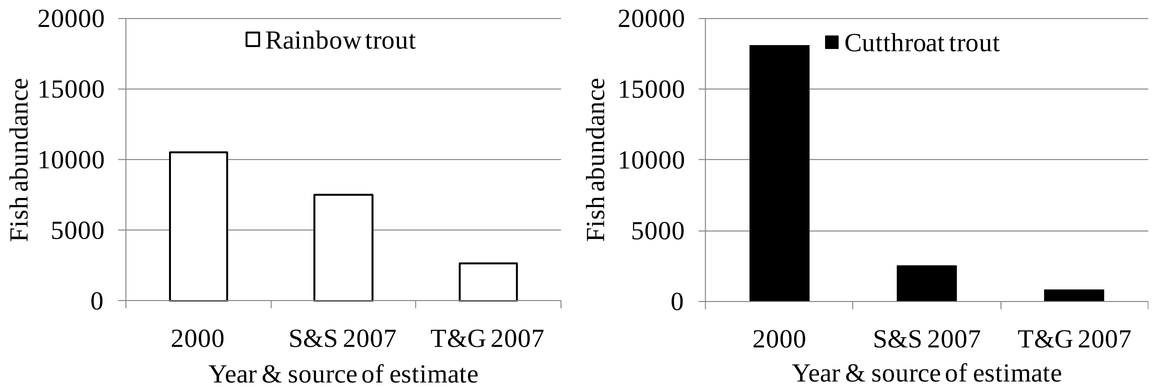
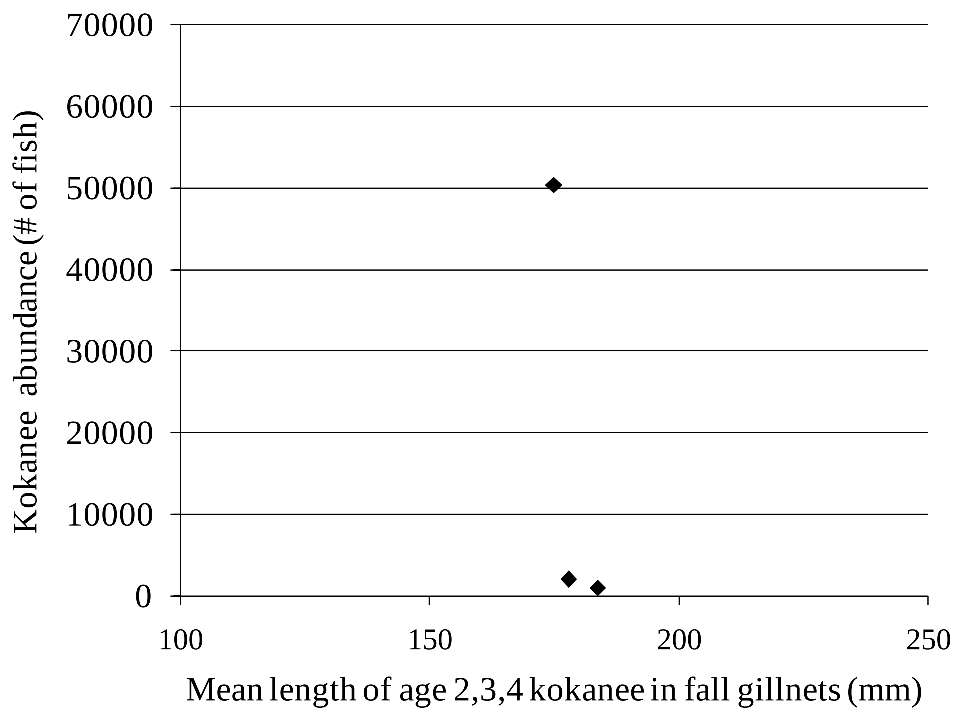


Figure 4-37 Acoustic estimates of rainbow and cutthroat trout abundance in Wahleach Reservoir in 2000 and 2007. For 2007 both S&S and T&G method estimates are shown.

4.5.3.3 Kokanee response to fertilization

The response of kokanee after re-introduction and fertilization could be higher densities of similar sized fish (density dependent growth) if spawning habitat was underutilized, similar densities of larger fish if spawning habitat was limited, or enhancement of predation mortality that produces lower densities and even larger fish. Plots of kokanee abundance versus mean length of older age kokanee (Fig. 4-38 upper) and kokanee abundance versus size-at-age over time (Fig. 4-38 lower) both indicated that increasing abundance corresponded with increases in fish length. However, this conclusion is open to question because the data on kokanee abundance are sparse (Table 3-1), with no reliable estimates of kokanee abundance after 2000 due to the absence of pelagic gillnetting and trawling data to support the acoustic surveys of fish abundance (see Section 5.2).



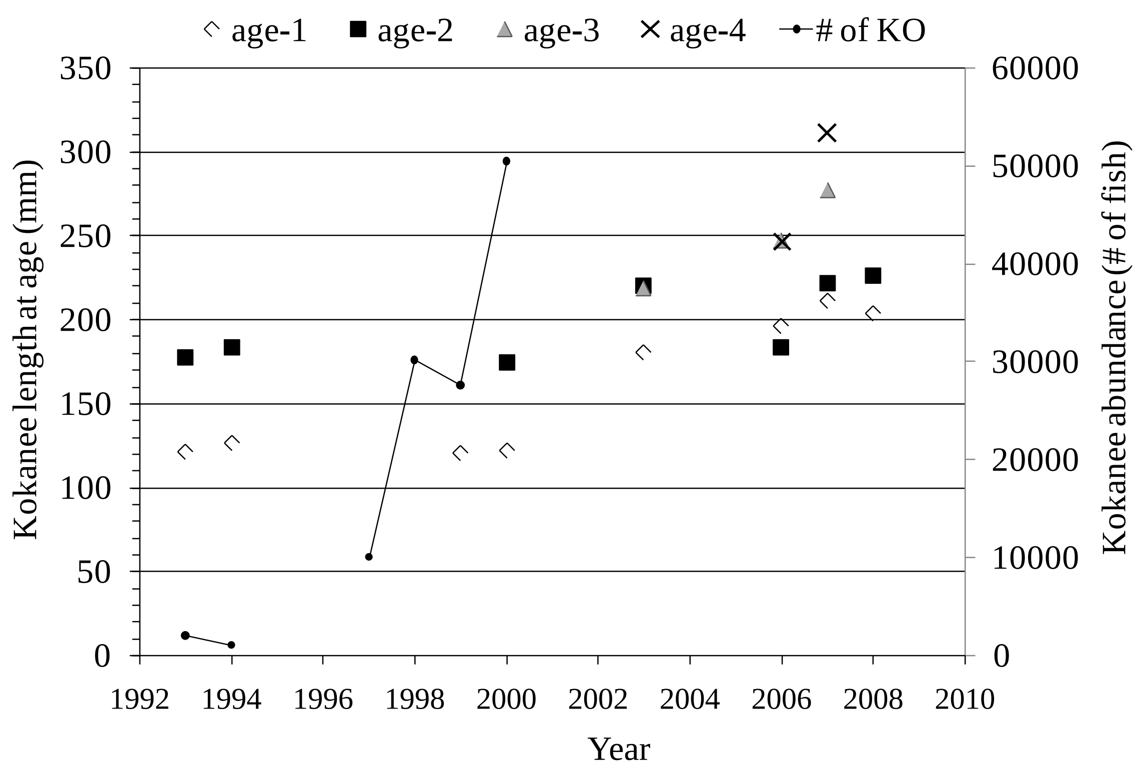


Figure 4-38 Kokanee abundance from 1997-2000 fall acoustic surveys versus mean length-at-age in fall gillnets (upper), and kokanee abundance and mean length-at-age in fall gillnets for 1993-2008.

4.5.3.4 Consumptive pressure by planktivores

Perrin et al. (2006) concluded that kokanee had a competitive advantage over sticklebacks by 2000, when their effective density for the first time exceeded that of sticklebacks (Fig. 4-39). Considering the uncertainties about species composition of the 2007 acoustic estimate, there is no new data reliable enough to add to this time series.

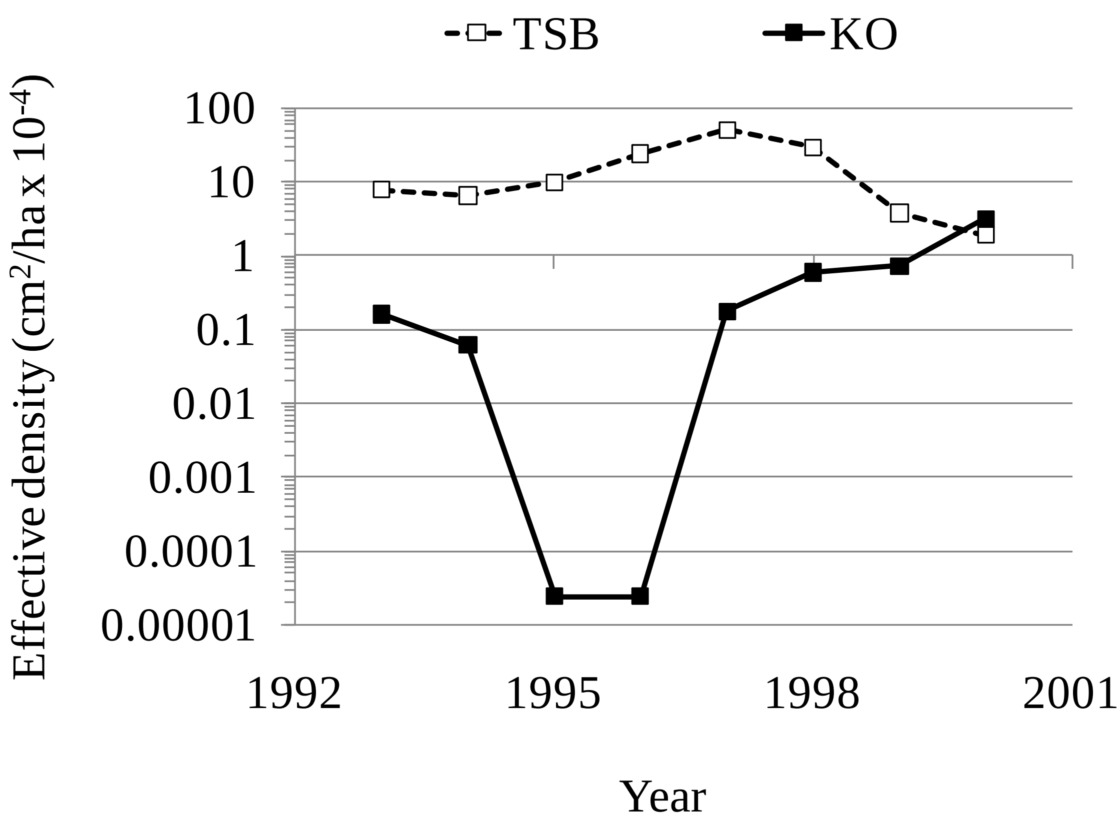


Figure 4-39 Effective density of stickleback (TSB) and kokanee (KO) from acoustic surveys since 1993.

4.5.4 Spawner habitat and counts

4.5.4.2 Spawning habitat

Approximately 3 km of stream were walked in 1995 to assess spawning habitat quality in tributary creeks, as follows: Boulder Creek - 650 m (200 m near the mouth, the balance 1km upstream); Flat Creek - 1 km; Glacier Creek 3- 200 m; Glacier Creek 4- 150 m; Wahleach Creek (Jones)- 750 m. Good quality spawning habitat was available, with a majority in Jones and Flat Creeks, but the amount of spawning habitat appears to be somewhat limited (Table 4-4). An assessment in fall 2002 found negligible in-lake spawning habitat compared with the amount of habitat available upstream (White Pine 2002).

5.4.2.1 Spawner counts

Kokanee

Numerous kokanee spawner counts were made between 1969 and 1995 (Fig. 4-40). The highest spawner count over the period of record was 16,000 in 1980, when a majority of spawners were found in Jones Creek and a moderate number of spawners was found in Flat Creek. In 1995, no kokanee spawners were observed in any tributaries (Inglis 1995).

Kokanee were re-introduced to Wahleach between 1997 and 2004. Since re-introduction, kokanee escapement has been estimated annually since 2001. Escapement has been variable, from 1000 in 2003 to 8000 in 2006, and was relatively low in 2007 and 2008 (Fig. 4-40). The 2008 escapement would have been the result of natural spawning in 2004 plus any kokanee stocked as age-0 in 2004 that spawned at age-4. In 2007, 22% of the kokanee caught in fall gillnets were age-3 to age-4, suggesting a fair number sometimes hold over for an extra year. In contrast, in 2008, no age-3 or older kokanee were caught in the fall gillnets.

Since re-introduction, Boulder Creek has been more heavily used by spawners than before extirpation when a majority of spawners were found in Jones and Flat Creeks (Fig. 4-40). The preference for Boulder Creek seems surprising given the relatively small amount of spawning gravel in it, that flow may be insufficient to maintain redds, and that the re-diversion in 2007 of some Boulder flow to below the dam (Table 4-4) could result in a loss of fry (White Pine 2002). The large return to Boulder Creek is probably because kokanee fry were stocked in the lake near its mouth. In recent years, there has been evidence that spawners may be shifting from Boulder to Jones and Flat Creeks where spawning habitat appears to be relatively more plentiful (Table 4-4), and where most spawners were found before re-introduction (Fig. 4-40).

Rainbow trout

A total of 466 rainbow trout spawners were counted in tributary creeks in April and early May 1995 (263 in Wahleach Creek, 80 in Glacier, 72 in Flat, and 51 in Boulder Creek, Inglis May 1995). In comparison, only 22 rainbow trout spawners were counted in 1981 (10 in Wahleach Creek, and 12 in Glacier Creek; BC Ministry of Environment, Lands and Parks, Surrey, unpublished data). Both these estimates were thought to be low because spawning was well under way when the surveys started.

Table 4-4 Summary of available spawner habitat quality and quantity information about Wahleach Reservoir tributary creeks.

Creek	% usable[1]	Habitat quality[2,4]	Accessibility[1,3,4,5]	RBT habitat[3]
Boulder **650 m surveyed**	1	-2005 diversion to supplement flow below the dam -fry are lost due to diversion -2006 no fish passage -steep; subject to high flows -winter flow (0.6 m^3/s) may be inadequate to maintain redds -sparse spawning gravel -2001-insufficient habitat for #of spawners -2001 no barrier to upstream migration	-1981 inaccessible due to low lake level & debris - access interrupted in 2005, 2006, 2007	-Boulder tributaries
Flat **1050 m surveyed**	12	- limited spawning habitat - high substrate mobility?	-1981 inaccessible due to low lake level & debris -2001 no barrier to migration	-1995- side-channels & braided streams w/ -2^{nd} highest # of spawner
Glacier 1-4 117 m 152 m 220 m 150 m surveyed	1, 9, 21, 1	- poor (predominantly fines) - small amount of good habitat upstream, possibly underutilized	-1995 1 & 2 inaccessible due to low water -2001 partially blocked by debris dam	
Wahleach -Jones 750 m surveyed	35	-2001 no barrier to migration - good up to 350 m & at 800 m - expect relatively good egg-to-fry survival	-1996 impassable at 680 m	-1995 mainstem w/ highest # of spawner -2001 relatively plentiful spawning habitat upstream

[1] Inglis 1995; [2] BC Hydro; [3] Inglis May 1995; [4]White Pine Environmental Resources April 2002 and, [5] BC Ministry of Environment, Lands and Parks, Surrey (unpublished data).

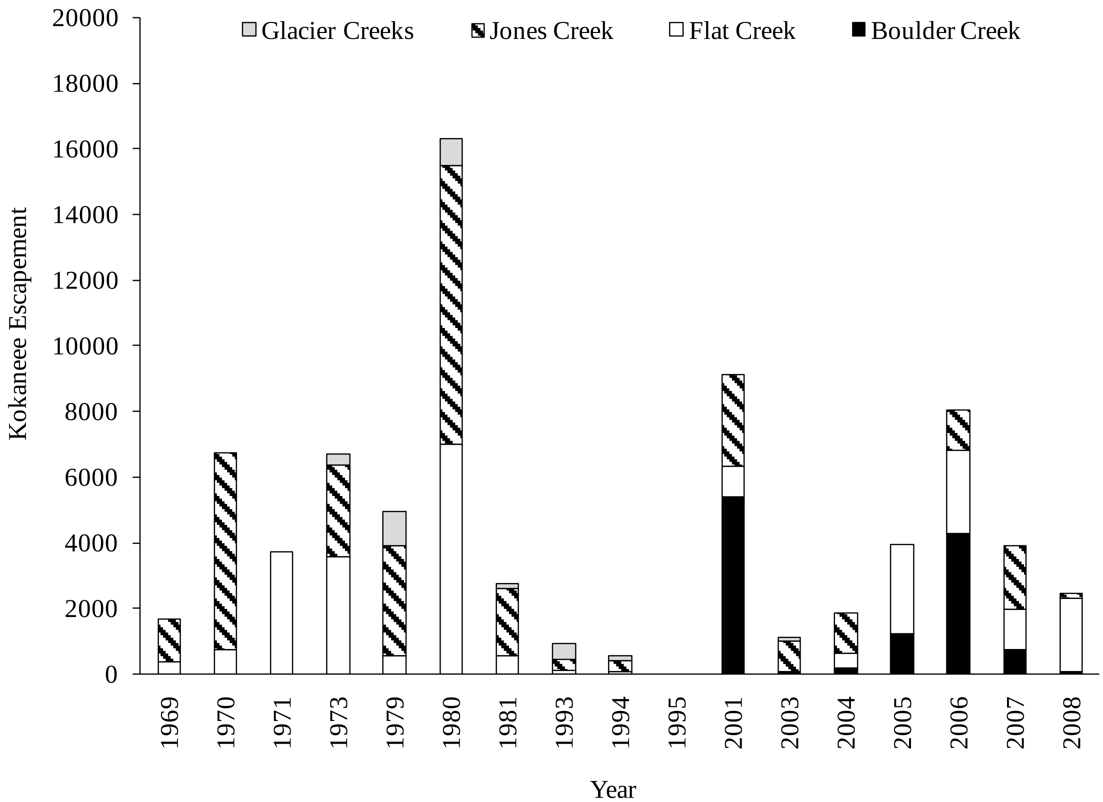


Figure 4-40 Kokanee spawner abundance data from the period of this report (1993-2008) compared to historical data (1969-1981). Data from for 1969 through 1994 are unexpanded counts (Inglis 1995), while later years are area-under-the-curve spawner escapement estimates. No kokanee spawners were observed in 1995.

4.5.5 Outcomes of fish stocking

4.5.5.1 Kokanee

Stocking of kokanee fry from 1997 through 2004 resulted in the establishment of an age structured population including ages 1-3 by 2003, with some age-4 fish as well from 2005 on (Table 4-5). From 2002 to 2004, recruitment of age-0 kokanee included both stocked and naturally spawned fish, and thereafter all recruitment was natural. Stocked kokanee were present in 2008 only as age-4 fish, from the final year of stocking (2004), so barring additional stocking in the future, from now on all kokanee spawners will be the result of natural reproduction in the lakes tributaries.

Table 4-5 History of kokanee cohorts from 1996-2007 brood years. Kokanee were stocked 1997-2004, except in 2001. Brood year is the year that a cohort was spawned.

	Age of Cohort During Sampling Year											
Brood	Sampling year											
Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
1996	(0)	(1)	(2)	(3)	(4)							
1997		**0**	**1**	**2**	(3)	(4)						
1998			**0**	**1**	(2)	(3)	(4)					
1999				**0**	(1)	(2)	**3**	(4)				
2000					(o)	(1)	**2**	**3**	**4**			
2001						(0+o)	**1**	**2**	**3**	**4**		
2002							(0+o)	**1**	**2**	**3**	**4**	
2003								(0+o)	(1)	**2**	**3**	**4**
2004									(o)	**1**	**2**	**3**
2005										(o)	**1**	**2**
2006											(o)	**1**
2007												**o**

Key to notation in table:
Bold = captured in trawl, gillnets, or on spawning grounds
( ) = not captured during any sampling
0 = fry that were stocked
o = fry from natural spawning
gray highlighting = no sampling was performed

4.5.5.2 Rainbow trout

Sterile rainbow trout were stocked in 1998 and 2002 at age-1. In 1998, the relative abundance of age-1 rainbow trout was typical of 1993-1998, showing no sign of stocking. There was no fall gillnetting in 2002, but in 2003 the age-2 rainbow trout abundance was not noticeably affected by stocking in the previous year. Throughout the period of the study the rainbow trout population has been sustained by natural spawning.

4.5.5.3 Cutthroat trout

All cutthroat trout in Wahleach are the result of stocking of age-1 fish between 1997 and 2007. Only sterile cutthroats were stocked, and there has been little evidence of any reproductive success among the sterile fish. Stocking outcomes are fully described above in the gillnetting section.

4.5.6 Sport Fishery Trends

At the beginning of the fertilization-stocking program there was no recreational fishery at Wahleach; however, within a few years of treatment, an unregulated trout fishery had developed (Perrin et al. 2006). In 1998, at 450 mm harvest limit was imposed on trout, which was lowered to 400 mm several years later.

The most recent creel survey indicated 1,521 angler days of effort in 2001 (Perrin et al. 2006). Compared with the creel survey in 1998, the catch rate of rainbow trout had decreased in 2001 from 1.1 to 0.5 fish /rod-h, and the catch rate of cutthroat trout had decreased from 0.03 to 0.08 (Perrin et al. 2006). Kokanee did not appear in the fishery until 2001, when catch rate was 0.1 fish /rod-h (Perrin et al. 2006). The data indicate a shift in the angler target from rainbow trout in 1998, to rainbow and cutthroat trout in 1999, and to rainbow trout and kokanee in 2001 (Perrin et al. 2006).

Since 1998 the fall mean length of age 3-4 rainbow trout in the fall gillnet catch has been near or above the size range (>230 mm) that may correspond with angler satisfaction in low productivity systems (Askey, P., J.R. Post & E.A. Parkinson, personal communication) (Fig. 4-41). Since their introduction in 1997, the mean length of age 2-3 cutthroat trout in the fall gillnet catch has exceeded the sport fishery satisfaction threshold. In recent years, the mean length of age 2-4 kokanee caught in fall gillnets has increased and, for the first time over the period of record, kokanee length was $\geq$230 mm in 2006-07. Overall, the mean length of older fish caught in fall gillnets compared to the satisfaction size threshold indicates that fish of a satisfactory size are available and that anglers may be satisfied with the Wahleach fishery.

On the other hand, anecdotal evidence from conversations with a small number of anglers in 2008 indicated some dissatisfaction because their catch was mainly 200-300 mm rainbow trout, which could not be kept because of the 400 mm size limit (E. Johnson, BC Ministry of Environment, personal communication). These conclusions are tentative, and should be verified with a creel survey that uses several metrics to evaluate angler satisfaction including catch /angler h.

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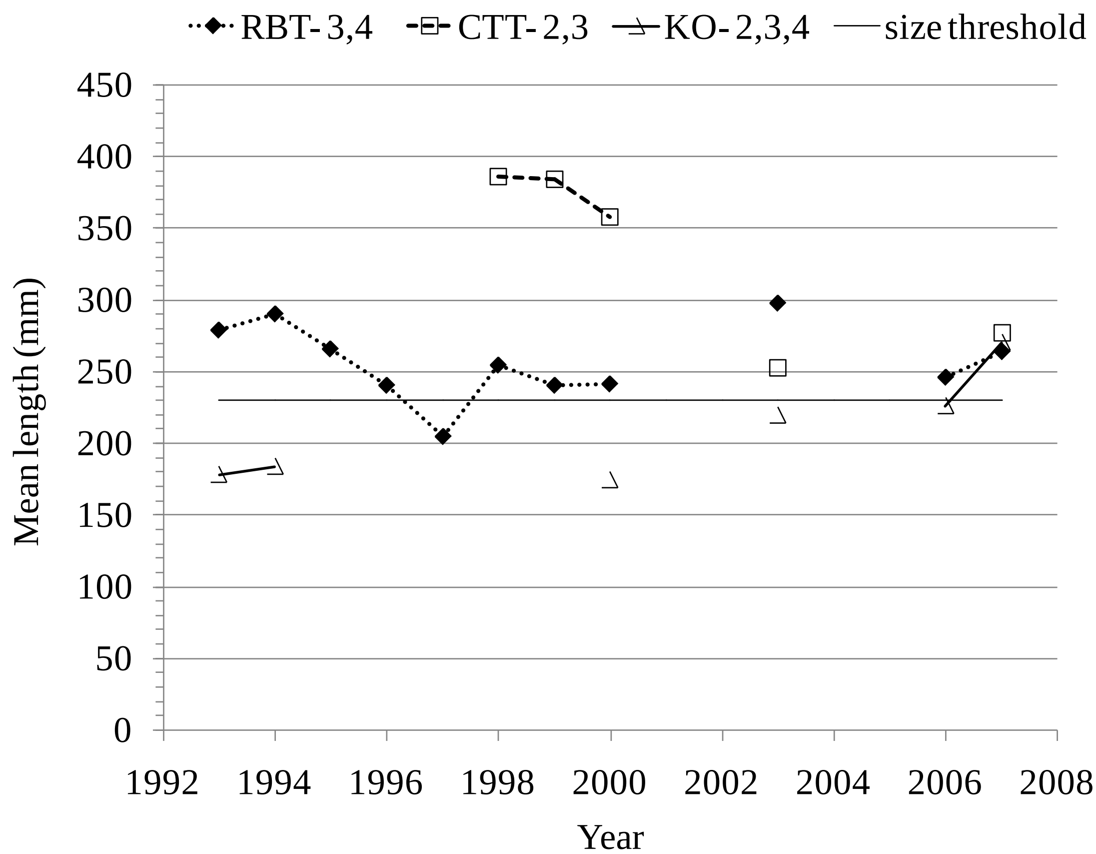

Figure 4-41 Mean length of kokanee (ages 2, 3, 4), and cutthroat (ages 2, 3) and rainbow (ages 3, 4) trout caught in fall gillnets compared with the threshold size thought to correspond with angler satisfaction in relatively low productivity systems.

5. Discussion

Five questions were identified as key to assessing the status of the fertilization-stocking program in restoring the Wahleach fishery, as follows: 1) have the nutrient additions increased the availability of edible algae and *Daphnia*?; 2) is the kokanee population self sustaining; 3) have kokanee and trout abundance and size increased?; 4) have angler satisfaction and success increased?; and, 5) has cutthroat trout stocking reduced the abundance of sticklebacks?

The 5 key questions are discussed below, and data gaps are identified that will need to be filled before the questions can be fully assessed. In addition, the uncertainty in the fish abundance estimates at Wahleach is discussed.

5.1 Key questions

(1) Have nutrient additions increased the availability of edible algae and *Daphnia*?

Increasing the supply of phosphorus, which limited phytoplankton growth Wahleach (Perrin et al. 2006), and providing sufficient nitrogen so it did not become limiting, brought about a decrease in total phytoplankton abundance, increase in total phytoplankton biovolume, and decrease in the biovolume of edible phytoplankton. The response to phosphorus loading was mixed because the surrogates of phytoplankton productivity (abundance and biovolume) can be affected not only by nutrients, which increase production, but also by grazing, which decreases standing crop (cf. Wehr & Sheath 2003; McQueen et al 1989; Carpenter & Kitchell 1988). At Wahleach, nutrient additions explain the increase in total phytoplankton biovolume. Selective grazing of relatively abundant small edible algae by zooplankton explains the decrease in phytoplankton abundance, and the decrease in biovolume of edible algae (which comprise only a small proportion of total biovolume).

The production of edible algae is critical to increasing productivity at higher trophic levels because too much inedible algae may prevent the full benefits of fertilization from propagating up the food web to fish. The apportionment of phytoplankton production between edible and inedible algae can be affected by the balance of nitrogen and phosphorus in the fertilizer and also the seasonal loading pattern (Stockner & Shortreed 1988; Perrin 1997; Ashley et al. 2007). The ratio of nitrogen and phosphorus in nutrient additions and seasonal pattern of nutrient loading at Wahleach were selected based on the response of edible phytoplankton to nutrient loading in the early years of the project (Perrin 2000) and other nutrient loading experiments (e.g. Stockner & Shortreed 1988). Although nutrient loading experiments have indicated that the ratio of nitrogen to phosphorus should exceed 15 to 1 (by weight) to avoid growth of inedible algae such as many Cyanobacteria, the early responses in Wahleach suggested a ratio as low as 13 to 1 resulted in increases in the production of edible algae (Perrin et al. 2006). Since 2000, however, blooms of nitrogen-fixing Cyanobacteria have occurred at Wahleach (e.g. in

2005 and 2008), and have tended to coincide with periods when the nitrogen to phosphorus ratio of fertilizer was relatively low. As a result, in 2008, the ratio was increased to 15 to 1 in mid-to-late summer (earlier than prescribed). In addition to cyanobacterial blooms, there are other indications that the current ratio of nitrogen to phosphorus and nutrient loading pattern may fail to meet the nitrogen demands of phytoplankton. The other indicators include drawdown of dissolved nitrate + nitrate to concentrations thought to limit phytoplankton growth, and mismatch between the concentration of total nitrogen in surface waters and seasonal pattern of nitrogen loading that could be the result of nitrogen-supplementation by nitrogen-fixing cyanobacteria. Alternatively, it is possible that brief mid-summer mixing events, such as the one observed in 1994 (Inglis 1995) which resulted in increase in surface water nitrate concentrations, explain the lack of close correspondence between nitrogen loading and total nitrogen concentration. Such mixing events could occur relatively frequently at Wahleach given its high altitude and mountainous watershed but the current monthly sampling frequency is not likely to catch such events. Another indication that the balance of nitrogen to phosphorus may have been less than optimal at Wahleach was dissolved oxygen peaks, which are likely a byproduct of photosynthesis, beneath the relatively shallow mixed layer where nitrogen may be relatively more available than in the well-lit surface waters where photosynthetic rates and nutrient uptake tend to be relatively rapid. In such a situation, edible flagellates may be predominant in deeper waters (Lund & Reynolds 1982) which can benefit zooplankton. Last, inedible diatoms have comprised a large portion of phytoplankton biovolume in recent years, and although reactive silica (required for diatom cell walls) appears to be drawn down over the growing season to a greater degree than during the baseline years, silica concentrations do not appear to be low enough to limit diatom production (ca. Wehr Sheath 2003).

At Wahleach, the depth of epilimnion is usually relatively shallow (4-5 m, Fig. 4-2) possibly due to slope failures that introduce terrestrial debris into the lake, lowering water clarity. Whatever the cause, the shallow depth of the epilimnion means that nutrient applications are added to a relatively small volume of water. As a result, the annual loading rate (target- 1770 mg N /m^2/year and 204 mg P /m^2/year) can result in peak chlorophyll concentrations and water clarity that are more typical of mesoeutrophic waters (chlorophyll range, 3-11 µg/L; Wetzel 2001). The assemblage of phytoplankton may change as primary production increases from oligotrophic to eutrophic levels (e.g. Burns & Stockner 1991), but the increases in production may not correspond with increases in the desirable edible species of phytoplankton (e.g. Suttle et al. 1987), as appeared to be case at Wahleach from mid-summer to fall when there was preponderance of inedible algae (J.G. Stockner, personal communication).

During the period of fertilization, zooplankton biomass increased in correspondence with increases in phosphorus loading, while the presence of grazing by planktivorous fish (stickleback and kokanee) corresponded with decreases in zooplankton biomass. There fore, selective removal of large zooplankton (e.g. *Daphnia)* could have had a larger effect on total zooplankton biomass than on abundance. Grazing pressure on the zooplankton food resource appears to have peaked during the period of kokanee stocking, and to have declined during the period of decrease in stickleback abundance and discontinuation of kokanee stocking, as might be expected. In addition, in 1994, temperature profiles indicated a brief mixing event in mid-summer which coincided with a crash in zooplankton density (Inglis 1995) indicating that strong winds can also affect zooplankton standing crops at Wahleach, although the current sampling frequency (monthly) is too low to detect most such events.

The patterns of phytoplankton and zooplankton standing crop suggest the following responses to the fertilization-biomanipulation treatment at Wahleach: 1) nutrient additions appear to have initially increased the production of edible phytoplankton and large zooplankton, but any increases do not appear to have been sustained; 2) large zooplankton and small *Bosmina* (Perrin and Stables 2000) may have reduced the biovolume of edible algae; 3) planktivory may have damped somewhat the response of zooplankton biomass to nutrient loading, and planktivory may have declined with the sharp decline in stickleback abundance after 2000 and discontinuation of kokanee stocking after 2004; 4) plankton species assemblage was affected not only by the availability of phosphorous but also by the availability of nitrogen; and, 5) occurrence of mesoeutrophic conditions can alter the phytoplankton species assemblage, and possibly resulted in a lower proportion of edible algae than might have occurred if conditions at Wahleach had been more oligotrophic. In addition, the occurrence of deep mixing events may increase nitrogen concentrations in surface waters and decrease zooplankton standing crop. Last, if the observed decrease in the abundance and biovolume of flagellates and dinoflagellates with increased phosphorus loading was due increased cropping of edible algae by the larger or more abundant zooplankton, then this implies that planktivory may not have been substantial enough at Wahleach to reduce zooplankton abundance and, in turn, allow the standing crop of edible algae to increase.

Although the annual loading rate and seasonal nutrient loading pattern were selected to promote the growth of edible algae at Wahleach, the observations of chronic nitrogen limitation and chlorophyll concentrations which approach mesoeutrophic levels suggest that improving food quality for zooplankton might be achieved through lower phosphorus loading rates, higher nitrogen to phosphorus ratio, and selection of seasonal loading rates that fit the evolving physico-chemical status of surface waters at Wahleach (Stockner 2005). Tailored nutrient loading should be combined with more quantitative information on the abundance and biovolume of edible algae (time was insufficient for such analysis in the report).

(2) Is the kokanee population self sustaining?

Stocking with age-0 kokanee appears to have successfully re-introduced kokanee to Wahleach Reservoir, although population abundance appears to fluctuate considerably year-to-year. Kokanee have not been stocked since 2004. The 2008 escapement would have been the result of natural spawning in 2004 plus any kokanee stocked as age-0 in 2004 that spawned at age-4. In 2008, no age-3 or older kokanee were caught in the fall gillnets, and the low proportion of age-2 kokanee may mean a low escapement in 2009 (dependent upon total abundance) when spawners will be 100% the result of natural recruitment. Since 2006, escapement has steadily decreased. In 2008 escapement was 2000, and spawners were found almost exclusively in Flat Creek. Although the pattern of escapement could reflect stocking (1997-2004), even with fairly consistent stocking (50,000 per year), escapement has been variable, suggesting inconsistent survival during incubation or while rearing in the lake. Further, based on nearshore fall gillnetting, the relative abundance of age-1 and older kokanee in Wahleach has been lower during the period of fertilization than during baseline years. Several potential bottlenecks to successful recruitment seem plausible, and these are discussed below.

Age-0 kokanee were released in the vicinity of Boulder Creek, where quality spawning habitat is more limited than in any other tributary at Wahleach (Table 4-4). In the years since kokanee re-introduction, Boulder appears to have been over-utilized by spawners, and Boulder has been disrupted by major storms, thus almost certainly egg-to-fry survival has been relatively low. In recent years, it appears that spawners may be shifting to Jones and Flat where quality spawning habitat is relatively more plentiful, and where most spawners were found before 1981. If it is the case that spawners are being drawn over time to the best available habitat, then escapement may build in coming years. However, it is also possible that high flows and slope failures affect incubation in some tributaries in some years resulting in low egg-to-fry survival, and/or that in-lake mortality may affect recruitment. Cutthroat predation on fry may affect recruitment, as well as the quality of in-lake rearing habitat, including year-to-year variability in the production of edible algae and large zooplankton, competition for the zooplankton food resource, and sub-optimal temperature and dissolved oxygen concentrations in the pelagic zone during the warmest part of summer. It is not possible with the available data to assess the relative roles of in-stream versus in-lake mortality in regulating recruitment.

Among reservoirs and natural kokanee lakes, Wahleach is relatively shallow and the deepwater pelagic habitat preferred by kokanee is limited. Kokanee tend to avoid temperatures >17°C and dissolved oxygen concentrations <4 mg/L (Berge 2009), although juveniles may be more tolerant of these conditions than larger fish (Brett 1971; Coutant 1985; Rosland & Giske 1994). In general, the minimum dissolved oxygen concentration considered adequate for the protection of freshwater fish is 6.5 mg/L (CCME 2003). On July 30, 2007, the dissolved oxygen concentration in Wahleach Reservoir was <6.5 mg/L over much of the water column (Fig. 4-3). Low DO was also seen below 15 m in October 2008. On July 30, 2007, kokanee would have faced temperatures >17°C above 4 m and DO <6.5 mg/L below 10 m. Such a "temperature-DO squeeze" can reduce the amount of habitat suitable for kokanee, which is already limited in Wahleach, affecting feeding levels and growth, or altering activity and distribution in response to predation (Berge 2009, Hartman & Hayward 2007) for portions of the growing season when conditions are suboptimal. This situation may worsen if summer temperatures continue to increase over time due to climate change.

(3) Have kokanee and rainbow trout size and abundance increased?

Kokanee

Since kokanee were reintroduced to Wahleach Reservoir in 1997 their abundance has increased, but the current population size appears to be lower than before they were extirpated in 1995, and there may be large fluctuation in year class abundance. Fall gillnet catch rates indicate that abundance of age-1 and older kokanee increased 1998-2003, and has fluctuated since then below the maximum level observed in 1993. Absolute abundance estimates of all age groups from acoustics show that after re-introduction, kokanee abundance increased from 0 fish in 1997 to about 50,000 in 2000 (Perrin et al. 2006). The single acoustic survey available since then estimated kokanee abundance at 60,000 fish in 2007 (Scholten & Sebastian 2008), although this estimate is speculative because no trawl or pelagic gillnet data were collected to support the species apportionment. The very low catch rate of kokanee fry in 2008 trawl samples suggests very poor recruitment from the 2007 spawning, and gillnet catches suggest large fluctuations (e.g., 10-fold) in recruitment of age-1 kokanee in recent years.

For age-1 and older fish, mean length-at-age 1993-1994 (before extirpation) and 1999-2000 (shortly after reintroduction) were similar, whereas length-at-age has been greater since then. Correspondingly, biomass of this age group has been greatest since after 2000, based on fall gillnetting. In contrast, trawl sampling indicated that mean size of age-0 kokanee was larger 1998-2000 than in 2008, although small sample sizes in all years weaken this comparison.

Several factors have probably played a part in the biomass and length-at-age trends. Increases in kokanee abundance since 2000 were partly due to the presence of more age groups (including age 3 & 4) in later years. Over the period of fertilization, the size of age-1 and older kokanee has steadily increased, suggesting that fertilization and the increased abundance of zooplankton, especially *Daphnia*, has increased kokanee growth, and that competition for food with sticklebacks is not limiting the growth of this age group. Considering this, the small size of age-0 kokanee in 2008 is surprising, and may indicate growth limitation of fry due to inter- or intra-specific competition, although larger sample sizes are needed to be sure of size trends. The continued presence of sticklebacks in pelagic habitat in 2008 also suggests the possibility of competition with kokanee fry. Although kokanee abundance increased through 2003, it appears to have plateaued since then. This failure to increase further in recent years may be in part due to variable spawning or incubation success (see discussion of self sustaining kokanee population), limited suitable pelagic habitat (see discussion of self sustaining kokanee population), or predation by cutthroat trout (see cutthroat stocking rate discussion).

Rainbow trout

In the case of rainbow trout, both relative abundance and biomass have decreased to levels ≤baseline during the period of fertilization, but since 1993 there has been little or no change in rainbow trout length. Possible causes of the decreases in biomass and abundance include some combination of harvest, spawning/incubation losses, cutthroat predation, and decrease in benthic productivity. A creel survey will help quantify rainbow trout harvest, a spawner survey will help quantify rainbow trout escapement, and a fish diet study should help quantify cutthroat predation pressure on rainbow, and also identify the relative importance of benthic, pelagic, and terrestrial food items to kokanee, cutthroat trout, and rainbow trout. The information available on benthic productivity at Wahleach is discussed below.

Initially it was hypothesized that nutrient additions that increased zooplankton production might increase the abundance and size of rainbow trout in Wahleach (Perrin et al. 2006), as has occurred in some fertilized systems (e.g. Johnston et al. 1999). However, diet analysis indicated that the rainbow trout in Wahleach consumed terrestrial and invertebrate insects, and thus were not likely to directly benefit from nutrient additions that increase the supply of zooplankton (Perrin 1997), though there was potential for indirect effects of fertilization on rainbow trout via changes to littoral productivity. Increases in phytoplankton productivity may have positive or negative effects on littoral productivity and, in turn, benthivoruos fish such as rainbow trout. Fertilization might increase trout production if phytoplankton settles out of the water column and thereby increase food availability for benthos (e.g. Clarke et al. 1997; Blumenshine et al. 1997). On the other hand, increases in phytoplankton biomass as a result of fertilization may reduce water clarity and, in turn intercept light and thereby reduce bed illumination and the amount of benthic algae available for benthic invertebrates (e.g. Vadeboncoeur & Carpenter 2001; Vadeboncoeur et al. 2003). Evidence in the literature is equivocal, suggesting both that fertilization may positively affect growth of rainbow trout by increasing the supply of zooplankton (Johnston et al. 1999) and/or enriching sediments via phytoplankton that settles out of the water column (Blumenshine et al. 1997), or negatively effect growth by replacing relatively nutrient-rich and energy-dense benthic invertebrates with nutrient-poor and dilute zooplankton (Vadeboncoeur & Carpenter 2001, Vadeboncoeur et al. 2003, Beauchamp 2008).

Among reservoirs in general, annual drawdown may negatively benthic production by exposing littoral substrata. At Wahleach, a draw-down of 15 m decreases lake area by 125 ha, and exposes a large area of lake bottom at the north and south ends of the reservoir, and an alluvial fan at mid-lake, with potential to alter benthic productivity, streamflow, and access to spawning tributaries (Perrin 1997). During the first 3 year of fertilization, the mean length of trout older than age-1 decreased relative to baseline (1993-94), and was lower in 1997 than in any other year. Perrin et al. (2006) hypothesized that the 17 m drawdown during winter and spring of 1996 may have lowered benthic productivity resulting in smaller rainbow trout, and limited the spawning success of rainbow trout contributing to the absence of age-1 fish, in 1997 (although harvest may have contributed to the decrease in rainbow trout size). Since 2005, to prevent chronic exposure of shallow substrate, restore some littoral productivity, promote production of benthivorous trout, and provide access to spawning streams at critical time windows, the minimum reservoir operating water level has been 628 since (Perrin & Stables 2001). With the exception of 1997, rainbow trout size-at-age has been remarkably consistent among years (before and since fertilization).

(4) Have angler satisfaction and success increased?

Although angler survey data is scant for the study period, angler success has almost certainly increased since inception of the Wahleach Reservoir fertilization-stocking experiment. Following the start of kokanee and cutthroat trout stocking in 1997 the sport fishery progressed from essentially no fishery, to a fishery for rainbow and large cutthroat trout, to one focused on smaller rainbow trout and kokanee by 2001 (Perrin et al. 2006). During this period, total catch rate decreased from 1.4 fish/rod hour in 1998, when the catch was mainly rainbow and cutthroat trout, to 0.8 fish/rod-hour in 2001, when most large trout were protected by a 45 cm minimum size limit and kokanee were first becoming large enough for harvest (Perrin & Masuda 2002). From 1999 to 2001, cutthroat trout catch rates dropped due to the minimum size limit coupled with slower growth as sticklebacks declined in abundance, plus reduced cutthroat stocking rates. More recent catch rates for trout and kokanee are not known, as no subsequent creel surveys have been conducted.

Angler satisfaction was not measured in angler interviews, but gillnet data has shown that fish of a length generally considered satisfactory by anglers in low productivity lakes (23 cm, Askey, P., J.R. Post & E.A. Parkinson, personal communication) are present in the reservoir. Considering the mean size of fish in the fall gillnet catch, this size threshold was exceeded by age-3 and older cutthroat trout in all years, by age-3 and older rainbow trout in most years, and by age-3 and older kokanee since 2006. However, anecdotal evidence from conversations with a small number of anglers in 2008 indicated some dissatisfaction because their catch was mainly rainbow trout smaller than the 400 mm size limit (E. Johnson, BC Ministry of Environment, personal communication). The conclusions about satisfaction are tentative, and should be verified directly with a creel survey that evaluates catch rate, size of fish in the harvest, and angler satisfaction.

(5) Has cutthroat stocking controlled stickleback abundance?

Predation by stocked cutthroat trout clearly played a part in the control of sticklebacks following fertilization of Wahleach Reservoir, although other factors may also have been involved (Perrin et al. 2006). From 1997, when to cutthroat trout were first stocked, to 2000, stickleback numbers declined 94%, from 6 million to 351,000 fish. During those years sticklebacks made up 42% and 20% of the spring and fall diet of cutthroat trout. It appears that the 2,300-10,800 age-1 cutthroat trout that were stocked per year at that time were enough to control the large stickleback population. Since then, age-1 cutthroats have been stocked at a rate of 1,000-5,000 fish per year. The one fish abundance estimate since 2000 indicates that stickleback numbers were no more than 185,000 in 2007 (the upper 95% confidence limit for the total acoustic estimate), suggesting that stickleback abundance has remained low since it collapsed. During this later period there has been no quantitative sampling of cutthroat stomachs to determine their diet or level of predation on sticklebacks, however.

Predicting the level of cutthroat stocking necessary to maintain stickleback abundance at an acceptable low level would be a valuable management tool. What actually constitutes an acceptable stickleback population size has not yet been decided, though. Generally, it must correspond to a stickleback density low enough to avoid significant competition with kokanee (assuming food is limiting for kokanee) and high enough that cutthroats do not switch to kokanee as prey, which could lead to a substantial loss of kokanee. Beauchamp et al. (1995) estimated that age 0 and 1 kokanee and sockeye salmon made up 40% of the diet of pelagic cutthroat trout during spring and summer in Lake Ozette, Washington. Cartwright et al. (1998) estimated that cutthroat trout consumed from 33-67% of sockeye fry planted in Margaret Lake, Alaska. This predation is mediated by overlap of predator and prey spatial distributions (Beauchamp et al. 1992, Quinn 2005), and the risk of predation can increase during summer if high surface temperature and low concentrations of dissolved oxygen in the hypolimnion confine kokanee and cutthroat trout to the same narrow depth range (Berge 2009). Gillnet data from Wahleach Reservoir show that distributions of kokanee, rainbow trout, and cutthroat trout can overlap appreciably in both the pelagic and nearshore zones during the fall, and temperature and dissolved oxygen profiles indicate that a temperature-oxygen squeeze may occur there in some years (e.g., in 2007 and 2008). Qualitative examinations of cutthroat stomachs from Wahleach Reservoir have detected low numbers of rainbow trout and kokanee in recent years (E. Johnson, BC Ministry of Environment, personal communication), so the potential for cutthroat predation on other salmonids undeniably exists there. Thus, the proper stocking rate for cutthroat trout must hold stickleback density low enough to avoid appreciable competition with kokanee and high enough that cutthroats do not prey significantly on other salmonids.

5.2 Uncertainty in Fish Abundance

Measurements of abundance, size, age, and species characteristics of the reservoir fish community are required to monitor the success of the Wahleach kokanee recovery program. Three primary sampling methods have been used in combination to supply this information over the years of the study. Acoustic sampling provides absolute abundance and approximate body size information about fish of all sizes (kokanee, trout, stickleback); gillnetting provides relative abundance, species, and accurate body size data for fish >100 mm in length (trout and age-1 and older kokanee); and, trawling provides species and accurate body size data for fish <100 mm in length (kokanee fry and sticklebacks). Each of these methods has strengths and weaknesses that affect the reliability of the results they produce; the way they are implemented and coordinated with each other also affects the final product. This section discusses sources of uncertainty pointed out by the results to date and suggests remedies for them when possible. Gee trapping, which has provided largely qualitative information about small fish in the shallows is not discussed.

Examination of the available gillnet, trawl, and acoustic data lead us to question both the S&S and T&G methods for estimating kokanee and stickleback abundance from acoustics. The T&G method used 2008 gillnet and trawl data to estimate species composition of the 2007 acoustic fish population estimate, under the assumption that species composition and vertical distribution were the same both years. This assumption seems to be invalid. The 2008 trawl data indicated a very low proportion of kokanee fry in that year, while the typical (for Wahleach) catch rate of age-1 kokanee in 2008 gillnetting suggested that fry abundance (and proportion) had been typical in 2007. This indicates that species composition of small fish differed considerably between years, and that the 2007 T&G estimate of kokanee fry was probably much too low. Additionally, fish vertical distribution patterns were much different in 2007 and 2008 (Scholten and Sebastian 2008, G. Scholten, BC Ministry of Environment, personal communication), making 2008 trawl data a poor match for the 2007 acoustic survey. On the other hand, the S&S method used typical ratios of kokanee-spawners to total-kokanee and kokanee-0 to older-kokanee from other BC lakes to estimate the number of kokanee fry in the total acoustic estimate, assuming that annual kokanee recruitment is consistent from year-to-year in Wahleach Reservoir. However, the situation described above suggests high annual variation in recruitment, as does gillnet data (e.g., a 10-fold difference in age-1 CPUE from 2006 to 2008, Fig. 4-22). Therefore, kokanee fry and stickleback estimates by the S&S method are likely too high. Given the uncertainty about the consistency of recruitment and species composition among years, it appears advisable that trawling and mid-lake gillnetting be conducted in conjunction with each acoustic survey.

The differences between the acoustic sampling methods and equipment used before and after 2001 should not have affected the basic conclusions about total fish abundance (species combined) and abundance of sticklebacks over the course of the study. The methods, equipment, and sampling coverage used to measure the sharp decline in abundance from 6 million to 351,000 fish from 1997 to 2000 were the same each year (Perrin et al. 2006), so the 17-fold drop in fish abundance observed in that period, or at least some large decline in abundance, appears to be real and not due to inconsistent methodology. The 2000 estimate of 351,000 fish was within the realm of the 2007 abundance estimate of 145,000 fish, suggesting that stickleback abundance was approaching a new lower equilibrium level by 2000 and has remained low since then. As recognized by Sebastian and Scholten (2008), the 2007 and 2008 acoustic surveys only partially sampled shallow areas and may have therefore underestimated stickleback abundance in comparison to 1997-2000 surveys when survey coverage was more complete. Even so, as a "worst case" scenario, if the 2007 S&S estimate was 100% low, the actual population size would have been 290,000 fish, which is still similar to the 2000 abundance estimate. In any case, consistent transect coverage year-to-year would improve comparability of annual abundance estimates.

The low catch rate of age-0 kokanee in 2008 trawl sampling points to uncertainty about the behavior of kokanee fry and the effectiveness of trawl sampling in Wahleach Reservoir. Such uncertainty can not be resolved with the data that is available. In small lakes such as Wahleach that have a limited amount of deep water, kokanee/sockeye are typically concentrated over the deepest areas, rising up in the water column at night under cool isothermal conditions (J. Hume, Department of Fisheries and Oceans, personal communication), such as those that existed during the 2008 trawl sampling. Preliminary acoustic results from 2008 showed highest fish densities between 10 and 18 m deep, with low densities at maximum depth on all transects (G. Scholten, BC Ministry of Environment, personal communication). The 2008 midlake gillnet and trawl catches of kokanee were in agreement with these acoustic results, as follows: gillnets had highest catch rates for large kokanee from 15-20 m and kokanee fry were only caught in 15-17.5 m tows. The small 2.5 x 2.5 m trawl used in Wahleach has proved effective for sampling kokanee and sockeye fry in many other situations (P. Rankin, Department of Fisheries and Oceans, personal communication Therefore, it was expected that 2008 trawling would have captured more fry than it did if many had been present. Sebastian and Scholten (2008) postulated that few fry were captured because they were too close to the bottom to be sampled with the trawl. Although possible, this would be aberrant behavior for fry under the conditions at the time of the survey.

Some simple experiments could help to answer the questions about the behavior of kokanee fry and the effectiveness of trawl sampling in Wahleach Reservoir. Even if kokanee fry do stay near the bottom at night, they typically move up in the water column at dusk and dawn, even in lakes much smaller and shallower than Wahleach Reservoir (J. Hume, Department of Fisheries and Oceans, personal communication). Crepuscular acoustic and trawl sampling could identify these movements and help determine whether or not trawling can be effective. Other measures that may improve trawl results include deeper tows, which would limit sampling to a smaller part of the deepest basin, or sampling a larger part of the lake, which would mean only shallow tows outside the deepest basin. Comparisons of trawl estimates of kokanee fry to gillnet catches of the same cohort in the following year would also provide a useful benchmark. This will be possible in 2009, by comparing the 2008 trawl results for kokanee fry to the 2009 gillnet catch of age-1 kokanee.

Abundance estimates from acoustics were made without depth-stratified species apportionment. This was true for all years of the study, including the S&S and T&G abundance estimates for 2007. The 2000 and 2008 midlake gillnet sampling and systematic 2008 trawling showed clear vertical stratification of all fish species, so lack of depth-stratified species apportionment introduced error into species abundance estimates. For example, although 99% of rainbow trout were in the uppermost 5 m of the water column in 2008 (from midlake gillnet CPUE) which contained less than 7% of the acoustic estimate, their relative abundance was applied to the acoustic estimate for the whole water column. Most significantly for this study, this means that some large kokanee in deep layers were erroneously classified as trout. Therefore, depth-stratified species apportionment would improve accuracy of abundance estimates for all species.

In Wahleach Reservoir, estimates of species composition from nearshore gillnets poorly represented the open water fish population sampled with acoustics, as has been shown to be the case in some other systems (e.g. Stables & Perrin 2008, 2009). Estimates of percent kokanee were about 25% lower for nearshore netting than for midlake netting in Wahleach. In relatively small reservoirs like Wahleach without a true pelagic zone, kokanee and semipelagic trout share the open water zone where species composition can very considerably over time. This was noted in particular for trout in Wahleach. In addition, midlake netting was more efficient than nearshore netting for obtaining a sample of kokanee from Wahleach (midlake kokanee CPUE was 2.5 to 5.0 times nearshore CPUE). Depth-stratified midlake gillnetting provides accurate information about species composition of larger fish in the open water zone that is sampled by acoustics (Beauchamp et al. in preparation). Nearshore netting remains valuable for its long term continuity as a data set, and for the habitat-use information it provides.

In years of high small fish abundance (e.g., 1994-1998 in Wahleach), the abundance estimates of age-1 kokanee and small trout may have been inflated due to misclassification of small fish as large ones by acoustics (Crockett et al. 2006). This is especially likely for early years of the study when the echo sounding frequency was 420 kHz. For the size of fish involved, the target strength to fish length relationship is less precise for 420 kHz than for 120 kHz, which was used after 2000 (Horne & Clay 1998).

Down-looking acoustics alone can seldom produce reliable estimates of trout abundance (Yule 2000). Side-looking sampling is usually required for fish such as trout, which are semi-pelagic and typically inhabit shallow depths (Stables and Thomas 1992, Yule 2000). Depth-stratified pelagic gillnetting in 2000 and 2008 showed that trout in Wahleach Reservoir, especially rainbow trout, were mostly in the upper 5 m of the water column, meaning that trout were undersampled by the down-looking acoustics. Both the S&S and T&G methods of estimating fish abundance from acoustics were affected by this error. Side-looking sampling should be added if absolute estimates of trout abundance are desired.

6. Conclusions

The annual nutrient loading rate and seasonal loading pattern at Wahleach were selected to promote the growth of edible algae. Observations of chronic nitrogen limitation and chlorophyll concentrations which approach mesoeutrophic levels suggest that improving food quality for zooplankton may possibly be achieved through lower phosphorus loading rates, higher nitrogen to phosphorus ratio, and selection of seasonal loading rates that fit the evolving physico-chemical status of surface waters at Wahleach (Stockner 2005). Tailored nutrient loading should be combined with more quantitative information than has been available in the recent past about the abundance and biovolume of edible algae.

Stocking with age-0 kokanee appears to have successfully re-introduced kokanee to Wahleach Reservoir, although population abundance appears to fluctuate considerably year-to-year. Because 2009 will be the first year that recruitment will be entirely natural, it and subsequent years will provide the true confirmation of success. Since re-introduction, escapement and recruitment have been highly variable, which could be linked with variable egg-to-fry survival in tributaries with relatively poor spawning habitat, or with variable conditions in tributaries during the period of incubation. Alternatively, or in concert, variable recruitment could be linked with poor in-lake rearing conditions due to relatively high predation, or limited optimal pelagic habitat. Additional years of escapement data, fish abundance estimates, and a diet study, would help discriminate among the various possible explanations and reveal whether the re-introduction of kokanee was successful.

Since fertilization, the relative abundance and biomass of rainbow trout have each decreased, though in recent years abundance and biomass had increased modestly. Rainbow trout size has been remarkably consistent throughout the baseline and fertilization years. Possibly, the decrease in fish abundance (due to harvest, predation, or other factors) has compensated for any negative effects on fish size of reduced bed illumination/benthic productivity and the supply of benthic invertebrates, or any negative effects of fertilization on benthic productivity have been compensated by enrichment of substrata as a result of the increased phytoplankton production. Additional information on harvest, diet, cutthroat predation, and spawning success of rainbow may help distinguish among the possibilities, though the minimum reservoir elevation may well be crucial to maintaining rainbow trout habitat in Wahleach. Accurate estimates of rainbow trout abundance at Wahleach could be obtained with side-looking acoustic sampling.

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Currently, most age-3 and older trout and kokanee are large enough to be attractive to anglers (>230 mm), but most of the rainbow trout catch may be smaller than the 400 mm size regulation, causing some dissatisfaction. Creel surveys have not been conducted since 2001, so angler catch rates are not known for recent years. The conclusions about angler satisfaction and success are tentative and a creel survey is needed to evaluate catch rate, size of fish in the harvest, and confirm the level of angler satisfaction.

Cutthroat stocking has reduced stickleback to low levels in Wahleach reservoir, though it is not clear what stocking rate will keep stickleback abundance low without increasing predation on kokanee. Predicting the level of cutthroat stocking necessary to maintain stickleback abundance at an acceptable low level would be a valuable management tool, but the available data are not useful for determining cutthroat stocking rates to meet this goal. Since 2000, when stickleback abundance reached a low level, there has been only one acoustic survey giving a rough estimate of stickleback numbers for comparison to cutthroat stocking rates. In the same period, there has been no quantitative sampling of cutthroat trout diet to determine predation rates on prey species. Yearly fall acoustic surveys with accurate species composition estimates (from trawling and pelagic gillnetting) and annual collection of cutthroat stomachs for diet analysis (from spring and fall gillnetting) could provide the information necessary for this analysis. Bioenergetic modelling of cutthroat predation on sticklebacks and colane, and of competition between kokanee and sticklebacks, might also provide insight into effective stocking rates.

The general trend of stickleback abundance that was measured with acoustic surveys (several million in 1997 declining to less than half a million by 2000) seems difficult to dispute. Despite differences in equipment and transect coverage between 1997-2000 surveys and next survey in 2007, it appears that stickleback abundance remained at a low level (<200,000 fish) in 2007.

Accurate estimates of kokanee and stickleback abundance from acoustic surveys are needed to assess fertilization and cutthroat predation effects on fish in Wahleach Reservoir. Obtaining accurate estimates has been hampered by the difficulty of gathering accompanying trawl data for species apportionment. This data is required to avoid "speculative" species composition estimates made without trawl data (Scholten and Sebastian 2008), however questions about kokanee behavior and trawl efficiency need to be resolved before trawl data can be considered reliable. The questions could be answered through some simple field experiments. Species composition of fish larger than sticklebacks and kokanee fry can best be supplied by depth stratified midlake gillnetting. Although nearshore gillnet data is a valuable time series that should be continued, it does not accurately represent the pelagic fish population in Wahleach Reservoir that is sampled by acoustics.

Trout abundance estimates from acoustic surveys conducted to date are considered unreliable because only a down-looking transducer orientation was used for acoustic sampling. Side looking sampling is considered necessary for acoustic surveys of trout (Yule 2000), which are often found very near the lake surface.

The ability to assess fertilization and cutthroat stocking effects would be improved by more frequent acoustic surveys coupled with trawling and midlake gillnetting, all with consistent seasonal timing (traditionally October for Wahleach Reservoir).

7. Management and monitoring recommendations

1) **Nutrient loading and chlorophyll a** Possibly, the productivity of edible algae could be increased by fine-tuning the fertilizer applications to the seasonally dynamic physico-chemical conditions in Wahleach. For instance, the current nutrient loading rates may occasionally favour blooms of Cyanobacteria, and possibly nitrogen limitation could be avoided by increasing the mid-summer nitrogen loading (relative to phosphorous loading), followed by nitrogen loading without phosphorus in the fall (J. G. Stockner, personal communication; Stockner & Shortreed 1988). In addition, during the period of strong stratification, the current nutrient loading rates may favour algae that are better suited to mesoeutrophic than to coastal oligotrophic conditions, and possibly mesoeutrophic conditions could be avoided by reducing phosphorous loading when the epilimnion is relatively shallow. Last, more frequent than monthly monitoring of the concentrations of nitrogen to phosphorus, and the phytoplankton assemblage, and distinguishing edible and inedible algae, may help fine-tune the fertilizer applications. Over the years there has been some uncertainty in the results of the chlorophyll analysis. As a result, the project has performed the analysis of chlorophyll on the project fluorometer for the last two years. More recently, questions have arisen about the efficiency of chlorophyll extraction with different filter types. Given the importance of chlorophyll concentrations in determining trophic status, it seems important to continue the efforts to strive for a high level of analytical accuracy.
2) **Physico-chemical condition and vertical distribution of zooplankton** The amount of deep, cool water habitat preferred by kokanee is limited in shallow systems such as Wahleach. During the period of strong stratification at Wahleach, the availability of optimal habitat for kokanee may be further constrained by the high temperature of surface water and low dissolved oxygen content of deep water. More frequent than monthly water column profiling of temperature and oxygen concentrations may help assess the quantity and quality of kokanee habitat, which may vary from year-to-year and, in addition, may help clarify if kokanee habitat is thermally separated from cutthroat trout habitat. Data on the vertical distribution of *Daphnia* would help assess if habitat squeezing may force kokanee into sub-optimal habitat to gain access to the zooplankton food resource.
3) **Future kokanee stocking** Any future releases of age-0 kokanee probably should probably be in the vicinity of Jones and Flat Creeks, rather than Boulder Creek, so there is a chance the kokanee will utilize the best available spawning habitat.
4) **Cutthroat stocking rate** Predicting the cutthroat stocking rate that may correspond with control of stickleback abundance, without substantial predation on kokanee, would be a valuable management tool. Possibly, rainbow trout stocking could alleviate predation pressure on kokanee by providing alternate prey for cutthroat trout. Additional data on spatiotemporal distributions, abundance, and the diet composition of cutthroat combined with bioenergetics

modelling would help identify cutthroat-stickleback and cutthroat-kokanee interactions and habitat overlap (e.g. Beauchamp et al. 1995).

5) **CREEL survey** A creel survey should be conducted to confirm angler satisfaction and harvest rates, and to provide details about the fish of interests of anglers. The survey should be conducted on at least 5 days per month, for 8 hours a day over a 4 month period (a sample survey form is in Appendix A2).
6) **Cutthroat diet study** A diet study is needed to assess cutthroat trout predation rates on stickleback, kokanee, and rainbow trout. In fall 2008, cutthroat trout were found at all depths but most cutthroat were in near-surface waters. At Wahleach, nearshore nets cover the epilimnion and part of the thermocline and therefore may provide a sufficient number of cutthroat trout for a reliable diet assessment.
7) **Rainbow trout fishery** The rainbow trout population at Wahleach may be self-sustaining. The rainbow trout fishery appears to attract anglers, though a creel survey is needed to confirm this. A creel survey would also help assess any effects of harvest on rainbow trout size and abundance, and help evaluate if the current restriction on catchable size (400 mm) can be lowered without affecting productivity.
8) **Accurate estimates of fish abundance** Comparison of trawl and nearshore and pelagic gillnet catches at Wahleach indicate that accurate apportionment of acoustic estimates of pelagic fish abundances probably cannot be achieved with out depth-stratified pelagic gillnetting and trawling. Moreover, given that earlier acoustic surveys in Wahleach have at times found stickleback concentrated near lake margins (observed on echograms), it seems important to sample shallow water habitat with acoustics.

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Appendix A1 Record of fish stocking

Release year	Release date	Species	Number Released	Mean wt (g)	Age at release
1930	1-Jan-30	Rainbow Trout	15000	0	1
1934	1-Jan-34	Kokanee	50000	0	0
1935	1-Jan-35	Kokanee	50000	0	0
1936	1-Jan-36	Kokanee	50000	0	0
1997	28-Apr-97	Kokanee	50000	1.02	0
	9-May-97	Cutthroat Trout	2273	157.95	1
1998	28-May-98	Kokanee	50000	3.21	0
	17-Jun-98	Cutthroat Trout	1498.5	103.09	1
	25-Jun-98	Rainbow Trout	2010	186.57	1
	8-Sep-98	Cutthroat Trout	1057	89.34	1
1999	27-May-99	Cutthroat Trout	4066.5	125.035	1
	3-Jun-99	Cutthroat Trout	1315.5	125.05	1
	10-Jun-99	Kokanee	51682	4.48	0
2000	7-Jun-00	Cutthroat Trout	3045	111.66	1
	8-Jun-00	Kokanee	52000	4.77	0
2001	-	-	-	-	-
2002	21-Jun-02	Cutthroat Trout	1000	137.39	1
	27-Jun-02	Kokanee	35200	7.61	0
	4-Jul-02	Rainbow Trout	2866	174.81	1
	15-Jul-02	Rainbow Trout	2860	178.57	1
2003	14-May-03	Kokanee	50000	3.49	0
	20-May-03	Cutthroat Trout	3000	63.56	1
	26-Jun-03	Cutthroat Trout	493	95.3	1
2004	13-May-04	Cutthroat Trout	3000	65.8	1
		Kokanee	50000	3.39	0
	28-Jul-04	Cutthroat Trout	1995	113.74	1
2005	27-Jun-05	Cutthroat Trout	2994	89.96	1
2006	5-May-06	Cutthroat Trout	3000	64.67	1
2007	29-Jun-07	Cutthroat Trout	782	64	1
	11-Jul-07	Cutthroat Trout	1220	64	1
2008	-	-	-	-	-

Appendix A2 WAHLEACH CREEL SAMPLE SURVEY FORM

WAHLEACH CREEL SURVEY

May	June	July	August	Sept
2	9	2	2	6
4	11	11	4	16
15	12	17	6	26
28	14	20	17	28
31	29	26	22	29

per month, randomly selected Friday, Saturday, Sunday, and two weekdays

LAKE	WAHLEACH	**NOTES:**	kokanee	KO
	yr/mo/day	Use the official fsh species codes:	Cutthroat trout	CT
DATE		Residence Codes:	Rainbow trout	RB
		R - resident		
DAY		NRC = nonresident Canadian		
		NRA = nonresident American		
WEATHER				

# of angLers per boat	residence (R, NRC, NRA	# rods	# hours on lake fishing	Sp. sought	Sp. killed	# killed	# released	length of fish killed (mm)	weight of fish killed (g)
	DAILY SUMMARY								
	# of fish of each species								
	KOK			CT			RB		
# anglers									
# rods									
# rod hours									
# killed									
# released									

Appendix A3 October 2007 hydroacoustic survey of Wahleach Reservoir (G. Scholten & D. Sebastian)

Stock Management Report No. 32, 2008, Province of British Columbia, Ministry of Environment Ecosystems Branch

INTRODUCTION

The Wahleach 2007 Hydroacoustic survey was conducted as part of an ongoing kokanee restoration project initiated in 1993. Nutrient additions and fish stocking strategies have been applied to reduce in-lake competition of introduced stickleback to benefit kokanee. Fish stock monitoring efforts have included gillnetting, minnow trapping, spawner enumeration, trawl sampling and hydroacoustics. This report presents the results of the hydroacoustic survey conducted during the night of October 30, 2007.

METHODS

A Simrad EK60 120 kHz split beam echosounder with a downward looking transducer was employed to collect the survey data. The transducer was towed from the side of the survey boat at a depth of 0.5m. Survey data was collected continuously along 11 predetermined transect lines run diagonally across the Reservoir. Transects were navigated with the aid of a Lowrance LCX27-C GPS, boat speed was approximately 2m/s. Data collection and analysis parameters are found in Appendix 1. Acoustic data was monitored on a computer screen during collection and stored on hard disk for later analysis.

Split beam data was analyzed using Sonar5 post processing software. Estimates of fish size and abundance were reported as traced fish/ha per 2m depth strata. Program outputs provided density by 12 size groups of 3dB increments from –62 to –26 dB, (Appendix 2). A size apportioned population estimate was computed by multiplying the average layer densities by the corresponding habitat strata area and summed for the Reservoir population. A maximum likelihood estimate and 95% confidence interval for all fish was computed through a Monte Carlo Simulation procedure using 30,000 iterations.

Echo target strengths from tracking were plotted in 1dB increments to determine the cut-off points between two main size groups of fish in the Reservoir. Age 1-3 kokanee, cutthroat trout and rainbow trout being the larger sized component and age 0 kokanee and stickleback being the smaller sized component, tracking criteria are found in Appendix 1.

Species proportions between stickleback and age 0 kokanee are speculative and were based on a range of proportions of kokanee spawners to total kokanee and age 0 kokanee to the older age classes of kokanee that would typically occur in other BC lakes. The non-kokanee components were apportioned to stickleback for small fish and to rainbow and cutthroat trout for large fish. Wahleach gillnet and spawner length data were used to determine acoustic cut offs and overlaps for kokanee, rainbow and cutthroat. The 2008 trawl data was used to determine target strength ranges form stickleback length measurements. Love's 1977 empirical formulas were used to convert fish length data to acoustic (dB) equivalents, (Appendix 2).

RESULTS

Survey Conditions and Effort

The Reservoir surface elevation, ambient air and lake surface temperature were 637.13m, 2°C and 5°C at the time of the survey. The survey was conducted from a 5.5m open work boat. Navigation of the Reservoir was made possible by use of a portable GPS and a 10 million-cp flashlight mounted on the bow. All transects were run using predetermined GPS start and end points (Fig 1). Transects were run diagonally across the Reservoir in attempt to simplify data collection. The combined linear length of the 11 transects was approximately 10km and represents about 85% of previous survey effort. Transects were aligned to assure representative sampling of habitats >6m depth.

The average start and end depth of the acoustic transects was 8.5m. An estimated 92 ha of habitat with a depth of < 8m was not surveyed.

Fish density

Total transect densities in 2007 ranged from 300 to 2300 fish$\cdot$ ha^{-1} with the highest densities found in the deeper central portion of the Reservoir (Fig 2). This has been the pattern for fall surveys conducted from 2000 – 2007. Prior to and during the onset of fertilization from 1993 – 1998 peak densities were found in the shallower habitats at the ends of the Reservoir according to Perrin and Stables (2001).

Very few fish were found in the upper 6m of the water column (Fig 3; Appendix 3). Average fish density increased with depth and the maximum occurred within a few meters of the lake bottom (Appendix 6). Perrin and Stables (2001) noted that the peak fish density had sequentially shifted lower in the water column since fertilization and stocking of triploided cutthroat trout. The precipitous declines seen in total fish abundance over the same period suggest that predation could be responsible for the reduction of fish from the surface and mid water zone.

Reservoir fish populations

The total in-lake acoustic fish population estimate for all species in the Reservoir was 145,400 (114,700 - 184,400) (Table 1; Appendix 4). The population estimate does not include the 2007 kokanee spawners which had left the Reservoir. Habitat areas used for expansion of fish densities to a Reservoir population were derived from Perrin and Stables (2000) using the 640m elevation as the benchmark for a full pool surface area of 410 ha. Habitat areas were adjusted to reflect the Reservoir elevation at time of survey which was down ~ 3m from full pool. Pool elevations have ranged from 639.30 to 637.13 for surveys conducted from 1997 to 2007. Average stratum densities, habitat areas, and maximum likelihood estimate (MLE) statistics can be found in Appendix 4. Sampling of shallow habitats using Gee traps would help to verify if the acoustic survey missed any significant numbers of stickleback in areas not sampled. The un-surveyed habitat represents 25% of the Reservoir and could boost the total population significantly if densities near bottom continue into shallower water.

Table 1. **Wahleach Reservoir population estimates size based on hydroacoustics surveys.**

	Population estimates ± 95% confidence interval				
Year	Kokanee	Stickleback	Cutthroat	Rainbow	All Species
1993	Undetected	1,173,850 ± 24%	0	No estimate	1,173,850 ± 24%
1997	Undetected	6,046,685 ± 41%	No estimate	No estimate	6,046,718 ± 41%
1998	30,134 ± 35%	4,274,685 ± 35%	No estimate	No estimate	4,304,819 ± 35%
1999	27,562 ± 27%	464,628 ± 27%	No estimate	No estimate	492,190 ± 27%
2000	50,409 ± 25%	351,181 ± 25%	18,084 ± 25%	10,549 ± 25%	424,263 ± 25%
2007[1]	60,000 ± 27%	75,000 ± 27%	2,500 ± 27%	7,500 ± 27%	145,400 ± 27%

1 See Species Composition section for details on species proportioning of the population

DISSCUSSION

Fish Size

Tracking was used to look at acoustic size distribution of fish targets throughout the Reservoir to discern possible size groupings and help determine species composition. Tracking functions employed to analyze target distributions were fish size, aspect angle, and location relative to the surface and the bottom. Tracked target estimates of size (TS) at depth were evenly distributed from 8 - 26m relative to the surface. When the same fish are viewed in relation to the bottom, 80% of the tracked targets were found within 4m of the lake bottom (Fig 4). In viewing the cumulative TS frequency distribution of tracked targets the point of inflection found at - 47dB indicates a separation between a large group of small fish which include age 0 kokanee and stickleback, and the group of larger sized fish which are a mix of rainbow, cutthroat and age 1-3 kokanee (Fig 5).

Loves 1977 dorsal aspect formula was used to convert Wahleach 2007 fish length sample data to acoustic size equivalents for comparison with the echosounder TS distribution. Generally the size ranges of the fish samples fit the sounders frequency distribution, (Fig 6). The high proportion of smaller sized fish in the Reservoir was approximately 2 to 3 times higher than would be expected for a typical kokanee population. There was no correlation between fish size and depth to help separate stickleback from age 0 kokanee. Temperature was ruled out as a useful factor as the Reservoir was almost isothermal at the time of the survey. Light extinction is a strong driving factor affecting kokanee behavior in seeking refuge from predators. When there is insufficient water depth, kokanee will seek cover on the bottom. A slight difference in this behavior between kokanee and stickleback may be a factor contributing to low kokanee to stickleback proportions seen in trawl sampling to date. Kokanee in large lakes are typically found at 15 to 30m from the surface at night. In Wahleach this would put the majority of the kokanee fry within the bottom 2 to 4m of the Reservoir at night.

The long tail on the TS distribution beyond -47dB representing age 1 and older kokanee, cutthroat trout and rainbow trout may be slightly under estimated as kokanee spawners had left the Reservoir before the survey. By scaling the acoustic size distribution of the sounder for fish > - 47dB, the cutthroat trout, rainbow trout and kokanee samples can be fit surprisingly well to the acoustic size frequency curve. Interestingly one can see where the age 0 and age 1 kokanee not sampled in 2007 fit under the acoustic curve. Size ranges for age 0 and age 1 kokanee would be ~-56 to -47dB and ~-47 to 41dB respectively.

Applying Love's dorsal and 45° formula to real fish data produces size distributions slightly different from the TS data collected with the EK60. Love's 1977 empirical formula from the dorsal aspect may slightly under estimate the size of small (ie. fry sized) fish while the 45° aspect tends to overestimate the size of large fish. When the 45° aspect formula is applied to the echosounders acoustic size distribution, the upper bins of large fish cannot be accounted for in the fish sampling data base. The target aspect data from tracking suggested that mean TS estimates required minimal aspect correction in relation to the dorsal aspect formula.

Species Composition

Species composition of the acoustic population within the habitat sampled (depths >8m) was complicated by a number of factors: low acoustic population, high stickleback to age 0 kokanee expectation from trawling, insufficient data on stickleback habitat preferences and poor thermal stratification. Because we have more comparative data and a better understanding of age & size structure of kokanee populations (compared to stickleback), we used a range of kokanee data from other BC lakes to first determine a most likely range of kokanee in Wahleach Reservoir. Two approaches were taken. The first applied a range of spawner to total inlake kokanee proportions of 5 – 9% to the recent spawner count data. A second approach used gillnet catches of rainbow and cutthroat trout based on TS to subtract these fish from the total large fish group and assume the rest were age 1-3 kokanee. A typical proportion of age 0 to total kokanee (range of 50-90%) was then applied to the age 1-3 & reported kokanee spawners to estimate kokanee fry numbers. The remaining small fish were assumed to be stickleback. Gaming with proportions provided a range of stickleback to kokanee fry ratios of 1 : 0.25 to 1 : 3.0, Appendix 5. Gillnet catch proportions of 3 : 1 (RB : CT) were used to proportion rainbow and cutthroat trout to the acoustic population (Fig 7).

SUMMARY

Results are in agreement with Perrin and Stables (2000) conclusion that combined "bottom up" and "top down" control mechanisms can be successful in fish population restoration in oligotrophic reservoirs subject to tropic depression and dominance by an introduced nuisance species. The abundance of kokanee in the Reservoir has increased since treatments started and may have leveled off in 2007 at around 60,000 fish.

Reduction of the stickleback population has been very significant and may have reached a point where cutthroat trout are starting to predate more heavily on kokanee. The ratio of stickleback to kokanee may have shifted from 7:1 to 3:1 since 2000. The 2004 Cutthroat stomach analysis suggests there is more unidentifiable fish flesh than stickleback per stomach indicating a possible shift in diet.

Stocking of cutthroat trout may need to be reduced and replaced with more rainbow trout to maintain angler interest and reduce predation pressure on the building kokanee population. Currently 2 -3 thousand cutthroat trout yearlings are stocked annually. Perrn and Stables (2000) recommended that stocking of cutthroat be reduce to 1000 fish per year after 2000.

Additional Gee trapping of shallow habitats would help to verify if the acoustic survey missed any areas with significant numbers of stickleback in areas not sampled. The un-surveyed habitat represents 25% of the Reservoir and could boost the total population.

DISCLAIMER

The Wahleach 2007 acoustic survey was the first survey conducted by MINISTRY OF ENVIRONMENT- FSS[1] staff using the EK60 sounder. Prior to analysis and reporting on the survey some paired comparative data collections and analyses were required In 2008 to understand the EK60 performance in respect of the equipment used for large lake time series acoustic surveys conducted from 1991 – 2008. As such this is a Draft subject to revision.

[1] Ministry of Environment, Fisheries Science Section, Victoria BC

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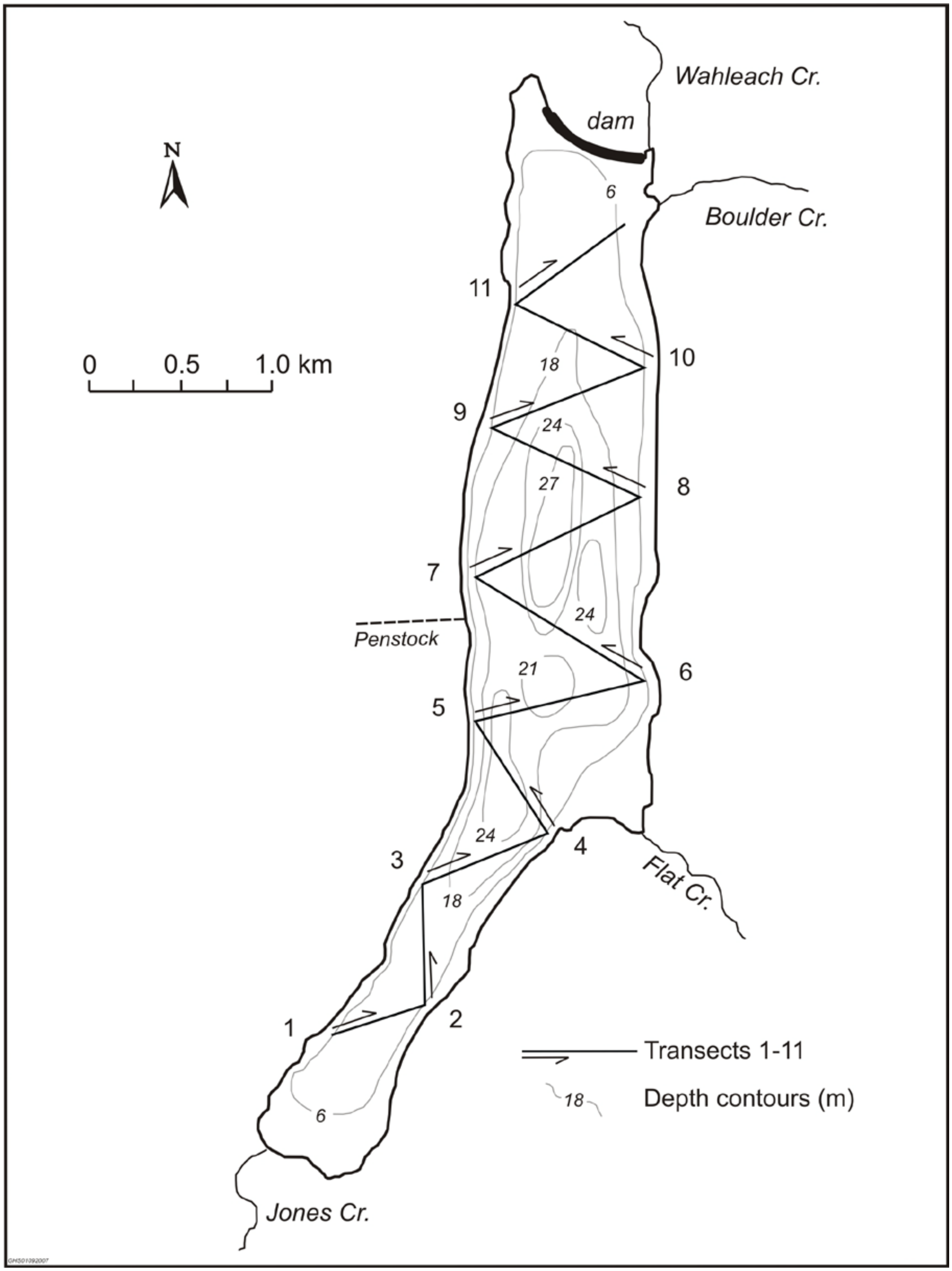


Figure 1. Wahleach Reservoir hydroacoustic survey transect locations, October 2007.

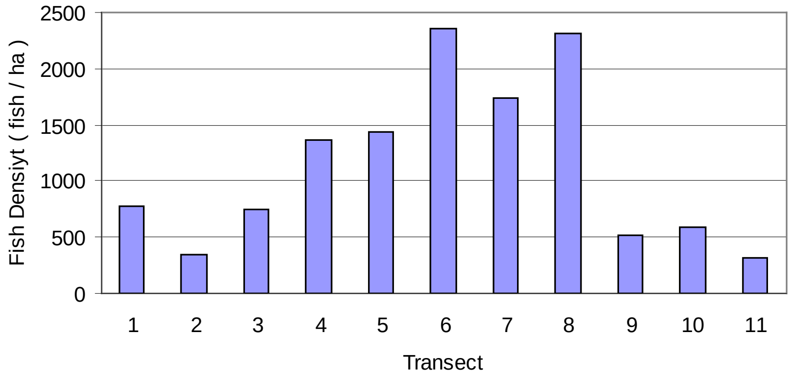


Figure 2. Wahleach Reservoir transect fish density distribution, October 2007.

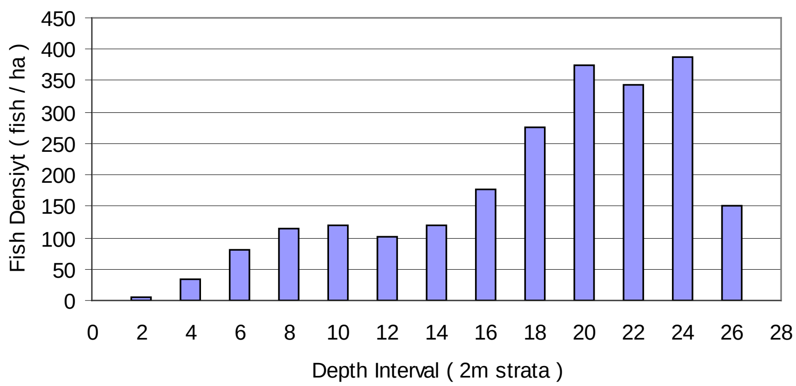


Figure 3. Average fish density at depth for 2m strata from 2007 survey transect data.

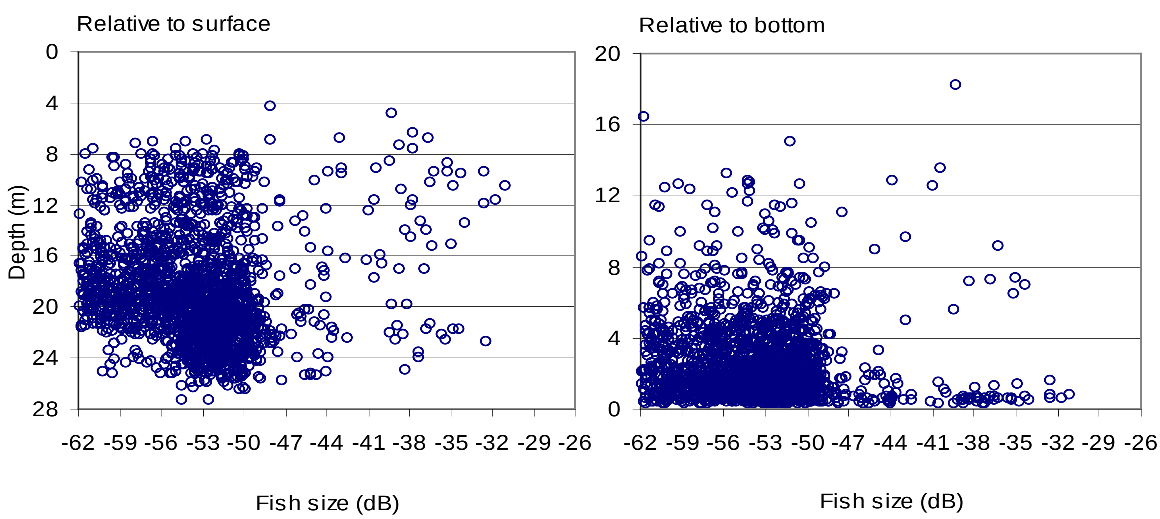
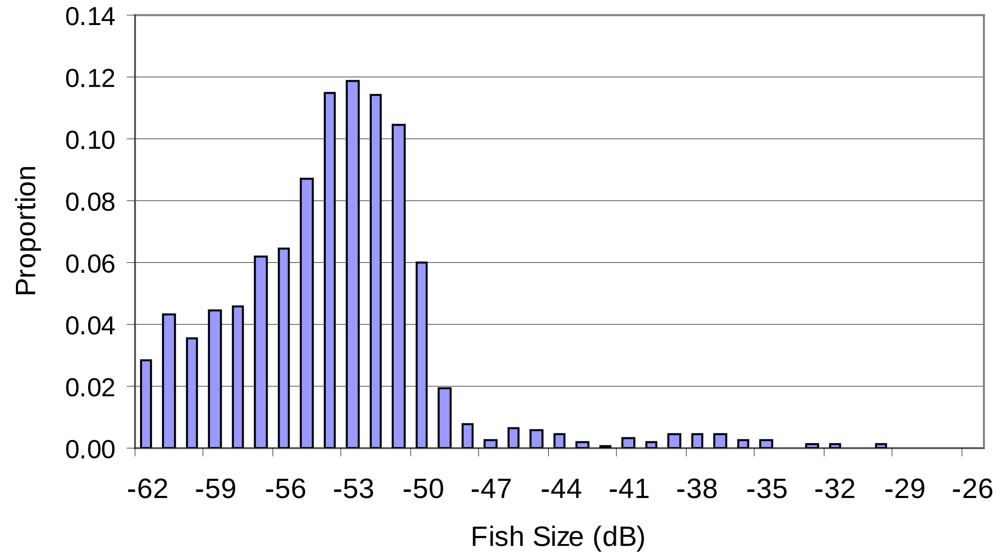


Figure 4. Location and size of tracked fish targets relative to surface and bottom at time of survey, from 2007 tracking data.



Note: size distribution is by 1dB increments

Figure 5. Tracked fish size (dB) distribution from all transects and all depth strata, from 2007 tracking data.

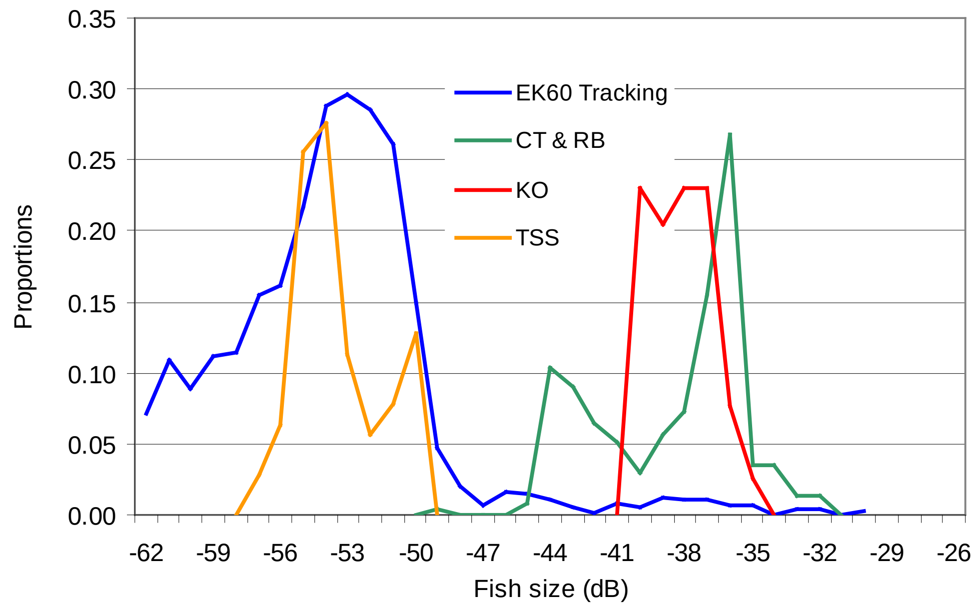


Figure 6. Comparison of acoustic fish size (dB) equivalents from fish samples and EK60 tracked target data**.** Fish samples were converted using Love's 1977 dorsal aspect formula.

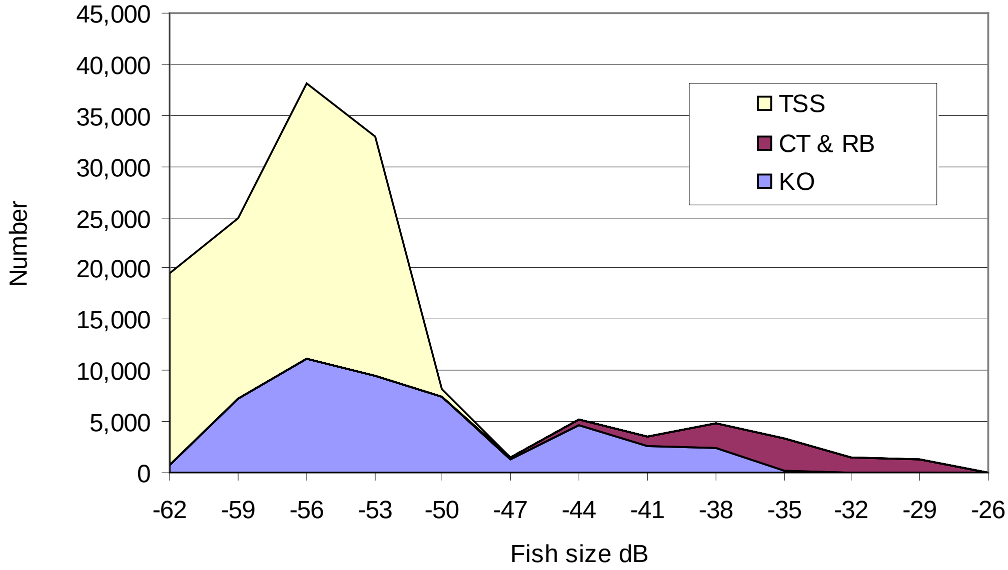


Figure 7. Possible species composition of kokanee, stickleback, rainbow trout and cutthroat trout based on acoustic size distributions, fish length data, spawner counts and population bio-statistics modeling.

Appendix 1. Hydroacoustic Equipment Specifications and Data Analysis Parameters used for the Whaleach 2007 Survey

Project Phase	Category	Parameter	Value
Data collection	Echosounder	Manufacturer	Simrad EK60
"	Transceiver	Frequency	120 kHz
"	"	Max power	500 W
"	"	Pulse duration	0.256 ms
"	"	Band width	8.71 kHz
"	"	Absorption coefficient	4.0 dBKm
"	Minimum echo value	Amplitude threshold	-70 dB (40 Log R TVG)
"	Transducer	Type	split-beam
"	"	Depth of face	0.5 m
"	"	Orientation, survey method	vertical, mobile, tow foil
"	"	Sv, TS transducer gain	27.0 Db
"	"	Angle sensitivity	23.0
"	"	nominal beam angle	7.0 dg.
"	"	Data collection threshold	-70 dB
"	"	Ping rate	6 – 8 pps
Analysis	Processing software		SONAR5 version 5.9.1.1
"	Single target filter	Min Threshold	-62 dB (12 3dB bins TS max -26 dB)
"	"	Min echo length	0.8 – 1.8
"	"	Max Gain compensation	6 dB
"	Fish tracking"	Minimum no. echoes	2
"	"	Max range change	0.20 m
"	"	Max ping gap	1

Appendix 2. 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).

Appendix 3. Wahleach 2007 acoustic survey transects densities (Fish/ha) by 2 meter depth intervals.

	Transect										
depth	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	26	0	0	0	31	0	0
4	169	9	0	6	93	0	0	36	0	0	50
6	609	42	2	17	77	24	17	22	5	15	47
8		94	66	47	25	151	40	83	77	325	224
10		201	69	114	48	108	30	69	186	247	
12			142	107	109	61	56	14	219		
14			111	124	117	124	91	146			
16			165	120	161	114	183	312			
18			145	190	300	236	271	508			
20			43	447	336	380	297	745			
22				200	150	575	422	373			
24						440	337				
26						150					
28											
Total	778	346	743	1372	1442	2363	1744	2308	518	587	321

Notes:

Depth intervals 0 = from 0.0 to 2.0m

Grey area max bottom depth

Transect 1: targets in the 6m strata need to be reassessed as most targets appear to be associated with bottom structures.

Appendix 4. Maximum likelihood estimates and bounds for October 2007 Wahleach survey based on Monte Carlo simulations.

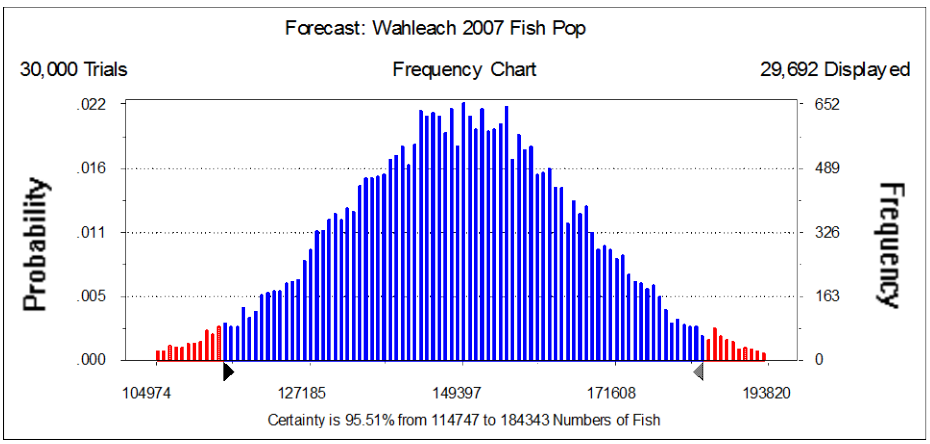
Depth	N	Average Density	STDEV	SE	Area	Population		
0	11	0	0.00	0.00	351	0		
2	11	5	11.58	3.49	314	1627	UB=	184,343
4	11	33	53.99	16.28	280	9240	MLE=	145,400
6	11	80	176.85	53.32	249	19852	LB=	114,747
8	10	113	94.81	29.98	217	24564		
10	9	119	75.59	25.20	187	22274		
12	7	101	66.96	25.31	159	16082		
14	6	119	18.06	7.37	131	15567		
16	6	176	71.93	29.37	93	16353		
18	6	275	126.95	51.83	48	13200		
20	6	375	228.01	93.08	19	7119		
22	5	344	172.23	77.03	8	2752		
24	2	389	72.83	51.50	2	777		
26	1	150			1	150		

Crystal Ball Report
Forecast: Wahleach 2007 Fish Pop

Summary:

Certainty Level is 95.51%
Certainty Range is from 114747 to 184343 Numbers of Fish
Display Range is from 104974 to 193820 Numbers of Fish
Entire Range is from 83200 to 227800 Numbers of Fish
After 30,000 Trials, the Std. Error of the Mean is 100

Statistics:	Value	Statistics:	Value
Trials	30000	Kurtosis	3.02
Mean	149485	Coeff. of Variability	0.12
Median	149500	Range Minimum	83200
Mode	145400	Range Maximum	227800
Standard Deviation	17258	Range Width	144600
Variance	297850568	Mean Std. Error	99.64
Skewness	0.03		



Appendix 4. (continued)

Waheach Reservoir Habitat Areas

Elevation	depth (m)	Area (ha)	Elevation	depth (m)	Area (ha)
640	0	410	624	16	159
639	1	397	623	17	**145**
638	2	383	622	18	131
637	3	368	621	19	**117**
636	4	**351**	620	20	93
635	5	334	619	21	**69**
634	6	**314**	618	22	48
633	7	295	617	23	**26**
632	8	**280**	616	24	19
631	9	264	615	25	**12**
630	10	**249**	614	26	8
629	11	234	613	27	**4**
628	12	**217**	612	28	3
627	13	201	611	29	**1**
626	14	**187**			

Note: Reservoir elevation at the time of the 2007 acoustic survey was 637.13m.Bolded areas are midpoints of 2m depth strata areas used for expansion of acoustic densities. The table was developed from data supplied by Shuksan Fisheries Consulting Ltd.

Wahleach reservoir depth interval areas and volumes			
based on data supplied by BC Hydro			
Depth 0 = surface elevation 640 m			
Depth interval	midpoint Depth (m)	Area (sq. m)	Volume (cu.m)
0-2m	1	3,974,726	7,949,452
2-4m	3	3,676,827	7,353,655
4-6m	5	3,335,652	6,671,303
6-8m	7	2,951,199	5,902,398
8-10m	9	2,642,585	5,285,170
10-12m	11	2,338,086	4,676,173
12-14m	13	2,009,801	4,019,602
14-16m	15	1,735,498	3,470,995
16-18m	17	1,451,880	2,903,761
18-20m	19	1,167,201	2,334,401
20-22m	21	686,361	1,372,722
22-24m	23	264,841	529,681
24-26m	25	123,223	246,446
26-28m	27	41,074	82,149

Note: Provided by Shuksan Fisheries Consulting Ltd, 2008

Appendix 5. Kokanee and Stickleback Proportions (Gaming with the Data)

(1) Age 0+ to total proportions
(2) Spawner to total proportions

CT & RB		2007 Acoustic Population	KO & TSS	KO	TSS
	-62	19,534	19,534	7,098	12436
	-59	24,839	24,839	9,026	15814
	-56	38,190	38,190	13,877	24313
	-53	32,898	32,898	11,954	20944
	-50	8,206	8,206	2,982	5224
228	-47	4,556	4,328	1,573	
522	-44	5,216	4,694	4,694	
878	-41	3,512	2,634	2,634	
2,388	-38	4,775	2,388	2,388	
3,184	-35	3,351	168	168	
1,537	-32	1,537			
1,272	-29	1,272			
	-26				
10,007	Total	147,886	137,879	56,392	78,731
		± 25%		44,936	78731

ɔ2 to -47.1d

(1) Age 0+ to total proportions

60%	KO 0+ to 1++ proportion, variable .5 to .8 Acoustic survey data, MOE Victoria
40%	KO 1++ proportion

(2) spawner to total proportions

7%	Spawner to total kokanee population Acoustic survey and Spawner data, MOE Victoria

KO Kokanee
TSS Three Spine Stickleback
CT Cutthroat Trout
RB Rainbow Trout

		Size Ranges
Kokanee 0+ and Stickleback	123,667	-62 to -47.1dB
Stickleback	78,731	
Kokanee 0+	44,936	
Kokanee 1++ non spawners	14,044	-47 to -35.1dB
2007 Spawner est	3931	-38 to -34.5
Total kokanee 1+ to spawners	17,975	-62 to -35.1dB

Note: 2007 Spawners had left the survey area and are not part of the acoustic size distribution

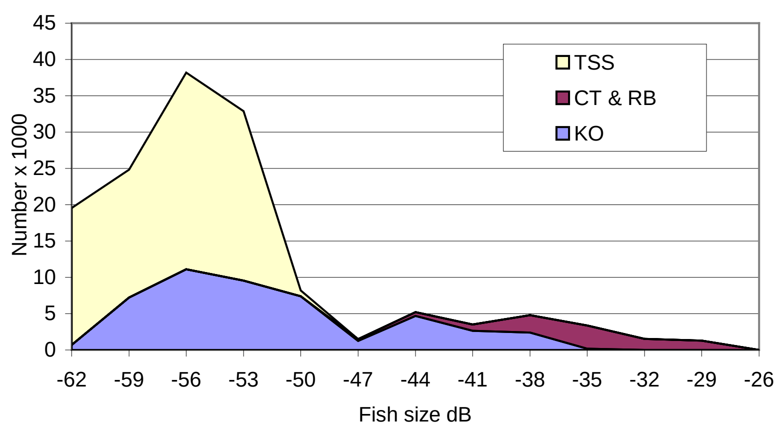
Spawwner Count	
3931	± 25%
3931	1

CT & RB > -35dB 10007 > -47dB 32.17736

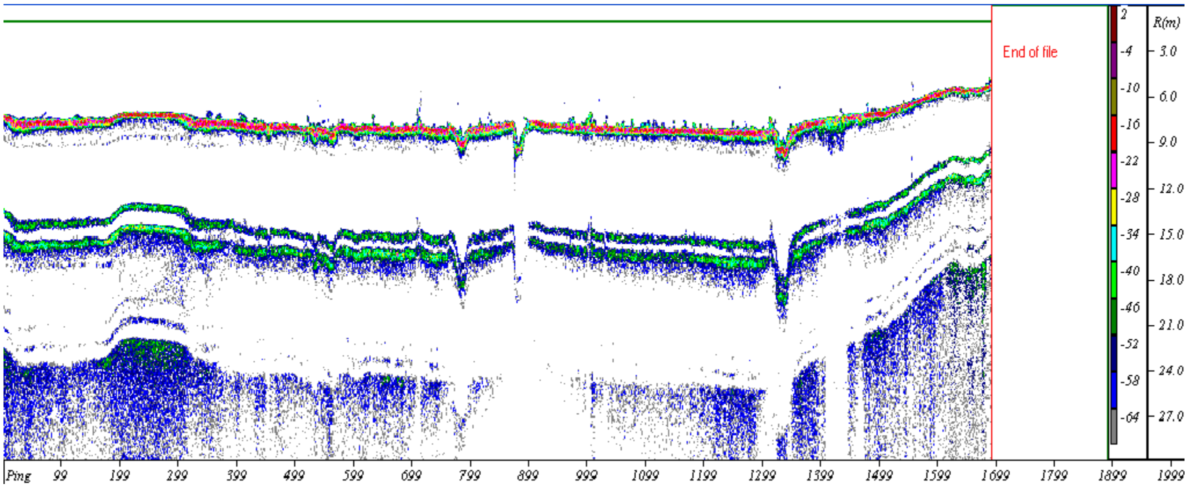
Age 0+ to total proportions			50%	60%	70%	80%	90%
Total Kokanee	62,911		53,924	62,911	77,890	107,848	197,721
Ko 0+	44,936		35,949	44,936	59,915	89,873	179,746
Stickleback	78,731		87,718	78,731	63,752	33,794	56,079
TSS : KO 0+	**1 :**	**0.57**	1 : 0.41	1 : 0.57	1 : 1.94	1 : 2.7	1 : 3.2

	Spawner to total kokanee population			5%	6%	7%	8%	9%
Using	**Total Kokanee**	56,157		78,620	65,517	56,157	49,138	43,678
60% fry to total	**Ko 0+**	33,694		47,172	39,310	33,694	29,483	26,207
	Stickleback	91,729		69,266	82,369	91,729	98,748	104,208
	TSS : KO 0+	**1 :**	**0.37**	1 : 68	1 : 0.48	1 : 0.37	1 : 0.3	1 : 0.25

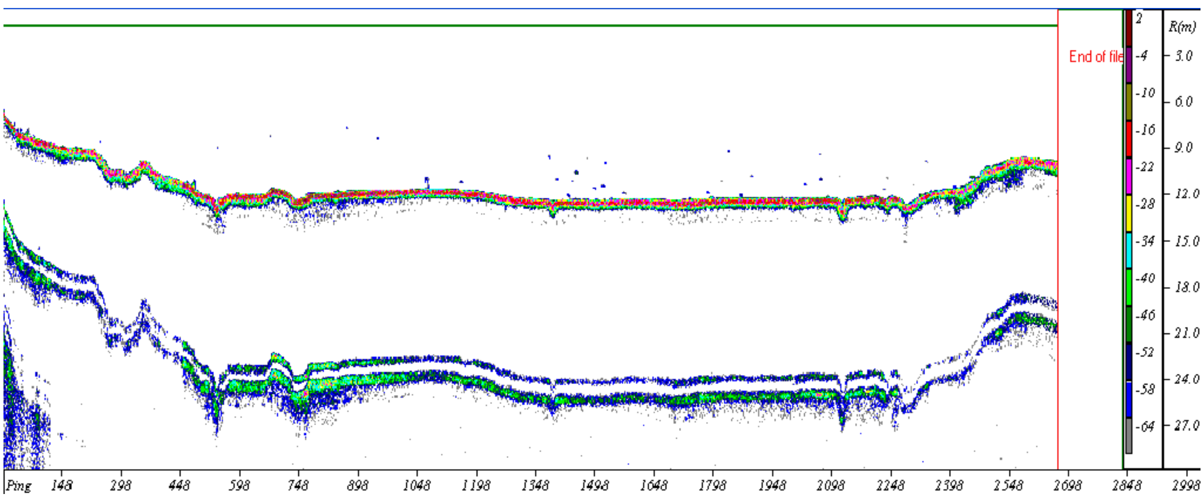
Kokanee and Stickleback adjusted by (1dB) tracking and length data



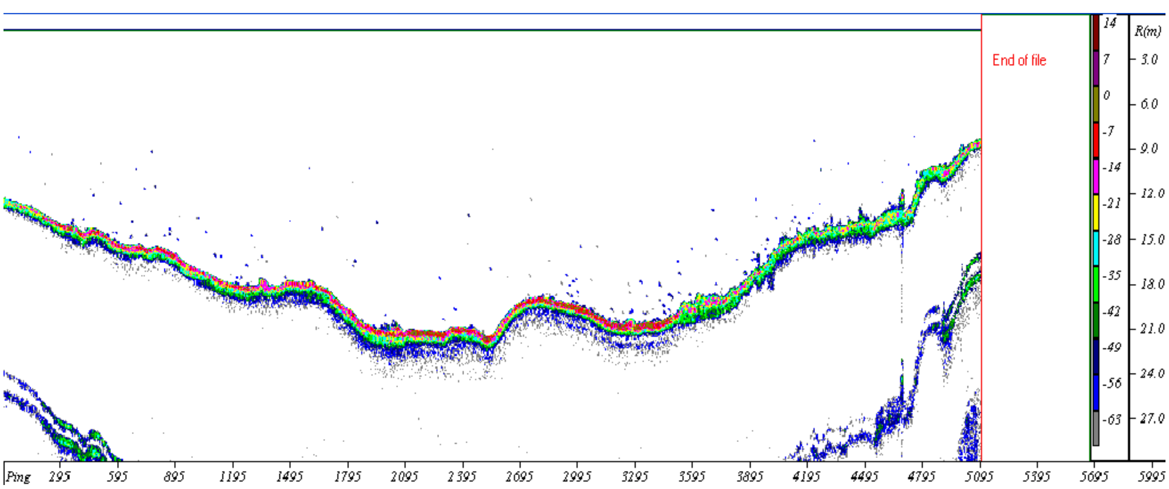
Appendix 6. **Wahleach October 2007 Transect Echograms**



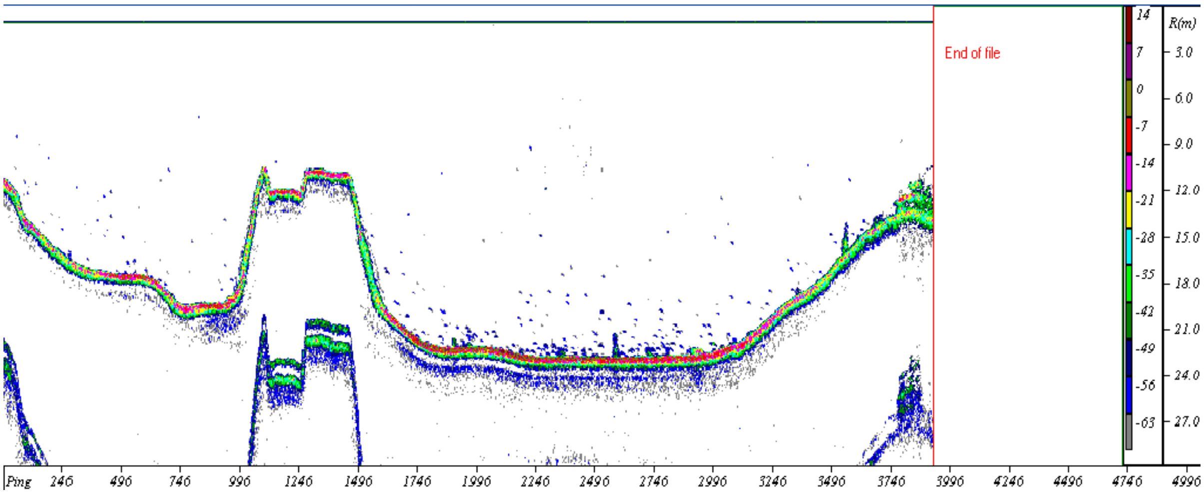
Wahleach Transect 1



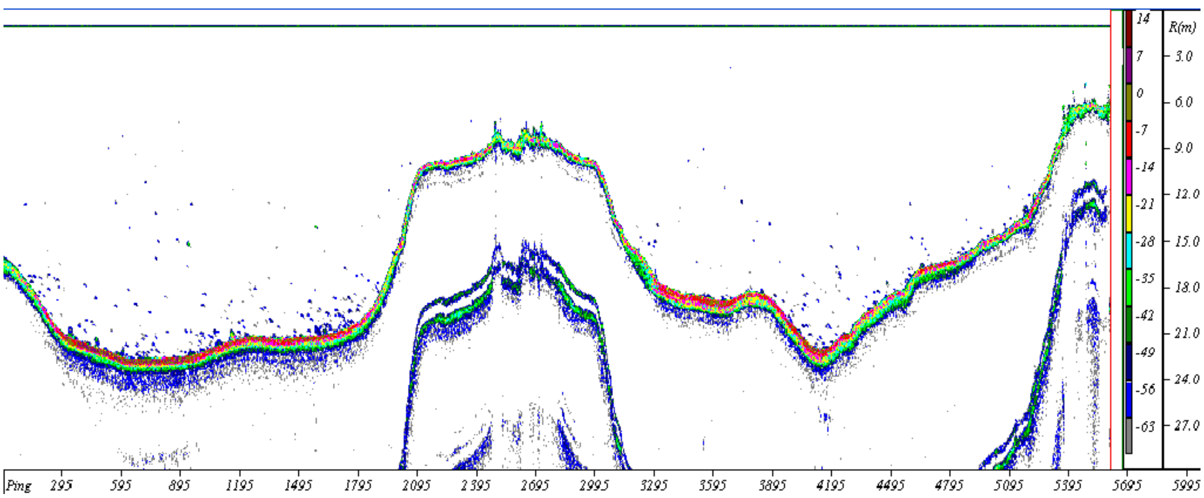
Wahleach Transect 2



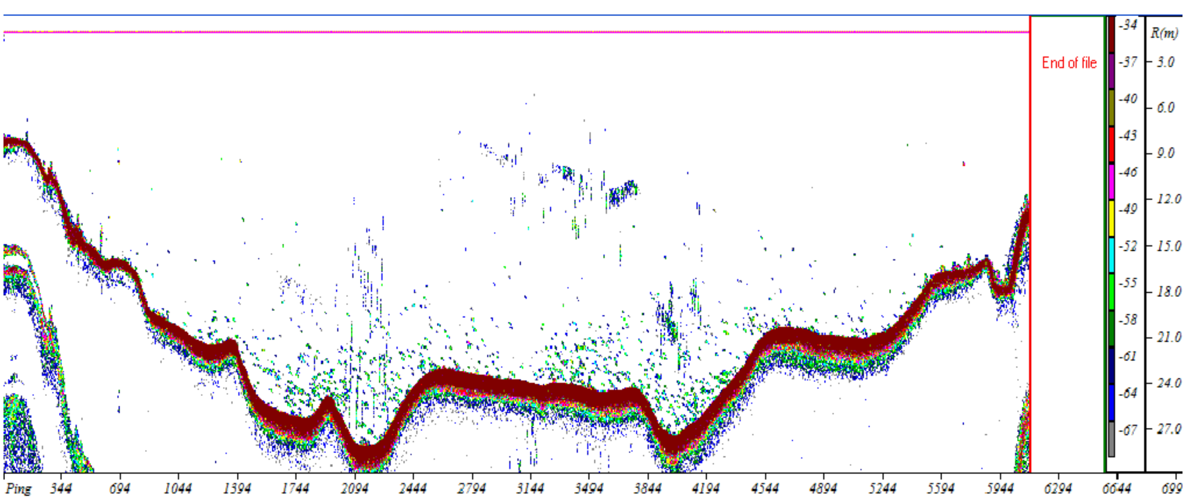
Wahleach Transect 3



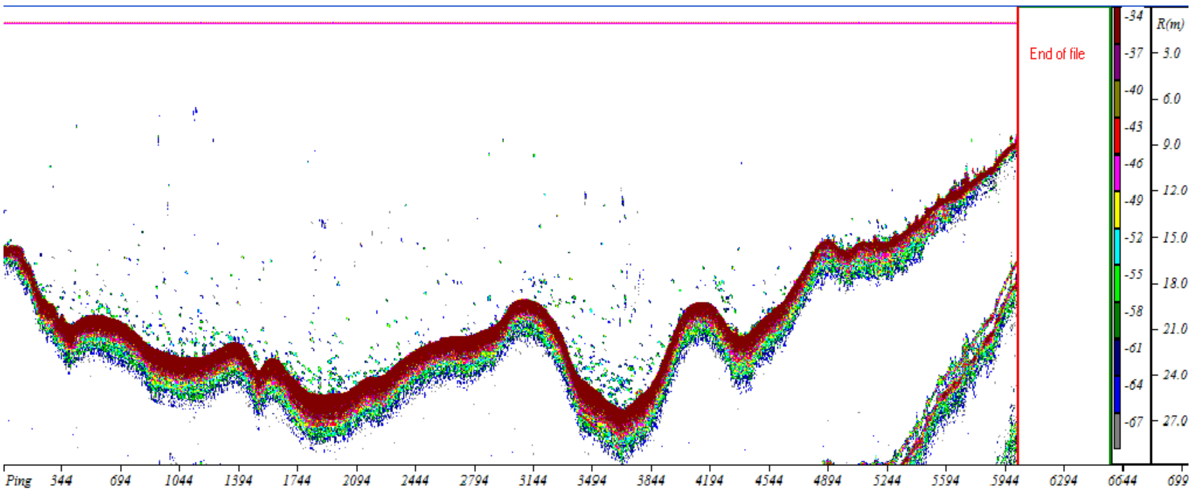
Wahleach Transect 4



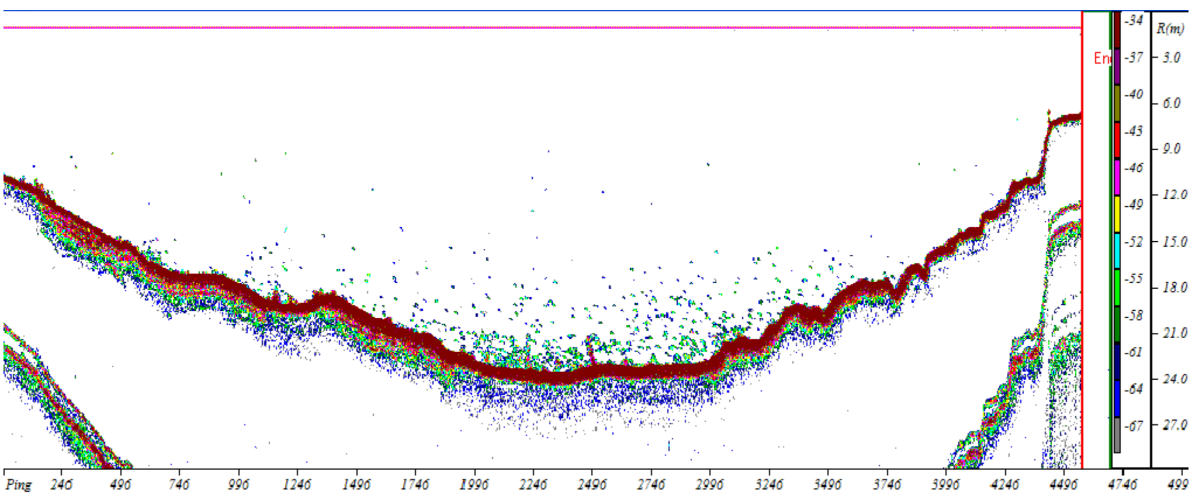
Wahleach Transect 5



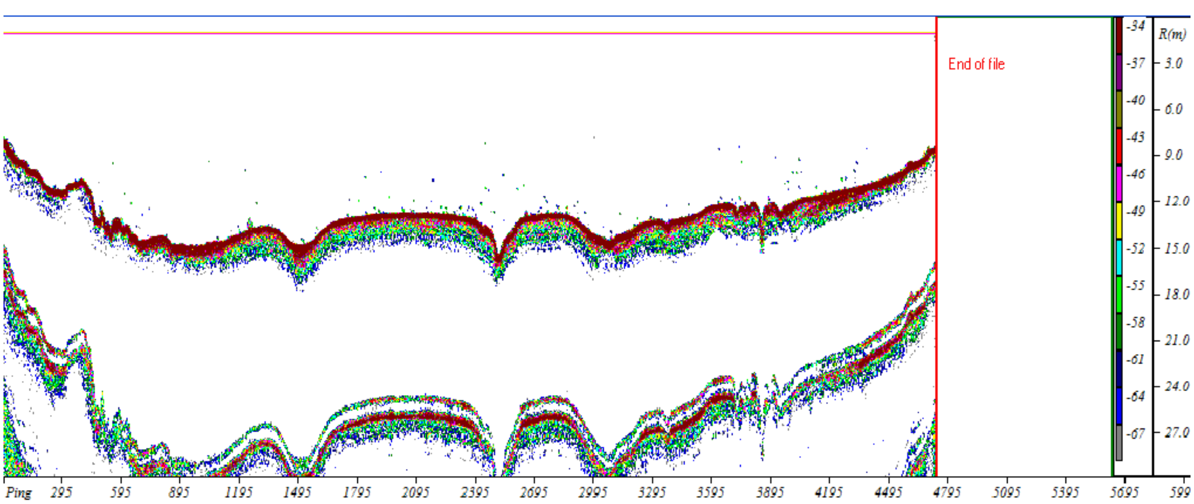
Wahleach Transect 6



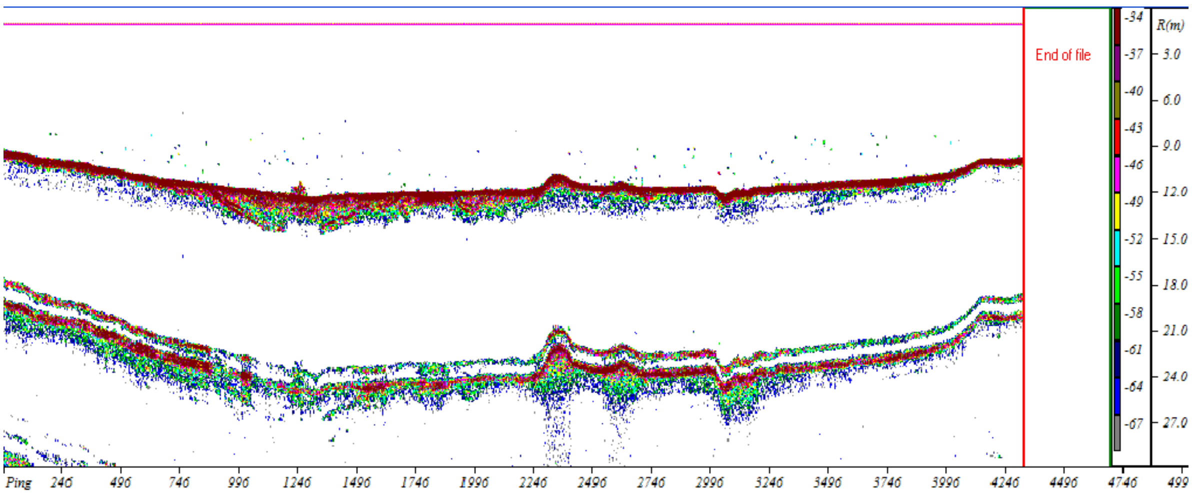
Wahleach Transect 7



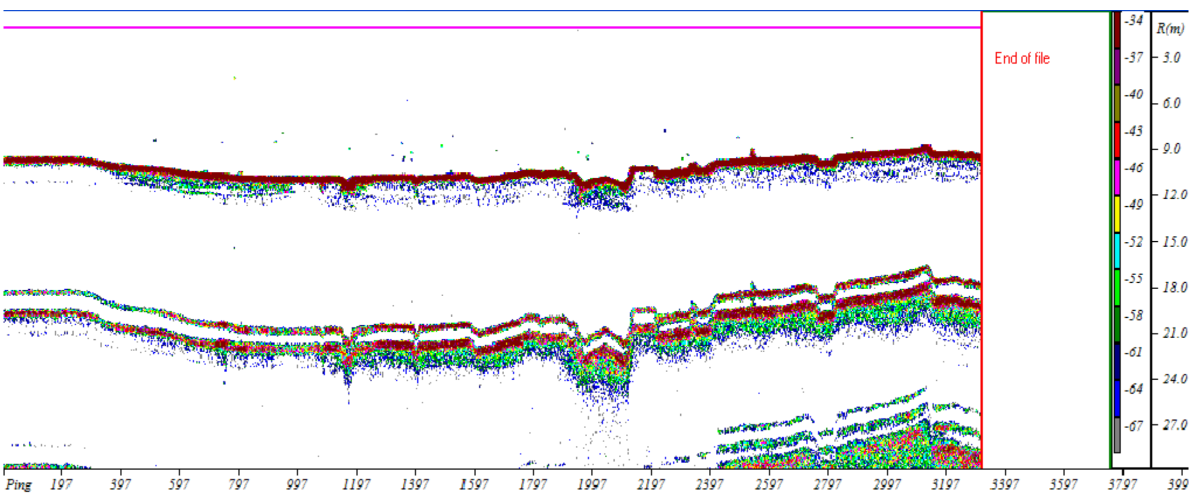
Wahleach Transect 8



Wahleach Transect 9

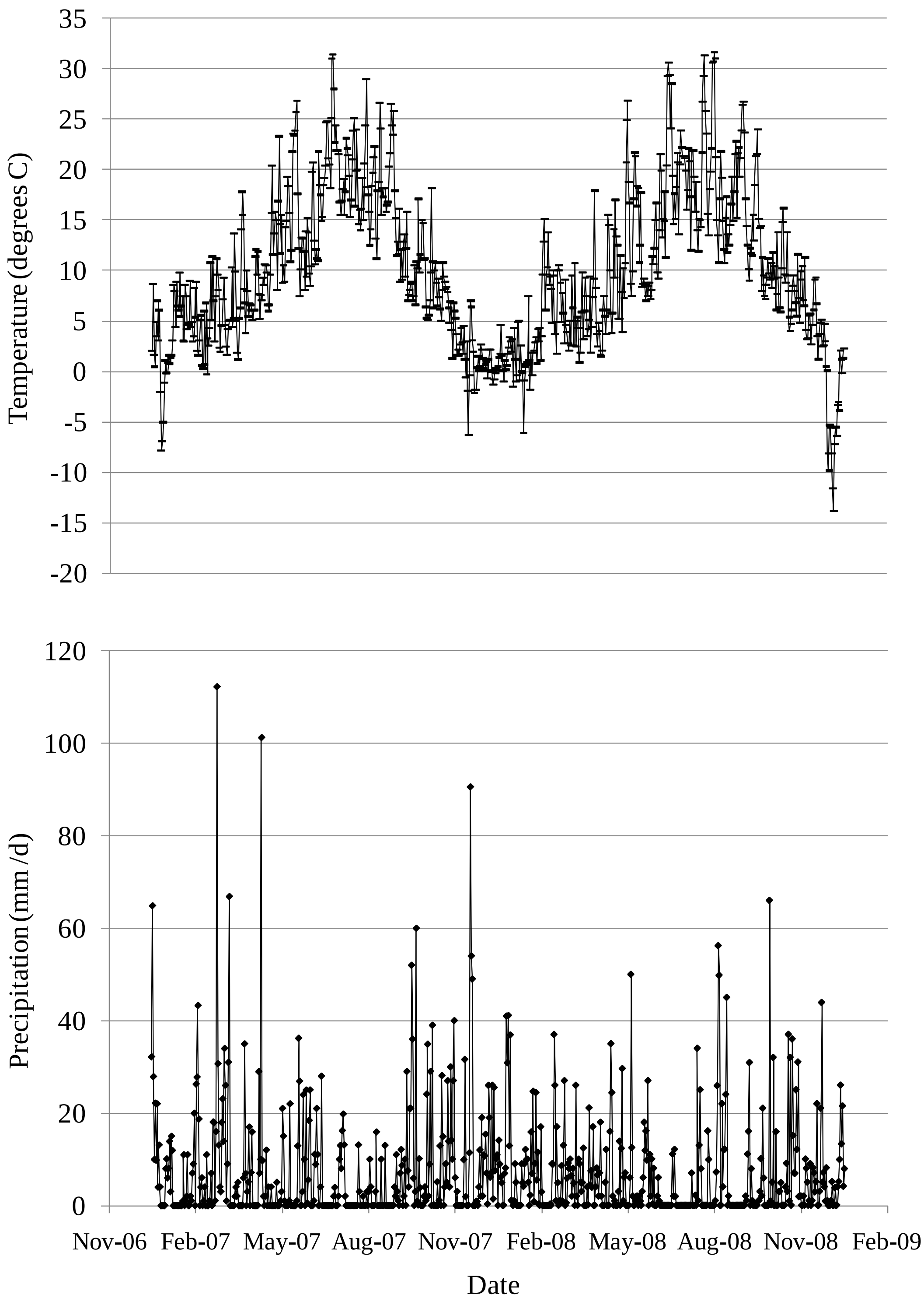


Wahleach Transect 10



Wahleach Transect 11

Appendix B1: Temperature and Precipitation data, 2007-08



Appendix C1: Phytoplankton abundance and biovolume, 2007-08.

units	*2007*	*29-May-07*	*13-Jun-07*	*21-Jun-07*	*19-Jul-07*	*22-Aug-07*	*17-Sep-07*
cells/mL	BAC	2123.7	40.5	192.6	3288.0	2640.7	1054.2
	FLAG	836.3	1561.1	2625.4	538.7	729.9	623.4
	DINO	1307.7	456.2	121.6	115.8	126.7	202.7
	CHLOR	71.0	91.2	40.5	380.1	147.0	81.1
	CYANO	334.5	821.1	486.6	167.3	258.5	577.8
	Total	4673.2	2970.1	3466.7	4489.9	3902.8	2539.2
mm^3/m^3	BAC	113.3	11.7	73.2	1274.3	1260.5	432.6
	FLAG	99.7	114.0	356.8	49.1	150.6	51.7
	DINO	700.7	289.4	78.6	76.8	119.6	282.3
	CHLOR	3.7	1.8	0.8	258.4	60.7	37.0
	CYANO	3.3	13.2	5.9	2.1	133.7	85.9
	Total	920.7	430.1	515.3	1660.7	1725.1	889.5

units	*2008*	*7-Jun-08*	*23-Jun-08*	*22-Jul-08*	*19-Aug-08*	*15-Sep-08*	*14-Oct-08*
cells/m	BAC	5.6	13.5	1165.7	2356.8	182.5	618.3
	FLAG	456.2	627.4	1753.7	532.2	755.2	760.3
	DINO	24.8	16.9	86.2	20.3	40.5	121.6
	CHLOR	18.0	7.9	344.7	91.2	91.2	60.8
	CYANO	144.2	37.2	912.3	420.7	968.1	638.6
	Total	648.8	702.9	4262.6	3421.2	2037.5	2199.6
mm^3/m^3	BAC	0.3	6.8	298.3	1178.4	82.6	185.8
	FLAG	34.2	83.5	75.2	64.4	56.2	73.0
	DINO	15.9	10.0	55.2	15.2	87.2	85.1
	CHLOR	4.4	0.2	207.2	65.9	42.3	22.0
	CYANO	1.2	1.7	10.0	251.9	645.4	326.7
	Total	56	102.2	645.9	1575.8	913.7	692.6

C2: Summary of phytoplankton data available for 1993-2008

Wahleach phytoplankton summary data specifications

0-20 m composite samples (or 0 - just off of the bottom)
stn 1 and stn 2 averaged when both sampled
when > 1 d/m sampled, mean for all days (after averaging stn 1 and 2) was reported

Notes:

In most cases, sampling was monthly; exceptions are below:
In most cases, two stns were sampled and the results averaged; exceptions are below:
1994- one stn sampled on July 1 and Oct 1 (two stns on other dates)
1994- results for Aug 1,15 & 28 averaged; Sept 12 & 26 averaged
1995- no sample collected in Jun
1995- Aug 1, 15, 29 averaged; Oct 3 & 17 averaged
1996- unusually high cyano abundance excluded and replaced interpolated value
1996- Jun 2 & 17 averaged; Jun 1, 15 & 28 averaged; August 11 & 26 averaged; September 9 & 8 averaged; October 8 & 9 averaged
1996- one stn sampled on Jun 3 (two stns sampled on other dates)
1997-99 only stn sampled for abundance
2003 & 2004- one stn sampled on all dates
2003 & 2004- samples collected in November but are not shown in plots
2006- one stn sampled on Aug 1 (two stns sampled on other dates)
2008, 05, 04, 03, 02, 96, 95, & 94- no samples collected in May

Appendix D1: Zooplankton abundance and biomass (dry weight), 2007-08.

units	*2007*	*May-07*	*Jun-07*	*Jul-07*	*Aug-07*	*Sep-07*
ind/L	Cladocera	3.4	14.6	1.0	5.5	2.5
	Copepoda	0.2	0.4	2.3	1.4	0.3
	Total	3.6	15	3.3	6.9	2.8
µg/L	Cladocera	6.1	95.9	20.6	111.2	42.3
	Copepoda	0.3	0.4	4.0	2.4	0.3
	Total	6.4	96.3	24.6	113.6	42.6

units	*2008*	*May-08*	*Jun-08*	*Jul-08*	*Aug-08*	*Sep-08*	*Oct-08*
ind/L	Cladocera	0.9	16.9	13.7	3.0	0.6	1.5
	Copepoda	0.1	0.3	1.1	0.8	0.2	0.7
	Total	1	17.2	14.8	3.8	0.8	2.2
µg/L	Cladocera	3.6	120.2	99.3	53.2	43.4	21.3
	Copepoda	0.1	0.8	1.5	1.5	1.1	0.7
	Total	3.7	121	100.8	54.7	44.5	22

D2. Summary of zooplankton data available for 1993-2008

Wahleach zooplankton summary data specifications

abundance of Cladocera and Copepoda : 1993 - 2000 and 2000-2008
abundance of Rotatoria : 1993 - 2000 and in 2004-2005
biomass of Cladocera and Copepoda : 1993 - 2000 and 2000 - 2008

year	month	# of stations	# of samples
1993	June	2	8
	July	2	8
	Aug	2	10
	Sep	2	8
	Oct	2	4
1994	June	2	10
	July	2	4
	Aug	2	4
	Sep	2	4
	Oct	2	2
1995	Aug	1	2
	Sep	1	2
	Oct	1	3
1996	June	2	4
	July	2	6
	Aug	2	4
	Sep	2	4
	Oct	2	4
1997	June	2	6
	July	2	4
	Aug	2	6
	Sep	2	2
	Oct	2	4
1998	May	2	2
	June	2	2
	July	2	2
	Aug	2	2
	Sep	2	2
	Oct	2	2
1999	June	2	2
	Aug	2	2
	Oct	2	2
2000	May	2	2

	June	2	2
	July	2	2
	Aug	2	2
	Sep	2	2
	Oct	2	2
2003	May	2	2
	June	2	2
	Aug	2	2
	Sep	2	2
	Oct	2	2
	Nov	2	2
2004	June	2	2
	July	2	2
	Aug	2	2
	Sep	2	2
	Oct	2	2
	Nov	2	2
2005	May	2	4
	June	2	4
	July	2	4
	Aug	2	4
	Sep	2	4
	Oct	2	4
2006	May	2	4
	June	2	4
	July	2	4
	Aug	1	4
	Sep	2	4
	Oct	2	4
2007	May	2	4
	June	2	4
	July	2	4
	Aug	2	4
	Sep	2	4
2008	May	2	4
	June	2	4
	July	2	4
	Aug	2	4
	Sep	2	4
	Oct	2	4