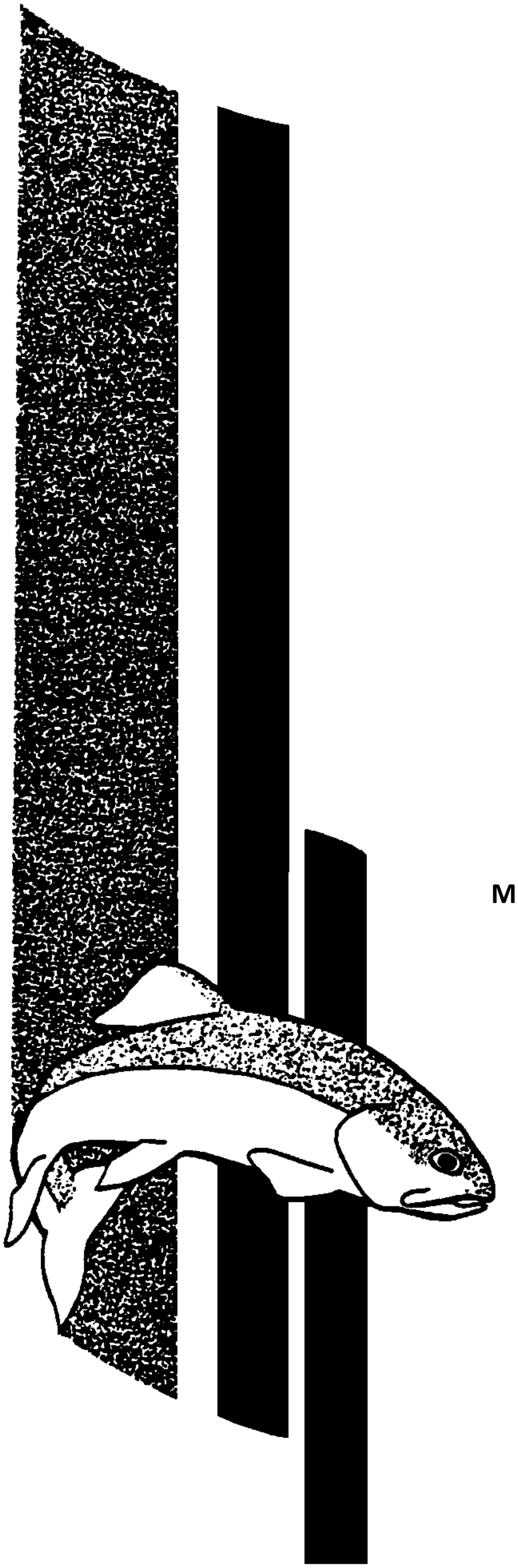

KOOTENAY LAKE
NUTRIENT RESTORATION PROGRAM
YEAR 22 (NORTH ARM) and
YEAR 10 (SOUTH ARM)
(2013) REPORT

by

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KOOTENAY LAKE NUTRIENT RESTORATION PROGRAM YEAR 22 (NORTH ARM) and YEAR 10 (SOUTH ARM) (2013) REPORT

by

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The Fish and Wildlife Compensation Program is a joint initiative of BC Hydro, the Province of British Columbia, First Nations, and the public, who work together to conserve and enhance fish and wildlife impacted by the construction of BC Hydro dams.

The contributions from the Province of British Columbia are primarily from the Ministry of Forests, Lands and Natural Resource Operations and the Ministry of Environment.

The Kootenai Tribe of Idaho receives funding from the Bonneville Power Administration through the Northwest Power and Conservation Council's Columbia Basin Fish and Wildlife Program.

Numerous individuals have worked on Kootenay Lake over several decades. Appendix 1 lists the individuals who participated in the Kootenay Lake Nutrient Restoration Program in 2013.

EXECUTIVE SUMMARY

This report summarizes 2013 results from the 22nd year of nitrogen and phosphorus additions to the North Arm of Kootenay Lake and 10th year of nitrogen additions to the South Arm. The program was conducted using an adaptive management approach in an effort to restore lake productivity lost as a result of nutrient retention and uptake in upstream reservoirs. The primary objective of this program is to restore kokanee (*Onchorhynchus nerka*) populations, which are the primary food source for Gerrard rainbow trout (*Oncorhynchus mykiss*) and bull trout (*Salvelinus confluentus*).

Kootenay Lake is a warm, monomictic lake with a water renewal time of approximately two years. It is 395 km2 in area with an average depth of 94 metres and a maximum depth of 154 metres. Surface water temperatures are typically warmest in August. The lake is well oxygenated from the surface to bottom depths at all stations throughout the year.

Secchi disc measurements in 2013 were typical of previous years' results. The seasonal pattern exhibited decreasing spring-to-summer transparency associated with increased phytoplankton biomass and increased turbidity from spring runoff, followed by increasing transparency in the late summer and fall months.

The dissolved forms of nitrogen and phosphorous are the fractions most ready available to phytoplankton uptake. Total dissolved phosphorus ranged from below the reportable detection limit (2 µg/L) to 6.8 µg/L. Dissolved inorganic nitrogen (NO2-N+NO3-N+NH3-N) collected from epilimnetic integrated samples ranged from 42.7 µg/L to 172.1 µg/L and reached nadir in the summer, this seasonal trend corresponds with phytoplankton uptake and use during summer stratification.

Abundance of phytoplankton in integrated epilimnetic samples was dominated by chryso-cryptophytes and bacillariophytes. Chryso-cryptophytes were highest in the late spring and early summer and bacillariophyte abundance peaked in the summer. The trend of decreased chryso-cryptophytes into the summer coincided with increased zooplankton, suggesting grazing on phytoplankton.

Zooplankton density in 2013 was significantly higher than the pre and post nutrient addition long-term averages. Copepods were the main contributor to the overall zooplankton population in the spring with Daphnia sp. appearing in August, peaking in September, and maintaining a population through November. Daphnia biomass was significantly higher than in previous years, particularly in the North Arm.

Mysis diluviana annual biomass was below the pre and post nutrient addition long-term averages. Average biomass was higher in the South Arm than the North Arm in deep sites and immature and mature developmental stages contributed the most to overall biomass.

The results from 2013 indicate the trophic level response has been positive as a result of nutrient additions to the North and South arms of Kootenay Lake. Phytoplankton composition was favourable to transfer carbon efficiently through the food web to kokanee. This is indicative of a positive response to closely monitored seasonal applications of limiting macronutrients.

Kokanee in Kootenay Lake exhibited a range of responses in 2013, some of which have not been documented previously in Kootenay Lake. Size at age increased in the 2+ and mature kokanee to lengths among historic highs while size of 1+ decreased to among the lowest on record. Abundance of fry remained similar to the last few years and was about average since the nutrient restoration programs began but the adult kokanee population continued to decrease to pre-nutrient restoration levels, indicating abnormally poor recruitment of fry to the older age classes. Despite the larger sizes obtained by the older age classes of kokanee the low abundance has resulted in a decrease in biomass similar to pre-nutrient restoration levels.

A notable response of kokanee to the small size at age experienced prior to 2013 is the shift of age at maturity from the normal 3+ to a majority 4+ in 2013. Although the increased growth experienced by these fish in their later years increased general fecundity, their relative fecundity was lower than average and points to abnormal physiological responses not previously noted on Kootenay Lake. Despite an increase in fecundity the overall egg deposition was below average.

Gerrard Rainbow peak spawner abundance remains high but dropped from the highest count on record in 2012.

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INTRODUCTION

The Kootenay Lake situation

Kootenay Lake is world renowned for its sport fishing for an exceptionally large strain of wild rainbow trout, the Gerrard rainbow trout (*Oncorhynchus mykiss*). Fisheries research on Kootenay Lake dates back to the 1950s when considerable effort was directed at understanding the life history of the Gerrard stock of rainbow trout. Over the last four decades, the status of Kootenay Lake's kokanee stocks has been well documented, as has its limnology.

Nutrient losses, resulting from upstream hydro-electric impoundment and a reduction in phosphorus inputs from a fertilizer plant located within the watershed in the late 1960s and early 1970s, caused Kootenay Lake to shift from oligotrophic to ultra-oligotrophic, which triggered a decline of the keystone species, kokanee (Oncorhynchus nerka). There was a concern, based on simulation modelling and populations declines,that the dominant North Arm kokanee stock might collapse and sport fish such as Gerrard rainbow trout and bull trout (Salvelinus confluentus) would decrease significantly, as kokanee are their main food source.

Therefore, since 1992, carefully monitored additions of limiting nutrients have been used as a restoration technique for reversing oligotrophication (Ney 1996) of the Kootenay Lake ecosystem. Nutrient additions have been used in British Columbia, Alaska, Idaho, and Sweden as a technique for rebuilding depressed stocks of sockeye, kokanee, and other salmonids in lakes and reservoirs (Stockner and MacIssac 1996; Ashley et al. 1999b; Mazumder and Edmundson 2002; Pieters et al. 2003; Perrin et al. 2006; Rydin et al. 2008).

Successful recruitment of fish depends partly on sufficient food supply (Beauchamp et al. 2004) and on food quality (Danielsdottir et al. 2007). Previous research has shown that the preferred food source for kokanee is Daphnia spp., a herbivorous zooplankton (Thompson 1999), which in turn mainly ingests nanoplankton (phytoplankton that range in size from 2.0–20.0 µm). Oligotrophic conditions tend to favour the growth of smaller phytoplankton (picoplankton, 0.2–2.0 µm) due to their higher nutrient uptake and growth rates (Stockner 1987). During light applications of nutrients, the picoplankton fraction responds first, but with increased nutrient loads, there is a shift to the larger phytoplankton; nanoplankton (2.0-20 µm) and microplankton (>20.0 µm) (Stockner 1987). Microplankton are considered too large to be edible by most zooplankton.

The strategy with the nutrient restoration program was to use a "bottom up" approach to rebuild depressed kokanee and rainbow trout populations (Ashley et al. 1997). Nitrogen and phosphorus, in the form of liquid agricultural grade fertilizer: nitrogen as urea ammonium nitrate, 28-0-0 (N-P2O5-K2O), and phosphorus as ammonium polyphosphate, 10-34-0 (N-P2O5-K2O), have been added annually to the North Arm of Kootenay Lake from mid-April through mid-September since 1992. Nutrient additions of nitrogen only as 28-0-0 (N-P2O5-K2O) began in the South Arm in 2004.

The restoration experiment has been complicated by the presence of *Mysis diluviana* (previously named *Mysis relicta*) (Audzijonyte and Vainola 2005), an exotic crustacean that competes with kokanee for zooplankton, particularly Daphnia. *Mysis diluviana* was introduced into Kootenay Lake in 1949 by Provincial Fish and Game staff.

Responses to nutrient additions

The experiment's primary objective has been to restore nutrient concentrations in the North Arm to pre-dam conditions, because upstream reservoirs were serving as nutrient sinks (Larkin 1998; Ashley et al. 1999b). The initial response of North Arm kokanee to lake fertilization was very positive. Kokanee escapements to the North Arm's Lardeau River and Meadow Creek systems once again surpassed 1 million fish.

There was a deliberate reduction in fertilizer loading from 1997–2000 to test the hypothesis that the nutrient additions were responsible for increasing the kokanee numbers through a bottom-up effect. Indeed, kokanee numbers declined in concert with the reduced nutrient loading (Schindler et al. 2009). This clear demonstration of a cause-and-effect relationship enabled fisheries managers to secure long-term funding and adjust the annual nutrient loading back to the 1992 level starting in 2001. The results of the Kootenay Lake (North Arm) fertilization have been documented in a number of technical reports and other publications (e.g., Ashley et al. 1997; Wright et al. 2002; Schindler et al. 2007a, 2007b, 2009, 2010, 2011, 2013, 2014).

Since the North Arm nutrient experiment began in 1992, there has been a comprehensive monitoring program aimed at measuring trophic level responses to lake fertilization (see Ashley et al. 1997; Ashley et al. in Murphy and Munawar 1999; Ashley et al. 1999a; Thompson 1999; Wright et al. 2002; Schindler et al. 2007a; b, 2009, 2010, 2011, 2013, 2014). Given that phytoplankton community composition and size structure can change quickly with the application of nutrients, the trophic levels need to be closely monitored to ensure efficient transfer of food through the food web to influence the recovery of kokanee.

Kootenay Lake kokanee are an important indicator of the success of the nutrient restoration program and the overall health of the ecosystem. There are various avenues for the uptake of base nutrients through the trophic system, not all of which benefit kokanee and piscivorous fish populations to the same degree, and some that may even do harm (e.g., advantage given to inedible plankton). Even when optimal production of large zooplankton, namely Daphnia, is achieved, kokanee population responses can be varied, since the temporal scale required for population change is longer and kokanee are influenced by other factors that can collectively affect their recruitment, survival, and growth.

Additional nutrient projects in the Kootenay Lake watershed

Despite the success experienced with the dominant North Arm kokanee stock, there have been no obvious benefits to the West Arm stock of kokanee (Redfish Consulting Ltd. 2002). Furthermore, the South Arm kokanee, a morphologically and genetically distinct stock (Vernon 1957), have been virtually extirpated from their natal spawning tributaries over the past three decades. Historically, the South Arm tributaries supported only modest numbers of spawning kokanee (Vernon 1957; Andrusak and Brown 1987) but this stock also began to decline in the late 1970s concurrent with declining lake productivity (Andrusak and Fleck 2007). Kokanee from Kootenay Lake that spawn in northern Idaho streams also underwent a complete stock collapse (Ericksen et al. 2009).

Idaho State Fish and Game (ISFG) and the Kootenai Tribe of Idaho (KTOI) recognized that kokanee spawners observed in northern Idaho streams could only be restored if growth and survival conditions improved in the South Arm of Kootenay Lake. In response, these entities secured funding from the Bonneville Power Administration (BPA), and beginning in August 2004, a nitrogen-only nutrient addition experiment comparable in size to the North Arm project was simultaneously undertaken in the South Arm in an attempt to increase productivity and restore South Arm kokanee. This program is managed by the Ministry of Forests, Lands and Natural Resource Operations (MoFLNRO) in Nelson, BC.

A third nutrient addition experiment in the Kootenay watershed began in 2005 in northern Idaho. Low concentrations of ammonium polyphosphate were added to the Kootenai River at Bonners Ferry, ID during the growing season in an effort to restore river nutrients and productivity lost due to impoundment of the Kootenai River by the Libby Dam and Kookanusa Reservoir. A comprehensive monitoring program has been established by the KTOI and ISFG, and to date lower trophic level responses have been positive (Hoyle et al. 2014, Minshall et al. 2014).

In order to re-establish kokanee populations to South Arm streams, it was necessary to use eyed-egg plants from North Arm stocks. Egg plants using Meadow Creek stock began in South Arm streams in BC during the fall of 2005. The KTOI began kokanee eyed-egg plants (also Meadow Creek stock) in Idaho tributaries as early as 1997, but they intensified their efforts during the last five years in conjunction with the South Arm fertilization experiment (Sebastian et al. 2010; Ericksen et al. 2009). In 2013, the IHN (Infectious hematopoietic necrosis) virus was detected in the spawning adults at the source of eggs, Meadow Creek Spawning Channel. Because of disease prevention protocol at the hatchery, eyed eggs were not available for planting in 2013.

The KTOI and ISFG recognize that to sustain recovered kokanee in Idaho requires improvement of survival rates for naturally produced eggs. Some stream restoration work has recently been undertaken in Kootenai River tributaries (in Idaho) in an effort to improve spawning and incubation habitat. Habitat restoration activities have been initiated on three streams to date:

Trout, Parker, and Long Canyon Creeks (Fig. 1). These streams were prioritized for habitat restoration based on potential water and riparian resource problems, as well as KTOI cultural significance and landowner interest. Habitat restoration activities have primarily focused on improving grazing management (i.e., rest, rotation, temporary fencing, off-stream watering options) and re-establishing native plant species within the riparian zone (Ericksen et al. 2009). Some stream restoration projects in BC have also been identified by Andrusak et al. (2004).

Study area

Kootenay Lake lies between the Selkirk and Purcell mountain ranges in the southeast corner of British Columbia (Fig. 1). The main lake is 107 km long and approximately 4 km wide with a mean depth of 94 m and a maximum depth of 154 m (Daley et al. 1981). The lake has two major inflowing tributaries—the Lardeau/Duncan system at the north end and the Kootenay River (spelled Kootenai in the US) at the south end of the lake. The outlet of the main lake is near the midpoint on the west side at Balfour, BC, where it forms the upper end of the West Arm. At this outlet, a sill lies at a depth of approximately 8 m, producing a distinct boundary between the main lake and the West Arm.

The West Arm is about 40 km long with a mean depth of only 13 m. It is physically and limnologically different from the main lake and consists of a series of rapidly flushed shallow basins interconnected by narrow riverine sections. The West Arm of Kootenay Lake flows in a westerly direction, forming the lower Kootenay River, which flows into the Columbia River at Castlegar, BC. The entire West Arm has an annual mean retention time of 5–6 days (Martin and Northcote 1991). The main basin of the lake has an average retention time of 1.8 years (Daley et al. 1981). Additional limnological information for Kootenay Lake can be found in Northcote (1973) and Northcote et al. (1999).

Figure 2 shows the location of limnological sampling stations (KLF 1–8), hydroacoustic transects (1–18), and trawl stations (KLF 1–7). The boundary between the North and South Arms can be described as a straight line between Pilot Point on the east side of Kootenay Lake and the lake outlet at Balfour.

In the North Arm, flows are dominated by the Lardeau/Duncan system. Smaller systems also important for spawning are Fry Creek, Campbell Creek, and Powder Creek on the northeast side and Coffee Creek, Woodbury, Cooper Creek, and Kaslo River on the west side. In the South Arm, flow is dominated by the Kootenay/i River.

In addition to Kootenay River, primary streams flowing into the South Arm in BC include the Goat River, Boulder Creek, Akokli Creek, Sanca Creek, Lockhart Creek, Grey Creek, and Crawford creeks on the east side and Boundary, Corn, Summit, Next, Cultus, and Midge creeks on the west side (Fig. 1). The kokanee work in northern Idaho focuses on tributary streams flowing into Kootenai River, including Boundary, Fisher, Smith, Parker, Long Canyon, Ball, Trout, and Myrtle creeks (Fig. 1).

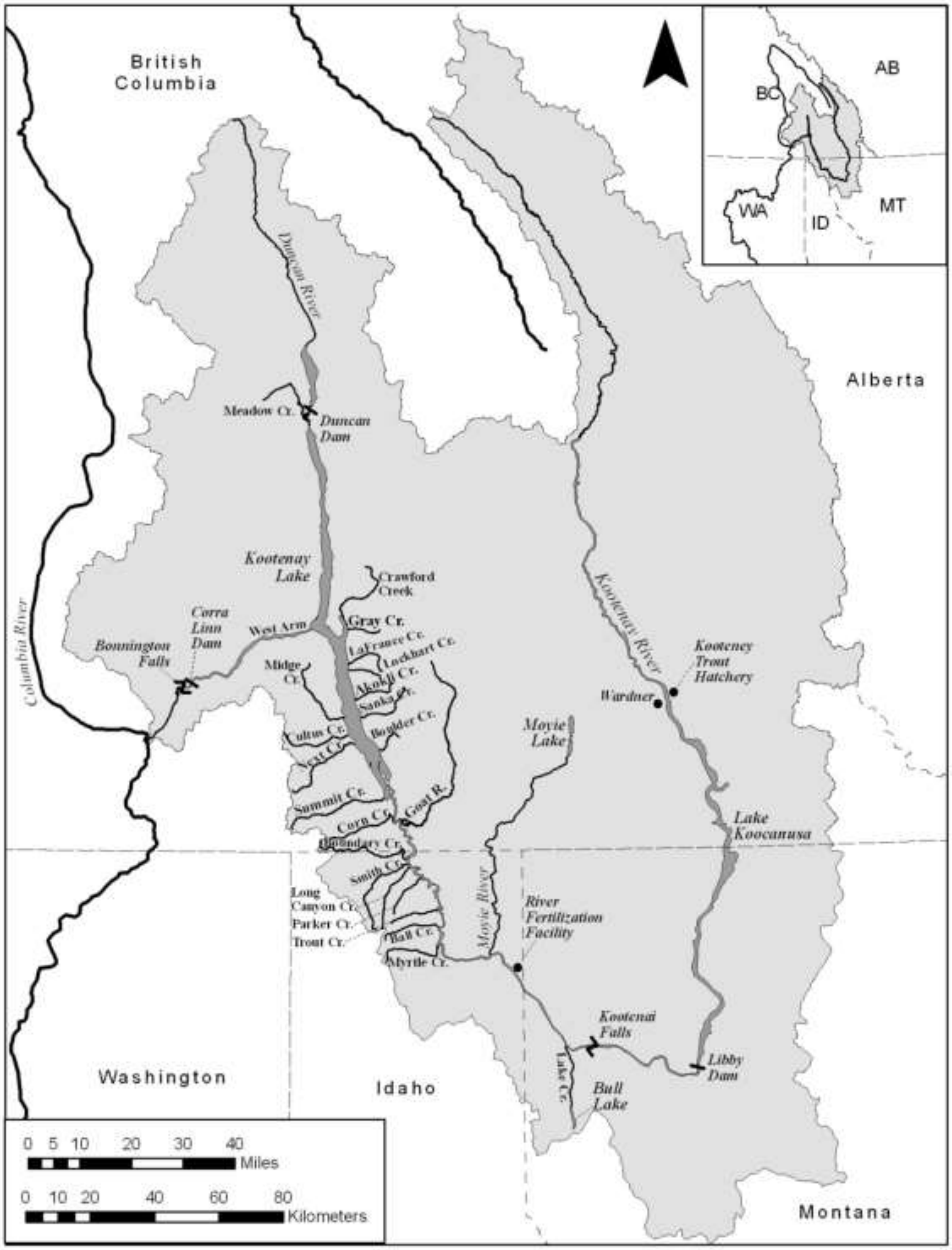


Figure 1. Map of the Kootenay River Basin in British Columbia, Montana, and Idaho showing South Arm tributaries (adapted from Ericksen et al. 2009).

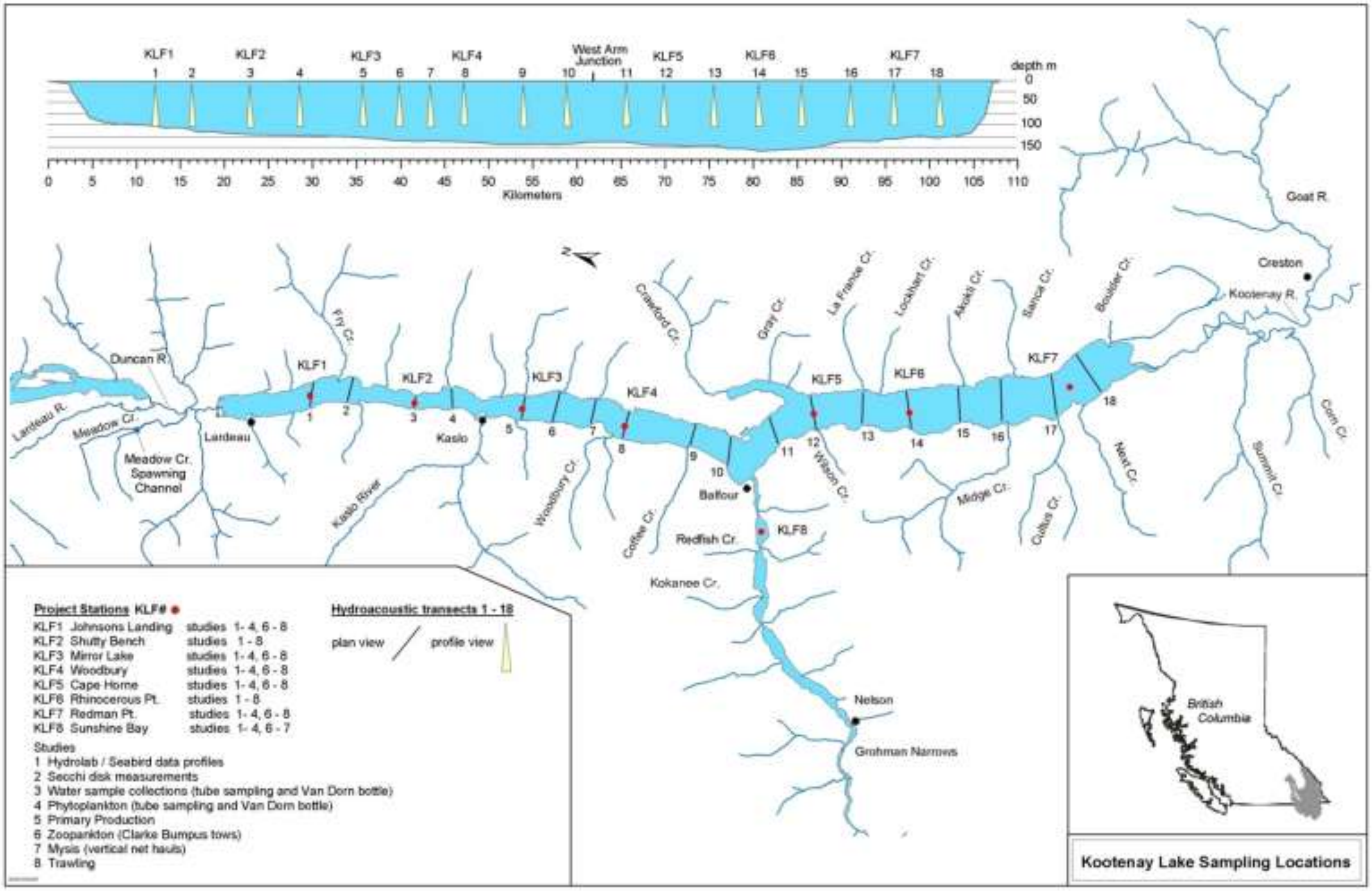


Figure 2. Kootenay Lake, British Columbia, sampling station sites.

Nutrient addition program reporting

This report summarizes the physical, chemical, and biological response data collected from various trophic levels from the North, South, and West Arms of Kootenay Lake in 2013, with comparisons to previous years. Detailed data from previous years are provided in the following reports: Schindler et al. 2006, 2007a, b, 2009, 2010, 2011, 2013, and 2014. Personnel contributing to the program in 2013 are listed in Appendix 1. The sampling activities are listed in Appendix 2.

METHODS

Fertilizer additions

North Arm

An agricultural grade liquid fertilizer blend of ammonium polyphosphate (10-34-0: N-P_2O_5-K_2O; % by weight) and urea-ammonium nitrate (28-0-0: N-P_2O_5-K_2O; % by weight) was used for additions to the North Arm of Kootenay Lake. The amounts of phosphorus and nitrogen added per season from 1992 to 2013 are listed in Table 1.

The total weight of fertilizer applied in 2013 was 33.0 tonnes of phosphorus and 207.9 tonnes of nitrogen. Applications started on April 29 and continued weekly (one week omitted) until September 11. Only nitrogen was added for 4 weeks following the one week of no nutrient additions (July 3). When a nitrogen/phosphorus blend of fertilizer was used, the nitrogen to phosphorus (N:P) ratio (weight:weight) varied throughout the season, with a range from 0.67:1 in the spring to 10.9:1. In August, the last 2 weeks of additions decreased to a ratio of 6.5:1. Phosphorus loading ranged from 0 to 26.6 mg/m^2 and nitrogen loading ranged from 5.1 to 101.6 mg/m^2 in 2013 (Fig. 3).

Fertilizer was applied to the North Arm from the Western Pacific Marine/Ministry of Transportation and Highways' MV Balfour ferry. Fertilizer trucks drove onto the ferry and nutrients were applied to the lake via two dispensing diffusers located at the stern of the vessel. The diffusers discharged into the propeller wash to ensure proper mixing and dilution. The area of application was located from two km north of transect 1 to four km south of transect 2, a distance of 10 km (Fig. 2). The load was distributed equally with one half of the fertilizer released on the departing trip and one half on the return trip.

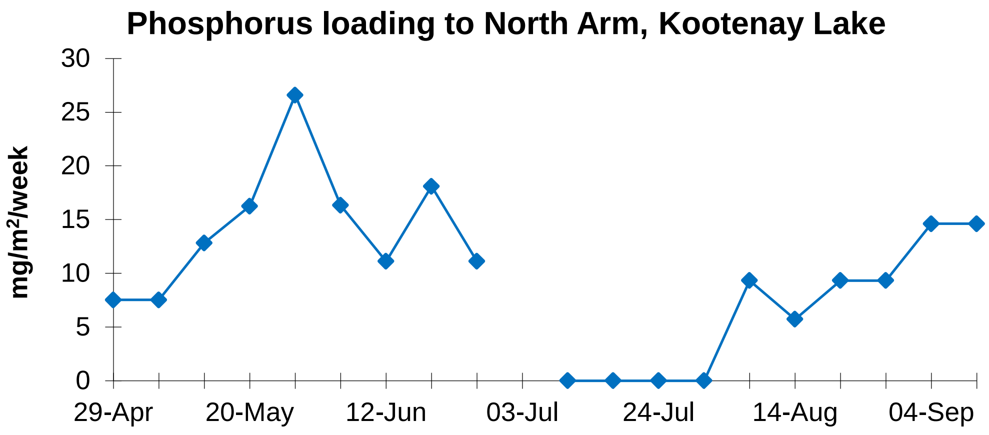
South Arm

In 2013, the previously used strategy of adding only nitrogen to the lake was maintained. In total, 257.9 tonnes of nitrogen were added in the form of urea-ammonium nitrate (28-0-0: N-P_2O_5-K_2O; % by weight). Additions occurred at weekly intervals from May 30th to August 20th at a loading rate of 85.9 mg/m^2, except on August 1st and 8th when the loading rate was 46.6 and 52.8 mg/m^2 (respectively) (Fig. 4).

Nutrients for the South Arm experiment were dispensed from the Western Pacific Marine/Ministry of Transportation and Highways' MV Balfour ferry. One or two fertilizer trucks, each carrying 35-43 tonnes of fertilizer, drove onto the ferry, and nutrients were applied to the lake via two dispensing diffusers located at the stern of the vessel. The diffusers discharged into the propeller wash to ensure proper mixing and dilution. The application zone in the South Arm was between transects 12 and 15, a distance of 12.5 km (Fig. 2). Fertilizer load was distributed with one half released on the departing trip and one half on the return trip.

Table 1. Total tonnes of phosphorus and nitrogen (from liquid agricultural fertilizer) dispensed into the North Arm of Kootenay Lake, 1992–2013, and tonnes of nitrogen to the South Arm, 2004–2013.

Year	**Phosphorus Tonnes (North Arm)**	**Nitrogen Tonnes (North Arm)**	**Nitrogen Tonnes (South Arm)**
1992–1996	47.1	207	
1997	29.5	112	
1998	22.9	93	
1999	22.9	93	
2000	29.5	112	
2001	47.1	207	
2002	47.1	207	
2003	47.1	241	
2004	37.6	243	124
2005	44.1	247	234
2006	44.7	248	257
2007	46.2	247	245
2008	45.8	242	265
2009	45.4	241	265
2010	42.5	230	265
2011	34.5	171	256
2012	23.8	140	192
2013	33.0	208	258



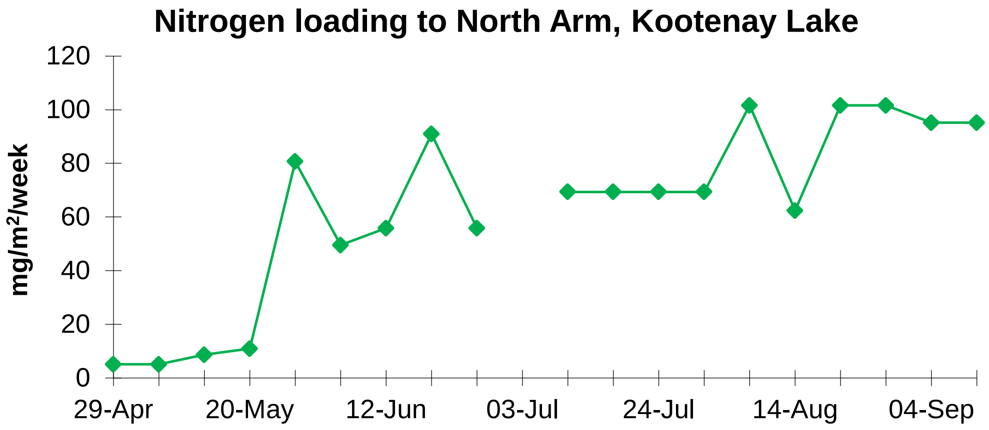


Figure 3. Weekly phosphorus and nitrogen inputs from fertilizer to the North Arm, April through September, 2013.

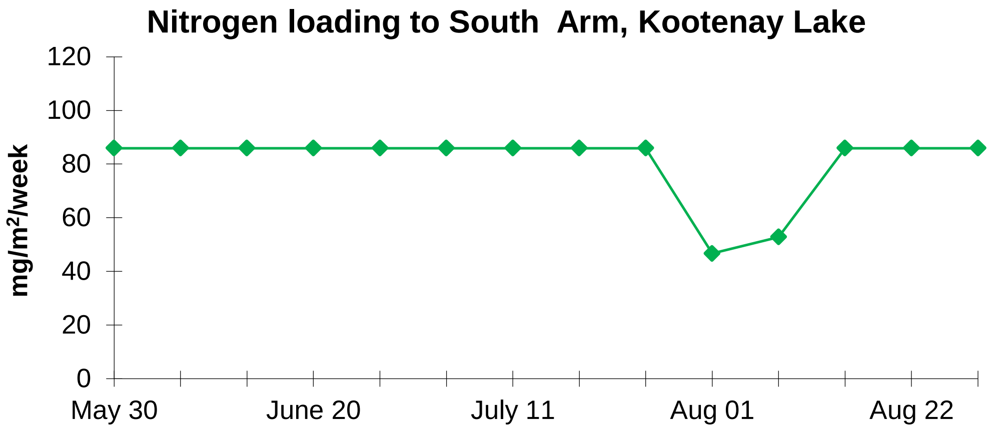


Figure 4. Weekly nitrogen inputs from fertilizer to the South Arm, April through September, 2013.

Physical Limnology and Water Chemistry

Physical and chemical data were collected at pre-established Kootenay Lake Fertilization (KLF) sampling sites simultaneously with the collection of phytoplankton samples (Fig. 2). Monthly sampling was conducted from April to November at eight stations—four in the North Arm, three in the South Arm, and one in the West Arm (KLF 1–8) (Table 2).

Table 2. Kootenay Lake Nutrient Restoration Program limnological sampling sites.

Site ID	EMS site no.	Site name	Depth (m)
KLF 1	E216949	Kootenay Lake at Johnson's Landing	100
KLF 2	E216950	Kootenay Lake at Kembell Creek	120
KLF 3	E216951	Kootenay Lake at Bjerkeness Creek	120
KLF 4	E216952	Kootenay Lake at Hendricks Creek	135
KLF 5	E216953	Kootenay Lake at Crawford Bay	140
KLF 6	E216954	Kootenay Lake at Rhinoceros Point	150
KLF 7	E218832	Kootenay Lake at Redman Point	125
KLF 8	E252949	Kootenay Lake – West Arm	35

Temperature and oxygen profiles were obtained using a SeaBird SBE 19-plus profiler. At all stations, the profiler logged information every 10 cm from the surface to 5 m off the lake bottom. Temperature, oxygen and specific conductivity profiles for KLF 2 represent the North Arm and KLF 6 represents the South Arm. Water transparency was measured at each station using a standard 20-cm Secchi disc (without a viewing chamber).

Air temperature (Daily Mean Temp ^{o}C) and precipitation (Total Precipitation (mm)) data was collected at the Nelson airport and can be found online at collected online http://climate.weather.gc.ca/index_e.html. Seasons were partitioned as; winter= Dec-Mar, spring= Apr–Jun, summer= Jul–Sep, and fall= Oct–Nov.

Water samples were collected at stations KLF 1–8 from April through November using a 2.54-cm (inside diameter) tube sampler to collect an integrated water sample from 0–20 m. A Van Dorn bottle was used to collect hypolimnetic water samples (5 m off the bottom) at stations KLF 1–4 and KLF 5–7 from May to October (Table 2). Water samples were immediately placed on ice and shipped within 24 h of collection to Maxxam Analytics, Inc. in Burnaby, BC.

Water samples were analyzed for turbidity, total phosphorus (TP), total dissolved phosphorus (TDP), orthophosphate (OP), total nitrogen (TN), nitrate and nitrite, silica, pH, total organic carbon (TOC), total inorganic carbon (TIC) and alkalinity. In 2012, the lab methodology changed to include an additional significant figure in the test for phosphorus samples; so as a result, there is a higher level of precision at or below the detection limit.

Integrated water samples were also analyzed for Chlorophyll *a* (Chl *a*) by the Ministry of Environment, University of British Columbia. Prior to shipping, Chl *a* samples were prepared by filtering a portion of the integrated water sample through a cellulose acetate filter (AMD Manufacturing Inc.) with 0.45 µm pore diameter.

Additional water samples were taken at discrete depths in the epilimnion using a Van Dorn sampling bottle from June to September at stations KLF 2 and KLF 6. Samples were obtained from depths of 2, 5, 10, 15, and 20 m for analysis of TP, TDP, OP, nitrate and nitrite, Chl *a*, and phytoplankton taxonomy (described below).

Physical chemistry results were analyzed with the statistics software R (ver. 3.1.2). Analysis of variance (ANOVA) tests were performed to compare group mean differences. Multiple comparisons of means were also performed (Tukey's Contrasts) among stations (KLF 1–8), among arms of the lake (North= KLF 1–4, South= KLF 5–7, and West= KLF 8), and among seasons (spring= Apr–Jun, summer= Jul–Sep, and fall= Oct–Nov), as appropriate to the dataset. Linear trends were analyzed with a linear regression model. In addition, the 2013 annual mean were compared with a pooled dataset for 1992–2012. For consistency across years, KLF 8 was omitted from this pooled dataset. Statistical significance was taken at a level of $p < 0.05$.

Phytoplankton

Phytoplankton samples were collected from integrated water column at stations KLF 1–8 from April through November. Additional phytoplankton samples were taken at discrete depths at stations KLF 2 and KLF 6 from June-September. Integrated and discrete sampling methods described above. Lugol's iodine solution immediately after collection and couriered to West Vancouver forprocessing by Eco-Logic Ltd. Prior to quantitative enumeration, samples were shaken for 60seconds, carefully poured into 25 mL settling chambers, and allowed to settle for a minimum of6–8 hours.

The 2013 integrated and discrete samples were analyzed as follows: Phytoplankton enumeration was typically performed within 15 days of receiving the samples. Prior to quantitative enumeration, the samples were gently shaken for 60 seconds and allowed to settle in a 25-mL settling chamber for a minimum of 6–8 hours. Counts were done using a Carl Zeiss inverted phase-contrast plankton microscope.

Initially, several random fields (5–10) were examined at low power (250X magnification) for large microplankton (20 –200 µm), including colonial diatoms, dinoflagellates, and filamentous blue-greens. A second step involved counting all cells at high power (1,560X magnification) within a single random transect that was 10–15 mm long. This high magnification permitted quantitative enumeration of minute autotrophic picoplankton cells (0.2–2.0 µm, Cyanophyceae) and small nanoflagellates (2.0–20.0 µm, Chrysophyceae and Cryptophyceae).

In total, about 175–225 cells were enumerated from each sample to ensure statistical accuracy (Lund et al. 1958). Taxonomic identifications were performed using the keys of Prescott (1978) and Canter-Lund and Lund (1995). The phytoplankton species and biomass list used for the computation of population and class biomass estimates for Kootenay Lake in 2013 appears in Appendix 1 from Stockner (2009) in Schindler et al. (2009).

Zooplankton

Samples have been collected monthly at stations (KLF 2 and KLF 6) from April to October in 1997 through 2002. In 2003 the sampling season was lengthened from April to November and samples were collected from all eight sampling stations (KLF 1-8).

At each of the stations, three replicate oblique tows were made. The net had 153-um mesh and was raised from a depth of 40 m to 0 m at a boat speed of 1 m/s. Tow duration was 3 min, with approximately 2,500 L of water filtered per tow. The exact volume sampled was estimated from the revolutions counted by the Clarke-Bumpus flow meter. The net and flow meter were calibrated before or after each sampling season. All calibrations were done in a flume at the Civil Engineering Department at the University of British Columbia. In September, mechanical issues with the sampling boat changed zooplankton sampling techniques. Instead, zooplankton samples were collected by vertical hauls with a Wisconsin net. A factor was applied to the results to standardize with results from the Clarke-Bumpus sampler.

Zooplankton samples were rinsed from the dolphin bucket through a 100-µm filter to remove excess lake water and were then preserved in 70% ethanol. Zooplankton samples were analyzed for species density, biomass (estimated from empirical length-weight regressions, McCauley 1984), and fecundity. Samples were re-suspended in tap water that had been filtered through a 74-µm mesh and were sub-sampled using a four-chambered Folsom-type plankton splitter. Splits were placed in gridded plastic petri dishes and stained with Rose Bengal to facilitate viewing with a Wild M3B dissecting microscope (at up to 400X magnification). For each replicate, organisms were identified to species level and counted until up to 200 organisms of the predominant species were recorded. If 150 organisms were counted by the end of a split, a new split was not started. Using a mouse cursor on a live television image, the lengths of up to 30 organisms of each species were measured for use in biomass calculations. Lengths were converted to biomass (ug dry weight) using an empirical length-weight regression from McCauley (1984).

Zooplankton species were identified with reference to taxonomic keys (Pennak 1989, Brooks 1959, Wilson 1959, Sandercock and Scudder 1996).

Mysis diluviana

Samples of mysids from Kootenay Lake were collected at seven stations (KLF 1-7) monthly from January to December in 1999-2005, February to November in 2006 and April to November in 2007-2013. From 2004-2013 mysid samples were collected from station KLF 8 located in the West Arm. Due to mechanical issues with the sampling boat, September samples were not collected in 2013. Sampling was conducted at night, around the time of the new moon, to decrease the chance of mysids seeing and avoiding the net. With the boat stationary, three vertical hauls were done at each station using a 1-m^2 square-mouthed net with 1,000 µm primary mesh, 210µm terminal mesh, and 100-µm bucket mesh. Two hauls were made in deep water (0.5 nautical miles from both west and east of lake centre), and one haul was made in shallow water near either the west or east shore. The net was raised from the lake bottom with a hydraulic winch at 0.3 m/s. The contents of the bucket were rinsed through a filter to remove excess lake water and were then preserved in 100% denaturated alcohol (85% ethanol, 15% methanol).

Samples have been analyzed for density, biomass (estimated from an empirical length-weight regression, Lasenby 1977), life history stage, and maturity (Reynolds and DeGraeve 1972). The life history stages identified were juvenile, immature male, mature male, breeding male, immature female, mature female, brooding female (brood pouch full of eggs or embryos), disturbed brood female (brood pouch not fully stocked with eggs, but at least one egg or embryo left to show that female had a brood), and spent female (brood pouch empty, no eggs or embryos remaining).

Samples were re-suspended in tap water that had been filtered through a 74-µm mesh filter, placed in a plastic petri dish, and viewed with a Wild M3B dissecting microscope at up to 160X magnification. All mysids in each sample were counted and had their life history stage and maturity identified. Using a mouse cursor on a live television image, the body length (tip of rostrum to base of telson) of up to 30 individuals of each stage and maturity was measured for use in biomass calculations. Lengths were converted to biomass (mg dry weight) using an empirical length-weight regression (Smokorowski 1998).

Kokanee

Kokanee Spawners

The numbers of kokanee spawners in Meadow Creek and the Lardeau River have been estimated for over 40 years. Enumeration methods have changed very little over this period, thus providing consistent time-series information. Since the mid-1960s, Meadow Creek kokanee numbers have been determined by manually counting fish moving upstream into the channel using a permanent fish fence located at the lower end of the channel. At the peak of spawner migration, visual estimates were also made of kokanee numbers in Meadow Creek downstream of the channel. In years of high spawner numbers, some fish were passed upstream of the channel using a permanent fence located at the top end of the channel. Kokanee were sampled each year for length, age, sex ratio, and fecundity. Annual estimates of egg deposition were made, and fry out-migration from the channel was monitored each spring. Age at maturity was determined from spawner samples using otolith interpretation methods described by Casselman (1990).

Methods used to conduct visual estimates of kokanee in lower Meadow Creek, Lardeau River, and Arrow Lakes Reservoir tributaries were described in detail by Redfish Consulting Ltd. (1999) and Sebastian et al. (2000). Due to the high cost of enumerating the Lardeau River via helicopter, a single peak count estimate was conducted to provide only an order of magnitude estimate useful for understanding population trends. This estimate was supported by several days of ground truthing visual estimates. The peak of spawning was reasonably well known based on the daily count information of nearby Meadow Creek. Nonetheless, these data are not accurate enough to provide information for population estimates.

South Arm spawning streams in BC were assessed by experienced fisheries personnel who walked each stream and visually counted spawning kokanee. The surveys occurred weekly from late August to the end of September. The index streams included Crawford, Grey, Lockhart, LaFrance, Akokli, Boulder, and Summit creeks and Goat River. At the same time, Kootenai Tribe of Idaho (KTOI) staff conducted kokanee spawner surveys on six northern Idaho tributaries to the Kootenai River. Similar to methods used in BC, the Idaho surveys were also generally conducted from mid-August to early October, but the frequency of surveys varies owing to few, if any, fish being observed.

Kokanee eyed-egg plants

All of the streams selected for eyed-egg plants are known to have historically supported spawning populations (see Ericksen et al. 2009). Kokanee eggs were usually developed at a hatchery to the eyed stage and then transported to the redd sites for placement. The number of eggs placed within a redd varied from 20,000 to 48,000 per redd depending on the tributary. Sites within streams were chosen primarily based on accessibility and habitat suitability.

Placement of eggs was done by pouring the eggs in water into a curved flexible standard PVC (polyvinyl chloride) pipe partially buried into the substrate. As the pipe filled with eggs it was gradually withdrawn from the redd, allowing the eggs to flow out the open end and disperse within the placed gravel. On occasions when eggs “leaked” out of the redd, small gravel and fines were placed to hold the eggs within the redd.

In the last five years, an alternate method was used to plant about half the eggs in the South Arm Kootenay Lake tributaries. Tubes (~20 cm long) were filled with 30,000–35,000 eyed eggs per tube, placed in a trench in the substrate, and covered with gravel. Redds were developed by excavating the stream substrate as deep as 0.5 m and about 0.75 m x 1.5 m in area. Size (area) of redds varied depending on ease of excavation. A 5-cm flexible PVC pipe was laid on the floor of the excavated area with one end at the downstream end of the excavated area and the other end protruding out of the water at the upstream end of the excavation. The pipe was held in place using nearby rocks (5–15 cm) and then smaller gravels (< 3 cm) were used to fill the hole around the pipe to the level of the stream bed.

Trawl and hydroacoustic sampling

Two complete night time hydroacoustic and trawl surveys were conducted on Kootenay Lake in 2013 during the nights of July 6–8 and September 1–4. Since 1985, both hydroacoustic and trawl surveys have been carried out concurrently each fall during the new moon period using consistent methods (Schindler et al. 2010). When the South Arm fertilization began in 2004, additional acoustic and trawl monitoring was added during the early summer period. The survey timing ranged from mid-June to mid-July, depending on when the new moon period occurred (Table 3). The intent of early sampling was to get a snapshot of fish distribution and abundance early in the growing season while the North and South arm fry populations are still segregated. Early sampling provides an index of South Arm fry abundance as well as some size information, which can be compared with the North Arm population (for all ages).

Table 3. Dates of early summer acoustic and trawl sampling, trawl location, and number of trawls conducted, 2004–2013.

Year	Month	Dates	Trawl location (number of trawls)	
			North Arm	South Arm
2004	June	13-16	Birchdale (1)	Rhino Point (3)
2005	July	8-10	Shutty (1), Woodbury (3)	Midge Cr(3)
2006	June	26-28	Shutty (2), Woodbury (2)	Rhino Pt (3),Redman Pt (3)
2007	July	4-7	Birchdale (1)	Redman Point(3)
2008	July	5-6	Shutty (1)	Redman Point (1)
2009	June	23-30	Shutty (1), Woodbury (3)	Redman (3) Rhino (3) Wilson(3)
2010	July	15-17	Shutty (2), Woodbury (3)	Redman (3) Rhino (2)
2011	July	5-8	Shutty (1)	Rhino(1)
2012*	July	17-20	-	-
2013*	July	6-8	-	-

*No early summer trawling due to low fry densities.

Trawl surveys

Late season trawl surveys (September) consisted of three stepped-oblique trawls at each of six stations (Fig 2) to capture a representative sample of fish from each depth strata where fish were observed on the echosounder. The net was fished for eight or 16 minutes at consecutive 5-m depth layers, targeting fish from 20–45 m depth (i.e., five layers). Trawl gear consisted of an opening and closing 5 x 5 m or 7 x 3 m beam trawl, holding a 20 m long net of graduated mesh size (6–92 mm stretched), towed at 0.80-0.95 m/s. The trawl net depth was initially calibrated against boat speed and cable length with a Notus net depth sensor system, after which depths were estimated by cable length. A Global Positioning System (GPS) was used to estimate distances travelled for calculating sampled volumes. Mid-water trawl samples provide species verification for the acoustic survey, age structure, size-at-age, and the proportion of mature fish in the catch.

The focus of early season trawling was for comparing fry size between North and South Arms early in the season prior to the stocks mixing, which was intended to provide insight into fry contribution from South Arm tributaries. Hydroacoustic data were inspected the day after surveying South Arm transects, and those transects with the highest fry densities were identified for trawl sampling. The net was typically towed for one hour, covering up to three depth layers but largely directed at depths where the highest concentrations of fry were found on the echosounder. If fry were not captured in three one-hour directed trawls, no further sampling was done (i.e., we concluded that trawling would not likely be successful at other locations in the South Arm where acoustic densities were even lower). During the 2013 early season survey, the fry were relatively low in abundance and not concentrated into dense enough layers to warrant any trawling.

Captured fish were kept on ice until they were processed the following morning. Species composition, fork length, weight, scale code, and stage of maturity were recorded. Scales were taken from fish >75 mm for aging. Fish lengths from fall sampling were adjusted to an October 1 standard using empirical growth data from Rieman and Myers (1992).

Hydroacoustics

Acoustic data for each survey were collected at 18 transect locations evenly spaced along the North and South arms of the main lake (Fig. 2). Survey data were obtained using a Simrad model EK60 120 KHz split beam system (specification and field settings are shown in Appendix 3). The echosounder system was calibrated in the field at the beginning of the survey following the procedure described by Kongsberg Maritime AS (2008). The transducer was towed on a planer alongside the boat at a depth of 1 m, and data were collected continuously along survey lines at 2–5 pings/s while cruising at about 2 m/s. Navigation was by radar, GPS, and a 1:75,000 Canadian Hydrographics bathymetric chart.

Echo counting was used to generate target densities for unit area by depth stratum. Echograms for each transect were analyzed from surface to 50 m depth in 10 equal depth layers (allowing two exclusion zones (surface to 3 m and 0.5 m above the bottom). Target sizes assumed to encompass the entire fish population and the upper cut off of fry were estimated using the split beam method, as described by Simmonds and MacLennan (2005), and by using Love's formula to convert target strength in decibels to fish length (Appendix 4, Love 1977). The fish densities in number/ha for each transect and depth strata were output in 1-decibel (dB) size groups and compiled on an Excel spreadsheet. The resulting layered fish densities were used to stratify transects of each survey into homogenous zones. These zones and respective habitat areas by 5 m depth strata were combined using a Monte Carlo simulation procedure. After 30,000 iterations, a maximum likelihood estimate (MLE) with statistical bounds was produced for the entire fish population and for fish larger than fry size.

Kokanee biomass

Biomass estimates for pelagic habitat were determined from acoustic abundance portioned into age groups based on both trawl and acoustic surveys. Fish abundance by age group was then expanded to biomass using mean weight of fish by age group determined from the trawl samples. Spawner biomass was estimated by applying the average weight of spawners measured at Meadow Creek spawning channel to the total estimated number of spawners from Lardeau River and Meadow Creek. For years where only spawner lengths were available, individual weights were estimated from a length–weight relation derived from previous

Meadow Creek data on file (MFLNRO). This number was then divided by the surface area of "pelagic habitat" to determine a biomass density (kg/ha). See Appendix 7 for biomass calculations and results.

Fry to adult survival rates

Kokanee fry-to-adult survival rates have been estimated using the Meadow Creek long-term data set for total fry production and adults returning. Fry production data used includes channel fry estimates plus an estimate of natural production from above and below the channel assuming 5% egg to fry survival.

Two separate estimates of fry to adult survival have been calculated and presented. As age at maturity has historically been dominant age 3+, calculation of fry to adult survival previously reported by Schindler et al. (2014b) has assumed age 3+ at return all years and presented survival rate by return year. We continued using this assumption in calculating the survival trend although these data are now presented in terms of survival rate by fry cohort. In addition, to better represent those years where age at maturity is mixed or shifts entirely away from age 3+, we have also calculated and presented fry to adult survival for each fry cohort based in adult return age proportions from otolith analysis. No attempt has been made to estimate or compare fry to adult survival for different age spawners within the same cohort, but rather the combined percent return of all ages from each fry year has been reported.

RESULTS

Physical Limnology

Temperature, Specific Conductivity and Oxygen

The shallow, riverine West Arm of Kootenay Lake is different from the main basin of the lake, with physical and chemical limnology similar to that of the epilimnion of the main lake (Daley et al. 1981). Temperatures were fairly uniform from surface to bottom, although more stratification was observed in summer months. Peak temperature was observed on July 29th, 2013 (Table 4).

Table 4. Seasonal mean (± 1 standard deviation) temperatures (^{o}C) in the West Arm (KLF 8) taken at 0–35 m depths, 2013.

	2013	
Month	Mean	±SD
April 8	5.62	0.36
May 6	7.80	0.34
June 3	10.96	0.37
June 18	12.97	0.10
July 2	13.46	0.43
July 29	20.00	0.28
September 25	16.63	0.36
October 28	10.81	0.22

In the North Arm, a maximum surface temperature was recorded in July at station KLF 1 (21.4 ^{o}C). In the South Arm, the maximum surface temperature was 23.5 ^{o}C in early July at station KLF 7. Hypolimnetic temperatures remained at 4–6 ^{o}C throughout the year.

Spatial and temporal differences in stratification exist between the North and the South Arms (Fig. 5) due to variation in temperature and discharge regimes from the Duncan/Lardeau rivers in the North and Kootenay River in the South, all of which are regulated by upstream hydroelectric dams and reservoirs. Surface inflows are probably the most important sources affecting water quality conditions of this large lake system (Northcote et al. 1999). The Kootenay and Duncan rivers comprise 56% and 21% of the total inflow to Kootenay Lake respectively (Binsted and Ashley 2006). Other differences in the thermal structure of the North and South Arms are also caused by many complex interactions of surface-driven processes (wind and heat exchange) and internal wave dynamics within Kootenay Lake (Northcote et al. 1999).

In 2013, the main body of Kootenay Lake (stations KLF 1–7) began warming in May with a strong thermocline developing by July and a maximum surface temperature occurring in late July (Fig. 5).

Kootenay Lake is well oxygenated from the surface to the bottom depths at each station (data on file at the Ministry of Forests, Lands and Natural Resource Operations in Nelson). In 2013, oxygen was consistent through the water column and typical of an orthograde profile (Fig. 6). Nutrient enrichment has had no detectable effect on hypolimnetic oxygen concentrations.

Conductivity or specific conductance is a measure of the resistance of a solution to electrical flow (Wetzel 2001). In an aqueous solution, the resistance of electrical current declines with increasing ion content (Wetzel 2001). I.e. the lower the salinity content is, the greater the resistance to an electrical current. Specific conductivity increased with depth and was higher in the South Arm (Fig. 5).

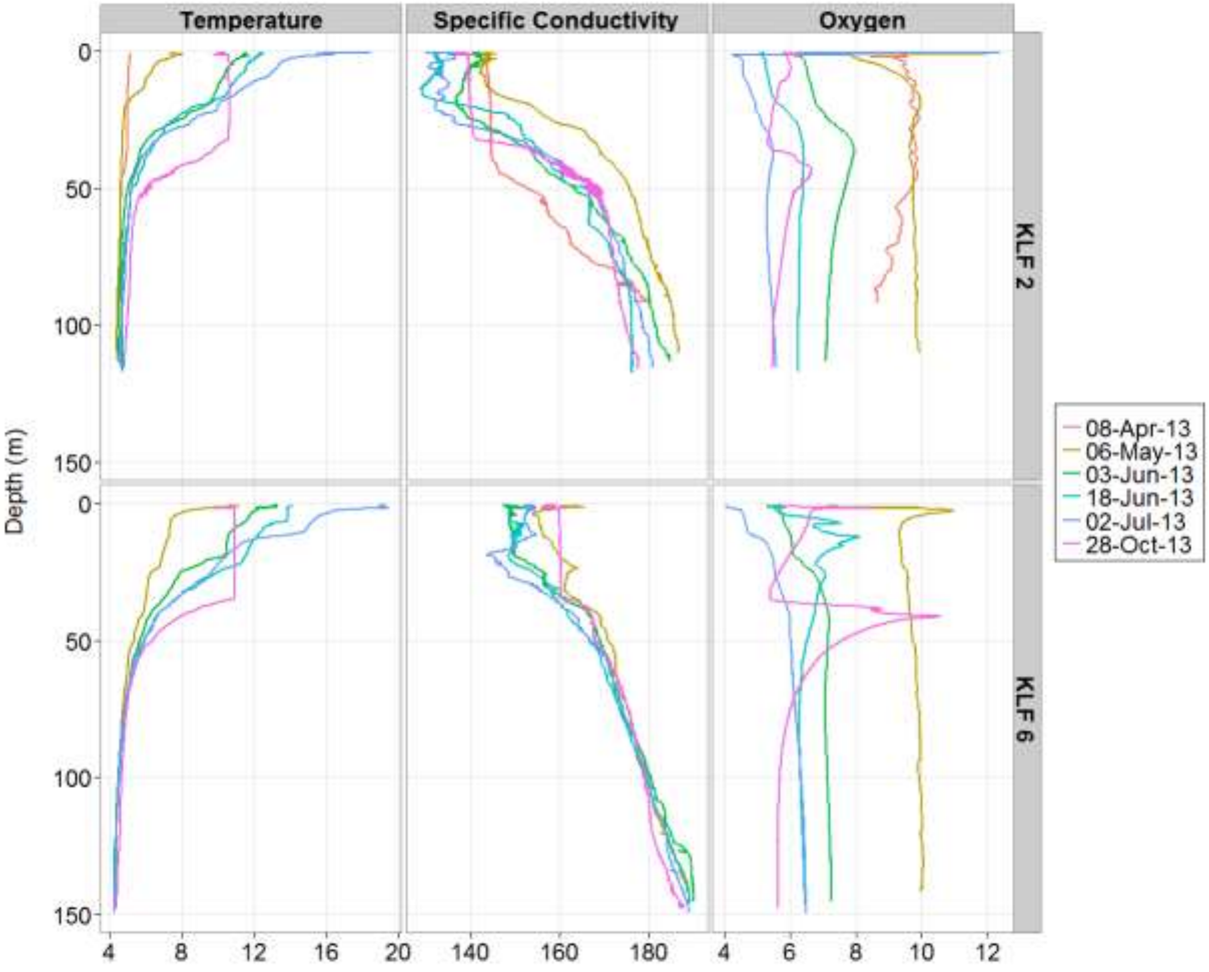


Figure 5. Temperature (^{o}C), specific conductivity (µs/cm) and oxygen (mg/L) profiles at stations KLF 2 and KLF 6, April to October, 2013. Data omitted due to instrument issues; 08-Apr (KLF6); 29-Jul and 25-Sep (KLF and KLF 6).

Air Temperature and Precipitation

Air temperature and precipitation recorded in Nelson can be used as an index of climate on Kootenay Lake. Seasons are differentiated as follows: spring= Apr–Jun, summer= Jul–Sep, fall= Oct–Nov and winter=Dec-Mar. In 2013, winter and spring air temperatures were similar to the average calculated from 1992-2013 (Fig.6). The summer temperature was higher than the long term mean and the fall temperature was lower than the long term mean. Precipitation in 2013 deviated from the long term 1992-2013 mean for all seasons (Fig.7). Winter and fall precipitation was lower than the long term average; however spring and summer precipitation was higher than the 1992-2013 mean.

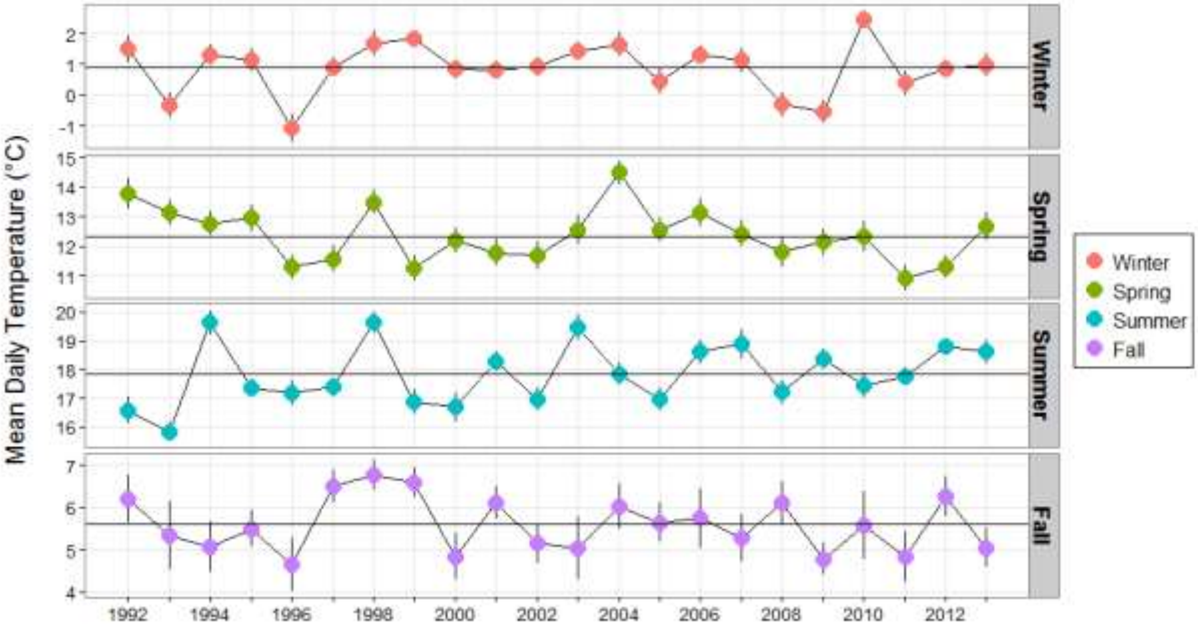


Figure 6. Seasonal daily mean air temperatures (˚C) recorded at the Nelson airport 1992-2013.

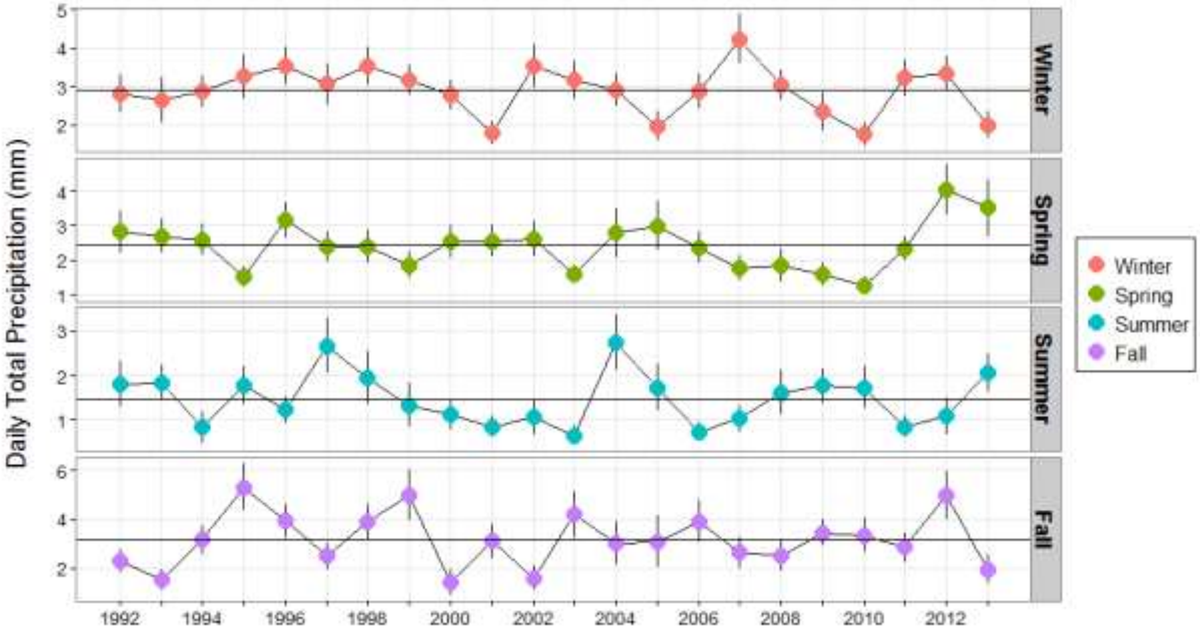


Figure 7. Seasonal total daily precipitation (mm) recorded at the Nelson airport 1992-2013

Secchi depth

Secchi measurements evaluate the transparency of water to light and can serve as a general indicator of productivity (Wetzel 2001). Secchi disk measurements on Kootenay Lake in 2013 indicated a typical seasonal pattern of decreasing transparency associated with the spring phytoplankton bloom, followed by an increase in transparency as the bloom gradually abated by the late summer and fall (Fig. 8). In 2013, there was a seasonal trend, where the spring, summer and fall means were all significantly different (spring=7.62 m, summer=5.65 m, fall 11.42 m) (Fig. 8). Importantly, this general pattern was observed for all stations and arms (Fig. 8). There was a significant difference between the pooled 1992-2012 (6.78 m) and the 2013 mean (7.82) (Fig. 9).

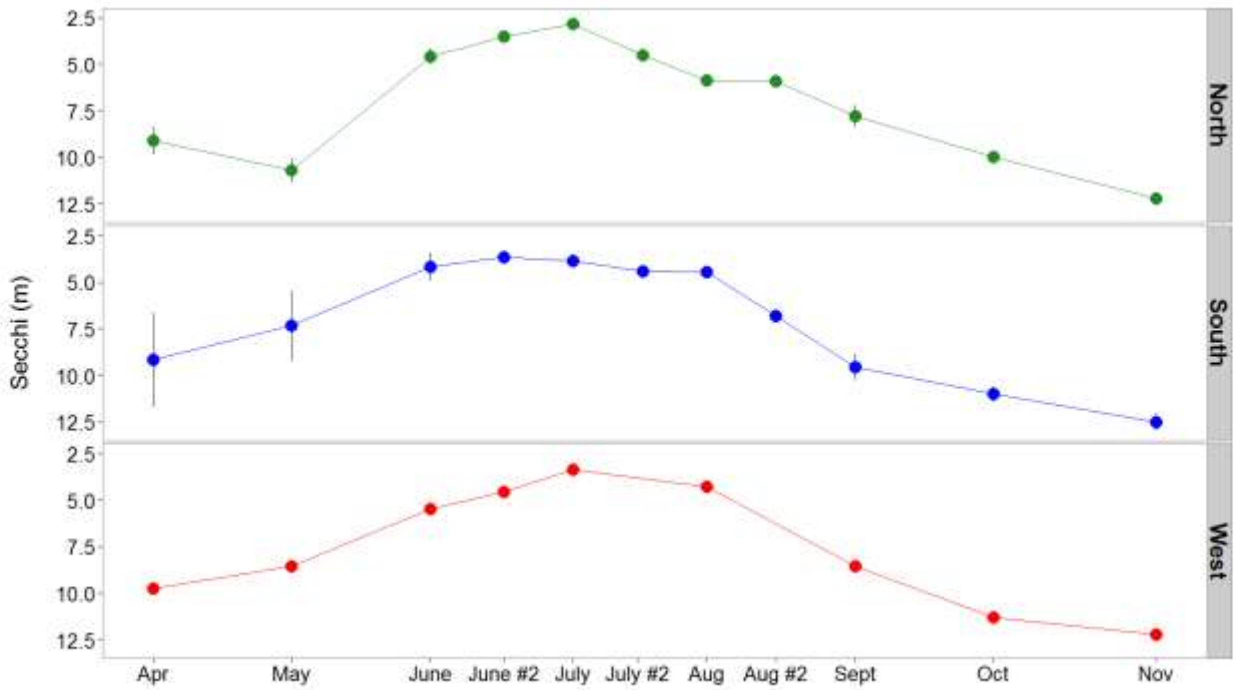


Figure 8. Secchi disc measurements, North (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November, 2013. July #2 and Aug #2 are stations KLF 2 and KLF 6 only. Note y axis in reverse.

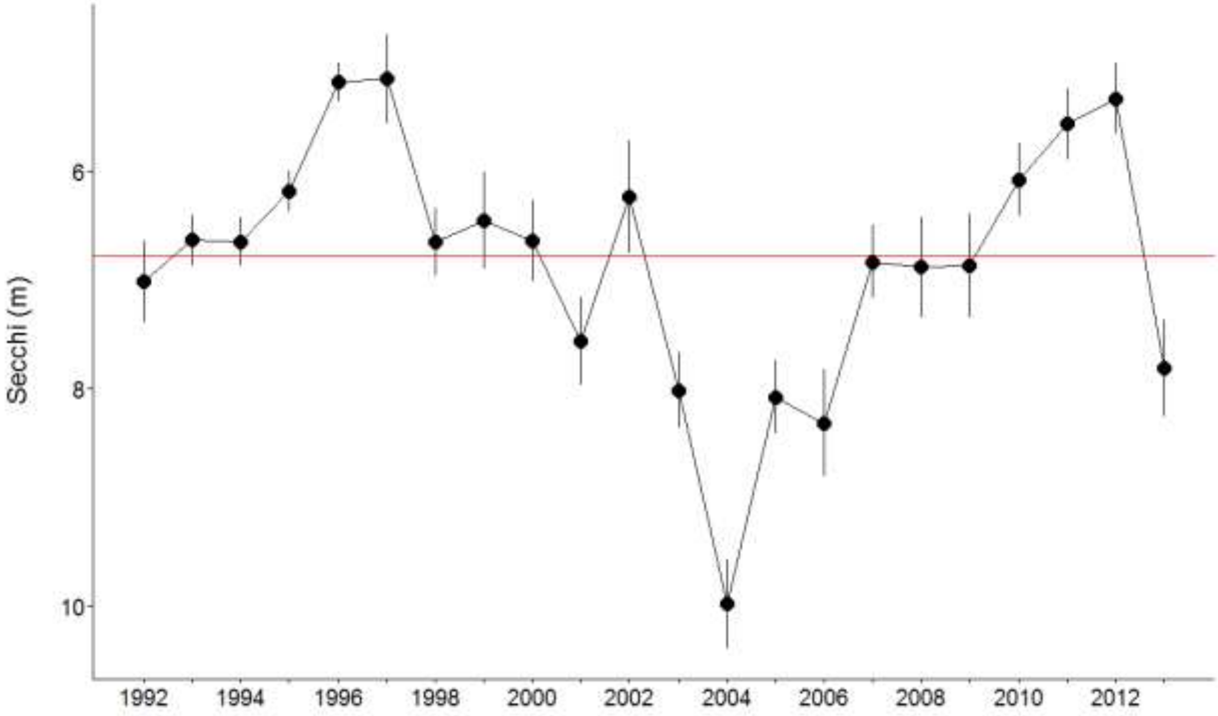


Figure 9. Annual Secchi disk depths from stations KLF 1–7, 1992 to 2013. Means ±SE. Pooled mean from 1992-2012 (red line). Note y axis in reverse.

Water Chemistry

Integrated Epilimnion

Turbidity

There was not a significant difference between stations or between the North, South and West Arms. Seasonal expression, however, was observed. Summer observations were highest (0.71 NTU), then spring (0.36 NTU), and fall means were the lowest (0.20 NTU) (Fig 10). The annual mean in 2013 (0.47 NTU) decreased from 2012, however was not significantly different than the pooled 1992–2012 mean (0.46 NTU) (Fig. 11).

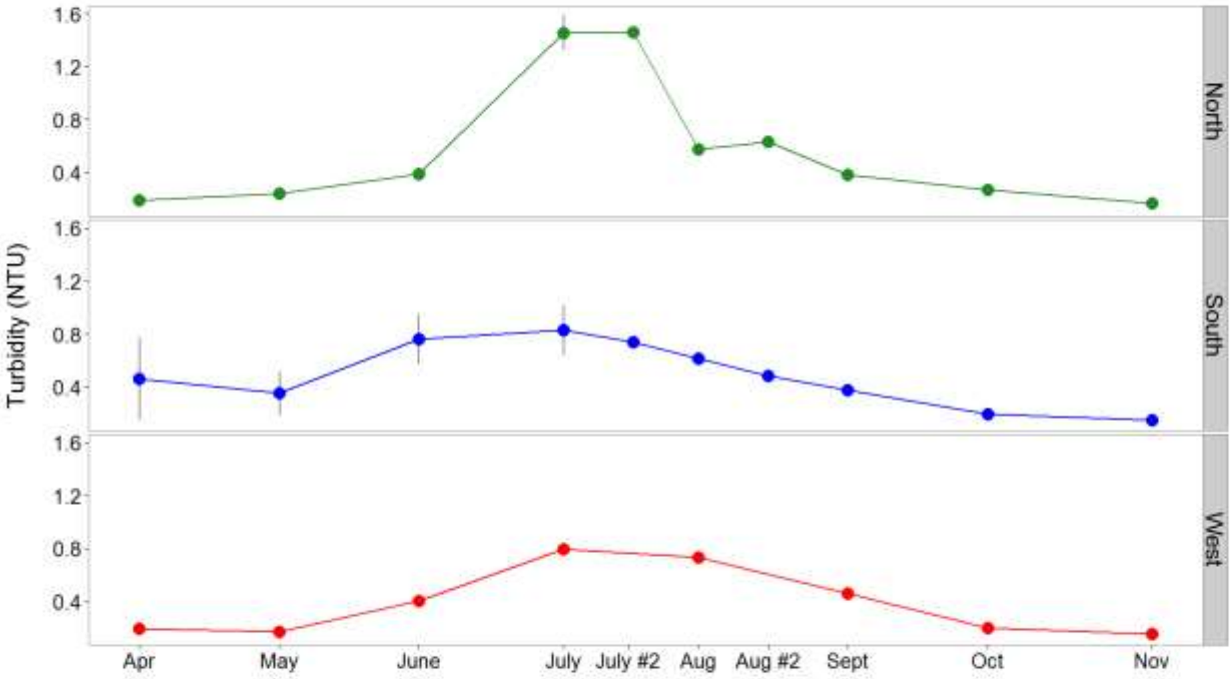


Figure 10. Turbidity, North (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November, 2013. July #2 and Aug #2 are stations KLF 2 and KLF 6 only.

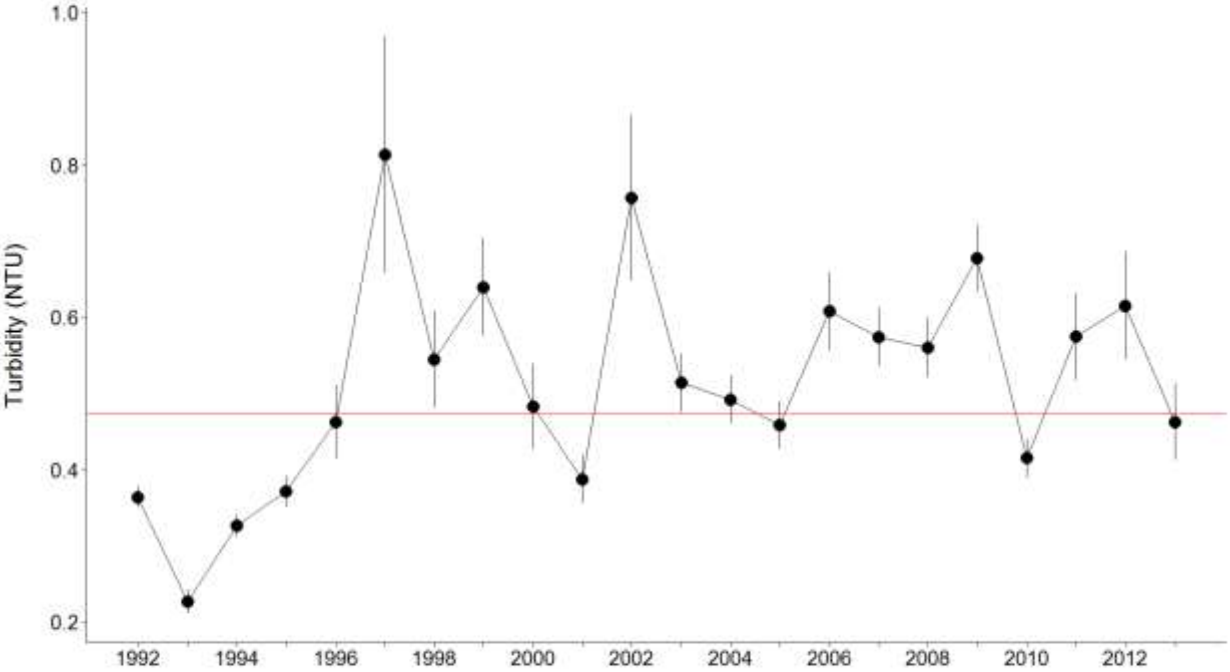


Figure 11. Annual turbidity from stations KLF 1–7, 1992 to 2013. Means ±SE. Pooled mean from 1992-2012 (red line).

Phosphorus

Phosphorus is commonly used as an indicator of productivity due to the central role it plays in regulating biological metabolism. Phosphorus is monitored throughout the season to both evaluate limitations and monitor the potential non-uptake of phosphorus associated with nutrient additions. Results for phosphorus may be slightly inflated, as values reported under the reportable detection limit (RDL) were set to the RDL of 2 µg/L. In 2013, all total phosphorus (TP) values were above detection. However, 20% of total dissolved phosphorus (TDP), and 51% of orthophosphate (OP) values were under the RDL.

In 2013, there was no spatial difference between arms observed (Fig. 12). Additionally, there was not a seasonal expression observed. High variability was observed in late October, due to a high TP result at station KL5. In 2013, the annual mean (4.99 µg/L) increased marginally from the previous year, and was not significantly different than the pooled average of 4.87 µg/L (Fig. 13).

Total dissolved phosphorus (TDP) did not express spatial or seasonal differentiation (Fig. 14). Other than a high value in July at station KL8, TDP varied minimally during the year. In 2013, annual TDP (2.72 µg/L) increased slightly from 2012, and was significantly lower than the 1992–2012 pooled average (3.35 µg/L) (Fig. 15).

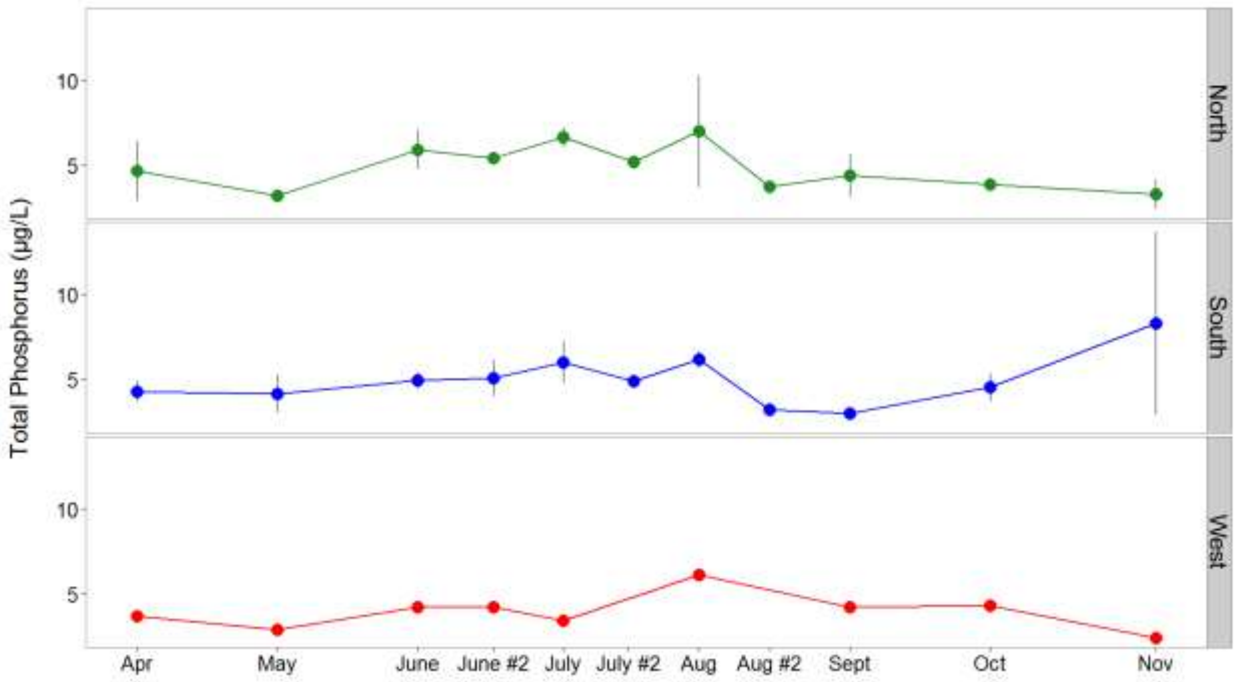


Figure 12. Total phosphorus, North (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November, 2013. Note: July #2 and Aug #2 are from stations KLF 2 and KLF 6 only.

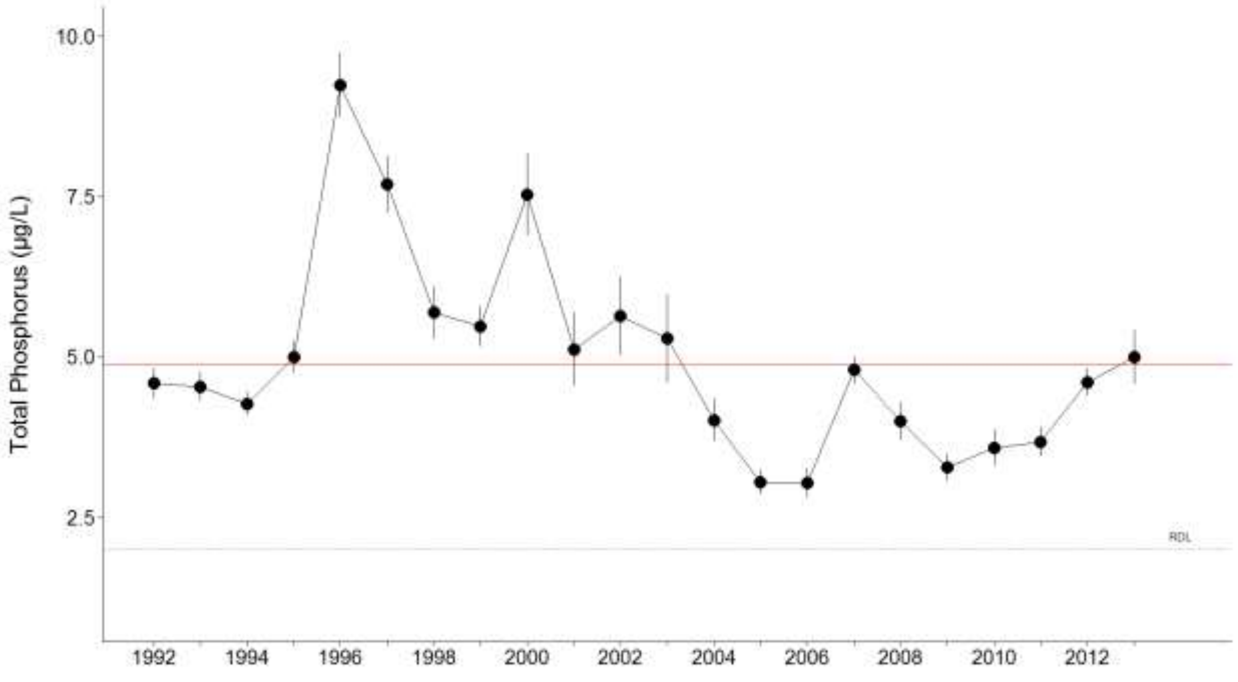


Figure 13. Annual total phosphorus from stations KLF 1–7, 1992 to 2013. Means ±SE. Pooled mean from 1992-2012 (red line).

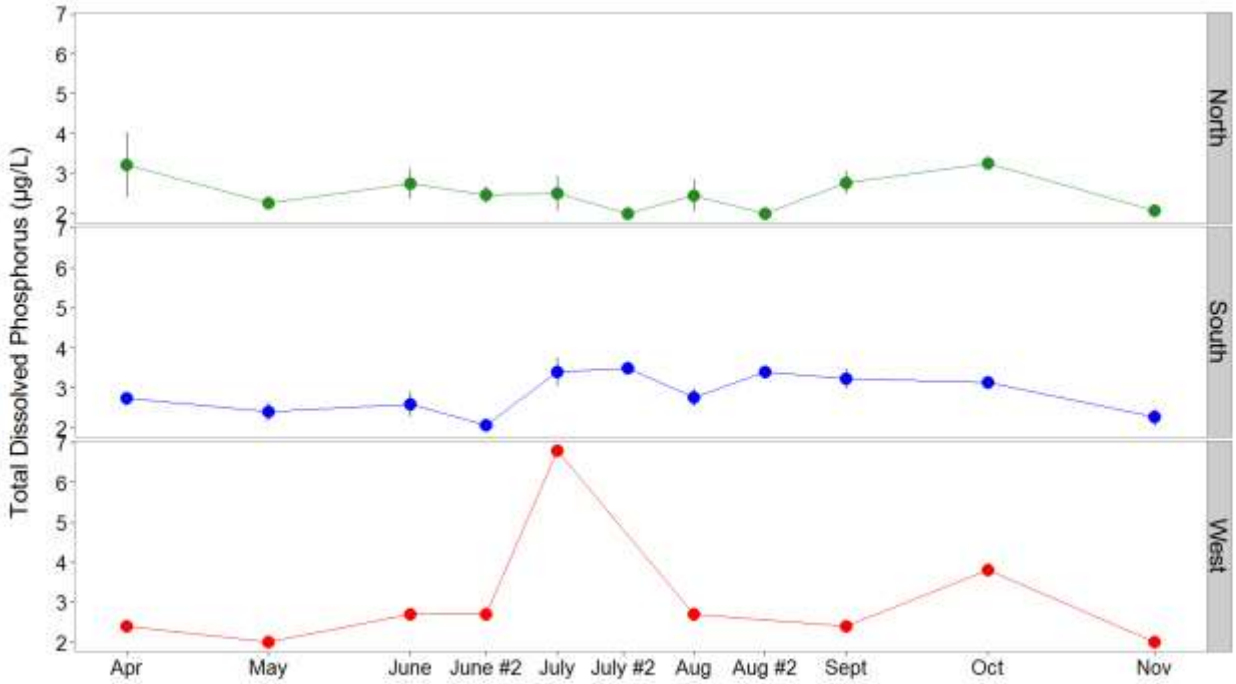


Figure 14. Total dissolved phosphorus, North (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November, 2013. July #2 and Aug #2 are from stations KLF 2 and KLF 6 only.

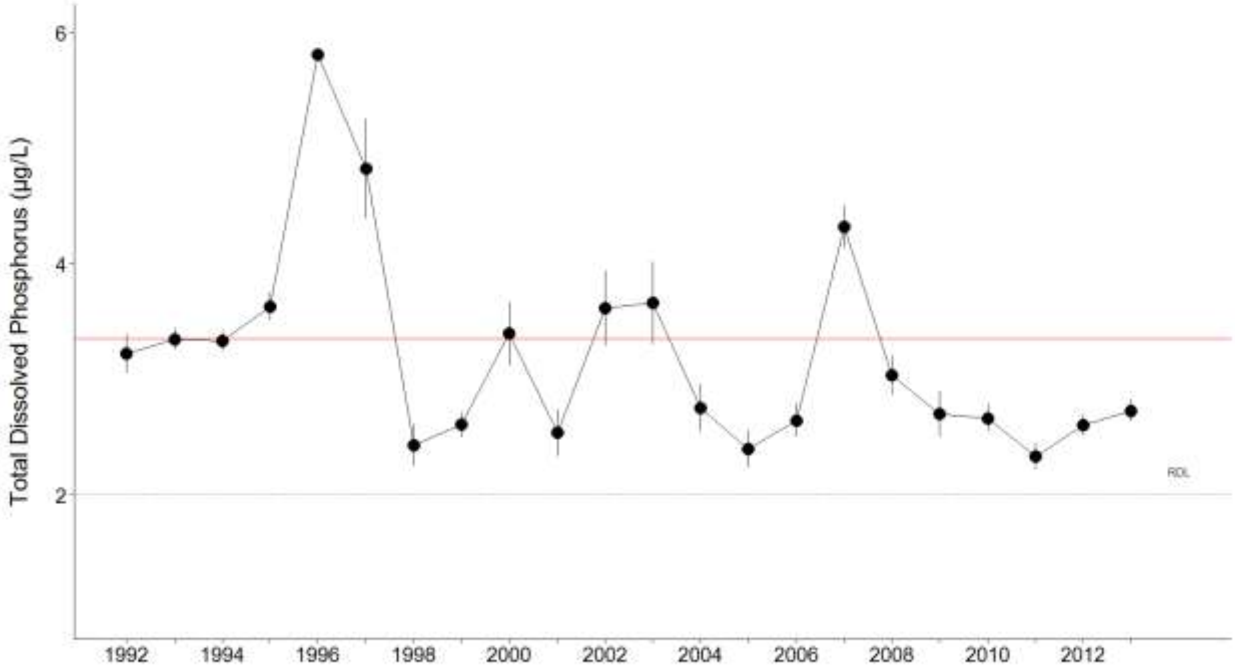


Figure 15. Annual total dissolved phosphorus from stations KLF 1–7, 1992 to 2013. Means ±SE. Pooled mean from 1992-2012 (red line).

Nitrogen

In fresh water, complex biochemical processes use nitrogen in many forms consisting of dissolved molecular N_2 (nitrogen gas), ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, and organic nitrogen. A major source of nitrogen in lakes is the nitrate in precipitation in lake watersheds (Horne and Goldman 1994). Nitrate is the most abundant form of inorganic nitrogen in lakes (Horne and Goldman 1994). Total nitrogen comprises dissolved inorganic forms (i.e., nitrate, nitrite and ammonia) and particulate nitrogen (mainly organic).

Total nitrogen in the North Arm was significantly lower than the South Arm, and the West Arm was between both basins (Fig. 16). Seasonally, TN in 2013 was high in the spring (231 µg/L) and decreased into the summer and fall (181 and 177 µg/L). Total nitrogen in 2013 (193 µg/L) was significantly higher than the 1992–2012 mean (180 µg/L) (Fig. 17).

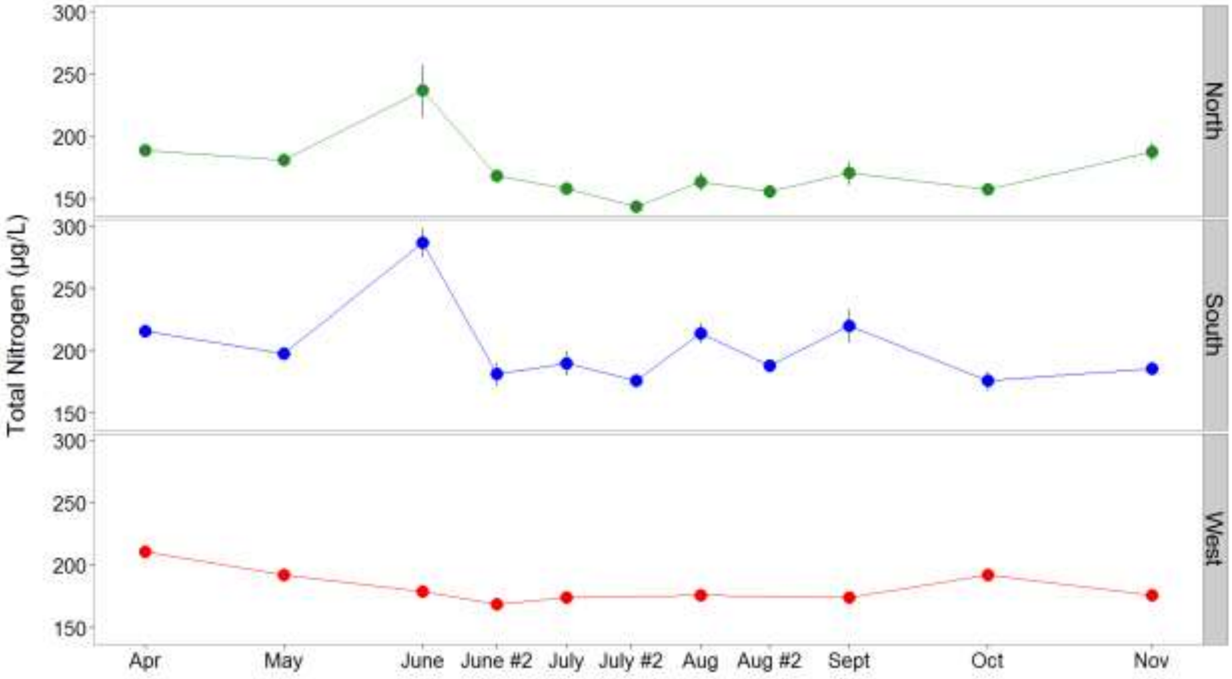


Figure 16. Total nitrogen, North (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November, 2013. July #2 and Aug #2 are from stations KLF 2 and KLF 6 only.

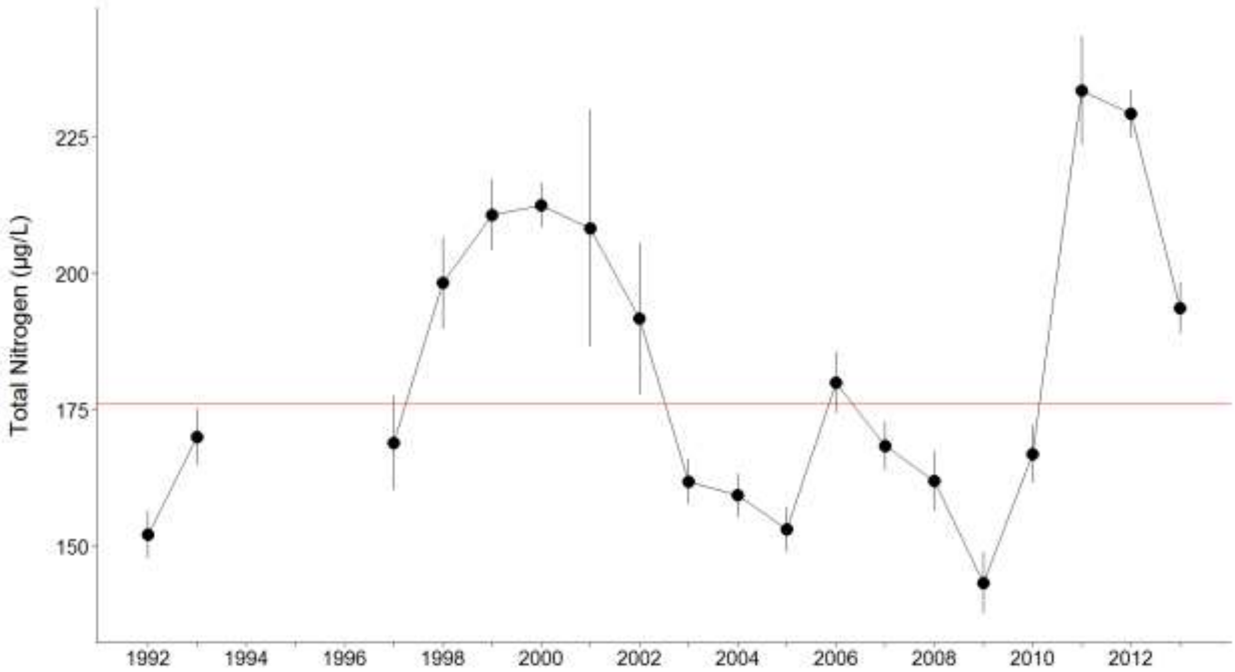


Figure 17. Annual total nitrogen from stations KLF 1–7, 1992 to 2013. Means ±SE. Pooled mean from 1992-2012 (red line).

Dissolved inorganic nitrogen (DIN), consists of nitrite (NO_2-N), nitrate (NO_3-N), and ammonia (NH_3-N). Nitrate and ammonia are the forms of nitrogen most readily available to phytoplankton (Wetzel 2001). Previous analysis primarily resulted in ammonia at or below the minimum detection limit of 5 µg/L in Kootenay Lake. Ammonia has not been analyzed since 2008; therefore, the dissolved inorganic nitrogen is represented by the nitrate and nitrite data plus an inferred ammonia value of 5 µg/L.

In 2013, a typical seasonal trend of DIN was observed in Kootenay Lake. All arms displayed a decreasing trend in DIN in the summer months (Fig 18). Minimum DIN was observed in late July at KLF 4 (43 µg/L). The seasons were significantly different, where spring observations were the highest (spring = 137, summer=85, and fall= 120 µg/L).

Dissolved inorganic nitrogen in 2013 (114 µg/L) was slightly lower than in 2012 and was significantly different from the pooled mean of 88 µg/L (Fig. 19). Although, sampling methodology changing in 2004 minimized water sampling from below the epilimnion. In 2013, DIN was significantly higher than the 2004-2012 mean (92 µg/L).

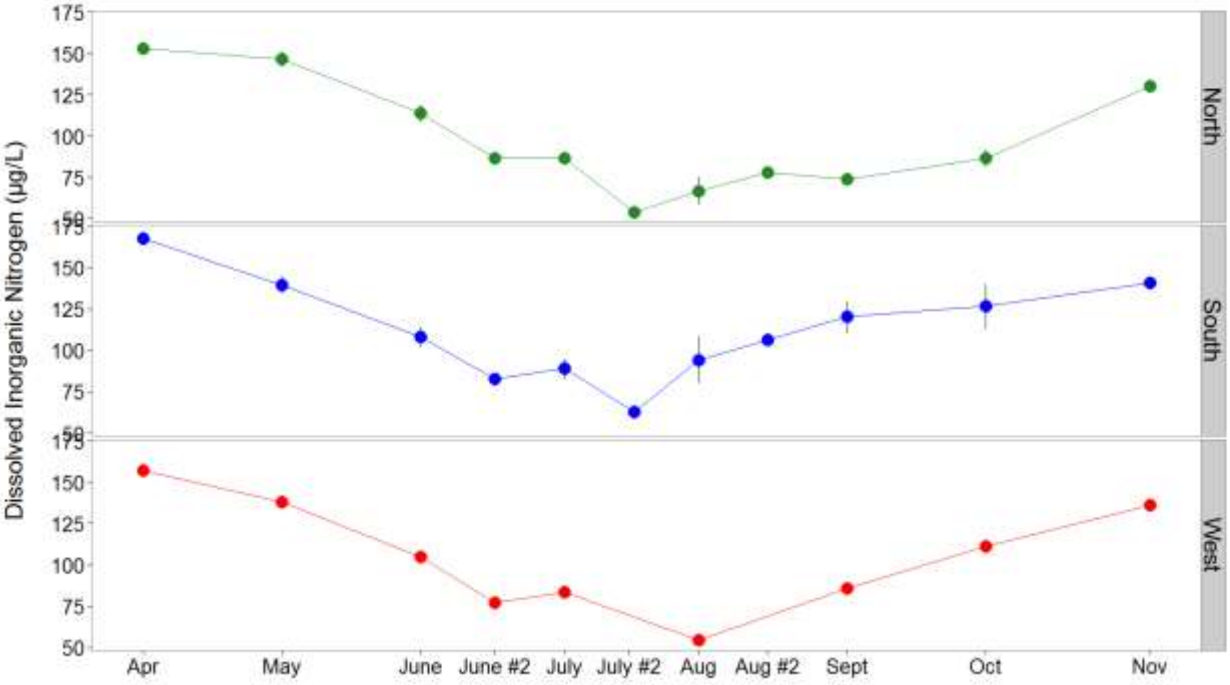


Figure 18. Dissolved Inorganic Nitrogen, North (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November, 2013. July #2 and Aug #2 are from stations KLF 2 and KLF 6 only.

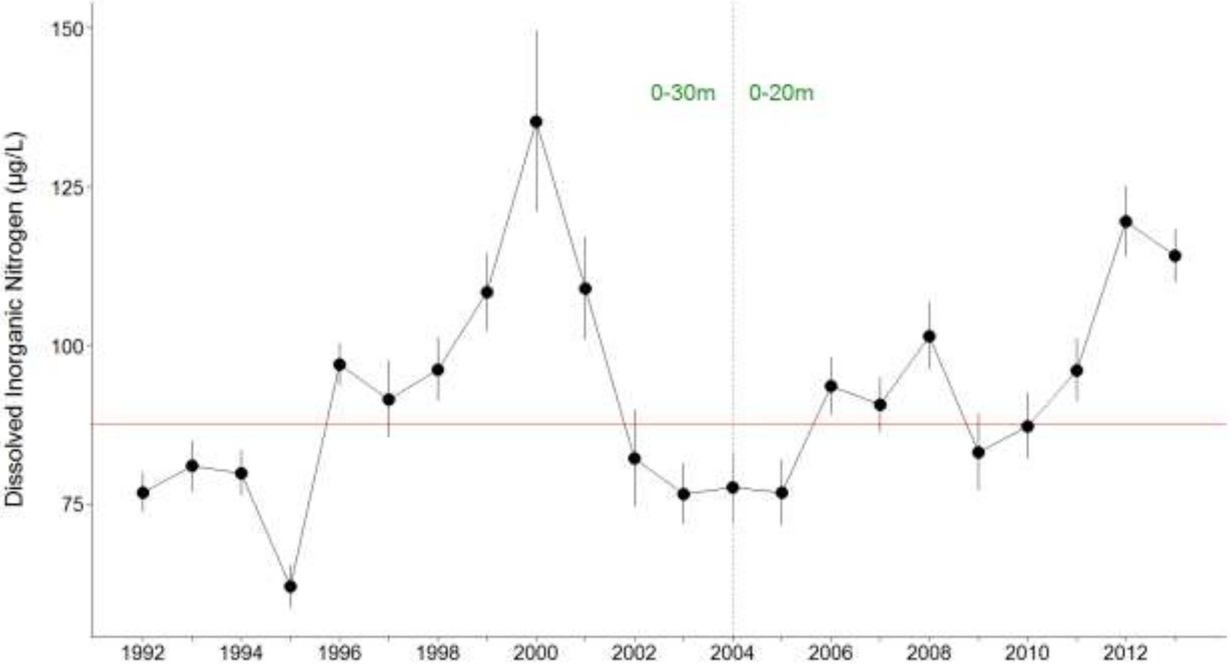


Figure 19. Annual dissolved inorganic nitrogen from stations KLF 1–7, 1992 to 2013. Means ±SE. Pooled mean from 1992-2012 (red line).

Nitrogen:Phosphorous

The ratio of DIN to TDP is the N:P ratio, and is a measurement of limitations of productivity in a lake. An N:P ratio < 14 (weight:weight) is indicative of nitrogen limitation, and a ratio >14 is indicative of phosphorus limitation (Koerselman and Meuleman, 1996).

There was seasonal expression of the N:P ratio in 2013 (Fig. 20). The summer mean (31) was significantly lower than the spring and fall means (55 and 48; respectively). The decreasing N:P ratio is reflective of the seasonal decrease in DIN (Fig. 18). There was not a significant difference between the Arm means. The N:P ratio decreased from 2012, and was significantly higher than the pooled 1992-2012 mean (Fig. 21)

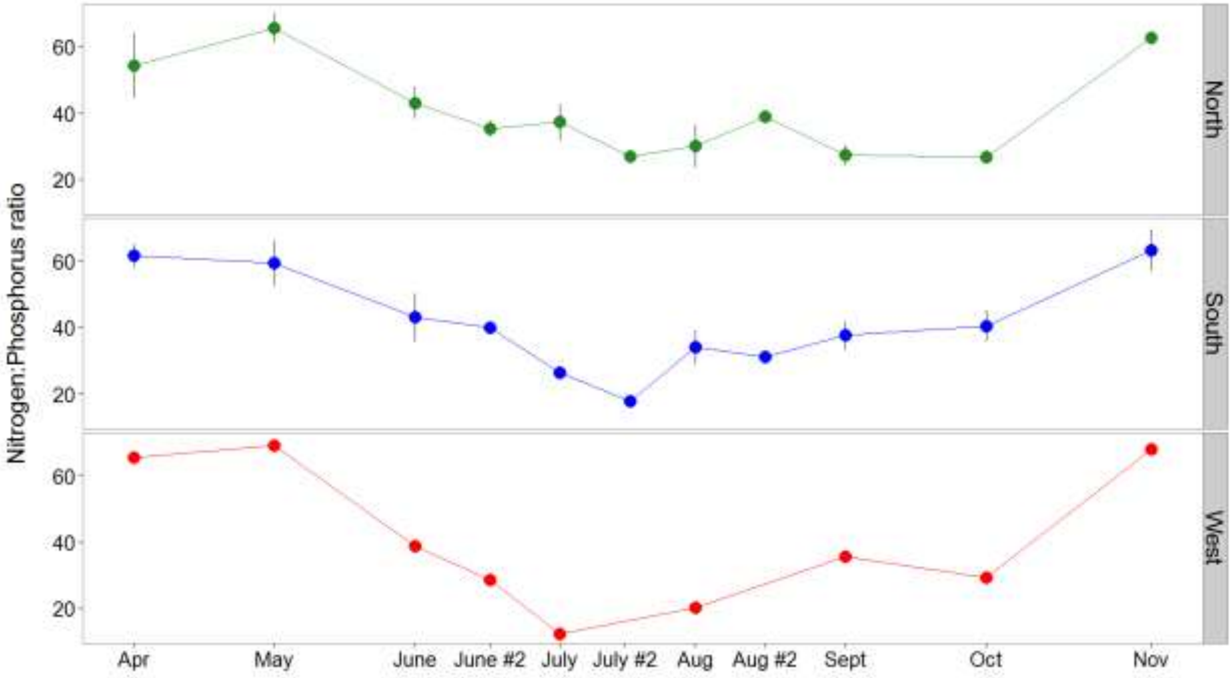


Figure 20. Nitrogen:Phosphorus ratio (dissolved), North (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November, 2013. July #2 and Aug #2 are from stations KLF 2 and KLF 6 only.

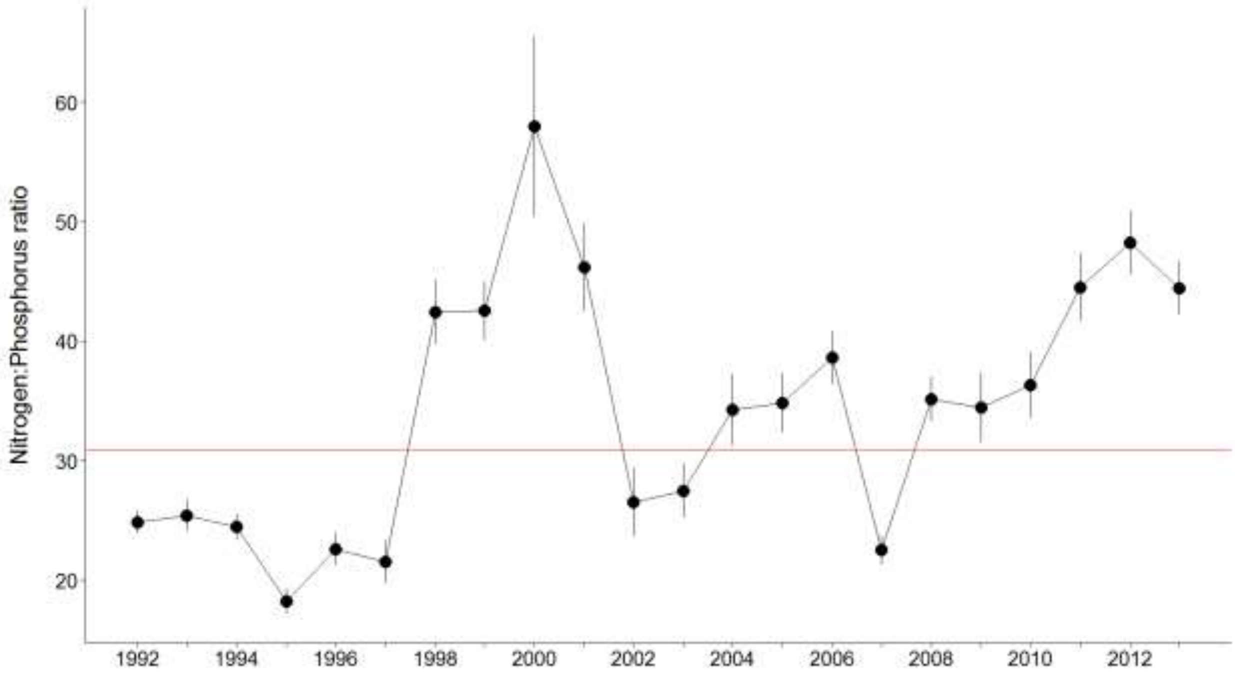


Figure 21. Annual Nitrogen:Phosphorus ratio (dissolved) from KLF 1–7, 1992 to 2013. Means ±SE. Pooled mean from 1992-2012 (red line).

Silica

Silica is an integral structural component in diatomaceous algae and is considered a major factor influencing algal production in many lakes (Wetzel 2001). Dissolved reactive silica was measured as an indicator of silica available to diatoms.

Silica was significantly different between the North and South Arms, where the South Arm was higher. As well, a seasonal decrease of silica was measured in 2013; spring results were significantly higher than the summer and fall results (Fig. 22). Silica decreased in 2013 from 2012. There was not a significant difference in the 2013 mean (3.9 mg/L) to the 1992–2012 pooled mean (4.3) (Fig. 23). Silica remained above 0.5 mg/L, the concentration at which it is considered limiting for diatoms (Wetzel 2001).

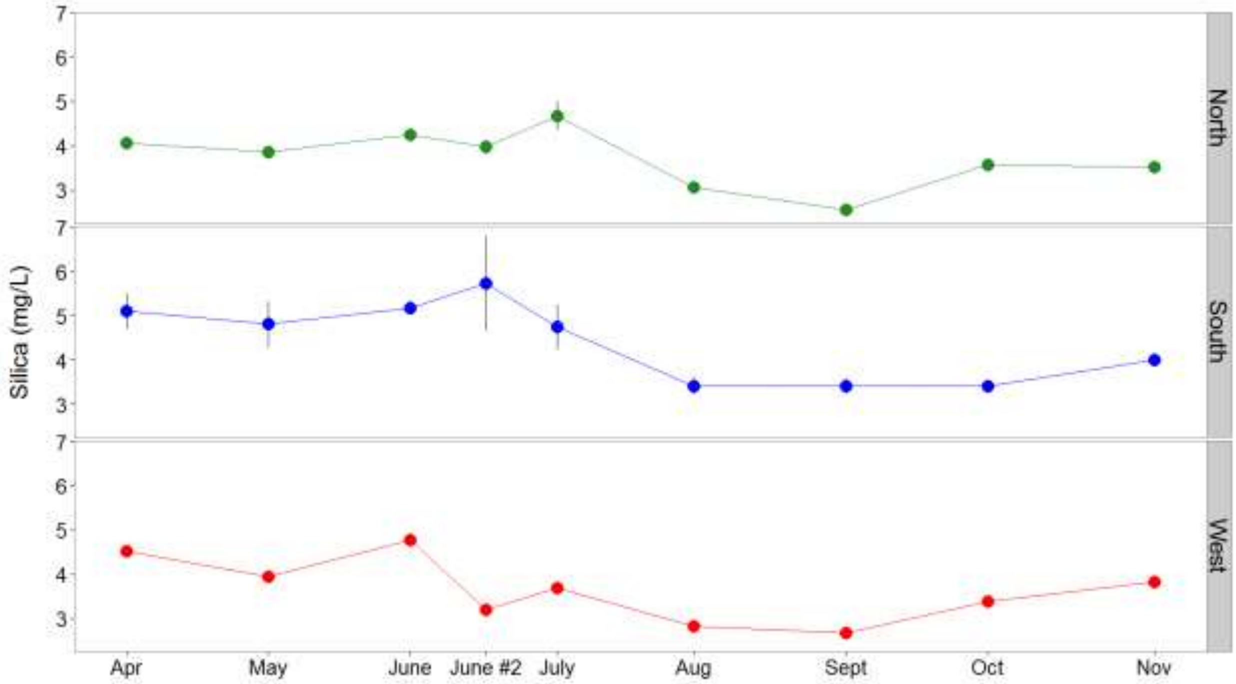


Figure 22. Dissolved silica, North (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November, 2013.

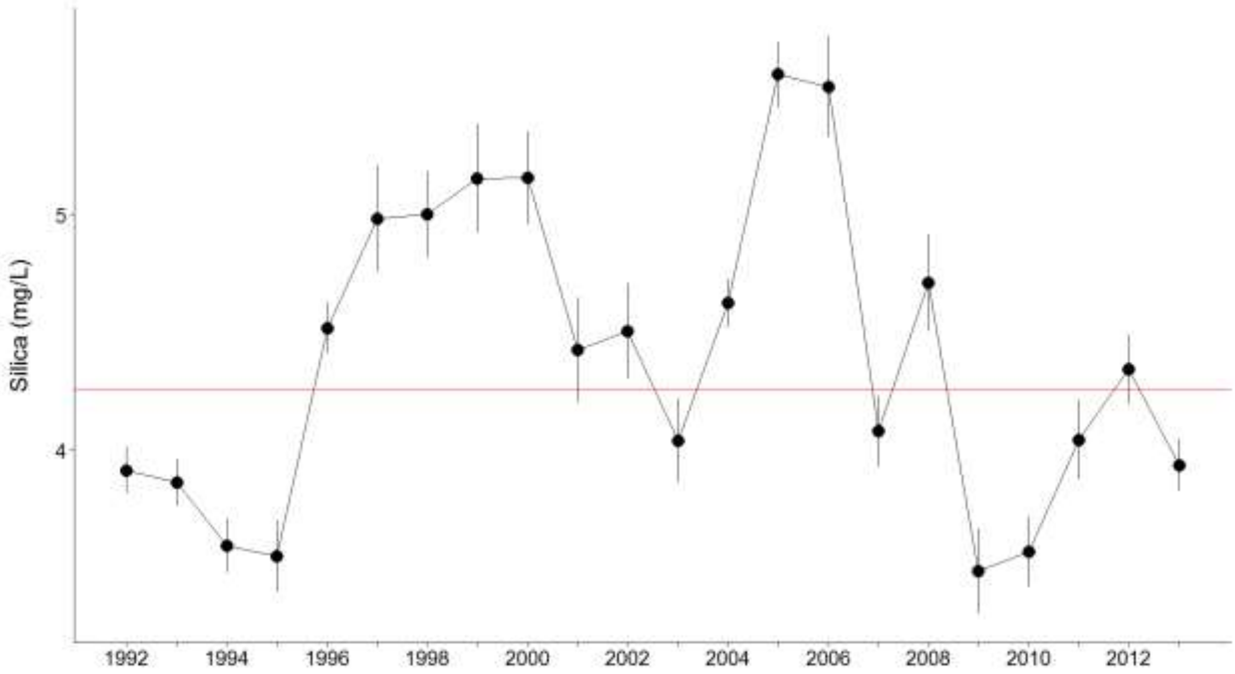


Figure 23. Annual silica from stations KLF 1–7, 1992 to 2013. Means ±SE. Pooled mean from 1992-2012 (red line).

pH

In 2013, pH was significantly lower in the North Arm than in the South and West Arms (Fig 24). Furthermore, the furthest north station (KLF 1) was significantly higher than the furthest south station (KLF 7) and the West Arm station (KLF 8). There was minimal variation in pH through the sampling season. Results from 2013 (7.92 pH units) did not differ significantly from previous years, and since 1997, pH has fluctuated minimally around 7.9 pH units (Fig. 25), with the exception of unexplained low pH in 2005.

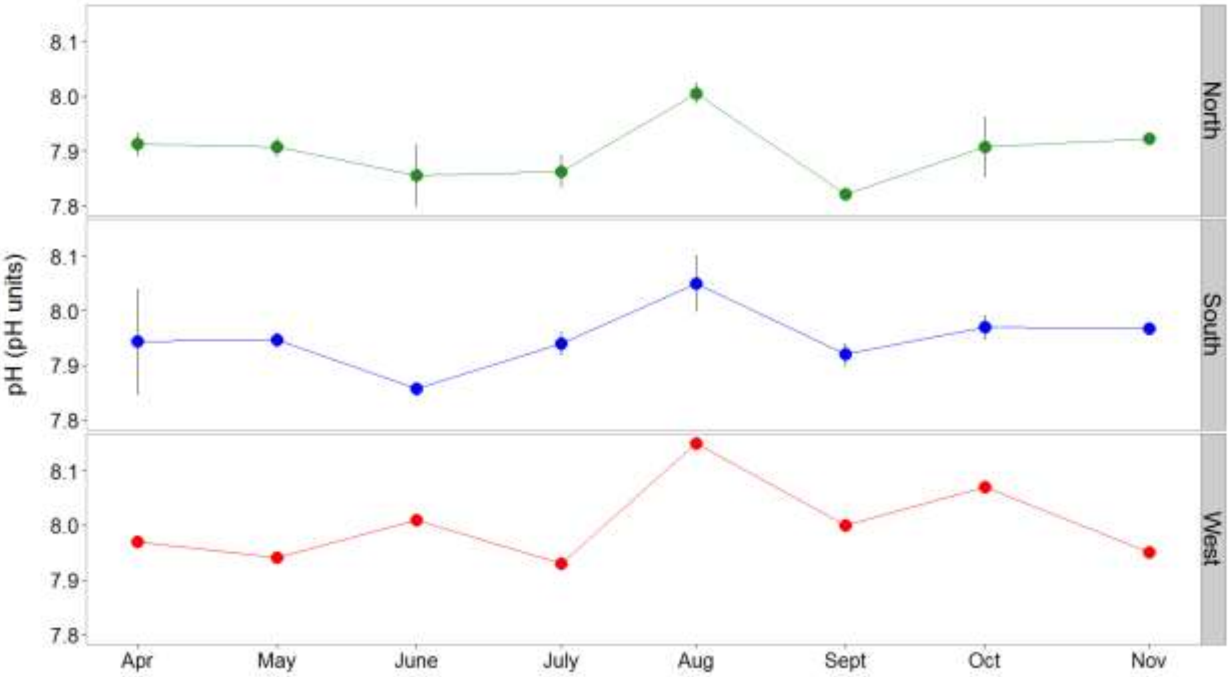


Figure 24. pH , North (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November, 2013.

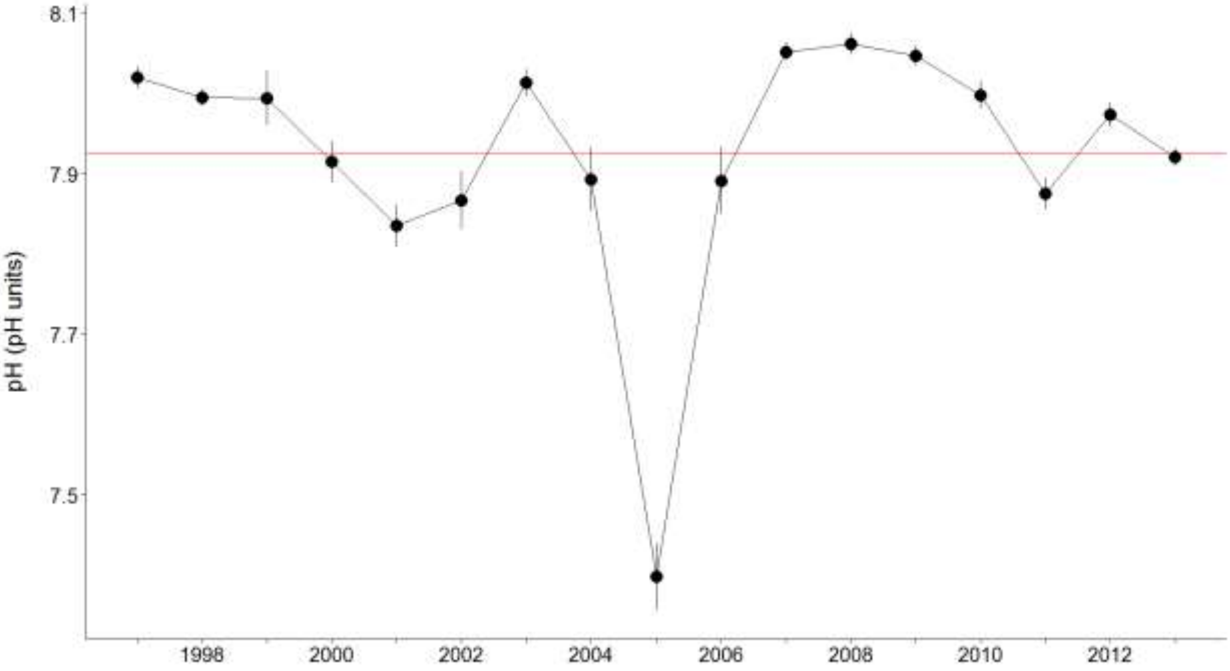


Figure 25. Annual pH from stations KLF 1–7, 1997 to 2013. Means ±SE. Pooled mean from 1997-2012 (red line).

Alkalinity

Alkalinity is the buffering capacity of lake water (i.e., the sum of the titratable bases) to resist pH changes and involves the inorganic carbon components in most fresh waters (Wetzel 2001). In 2013, there was not a seasonal change in alkalinity in Kootenay Lake (Fig. 26). The North Arm, alkalinity was slightly lower than the South Arm and West Arm. In 2013, there was a subtle decreasing trend in alkalinity moving north up the lake (R^2=0.20); the lowest station mean was KLF 1 (56.9 mg/L) and the highest station mean was KLF 7 (71.5 mg/L). The annual mean in 2013 (63.4 mg/L) was not significantly different from 1992–2012 pooled mean (64.4 mg/L) (Fig. 27).

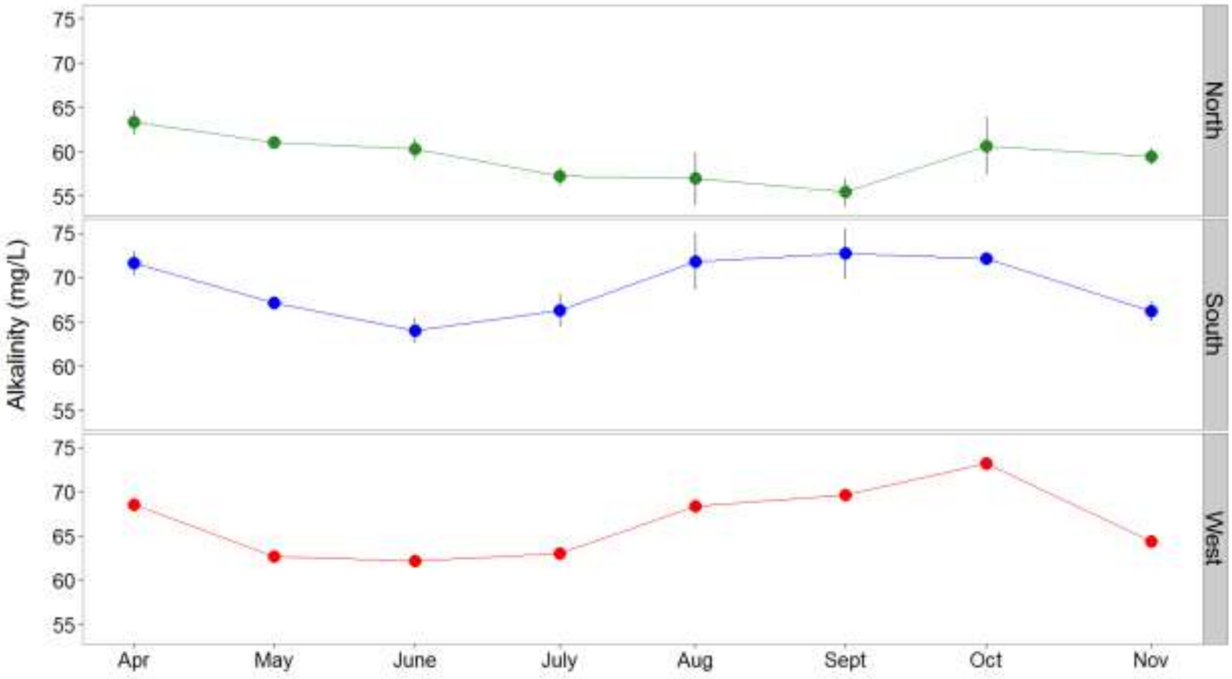


Figure 26. Alkalinity, North (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November, 2013.

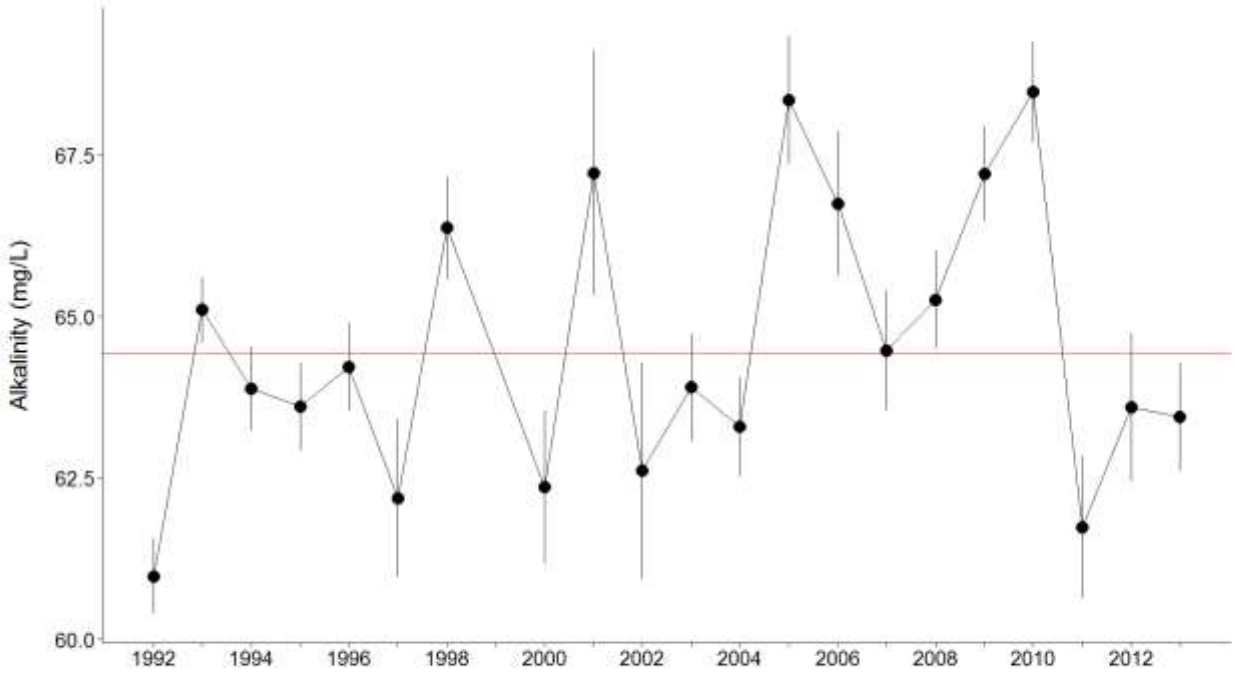


Figure 27. Annual alkalinity from stations KLF 1–7, 1992 to 2013. Means ±SE. Pooled mean from 1992-2012 (red line).

Total organic carbon

Total organic carbon (TOC) includes both dissolved and particulate organic carbon (Wetzel 2001). In 2013, total organic carbon varied by arm. The North and South Arms were significantly different, but not different to the TOC observed in the West Arm (Fig. 28). Additionally, TOC observations for spring and fall were lower than summer TOC observations. In 2013, a decrease in the mean annual TOC (1.49 mg/L) was observed from the previous two years, and was not significantly different from the pooled mean (1.45 mg/L) (Fig. 29).

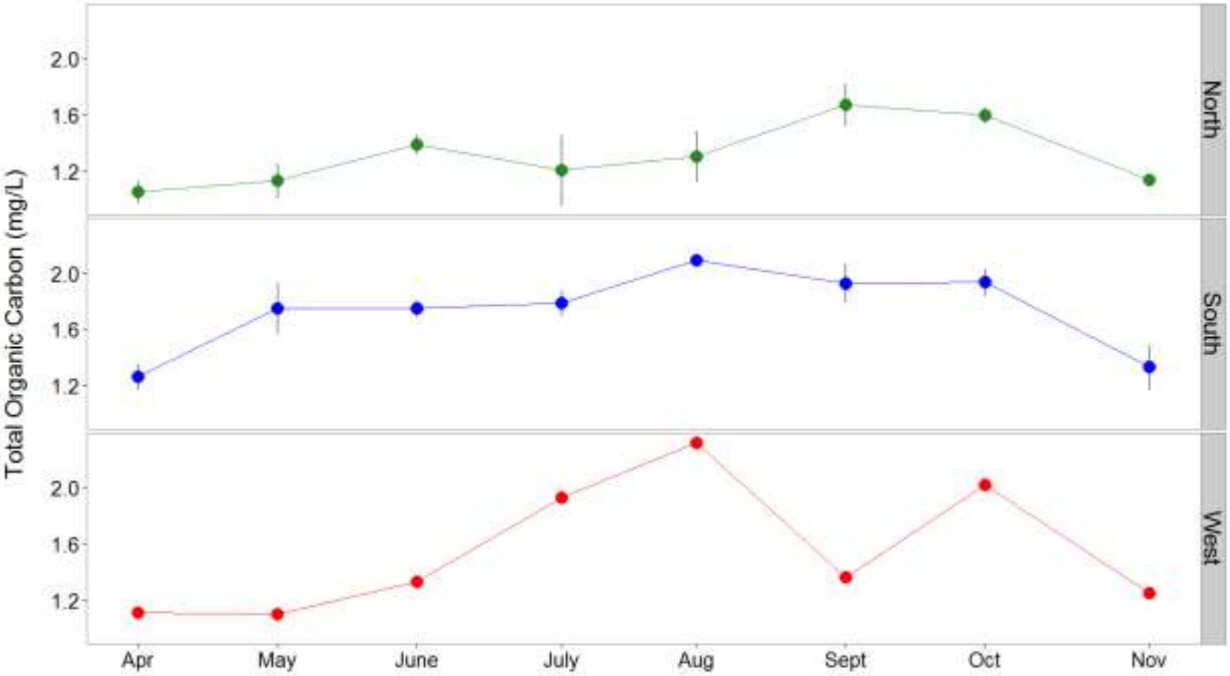


Figure 28. Total organic carbon , North (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November, 2013.

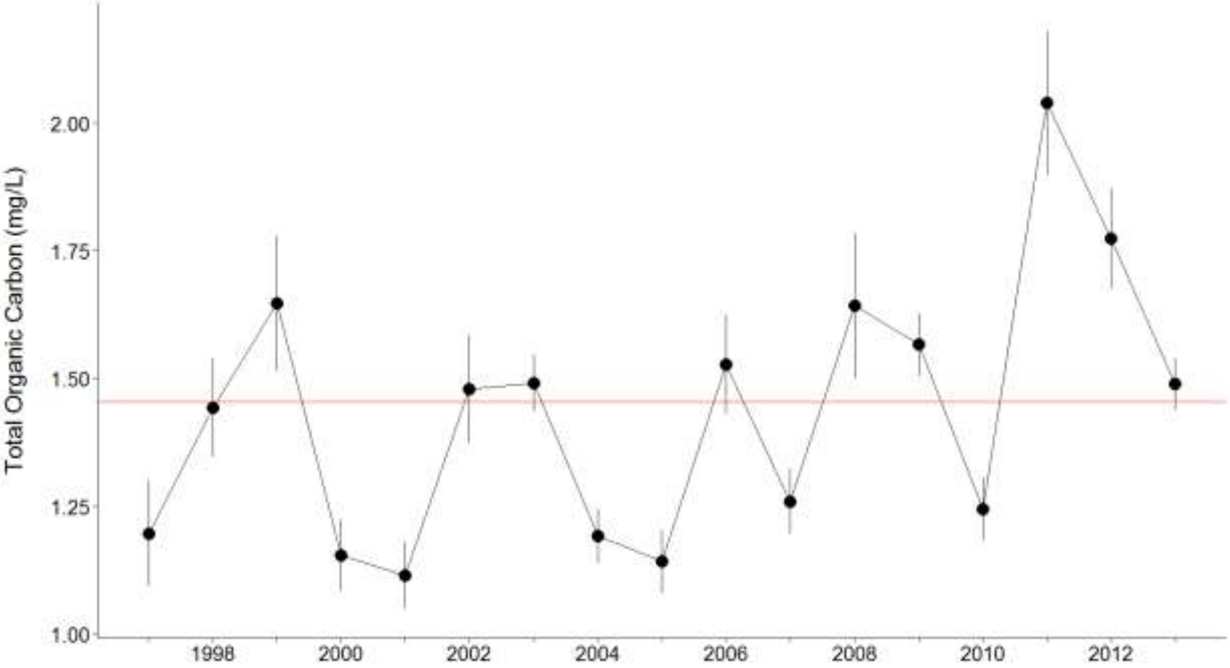


Figure 29. Annual total organic carbon from stations KLF 1–7, 1997 to 2013. Means ±SE. Pooled mean from 1997-2012 (red line).

Discrete epilimnion sampling: chemistry

Total dissolved phosphorus

In 2013 total dissolved phosphorus (TDP) ranged from the RDL (2 µg/L) to 5.5 µg/L. Stations KLF 2 and KLF 6 were both fairly consistent through the epilimnion (2–20 m), and through the four months of sampling, with the exception of a high TDP value observed at 5m at KLF 6 in August (Fig. 30).

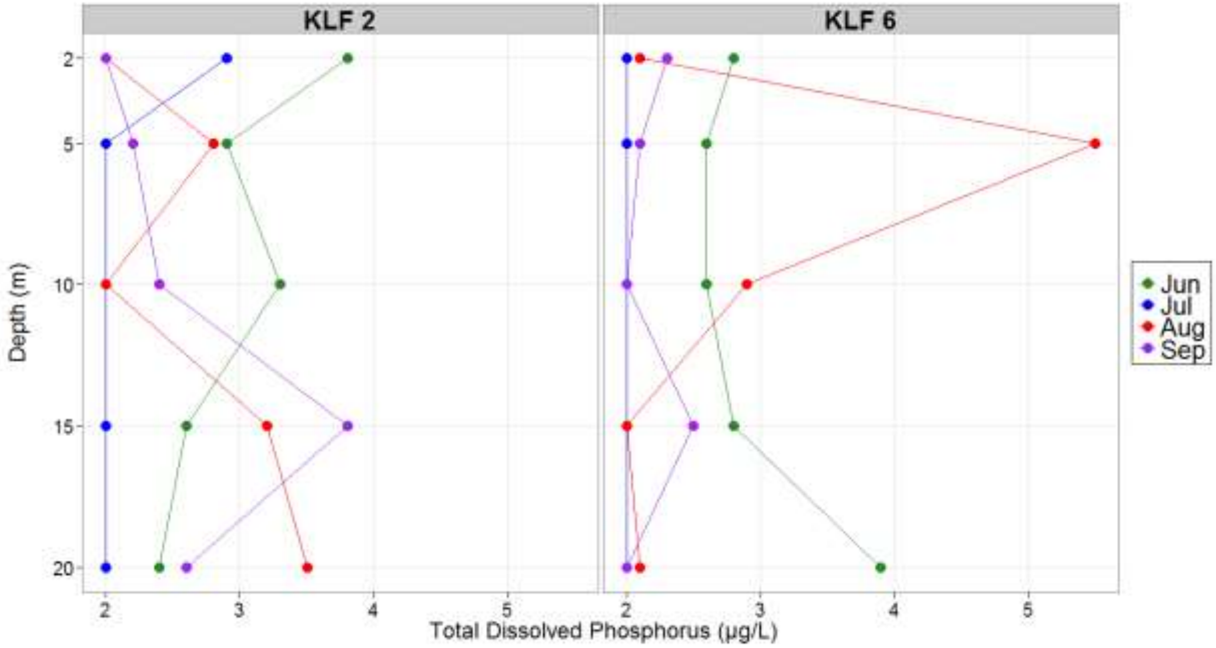


Figure 30. Discrete total dissolved phosphorus concentrations, stations KLF 2 and KLF 6, June–September 2013.

Dissolved inorganic nitrogen

In 2013, dissolved inorganic nitrogen (DIN) ranged from 43–156 µg/L and increased down the epilimnion (Fig. 31). As well, this trend became more pronounced as the season progressed. Higher concentrations were observed in June and July at station KLF 2, whereas at station KLF 6, high DIN values were observed in September, and were more pronounced at the deeper depths (Fig. 31).

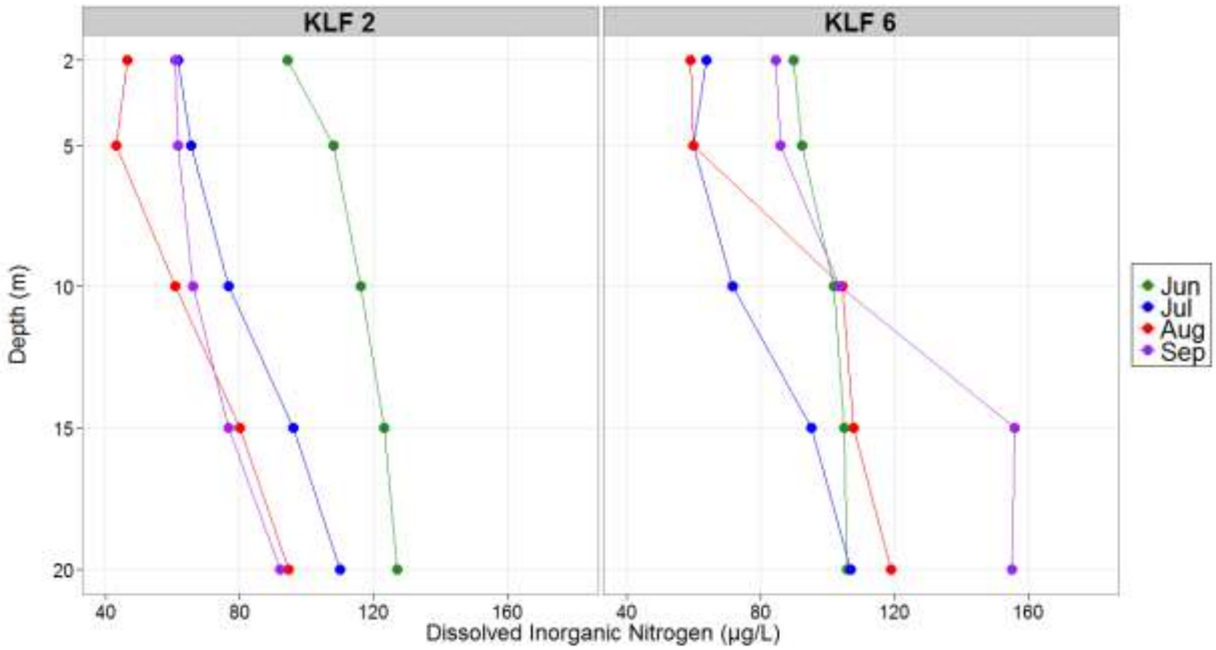


Figure 31. Discrete dissolved inorganic nitrogen concentrations, stations KLF 2 and KLF 6, June–September 2013.

Nitrogen to Phosphorus (N:P)

The ratio of N:P increased with depth in the epilimnion (Fig. 32). At station KLF 2, this increasing trend was stronger earlier in the season in June and July. At station KLF 6, this trend was most pronounced in September. There was nitrogen limitation in August at the 5m depth for both station KLF 2 and KLF 6.

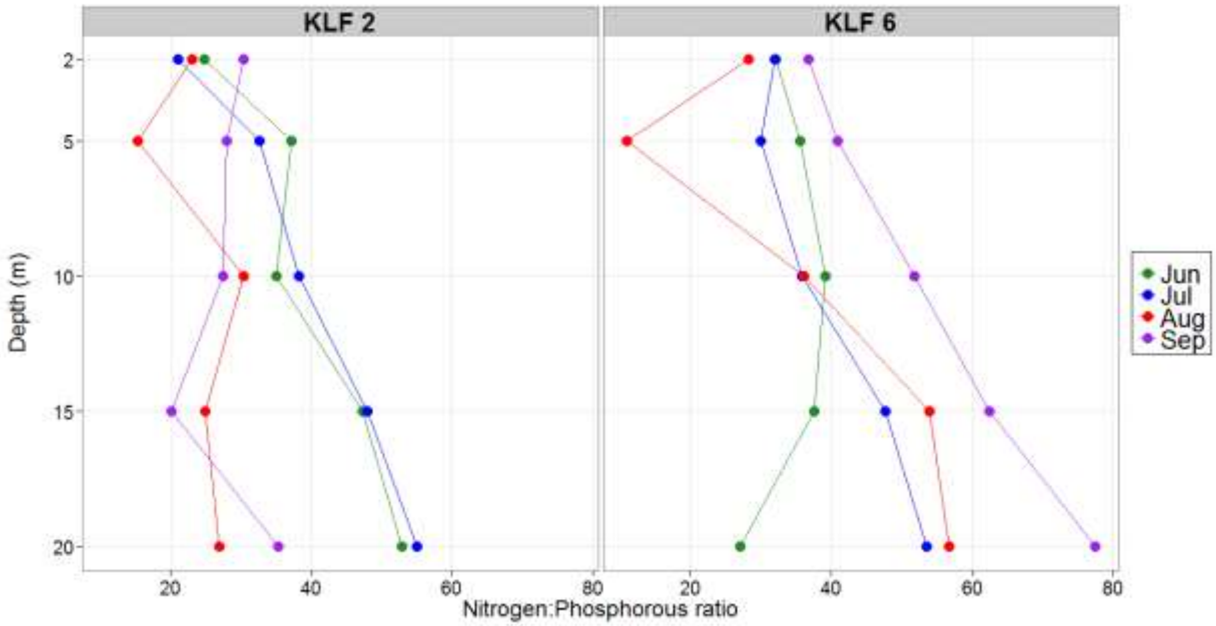


Figure 32. Discrete nitrogen to phosphorus (weight:weight) ratios, stations KLF 2 and KLF 6, June–September 2013.

Discrete depth hypolimnion sampling: chemistry

Turbidity

Turbidity results ranged from 0.12–5.45 NTU in the North Arm, and 0.1-0.39 NTU in the South Arm (Fig. 33). High turbidity in July was from a high result for station KLF 1. Turbidity was significantly higher in the North Arm than in the South Arm.

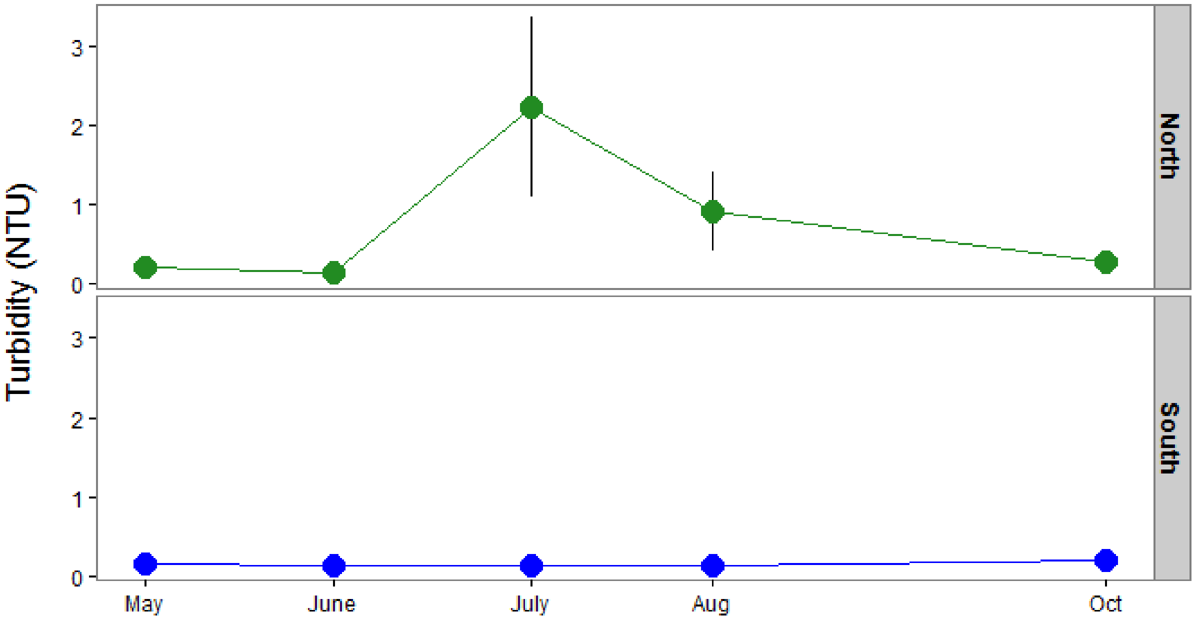


Figure 33. Turbidity, North (KLF 1-4), South (KLF 5-7) in discrete hypolimnetic samples, May to October. Means ±SE.

Phosphorus

As with phosphorus data from integrated water sampling, the hypolimnetic results may be slightly inflated, as values under the reportable detection limit (RDL) were set to the RDL of 2 µg/L. Although, in 2012 an increase in lab precision decreased this uncertainty. In 2013, no total phosphorous (TP) results were below the RDL. However, 6% of total dissolved phosphorus (TDP) and 3% of orthophosphate (OP) values were reported below the RDL.

Total phosphorous in 2013 ranged from 2.2 to 5.2 µg/L and increased into the fall (Fig. 34). There is no significant difference between the North and South Arms.

Total dissolved phosphorus (TDP) ranged from below the RDL to 6.1 µg/L (Fig. 35). There was no seasonal trend, and TDP was not significantly different between the North and South Arms (2.9 and 3.5 µg/L, respectively).

Orthophosphate ranged from below the RDL to 5.7 µg/L. There was not a significant difference between the North and South Arms (Fig 36). Although, higher values were observed in May in the North Arm, whereas higher values and more variability was observed in July in the South Arm.

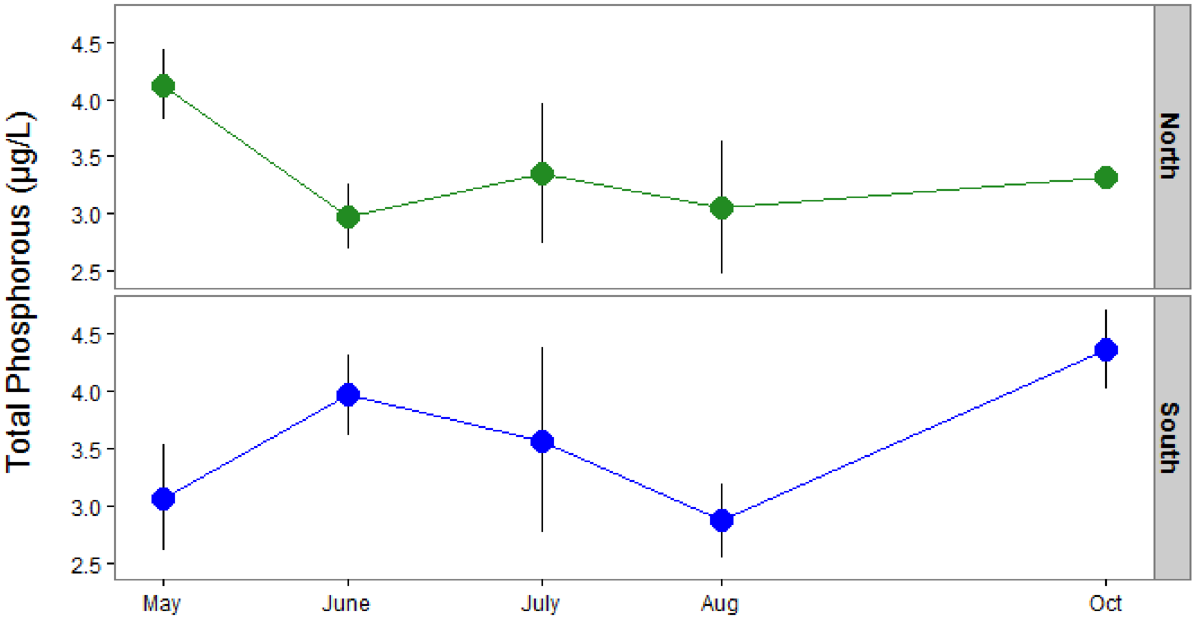


Figure 34. Total phosphorous, North (KLF 1-4), South (KLF 5-7) in discrete hypolimnetic samples, May to October. Means ±SE.

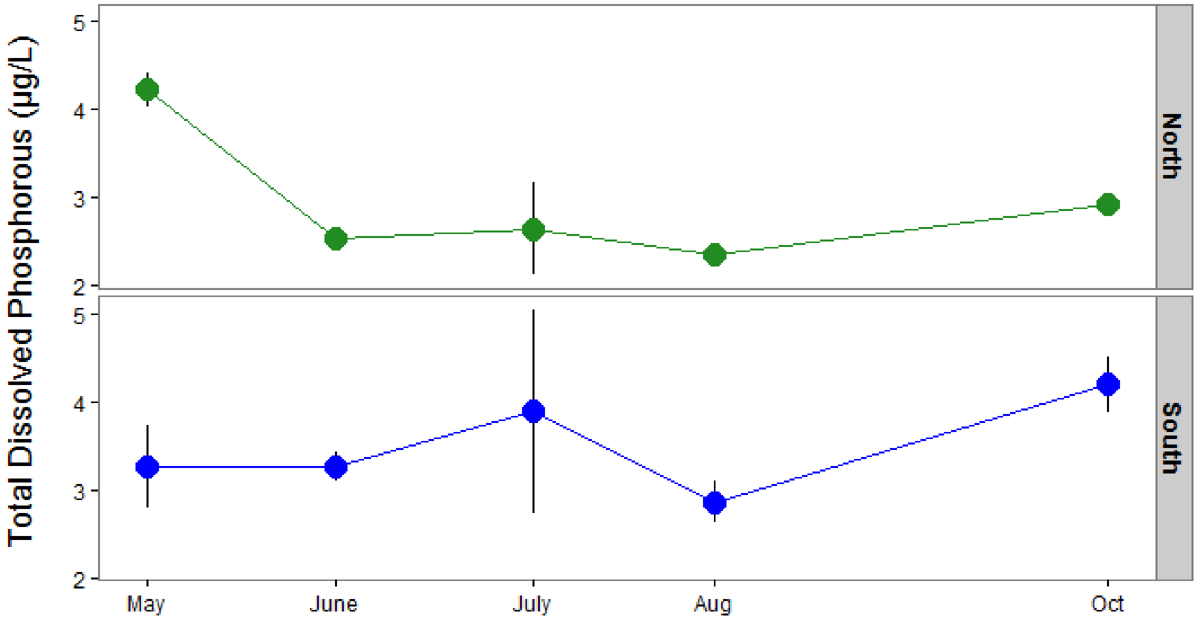


Figure 35. Total dissolved phosphorous, North (KLF 1-4), South (KLF 5-7) in discrete hypolimnetic samples, May to October. Means ±SE.

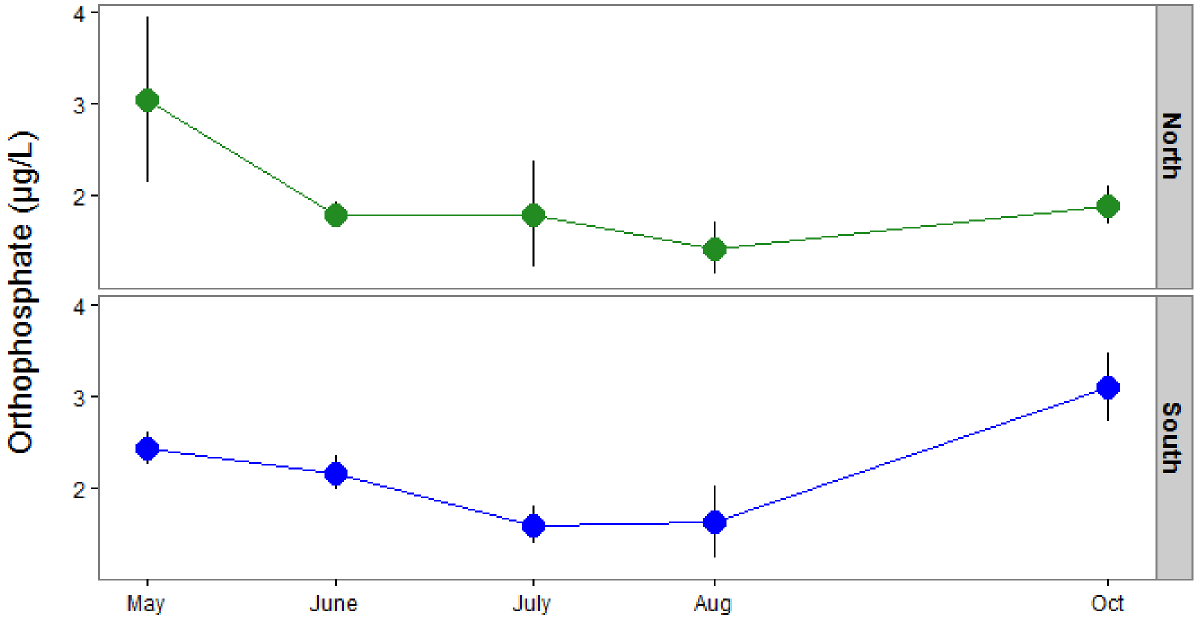


Figure 36. Orthophosphate, North (KLF 1-4), South (KLF 5-7) in discrete hypolimnetic samples, May to October. Means ±SE.

Nitrogen

Total Nitrogen ranged from 210-300 µg/L in the North Arm and higher observations were in August (Fig. 37). In the South Arm, TN ranged from 232-338, and higher observations were observed in June. There was not a significant difference between the North and South Arm annual means (258 and 269 µg/L; respectively).

Dissolved Inorganic Nitrogen ranged from 199-227 µg/L in the North Arm and in the South Arm, DIN ranged from 207-227 µg/L (Fig. 38). There was a significant difference between the North and South Arm annual means, where the North Arm (213 µg/L) was lower than the South Arm (217 µg/L).

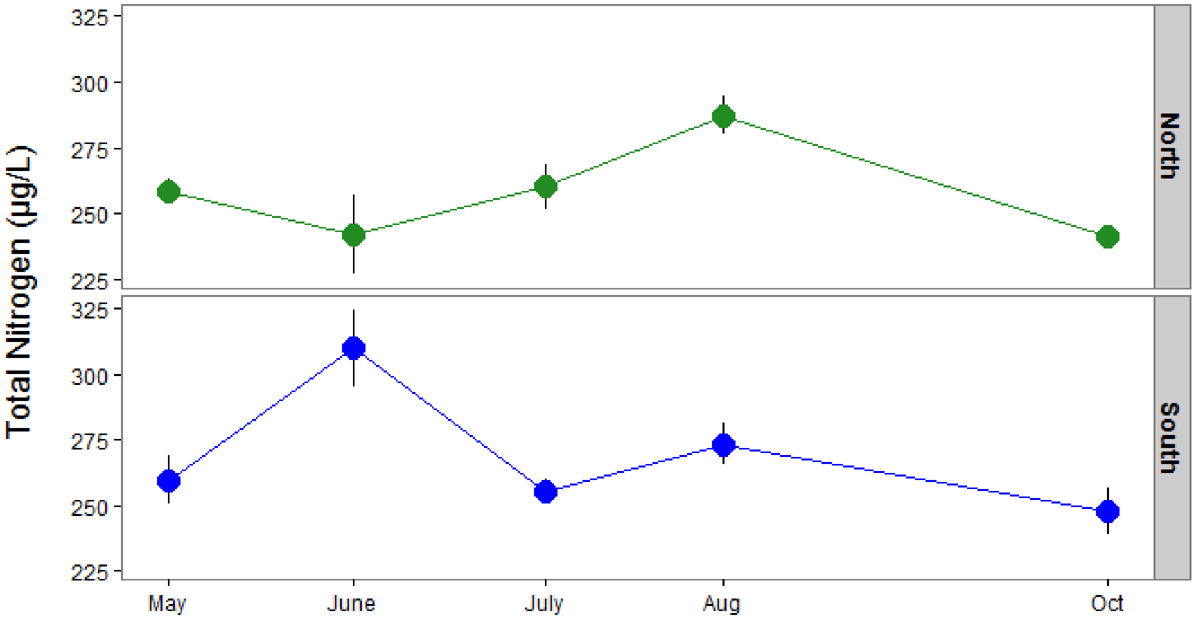


Figure 37. Total Nitrogen, North (KLF 1-4), South (KLF 5-7) in discrete hypolimnetic samples, May to October. Means ±SE.

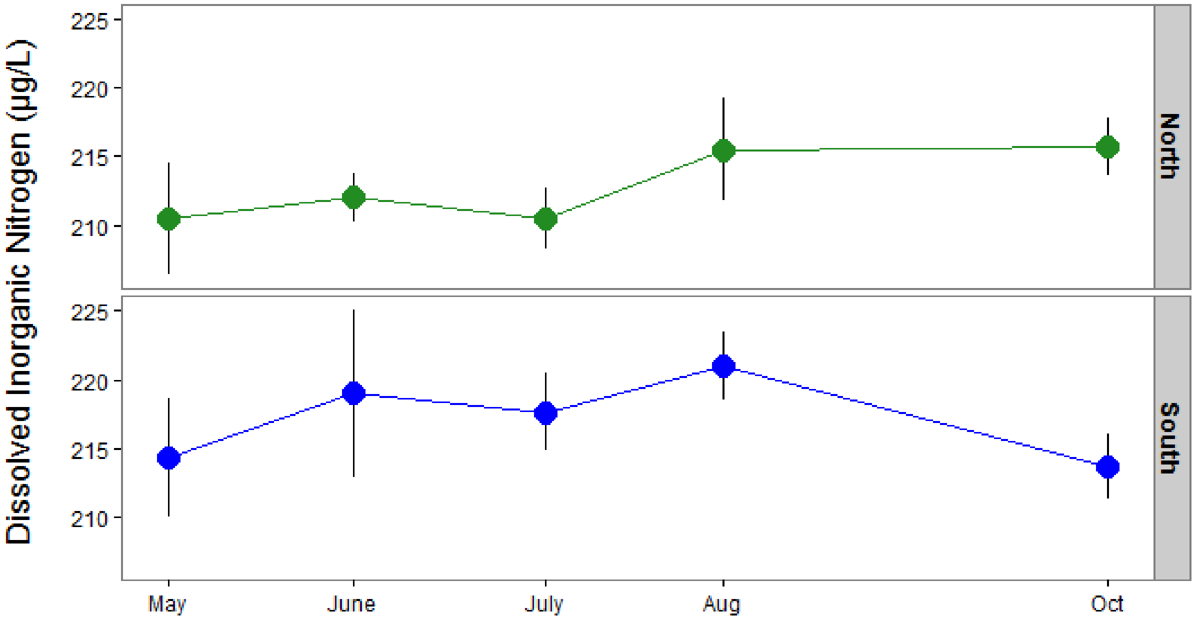


Figure 38. Dissolved inorganic nitrogen, North (KLF 1-4), South (KLF 5-7) in discrete hypolimnetic samples, May to October. Means ±SE.

Silica

Silica ranged from 2.54 to 5.78 mg/L (Fig. 39). There was not a significant difference between the North and South Arms, and both followed a similar seasonal pattern. However, lower values in the North Arm (specifically, KL1 and KLF 2) were observed in July.

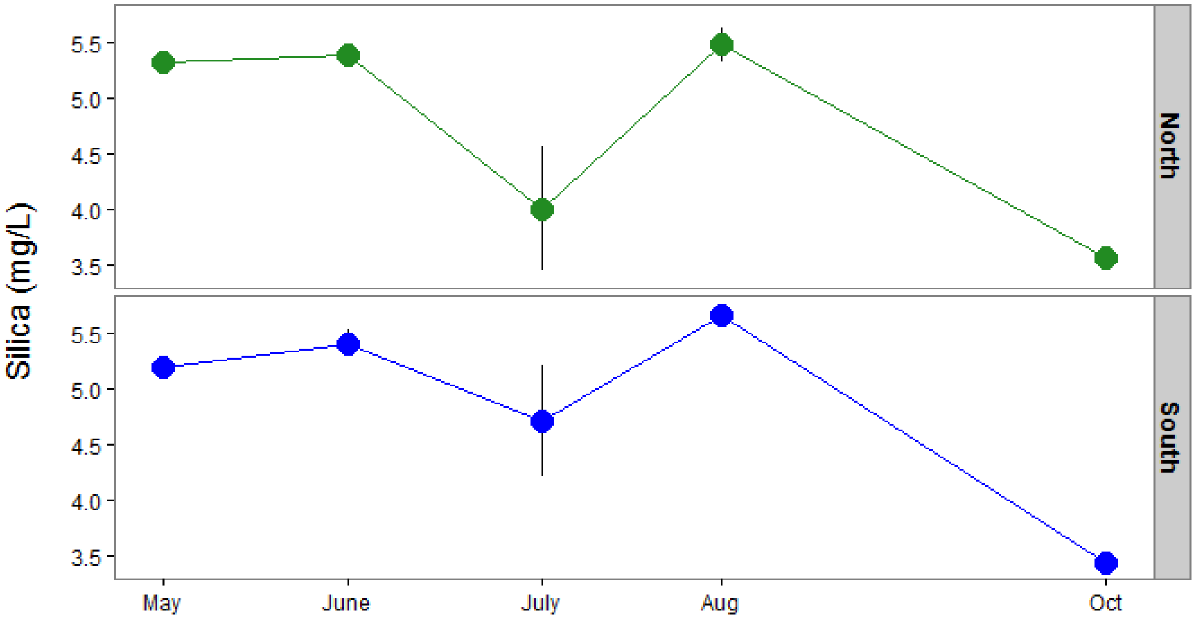


Figure 39. Silica, North (KLF 1-4), South (KLF 5-7) in discrete hypolimnetic samples, May to October. Means ±SE.

Alkalinity

Alkalinity ranged from 70.8–78.5 mg/L in the North Arm, and from 75.8-78.8 in the South Arm (Fig. 40). There was a significant difference between the North and South Arm annual means (75.6 and 77.2 mg/L; respectively).

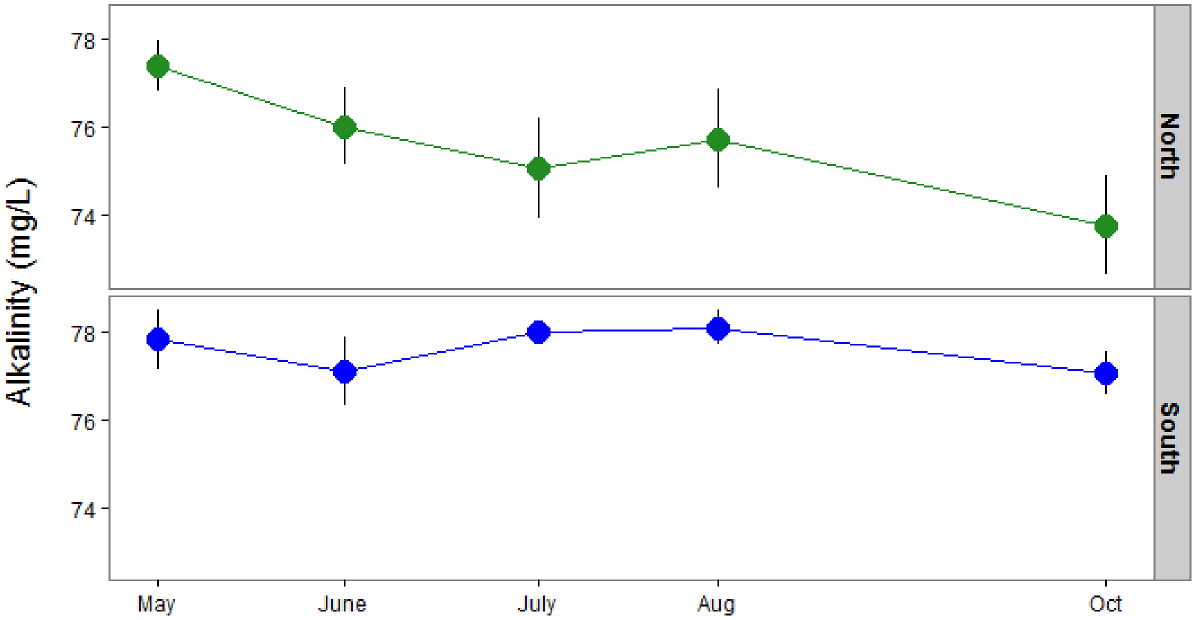


Figure 40. Alkalinity, North (KLF 1-4), South (KLF 5-7) in discrete hypolimnetic samples, May to October. Means ±SE.

Phytoplankton

Abundance

The abundance of phytoplankton did not differ significantly by station for all groups (Fig. 41). As well, there was not a significant difference between the North, South and West Arms, for all groups. Total abundance peaked in July, largely contributed by high bacillariophyte counts. High bacillariophyte densities were observed in the summer sampling periods. On June 18th, *Asterionella formosa* largely contributed to the high counts in the North and South Arms, whereas *Fragilaria crotonensis* was the dominant species in the West Arm. High abundance from July through August was mainly due to high numbers of *Fragilaria crotonensis.* A chlorophyte peak (dominated by *Chlorella species)* was observed in late June and early July. Substantial numbers of chlorophytes were sustained through until late September. Chryso-Cryptophytes were high in abundance from May through the end of August, and peaked in July. The species that contributed the most to that peak were *Cryptomonas*, *Komma and* small microflagellates. Cyanophytes were consistent throughout the sampling season, with the exception of high abundance observed in mid-July, which was largely from high *Microcystis* (large celled – microplankton) and *Synechococcus* (small celled – picoplankton) species. The abundance of dinophytes did not show a seasonal trend, and was dominated throughout the season by *Gymnodinium sp.*

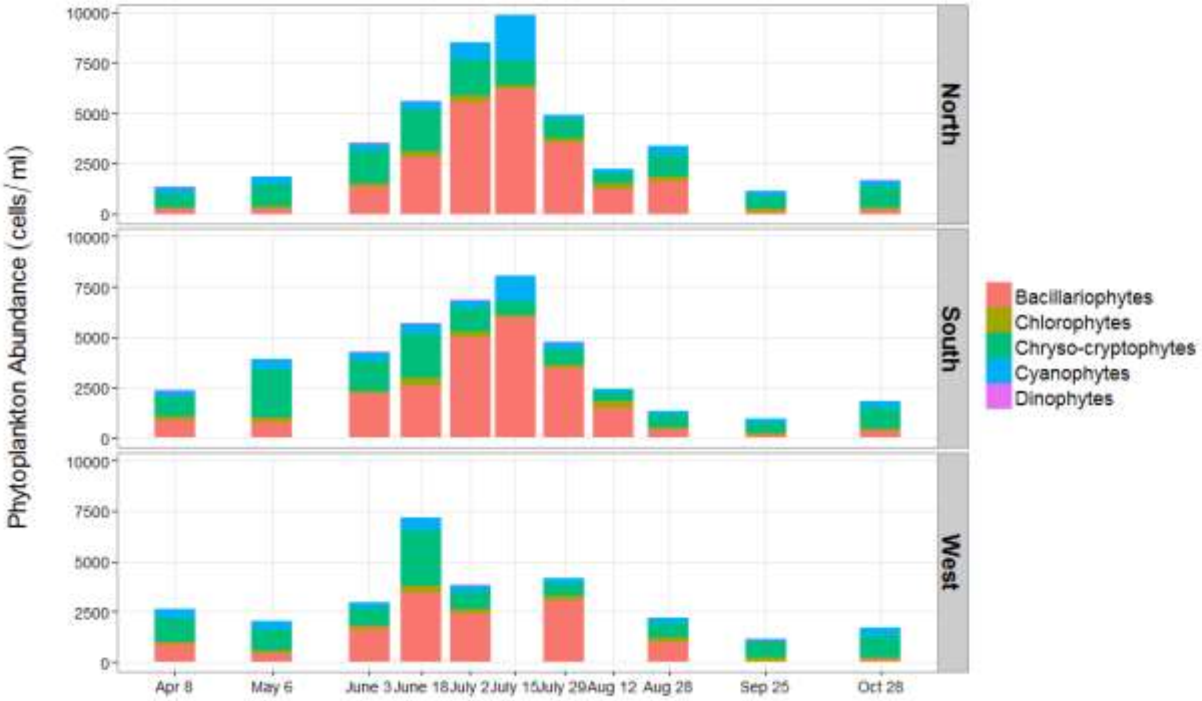


Figure 41. Phytoplankton group abundance by arm; North (KL 1-4), South (KL 5-7) and West (KL 8) Kootenay Lake. April to November, 2013. Only KLF 2 and KLF 6 sampled on July 15 and Aug 12.

Biomass

Phytoplankton biomass did not change significantly across stations, or by arm (Fig. 42). However, seasonal expression was observed for all groups with the exception of dinophytes, which did not differ during the sampling season. Bacillariophyte biomass peaked in mid-July due primarily to high biomass of *Fragilaria crotonensis* in the North Arm and high biomass of *Cyclotella stelligera* in the South Arm. However, during the summer months for all arms, the dominant species was *Fragilaria crotonensis.* Chlorophytes were high in early July and again in mid-August, and the species that largely contributed to the high biomass was *Planctosphaeria*. Chryso-Cryptophytes were high in biomass from May through the end of August, and peaked in on June 18th. The species that contributed the most to that peak were *Cryptomonas and Dinobryon.* Cyanophytes varied minimally throughout the sampling season, with the exception of high biomass observed in mid-July, which was largely from high *Microcystis and Limnothrix redekei*.

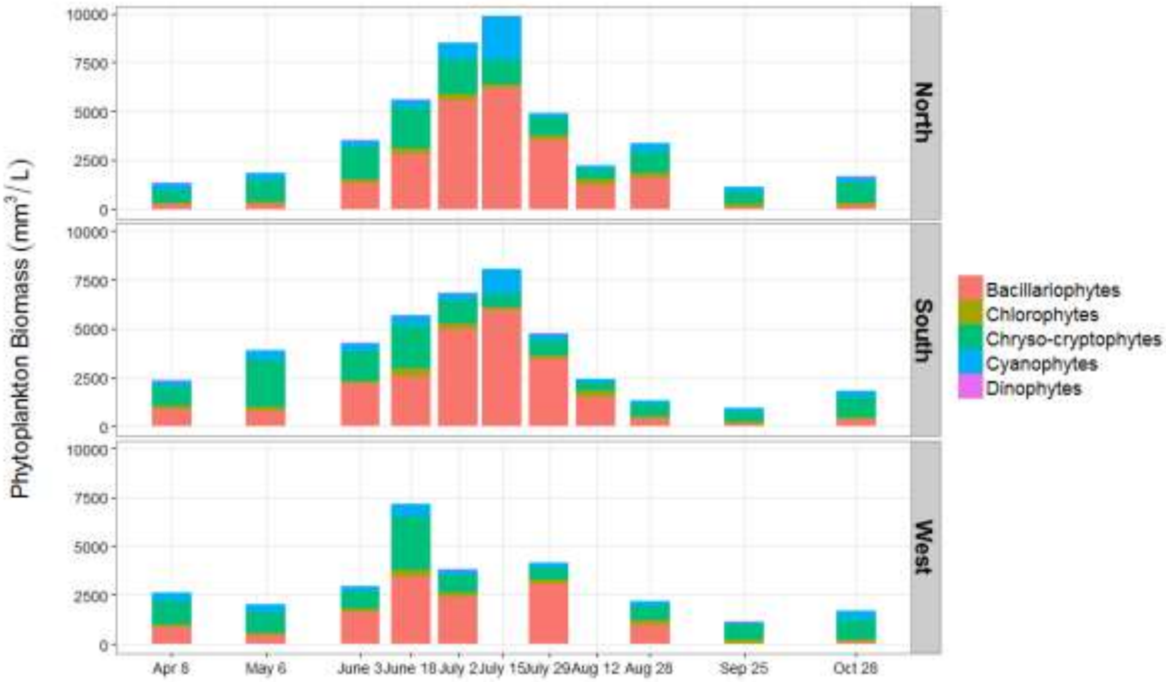


Figure 42. Phytoplankton group biomass; North (KL 1-4), South (KL 5-7) and West (KL 7) Arm of Kootenay Lake. April to November, 2013. Only KLF 2 and KLF 6 sampled on July 15 and Aug 12.

Edible and Inedible

The abundance and biomass of edible phytoplankton was not significantly different between the North, South and West Arms. Similarly, there was not a spatial difference for inedible phytoplankton in Kootenay Lake. There were, however, strong temporal changes for both categories of phytoplankton. The abundance of inedible phytoplankton increased from the spring to summer (Fig. 43), when the main lake (North and South Arms) peaked on July 15, and the West Arm peaked on June 18. The bacillariophyte species that most contributed to the high summer densities were *Asterionella formosa* and *Fragilaria crotonensis.* Abundance of edible phytoplankton showed less seasonal expression than the amounts of inedible phytoplankton. Edible phytoplankton results from June through the beginning of August were higher than April and fall values. Chryso-cryptophytes dominate the edible phytoplankton densities, specifically the species; *Cryptomonas*, *Komma,* and small microflagellates.

In the North and South Arms, biomass of inedible phytoplankton followed the same trend as abundance, where values increased from the spring. The peak occurred on July 15 with bacillariophytes, dominated by *Fragilaria crotonensis.* This species also contributed the most to the peak of inedible phytoplankton biomass in the West Arm, which occurred on June 18 (Fig. 44). Biomass of edible phytoplankton was highest on June 18. The group that dominated the edible fraction of biomass in the lake were the Chryso-Cryptophytes, specifically the species; *Cryptomonas* and *Dinobryon.*

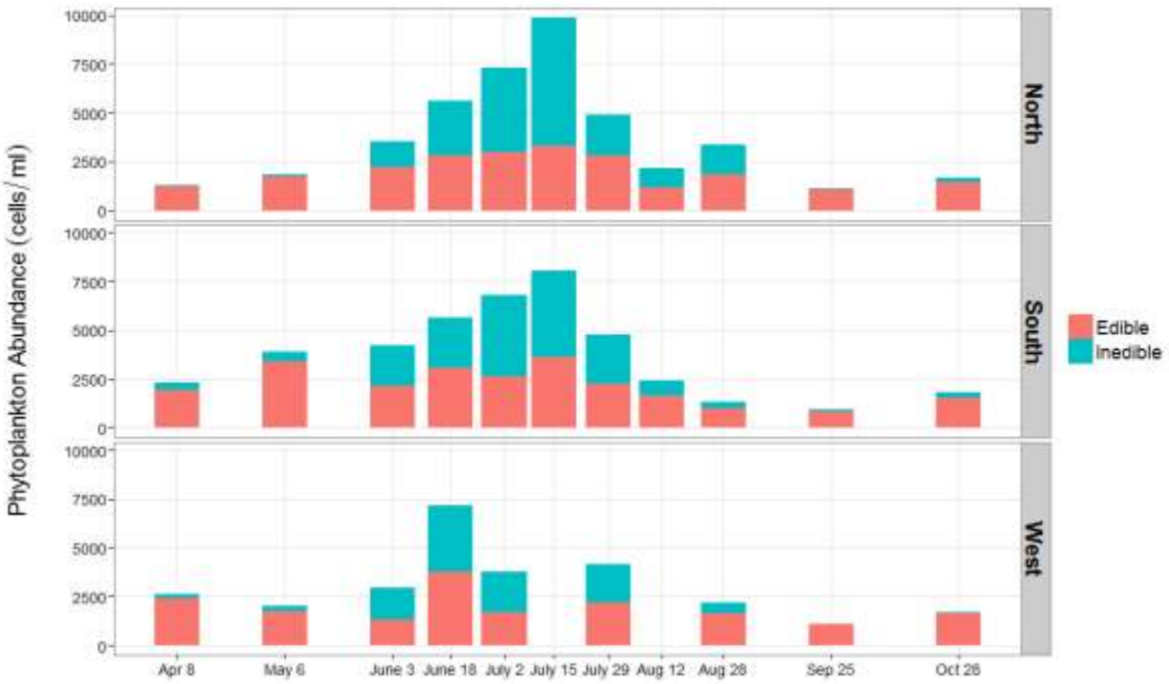


Figure 43. Abundance of edible and inedible phytoplankton by arm; North (KL 1-4), South (KL 5-7) and West (KL 7) Kootenay Lake. April to November, 2013. Only KLF 2 and KLF 6 sampled on July 15 and Aug 12.

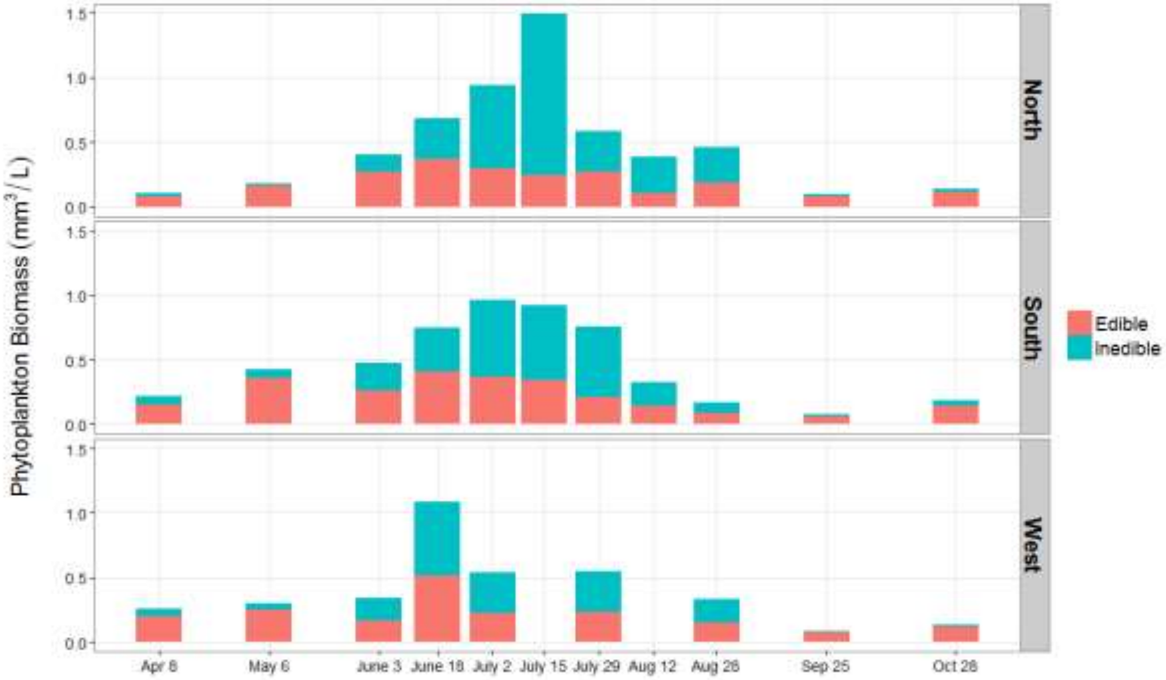


Figure 44. Biomass of edible and inedible phytoplankton arm; North (KL 1-4), South (KL 5-7) and West (KL 7) Kootenay Lake. April to November, 2013. Only KLF 2 and KLF 6 sampled on July 15 and Aug 12.

Comparisons amongst years

Yearly comparisons were made for both the North and South Arm by season. Bacillariophytes, the large celled algae, are mostly representative of the phytoplankton biomass that is inedible to zooplankton. Chryso-Cryptophytes represent the edible portion of phytoplankton as this group is the preferred food source by zooplankton. In 2013, phytoplankton biomass was marginally lower than in 2012 (Figs. 45 and 46).

In 2013, an overall decrease in bacillariophyte biomass from 2012 was observed (Fig. 45). In the North Arm, spring and fall biomass decreased from 2012, whereas summer biomass was similar to the previous year. However, in 2013, all seasonal means were significantly lower than the long term 1992-2012 seasonal means. In the South Arm, from 2012 to 2013 there was a decrease in fall biomass, however, spring and summer seasonal means were similar to 2012. Interestingly, there was not a significant difference between the 2013 seasonal means and the long term mean. High summer and fall bacillariophyte biomass in 2002 were from high volumes of netplankton in September and October. Overall, a slight decrease in 2013 was observed from the previous year, and the overall main lake 2013 mean (North and South Arms combined) was significantly lower than the 1992-2012 mean.

The biomass of Cryso-Cryptophytes in the North Arm also decreased in 2013 from 2012. (Fig. 46). The decrease in the summer mean from 2012 contributed the most to the difference between years. There was not a significant difference between the annual seasaonal means in

2013 compared to the 1992-2012 long term means. In the South Arm, total Cryso-Cryptophytes biomass was similar to 2012. However, in comparison to the long term (1992-2012) mean, spring biomass was higher, whereas the summer and fall means were not significantly different. In 1996, high spring and summer biomass was was attributed to microplankton spp. such as *Cryptomonas erosa.* In general, biomass of Chryso-Cryptophytes in the main lake in 2013, were marginally lower than in 2012, but were not significantly different from the long term mean.

Figure 45. Average yearly bacillariophyte phytoplankton biomass per season for the North Arm (stations KL 1-4) and South Arm (stations KL 5-7), 1992 to 2013.

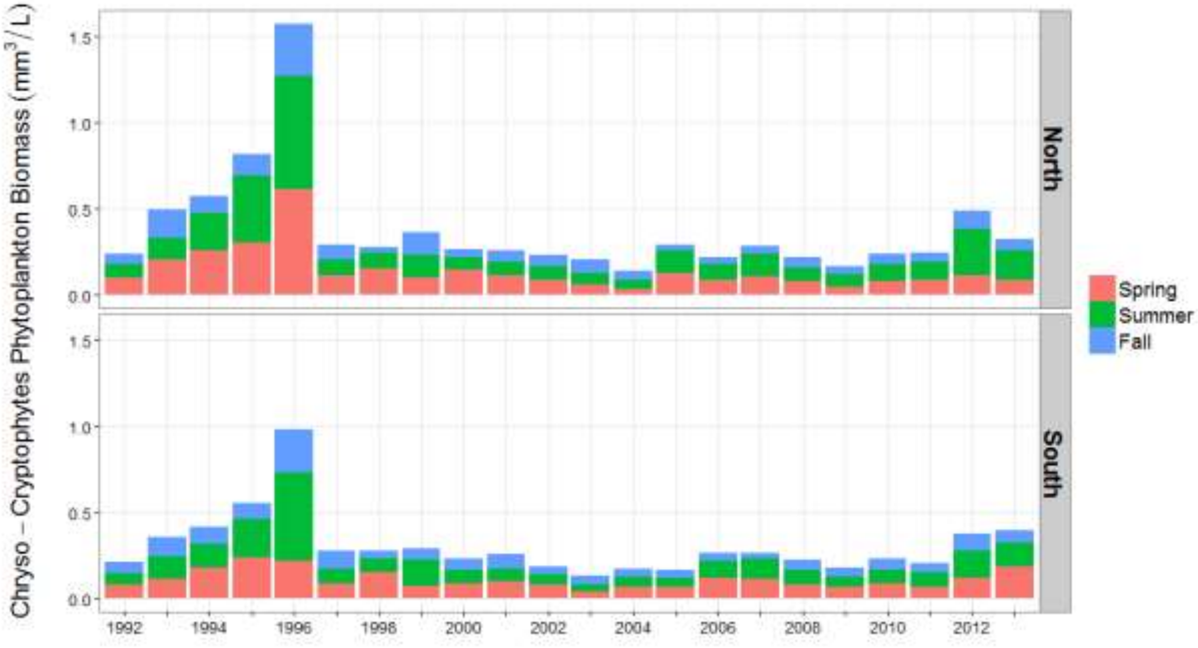


Figure 46. Average yearly chryso-cryptophytes phytoplankton biomass per season for the North Arm (stations KL 1-4) and South Arm (stations KL 5-7), 1992 to 2013.

Zooplankton

Twenty species of macrozooplankton were identified in the samples over the course of the study(1992-2013), with copepods such as *Leptodiaptomus ashlandi, Epishura nevadensis* and *Diacyclops bicuspidatus thomasi*, and the cladocerans *Daphnia galeata mendotae* and *Bosmina longirostris* being the most numerous. Four calanoid copepod species, *Epischura nevadensis* (Lillj.), *Leptodiaptomus ashlandi* (Marsh), *Leptodiaptomus pribilofensis* (Juday and Muttkowski) and *Leptodiaptomus sicilis* (Forbes), were identified in samples from Kootenay Lake. Only one cyclopoid copepod species, *Diacyclops bicuspidatus thomasi* (Forbes), was identified during the same time period.

In 2013 the following species were present: *Leptodiaptomus ashlandi* (Marsh), *Epishura nevadensis* (Lillj.), *Diacyclops bicuspidatus thomasi* (Forbes), *CerioDaphnia reticulata* (Jurine), *Daphnia galeata mendotae* (Birge), *Daphnia pulex* (Leydig), *Daphnia longispina* (O.F.M.), *Bosmina longirostris* (O.F.M.), *Leptodora kindtii* (Focke), and *Diaphanosoma brachiurum* (Liéven). One rare species *Alona affinis* (Leydig) was reported in April at station KLF 7.

The average zooplankton density in 2013 in the North Arm was dominated by copepods - 87% copepods, 8% *Daphnia* spp., and 5% cladocerans other than *Daphnia* sp. (Fig. 47). The annual average density of copepods was 31.97 individuals/L (ind/L), *Daphnia* sp. 2.94 ind/L, and cladocerans other than *Daphnia* spp. 1.94 ind/L (Fig. 48). In the South Arm, the composition was similar with 88% copepods (28.11 ind/L), 5 % *Daphnia* sp. (1.59 ind/L) and 7% cladocerans other than *Daphnia* sp. (2.30 ind/L). The West Arm station comprised of 86% copepods (26.30 ind/L), 9% *Daphnia* sp. (2.62 ind/L) and 5% cladocerans other than *Daphnia* sp. (1.44 ind/L).

The average zooplankton density amongst all stations (excluding West Arm) increased in 2013 with 35 ind/L compared to 27 ind/L in 2012 (Fig. 49).

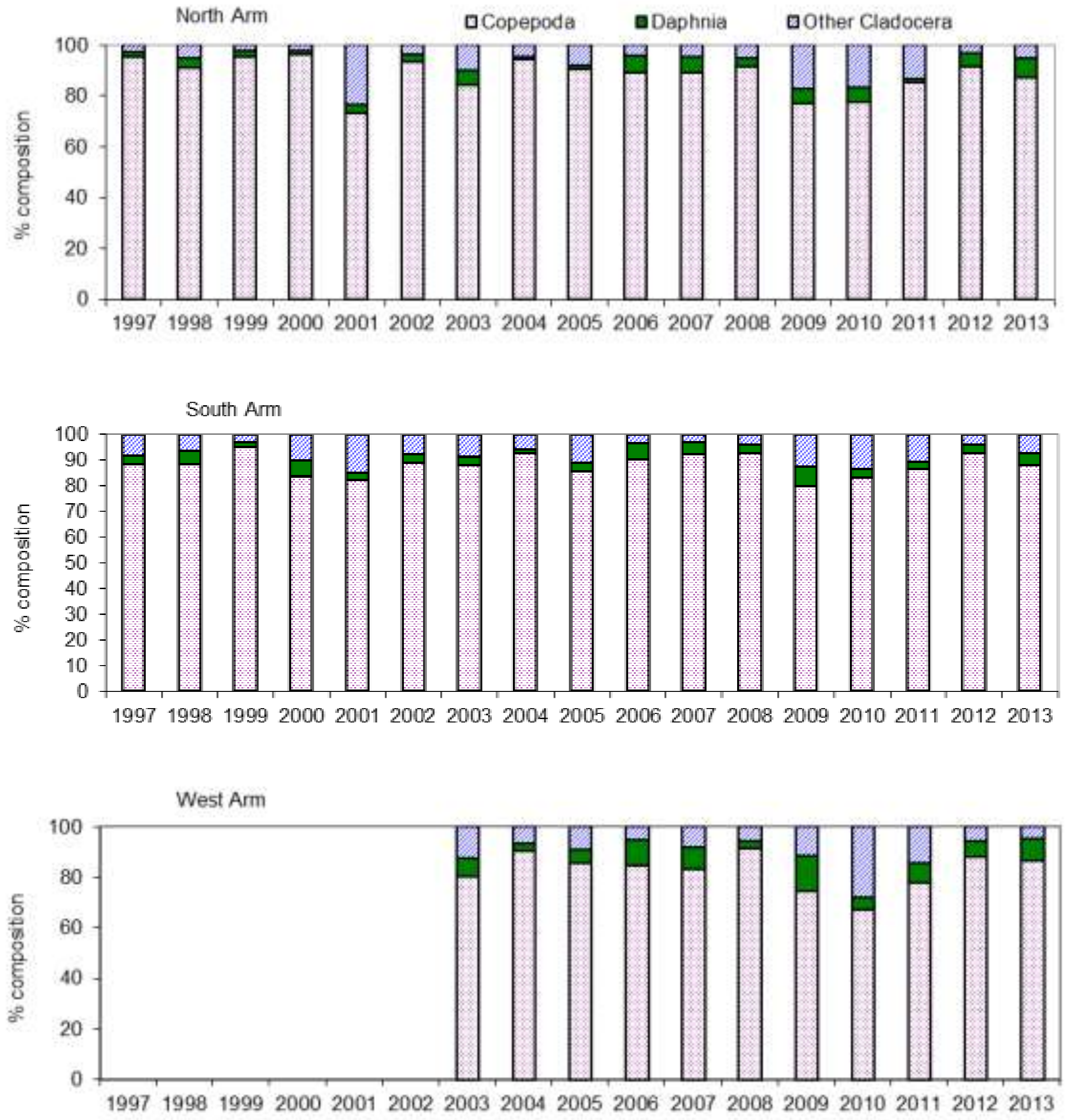


Figure 47. Seasonal composition of zooplankton as a percentage of average density in the North, South and West arms of Kootenay Lake, 1997 to 2013.

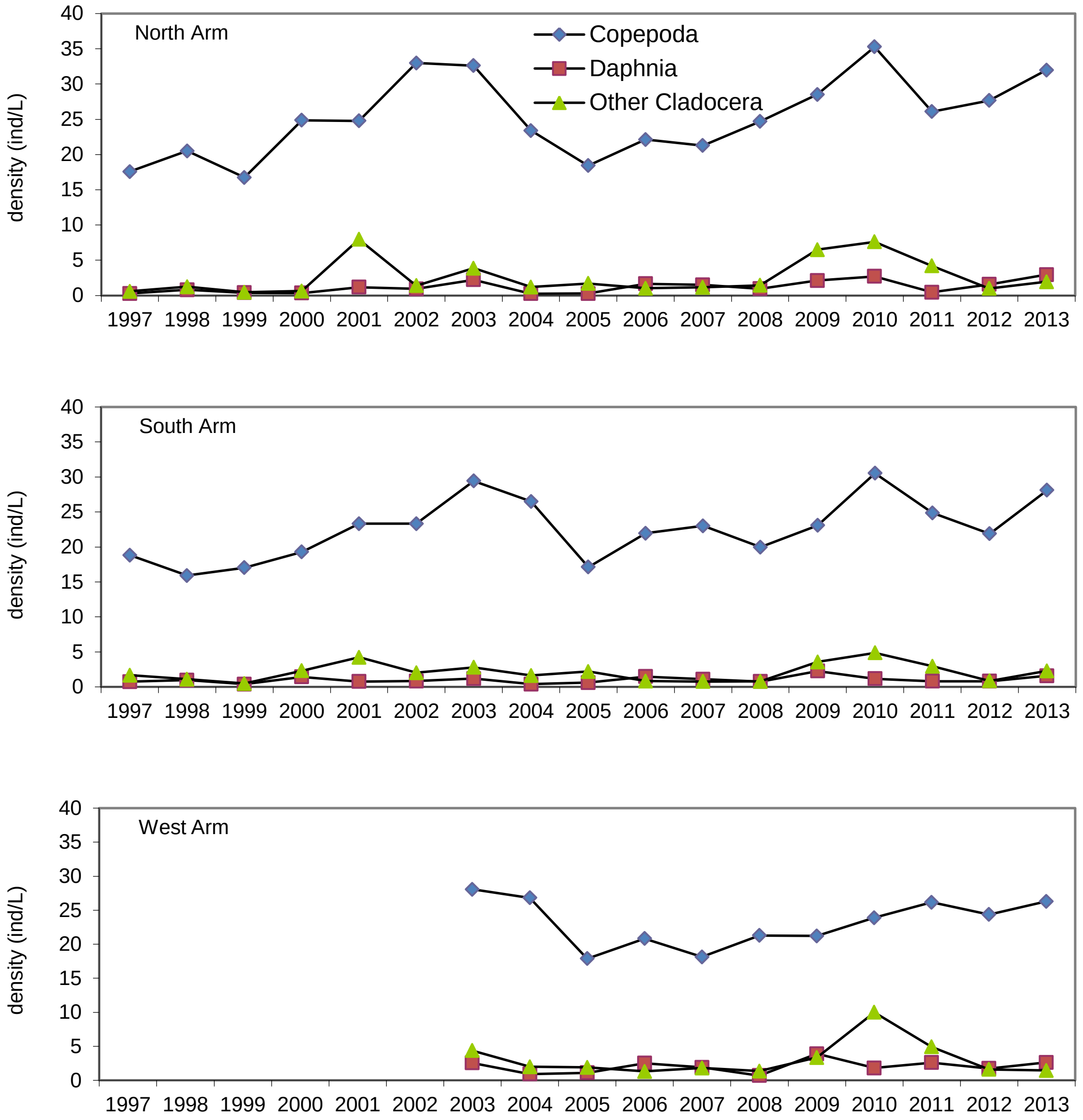


Figure 48. Seasonal average density of zooplankton in Kootenay Lake, North, South and West arms, 1997 to 2013.

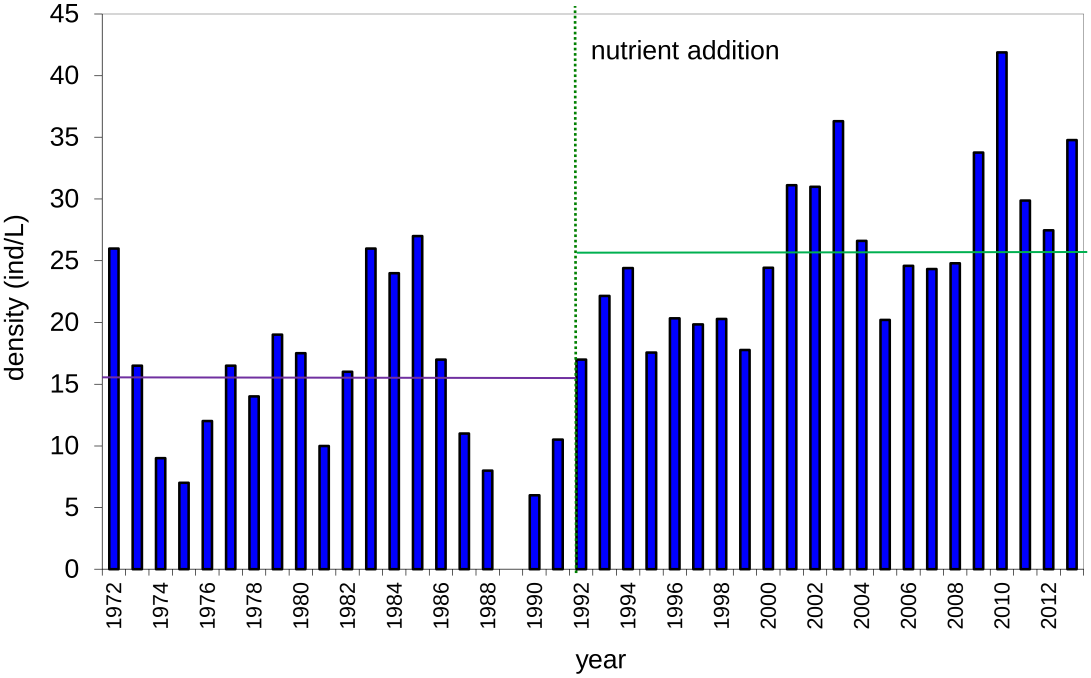


Figure 49. Average whole lake zooplankton density, 1972 to 2013. Pre nutrient addition density average (purple line) and post nutrient addition density average (green line). Note: 1972 to 1991 data collected from near present station KLF 5 and 1992 to 2013 data calculated as whole-lake average (excluding West Arm).

In the North Arm, the average zooplankton biomass in 2013 comprised of 32% copepods (50.86 µg/L), 66% *Daphnia sp*. (106.24 µg/L), and 2% cladocerans other than *Daphnia sp*. (3.61 µg/L) (Figs. 50 and 51). In the South Arm, the composition was similar with 38% copepods (44.17 µg/L), 57% *Daphnia sp*. (67.59 µg/L) and 5% cladocerans other than *Daphnia sp*. (5.32 µg/L). The West Arm station was 29% copepods (36.65 µg/L), 68% *Daphnia sp*. (84.12 µg/L) and 3% cladocerans other than *Daphnia sp*. (3.53 µg/L).

The average zooplankton biomass amongst all stations (excluding West Arm) increased by more than two fold in 2013 to 142.59 µg/L from 65.92 µg/L in 2012 (Fig. 51).

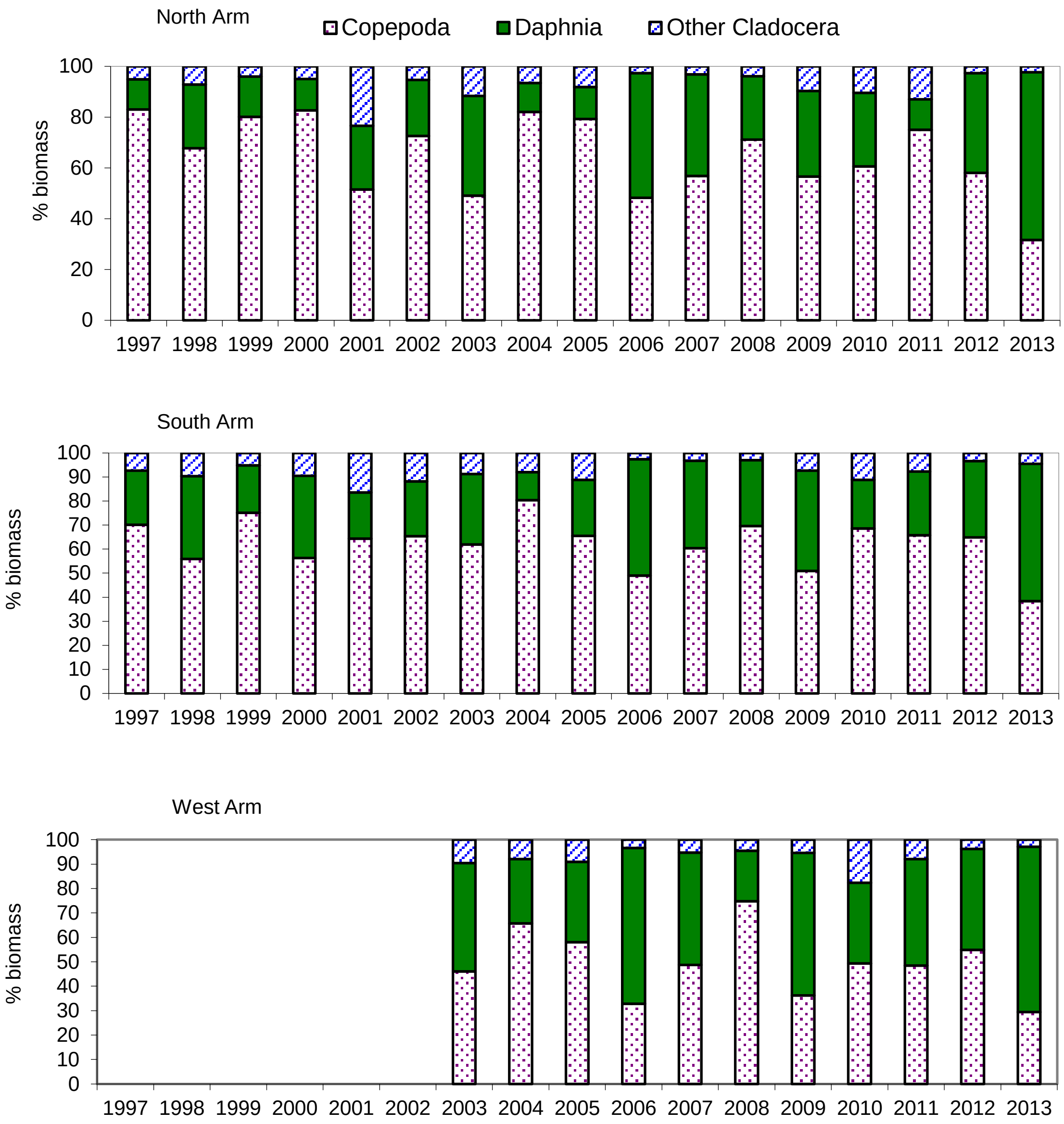


Figure 50. Seasonal composition of zooplankton as a percentage of average biomass in the North, South and West arms of Kootenay Lake, 1997 to 2013.

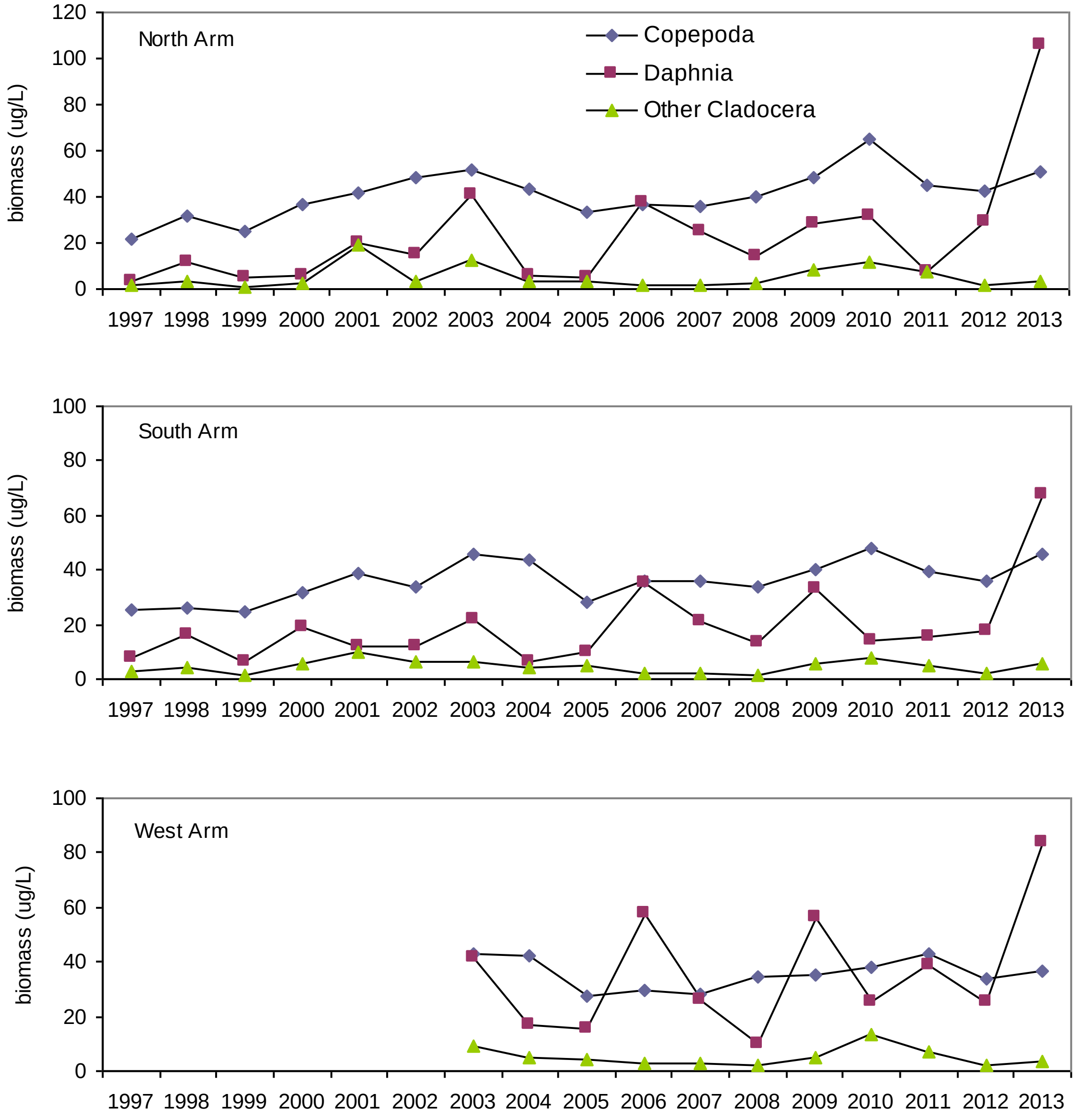
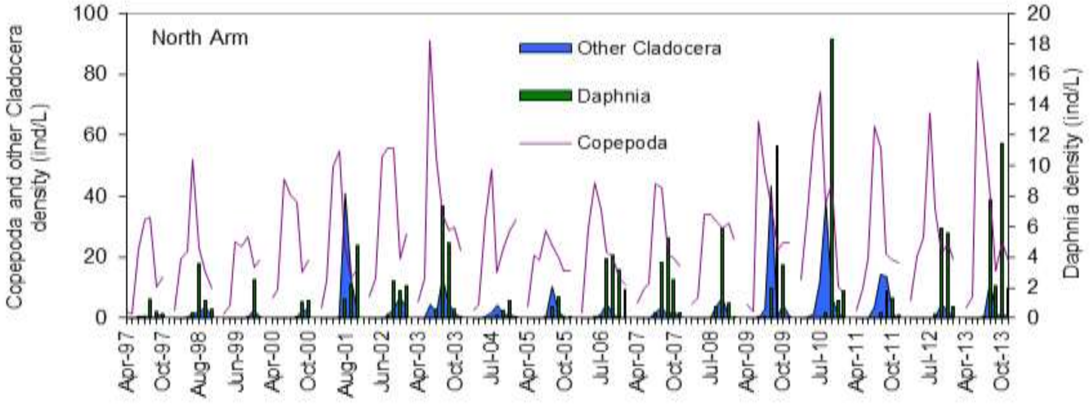


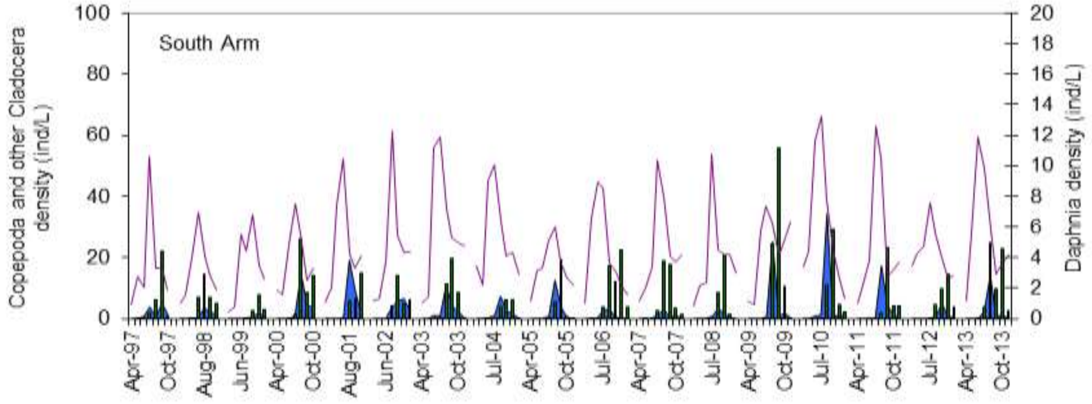
Figure 51. Seasonal average biomass of zooplankton in Kootenay Lake, North, South and West arms, 1997 to 2013.

Seasonal and lake patterns

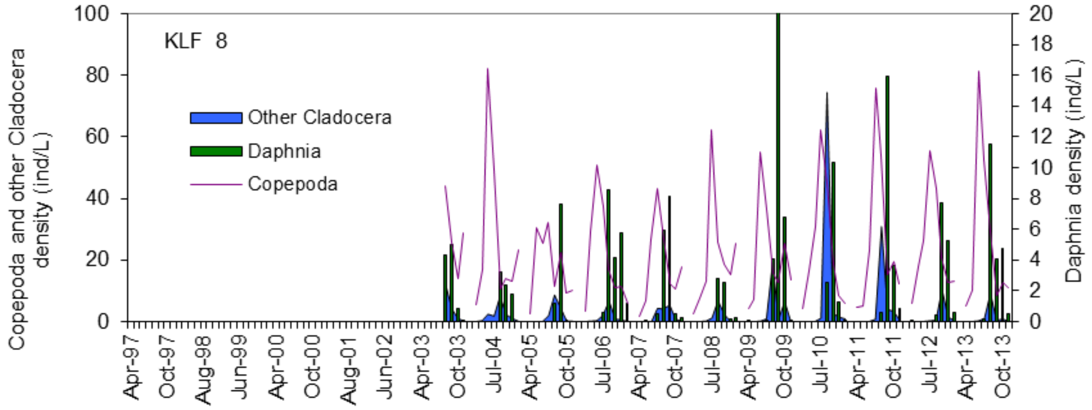
Copepods were the main contributor to the overall zooplankton population in the spring. *Daphnia* appeared in summer, peaked in fall and maintained a population through November. This pattern occurred in the North, South and West arms in 2013, *Daphnia* first appeared in June, peaked in August in the South and West arms while in the North Arm *Daphnia* peaked in October (Fig. 52 for density and Fig. 53 for biomass). Densities throughout the sampling season were dominated with Copepods, while biomass was dominated by *Daphnia* from August through October. These trends were typical in the previous years.



a. Seasonal density of zooplankton in the North Arm of Kootenay Lake, 1997 to 2013.

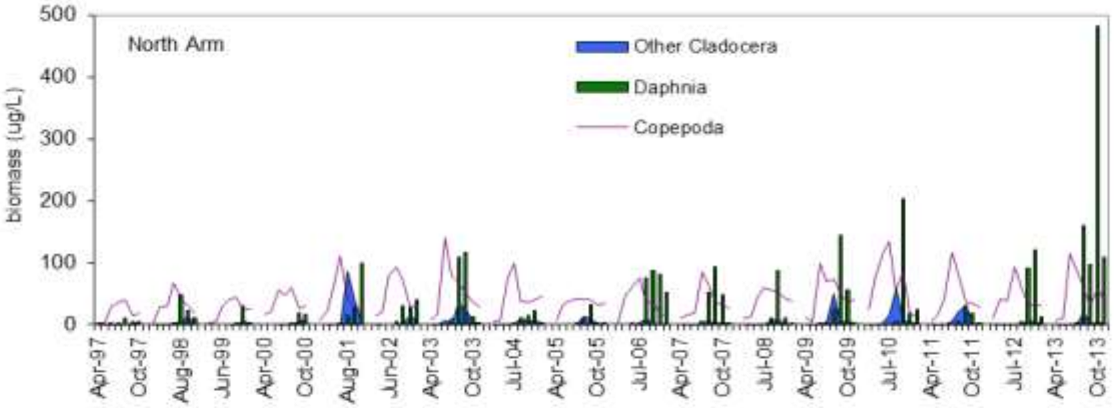


b. Seasonal density of zooplankton in the South Arm of Kootenay Lake, 1997 to 2013.

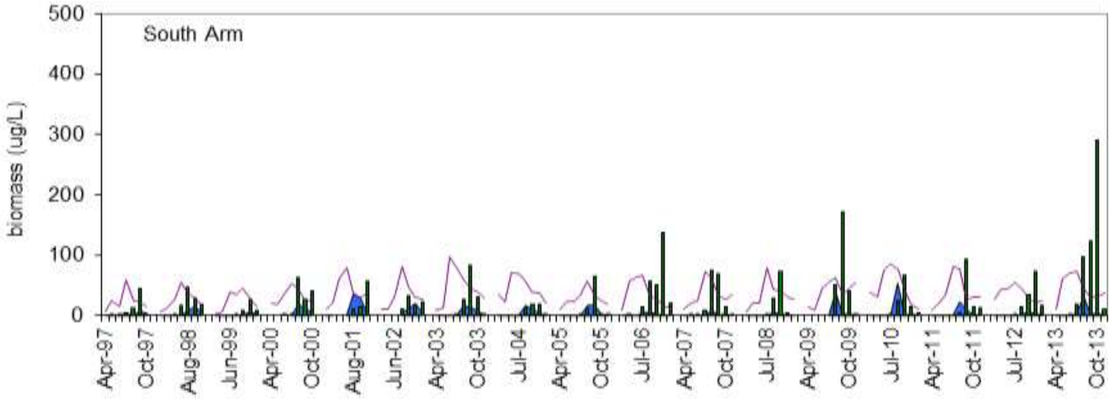


c. Seasonal density of zooplankton in the West Arm of Kootenay Lake, 1997 to 2013.

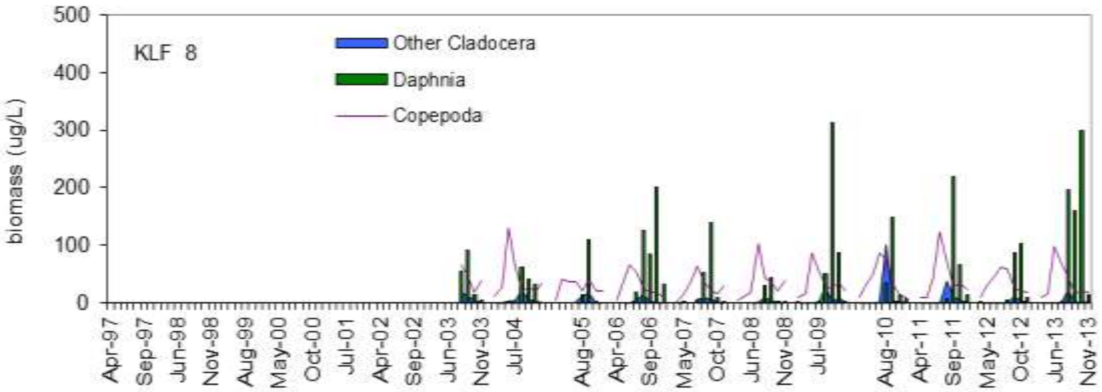
Figure 52. Zooplankton density in Kootenay Lake, 1997 to 2013.



a. Seasonal biomass of zooplankton in the North Arm of Kootenay Lake, 1997 to 2013.



b. Seasonal biomass of zooplankton in the South Arm of Kootenay Lake, 1997 to 2013.



c. Seasonal biomass of zooplankton in the West Arm of Kootenay Lake, 1997 to 2013.

Figure 53. Zooplankton biomass in Kootenay Lake, 1997 to 2013.

Total zooplankton density was higher in the North Arm than the South Arm in 2013, a pattern exhibited since 2008. The South and West Arms had similar average densities (Fig. 54). Total zooplankton biomass in all arms of Kootenay Lake in 2013 was the highest amongst all studied years (Fig. 55). It almost doubled in comparison to the previous year, due to appearance of very large *Daphnia* individuals. Total biomass was higher in the North Arm than in the South Arm, while in the West Arm biomass was slightly higher than the South Arm (Fig. 55).

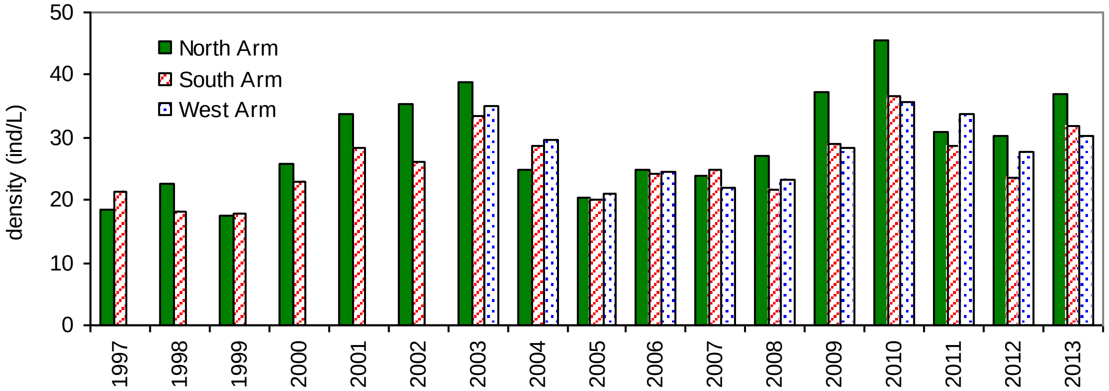


Figure 54. Seasonal average density of total zooplankton in North, South and West arms, 1997 to 2013.

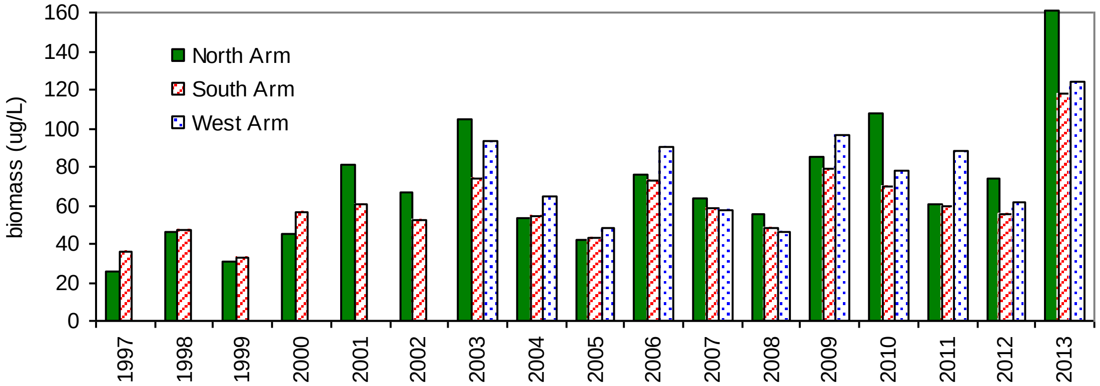


Figure 55. Seasonal average biomass of total zooplankton in North, South and West arms, 1997 to 2013.

When comparing densities amongst stations by months in 2013, results were similar amongst the North Arm stations except during July and August where results at station KLF 4 were higher than at the other stations, and in June when density at KLF 3 and KLF 4 were lower than at the other two stations in the North Arm (Fig. 56). In the South Arm densities at KLF7 were lower in June and July than at the other stations. Biomass results were similar among stations during all months except in October in the North Arm where biomass ranged between 400 and 800 µg/L at four stations.

In 2013 when using a one way ANOVA amongst stations KLF 1-8, there is no statistical significance in total density for stations KLF 1-8 (p=0.657; F=0.718)(Fig. 57A). When comparing months, there is statistical significance (p<0.0001; F=45.15) (Fig. 57B). For biomass, the variation amongst stations is not statistically significant (p=0.576; F=0.816) (Fig. 57C), while amongst months, there is statistical significance (p<0.0001; F=41.81) ((Fig. 57D).

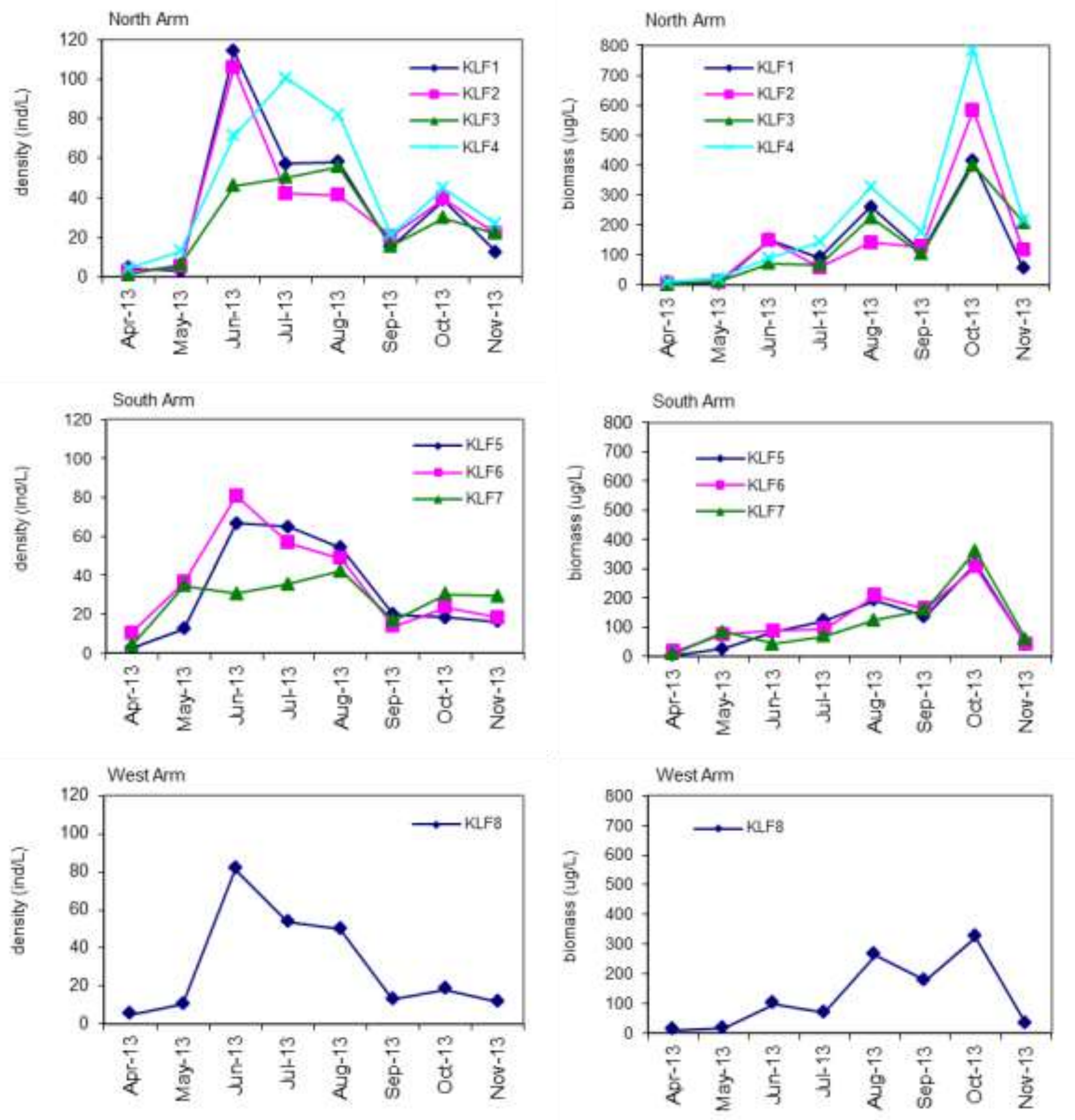


Figure 56. Total zooplankton density and biomass at each station, Kootenay Lake, April to November, 2013.

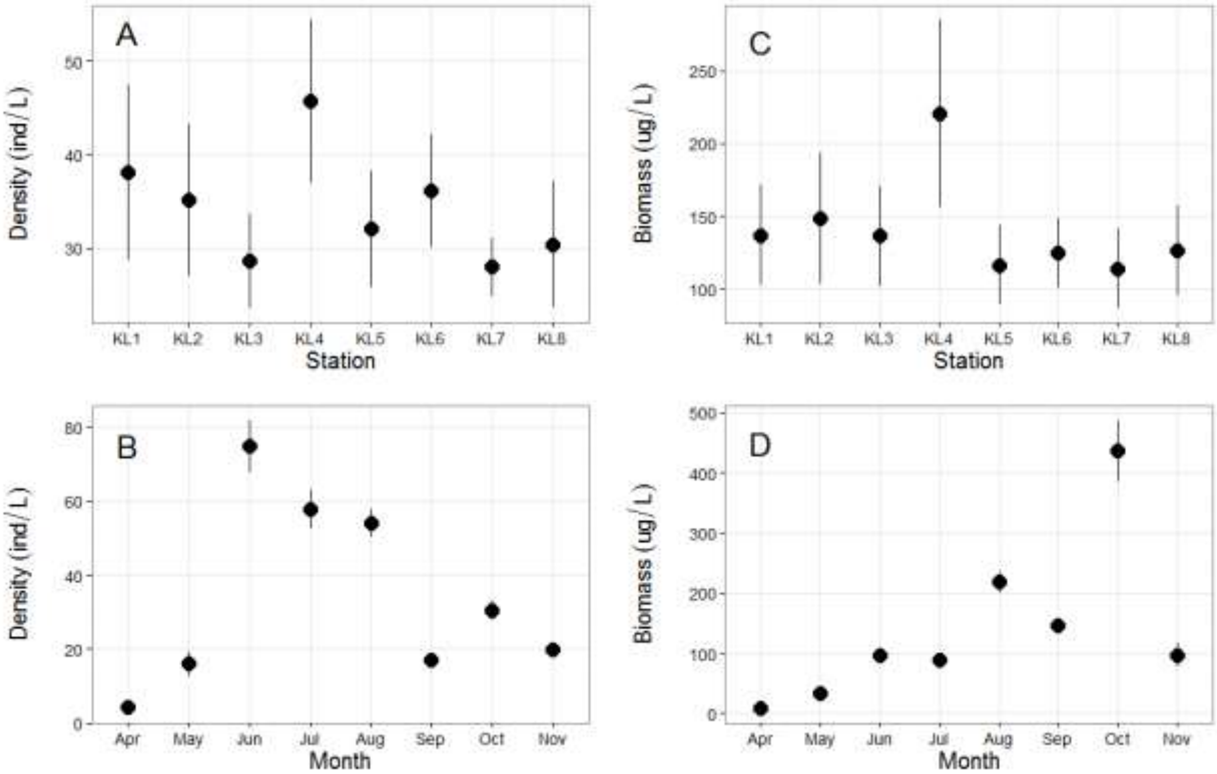


Figure 57. Total zooplankton. Density by station (A) and by month (B). Biomass by station (C) and by month (D). Means ± SE.

Mysis diluviana

In 2013, densities of mysids decreased in comparison to the 2012 results (Fig. 58). Average densities were higher in the South Arm than the North Arm in deep sites, a similar trend that was consistent from 2001-2002 and 2007-2010 (Figs. 59 and 60). The peak density in 2013 occurred in June at station KLF 5, mainly because of increased number of juveniles (Fig 61).

In the West Arm, peak density occurred in June in all years studied (2004 through 2013) (Fig. 62). The main contributors to total density were the immature male and female developmental stages.

When using a one way ANOVA amongst stations KLF 1-7 in 2013 (deep sites), the variation in density amongst stations is statistically significant (p=0.003; F=3.602). The variation amongst months (April to November) is also statistically significant (p=0.002; F=4.074) (Fig. 63). At shallow sites, the variation amongst stations KLF 1-7 was not statistically significant (p=0.698; F=0.639), while the variation amongst months sampled was statistically significant (p=0.0395; F=2.584) (Fig. 63).

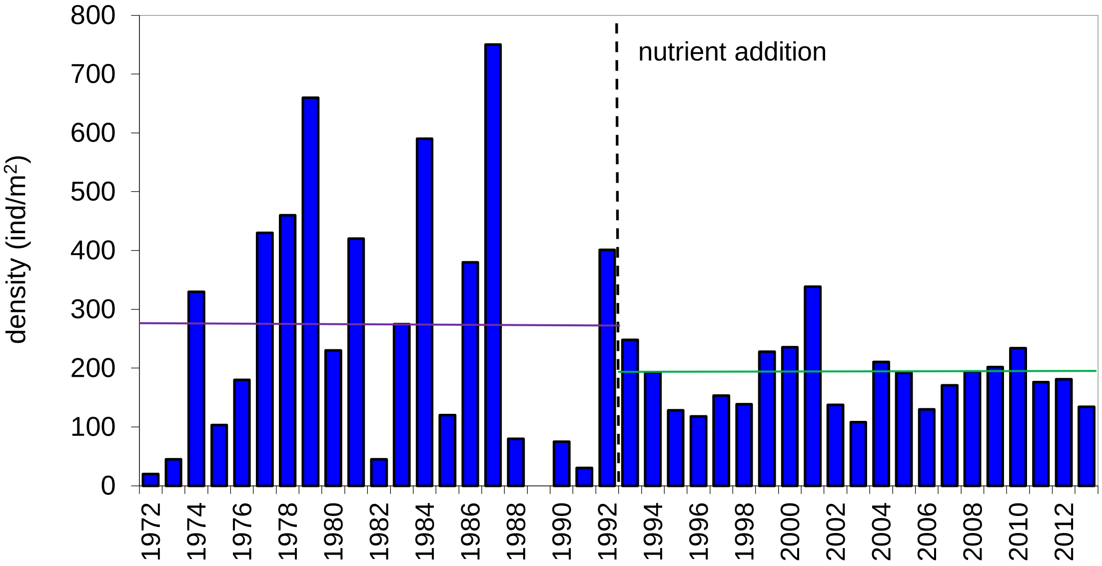


Figure 58. Annual average density of *Mysis diluviana* in Kootenay Lake, 1972 to 2013.

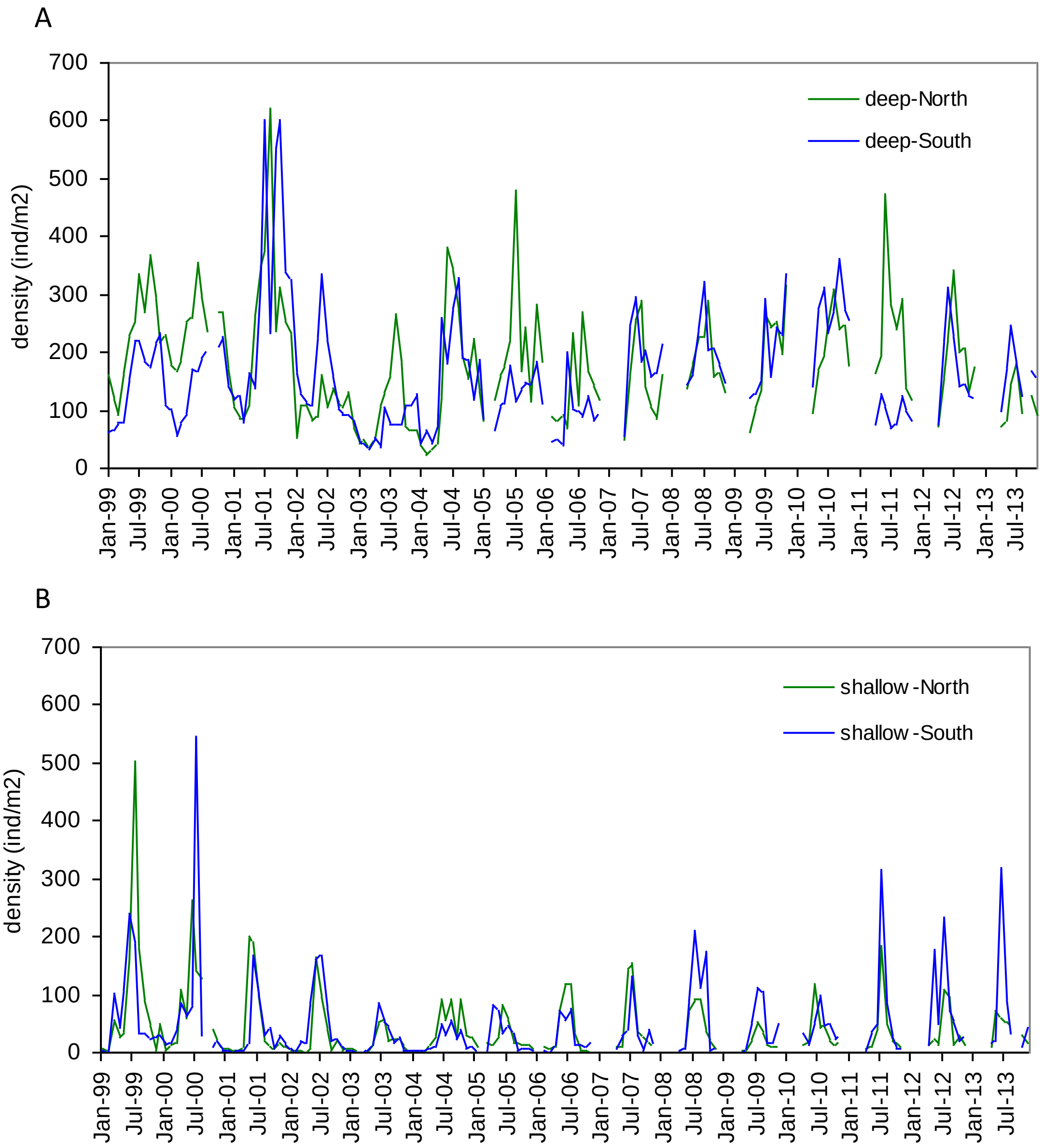


Figure 59. Seasonal average density of *Mysis diluviana* at pelagic (A) and near- shore stations (B) (1999 to 2013) in Kootenay Lake.

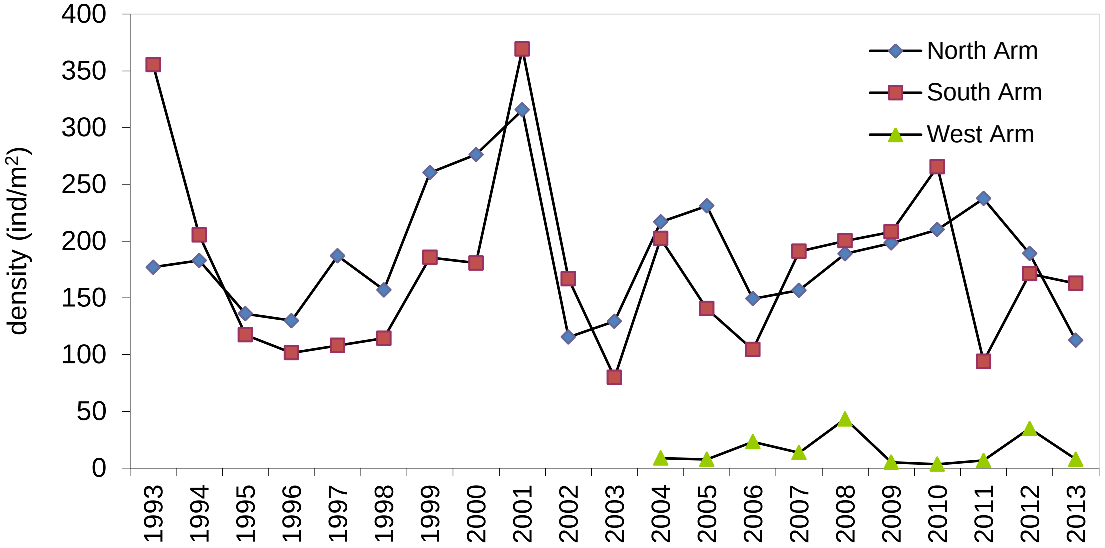


Figure 60. Annual average density of *Mysis diluviana* in deep sites in the North, South and West arms of Kootenay Lake, 1993 to 2013. Averages calculated from April to November.

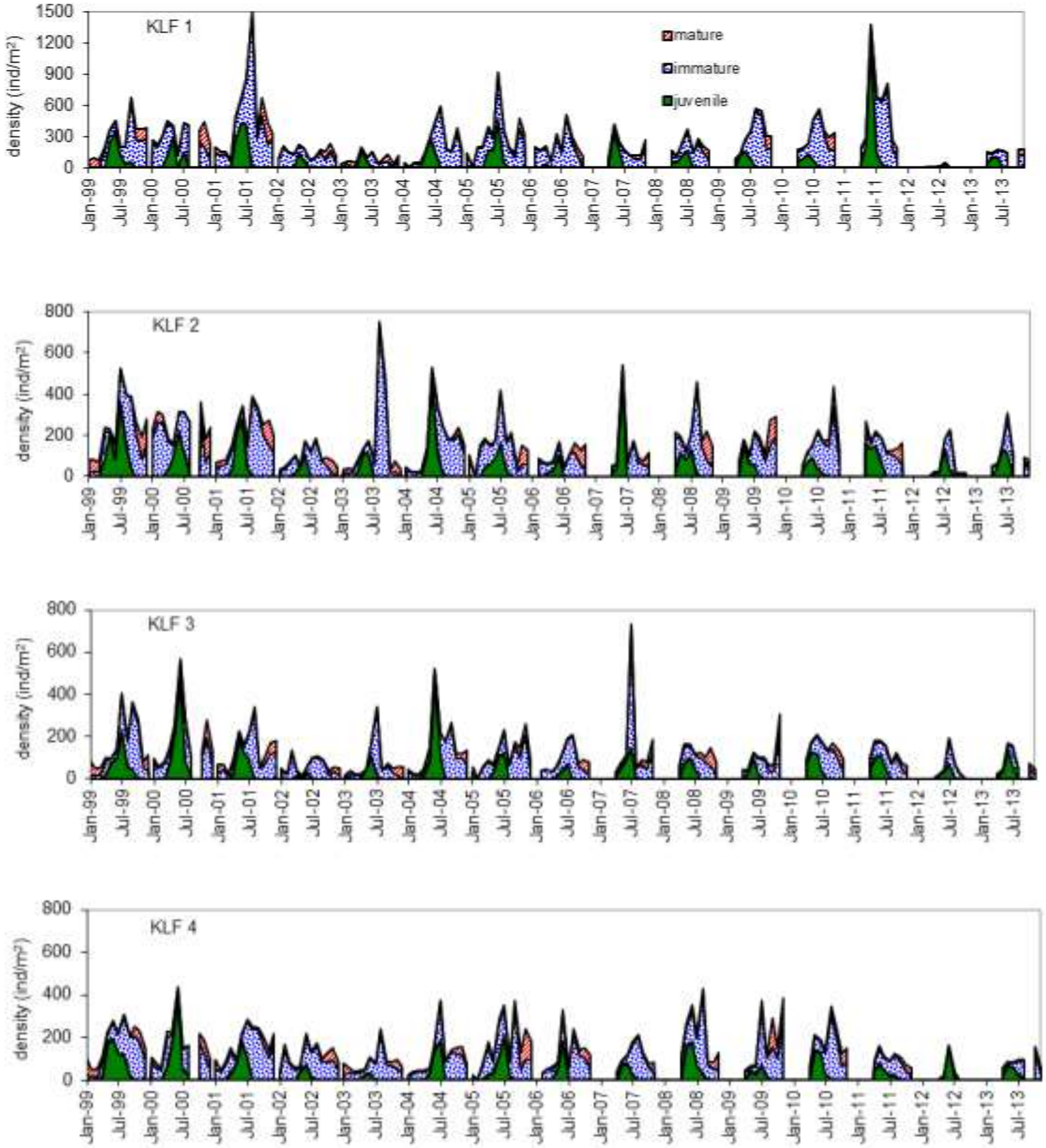


Figure 61. Densities of developmental stages of *Mysis diluviana* at deep sites, North Arm stations, Kootenay Lake, 1999 to 2013. Note: The graph for KLF 1 has different scale.

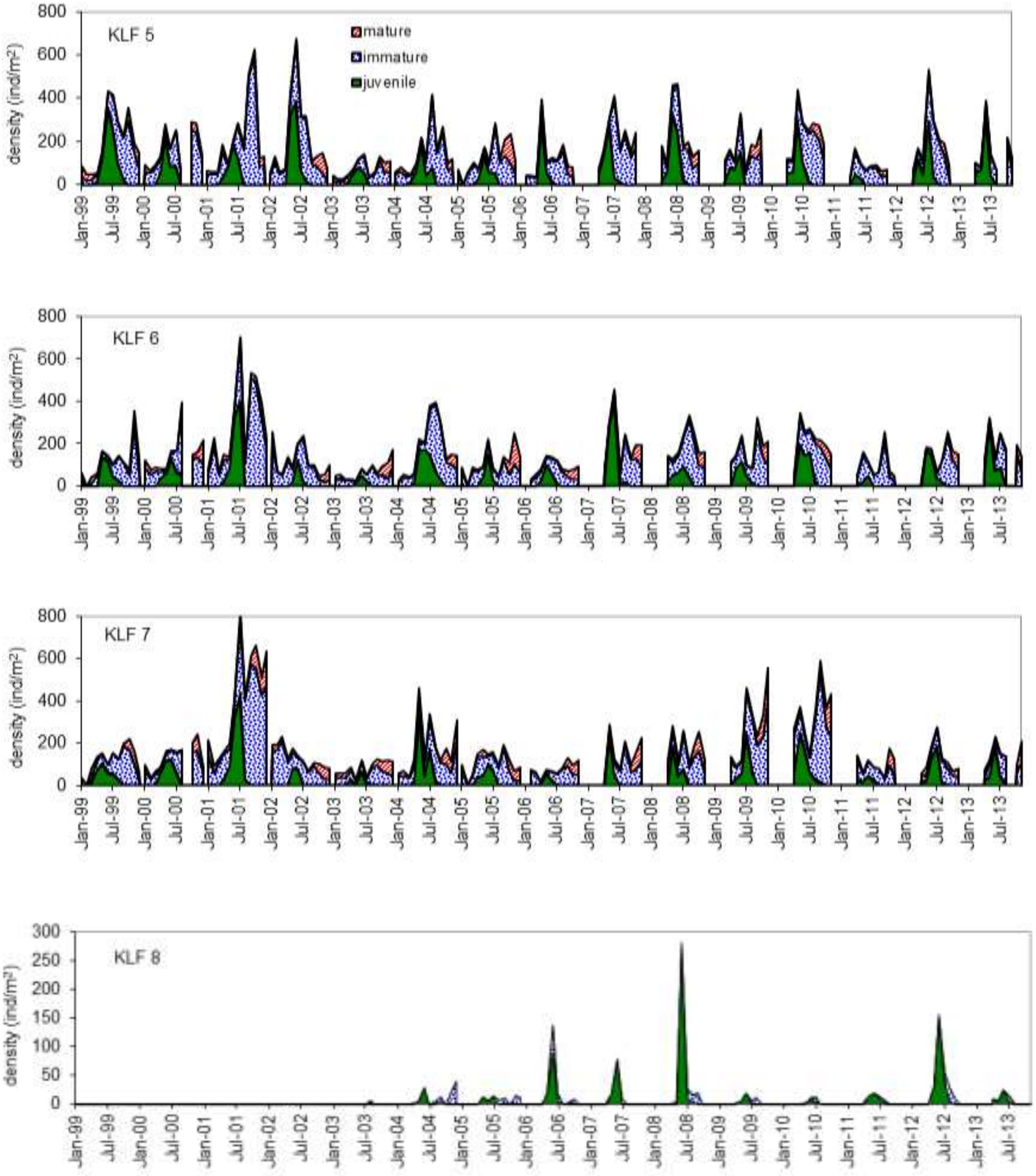


Figure 62. Densities of developmental stages of *Mysis diluviana* at deep sites, South Arm (KLF 5-7) and West Arm stations (KLF 8), Kootenay Lake, 1999 to 2013. Note: The graph for KLF 8 has different scale.

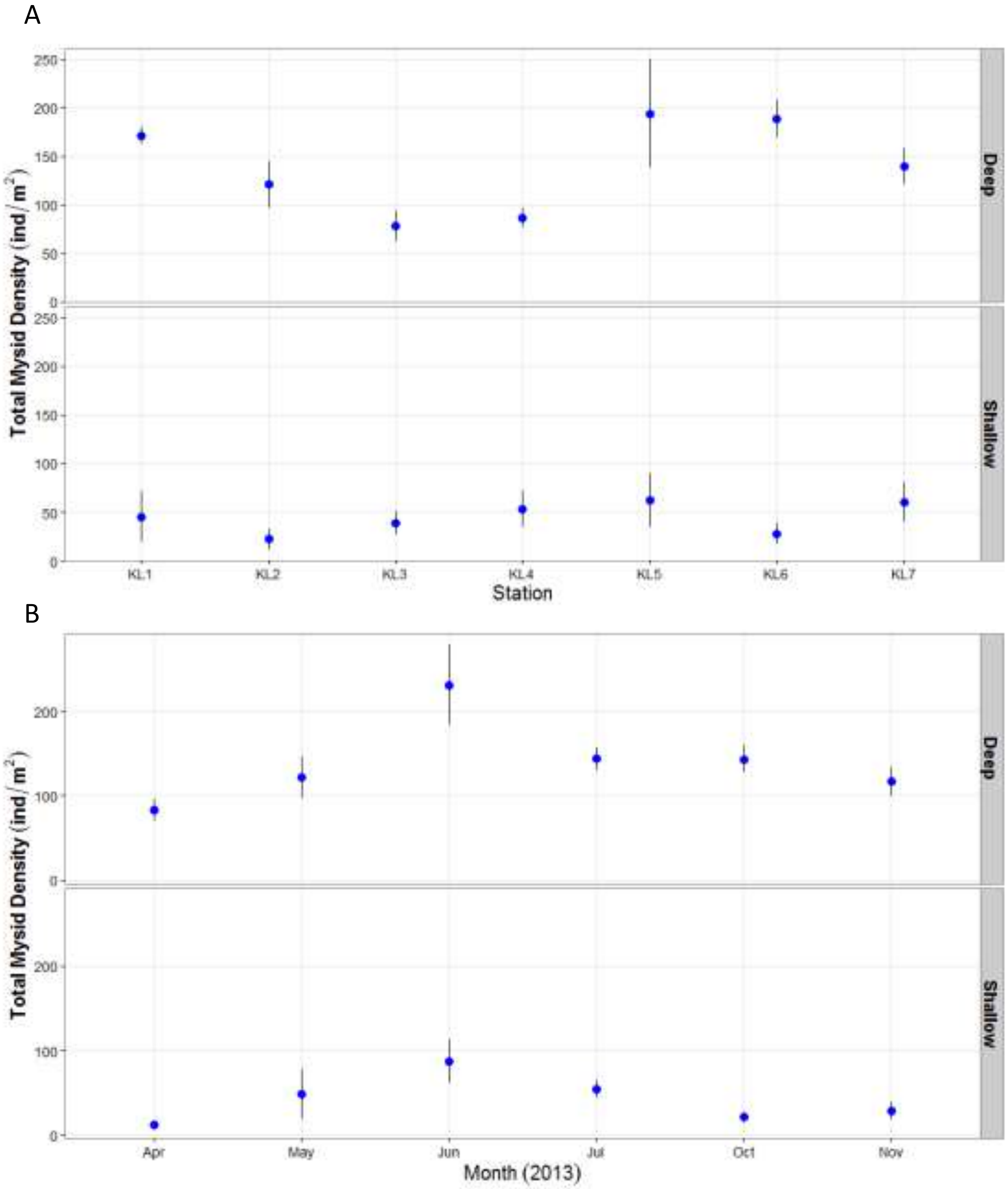


Figure 63. Total mysid density at deep and shallow sites of Kootenay Lake (KLF 1-7) in 2013, compared by sites (A) and by months (B).

In the main lake, seasonal average mysid densities during the nutrient addition period (1992 through 2013) were lower than results from the late 1970s and the mid-1980s (Fig. 58). Samples collected in the late 1970s and mid-1980s were less frequently sampled than during the current study, and the plankton net used to collect samples had a finer mesh (Crozier and Duncan 1984). From 1992 to 2004, sampling of mysids began in January and continued until December. In 2005, samples were not collected in February. In 2006 samples were collected for ten months, between February and November, and from 2007 to 2013 for eight months from April to November. All annual average data are calculated for the period from April to November in each studied year. During the nutrient addition period, the highest density was observed in 1992, the first year of nutrient additions. The second highest density occurred in 2001, when nutrients additions were similar to additions in the first five years of the program (1992-1996) (Table 1).

Biomass at deep sites decreased in the North Arm, but increased in the South Arm in 2013, compared to 2012 (Fig. 64). Average biomass was higher in the South Arm than the North Arm in deep sites. Biomass at shallow sites in 2013 decreased in both the North and the South Arm in comparison to the previous year (Fig. 64). Immature and mature developmental stages contributed the most to overall biomass. The release of juveniles from females' brood pouches occurs in early spring and is reflected by a density increase in April of each year (Figs. 65 and 66). By July, the juveniles have grown into the immature stage, therefore during the summer and fall, immature males and females dominate the mysid population. Brooding females and breeding males increase in density in the late fall as they reach maturity (Vidmanic, in Schindler et al. 2011).

Biomass in the West Arm decreased approximately threefold in 2013 in comparison to the previous year. The majority of biomass was comprised of the immature developmental life stage. Peak biomass occurred in June and July in 2013.

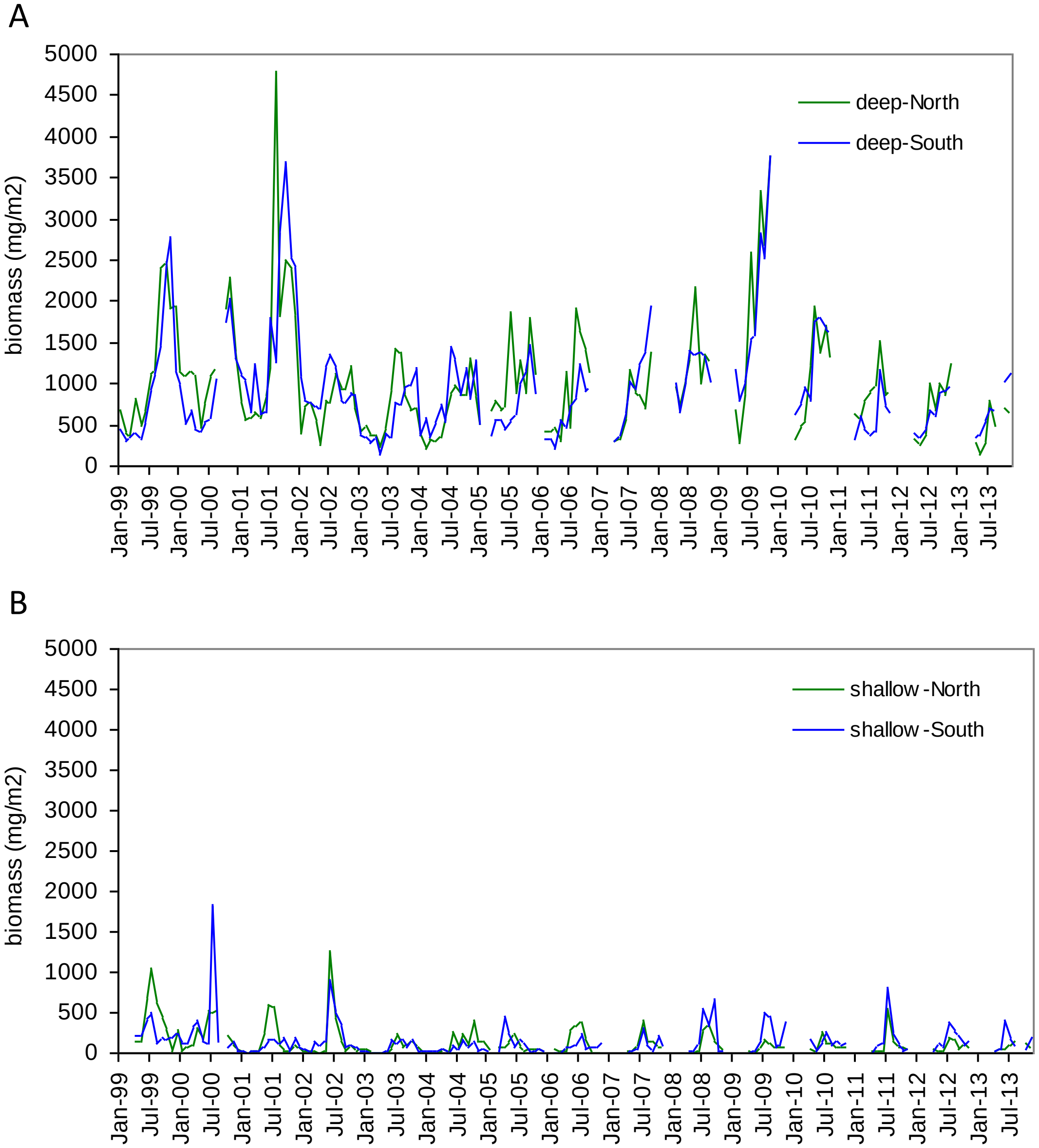


Figure 64. Seasonal average biomass of *Mysis diluviana* at pelagic (A) and near- shore stations (B) (1999 to 2012) in Kootenay Lake.

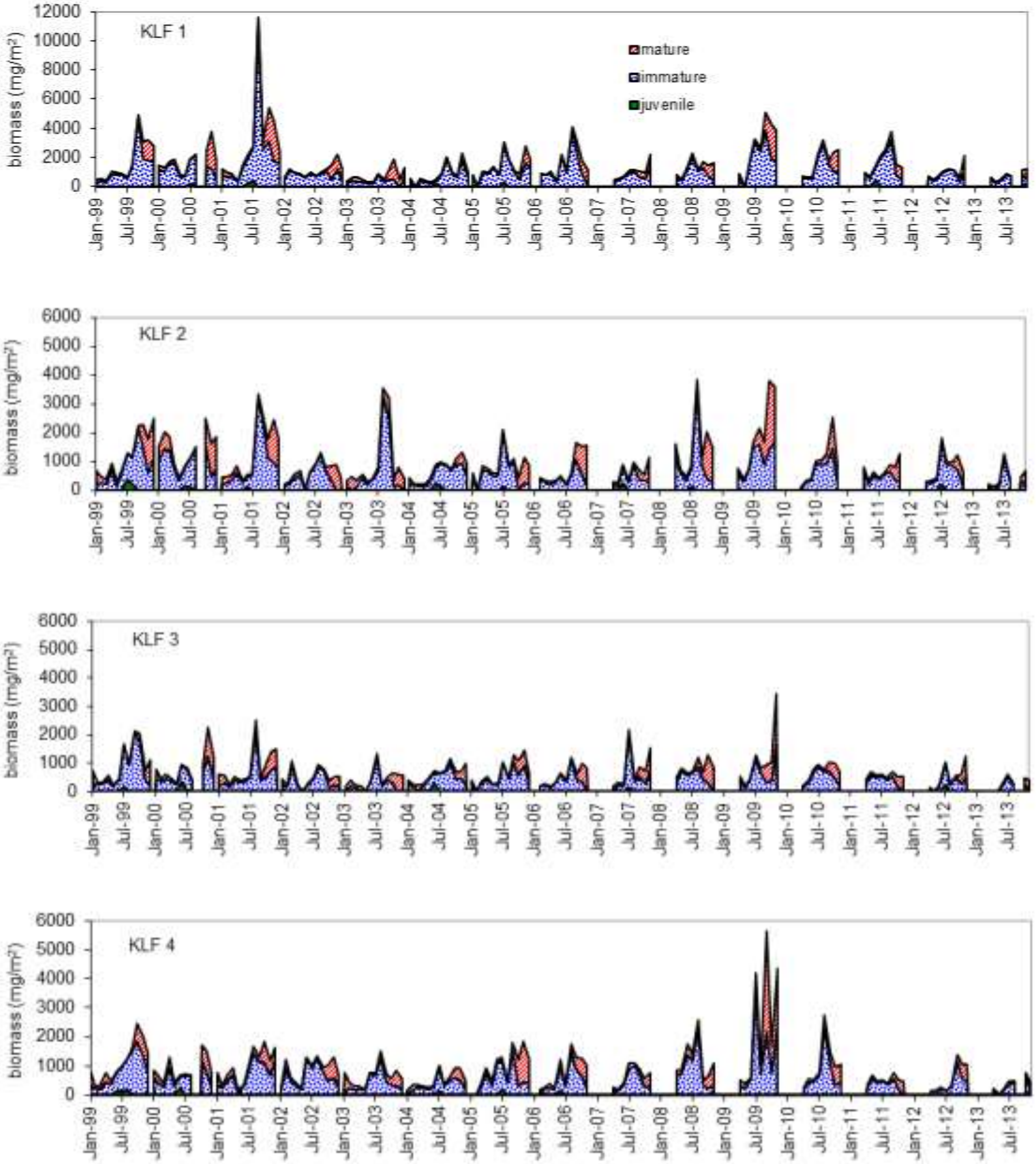


Figure 65. Biomass of developmental stages of *Mysis diluviana* at deep sites, North Arm stations, 1999 to 2013. Note: The graph for KLF 1 has different scale.

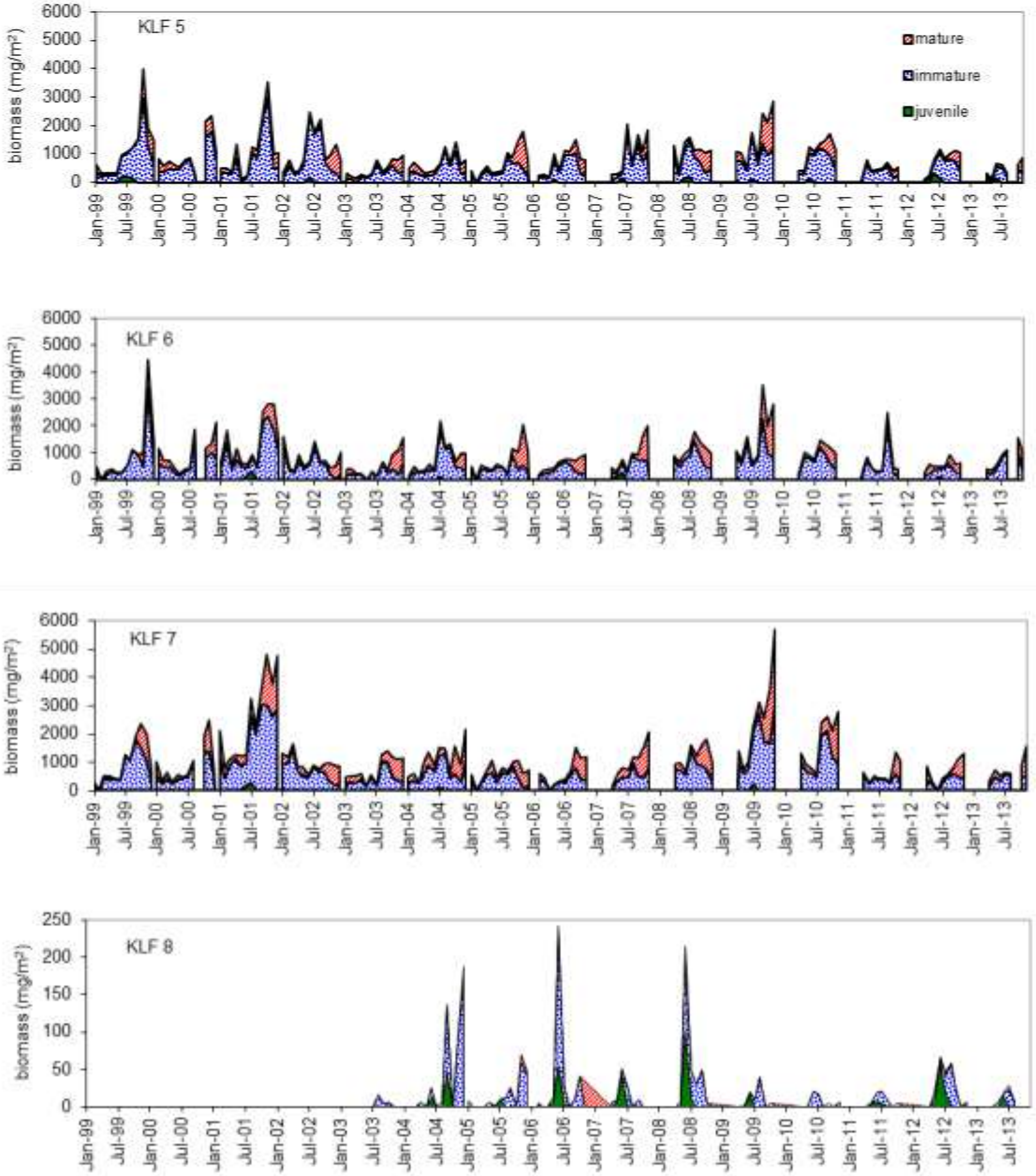


Figure 66. Biomass of developmental stages of *Mysis diluviana* at deep sites, South Arm (KLF 5-7) and West Arm stations (KLF 8), Kootenay Lake, 1999 to 2013. Note: The graph for KLF 8 has different scale.

When using a one way ANOVA amongst stations KLF 1-7 in 2013 (deep sites), the variation in biomass amongst stations was statistically significant (p=0.0002; F=5.058), as well as the variation amongst months (April to November) (p<0.0001; F=9.679) (Fig. 67). In contrast, at shallow sites the variation amongst stations KLF 1-7 was not statistically significant (p=0.147;

F=1.691). Variation amongst months sampled was also not statistically significant (p=0.127; F=1.829) (Fig. 67).

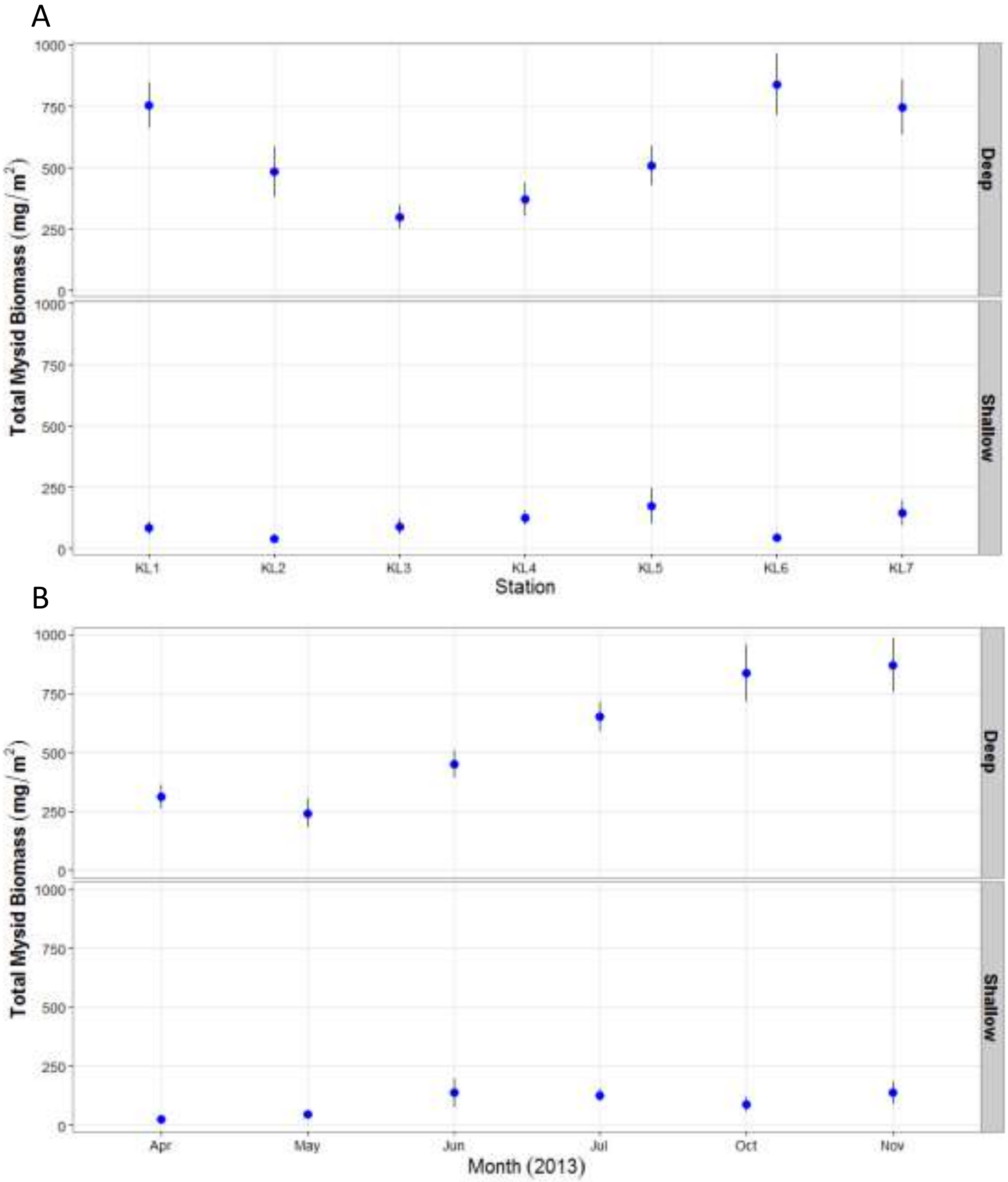


Figure 67. Total mysid biomass at deep and shallow sites of Kootenay Lake in 2013, compared by sites (A) and by months (B).

Kokanee

2013 Kokanee Escapements – North Arm

In 2013, escapements to both Meadow Creek and the Lardeau River decreased compared to 2012. Meadow Creek had the lowest count since the onset of the fertilization program with only 202,700 kokanee returning (Fig 68). This was the lowest escapement since 1965, followed closely by the 1991 escapement year just prior to fertilization. To demonstrate 'normal' conditions we have used 1 SD from the pre and post fertilization averages in figures 68 and 69. The 2013 Meadow Creek escapement of 202,700 was well below average and comes after a precipitous decline from the 2011 escapement which was well above average.

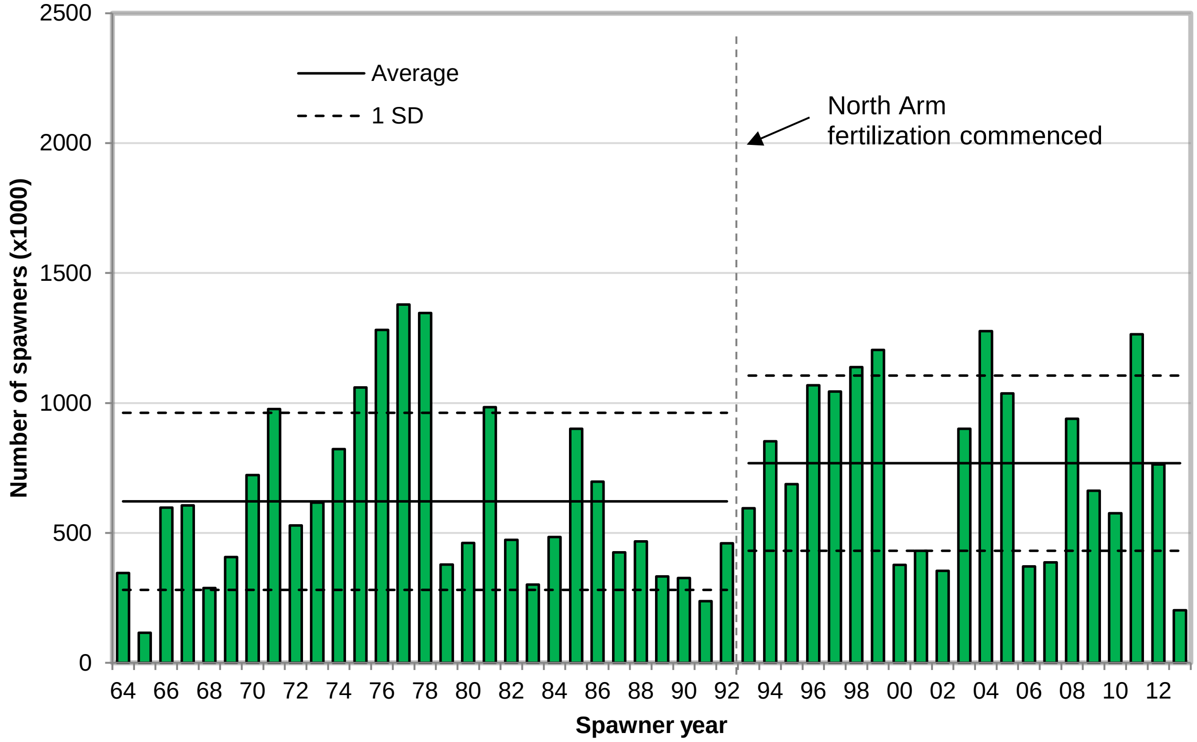


Figure 68 Kokanee escapements to Meadow Creek, North Arm of Kootenay Lake, 19642013. (Note: 1964–1968 data from Acara 1970 unpubl. MS).

The Lardeau River escapement decreased from a recent peak of 492,000 kokanee in 2012 to 251,000 kokanee spawners in 2013 (Fig 69), which was near average for the post fertilization period.

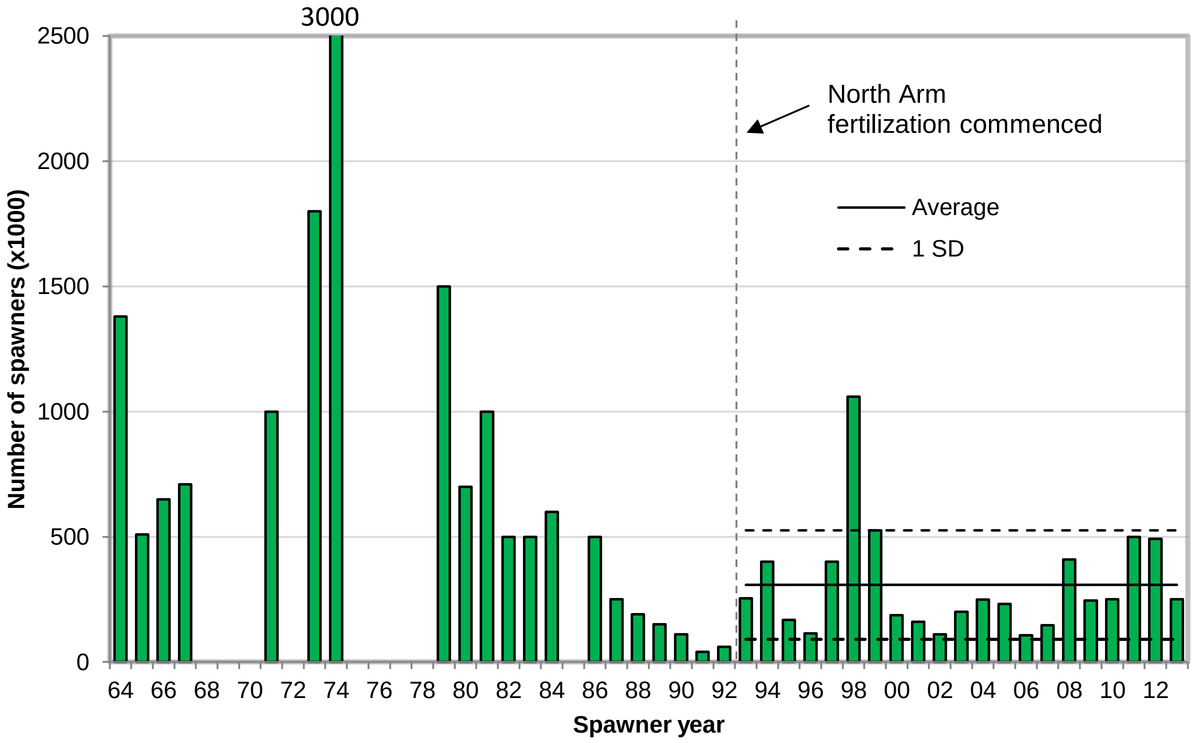


Figure 69 Kokanee escapements to the Lardeau River, North Arm of Kootenay Lake, 1964–2013. (Note: 1964–1967 data from Acara 1970 unpubl. MS). No data exist for 1968-70, 71, 75-78, 85; pre-fertilization average omitted due to missing data.

Kokanee egg plants and escapements – South Arm

Egg plants in select South Arm tributaries began in northern Idaho in 1997 and in British Columbia in 2005 with varying levels of effort and success. Since the detection of IHN (Infectious Haematopoietic Necrosis) at Meadow Creek in 2013, there have been no egg plants in order to mitigate the spread of the disease (Tables 5 and 6).

Adult kokanee returns to BC South Arm tributaries dropped substantially from the previous couple of years (Table 7). Only 100 spawners were counted in Goat River, 2 spawners in Crawford Creek, and 1 spawner in Summit. To date, Goat River has received a substantial amount of egg plants and has shown the highest rate of return. It is possible that a self-sustaining population is building and a portion of the 2013 spawners were the progeny of the187 spawners counted in 2009 and that those 2009 spawners were the progeny of the 1 million eggs planted in 2005,assuming age 3+ spawners. Given that the majority of spawners returning to Meadow Creek in 2013 were age 4+, it is possible that the return of 100 spawners to Goat River in 2013 may be partly due to the return of some age 4+ spawners from the 1.5 million eggs planted in 2008.

Boulder Creek escapement from four consecutive years of egg plants resulted in an index count of only three fish, with all fish counted during the 2012 season. 2013 could possibly have seen a return as a result of the 2008 eggplant if they had matured as age 4+ but none were observed. The most recent egg plants to Boulder Creek in 2010 of 1.2 million could return as 3+ in 2014 or 4+ in 2015.

In Idaho tributaries to the South Arm of Kootenay Lake the escapement was much lower than years prior (Table 8). Boundary Creek received egg plants in 2009 but no spawners were observed during the one survey that occurred in 2013. Trout creek was the only surveyed Idaho tributary where a kokanee escapement was observed, albeit minimal with only 25 fish counted. This is the lowest escapement for Idaho tributaries since 2006, before the expected increase in returns in 2007 from extensive egg plants that began in 2003. Egg plants were directed exclusively to Boundary Creek in 2009 instead of distributed more evenly amongst other tributaries so it is possible that Boundary Creek isn't as ideal for egg plants as some of the other tributaries. The next few years will indicate Boundary Creek's suitability since the majority of eggs were also planted there in 2010 through to 2012.

Table 5. Number of kokanee eyed egg plants in BC South Arm tributaries, 2005–2013. Eggplants in 2009 a and b (highlighted in green) were assumed to return as adults in 2013.

	British Columbia tributaries				
Year	**Boulder**	**Crawford**	**Goat R.**	**Summit**	**Combined**
2005	200,000	300,000	1,000,000	500,000	2,000,000
2006	175,000			210,000	385,000
2007	150,000	300,000	1,100,000		1,550,000
2008a	90,000	120,000	828,000	80,000	1,118,000
2008b	240,000	180,000	700,000	240,000	1,360,000
2009a				236,000	236,000
2009b				264,000	264,000
2010a	370,000				370,000
2010b	780,800				780,800
2011a			2,300,000	940,000	3,240,000
2012			1,500,000	700,000	2,200,000
2013*					

[a] Eggs planted in the gravel using a flexible PVC pipe
[b] Eggs placed in tubes and then buried in the gravel
*No eggs planted due to IHN at Meadow Creek (source of eggs)

Table 6. Number of kokanee eyed egg plants in Idaho tributaries 1997–2013. Data up to 2008 from Ericksen et al. (2009). Data from 2009-2013 received from Kootenai Tribe of Idaho. Eggplants in 2009 (highlighted in green) were assumed to return as adults in 2013.

Year	**Idaho tributaries**								
	Boundary	**Long Canyon**	**Parker**	**Trout (S. fork)**	**Trout (N. fork)**	**Ball**	**Myrtle**	**Fisher**	**Combined**
1997		100,000							100,000
1998		100,000	100,000	100,000					300,000
1999		200,000	150,000	150,000					500,000
2000		no egg plants							
2001		no egg plants							
2002		no egg plants							
2003		417,000	417,000	417,000	50,000		200,000		1,501,000
2004		500,000	500,000	587,500	325,000		587,500	500,000	3,000,000
2005		420,000	420,000	420,000	200,000		420,000	420,000	2,300,000
2006		100,000			25,000			25,000	150,000
2007		625,000	300,000	425,000	93,000		150,000	150,000	1,743,000
2008	1,000,000	500,000	50,000	325,000	200,000	325,000		100,000	2,500,000
2009	300,000								300,000
2010	700,000			300,000					1,000,000
2011	1,000,000			500,000					1,500,000
2012	400,000			300,000		300,000			1,000,000
2013*									

*No eggs planted due to IHN at Meadow Creek (source of eggs)

Table 7. Kokanee spawner counts in BC South Arm tributaries, 1992–2013. Data up to 2008 is from Ericksen et al. (2009). Blue shading indicates years and streams where we anticipated returns of age 3+ spawners from egg plants four years earlier (see Table 5).

Year	**Boulder**	**Crawford**	**Goat River**	**Summit**	**Gray**	**LaFrance**	**Lockhart**	**Akokli**	**Sanca**	**Midge**	**Cultus**	**Combined**
1992	3		20	30					6			59
1993												
1994	0	2	0	0	0	0	0	100	4	0	0	106
1995	0	0	0	0	0	0	0	0	0	0	0	0
1996	0	40	4	0	30	20	20	200	0	50	50	414
1997	0	0	0	0	10	3	1	150	7	0		261
1998	0	0	2	0	5	0	0	50	2	5		64
1999	0	0	0	0	20	2	0	20	2	0		44
2000	1	0	0	0	2	0	0	20	0			23
2001	0	0	0	0	8	0	0	6	0	33		47
2002	0	0	0	0	10	0	0	5	0			15
2003	0	5	2	1	35	0	0	151	8	0		202
2004	0	0	0	0	8	0	0	8	0	0	0	16
2005	0	0	0	0	0	0	0	1	0			1
2006	0	0	0	1	9	0	0	2	0			12
2007	0	8	0	0	40	0	3	4	0		100	155
2008	0	0	0	0	6	2	0	0	0			8
2009	0	22	187	114	4	0	0	2	0			329
2010	0	0	0	0	19	2	0	NS	0			21
2011	0	575	274	203	10	0	0	10	0			1,072
2012	3	57	1441	315	1	0	0	0	0	0	0	1,817
2013	0	2	100	1	0	0	0	0	0			103

Table 8. Kokanee spawner counts in Northern Idaho streams. Data provided by Kootenai Tribe of Idaho. NS = not sampled. Blue shading indicates years and streams where we anticipated returns of age 3+ adults from egg plants four years earlier (see Table 54).

Year	Boundary	Long Canyon	Parker	Trout	Ball	Myrtle	Smith	Combined
1980	2,000	2,000	500	100	0	0	2,000	6,600
1981	1,100	1,600	350	50	50	50	600	3,800
1982-92	No records							
1993	0	17	47	0	NS	0	NS	64
1994-95	No records							
1996	0	0	0	0	NS	0	0	0
1997	0	3	0	0	NS	NS	0	3
1998	8	0	0	0	NS	NS	0	8
1999	38	0	0	0	NS	NS	0	38
2000	17	30	7	0	NS	NS	NS	54
2001	31	25	0	7	NS	NS	NS	63
2002	0	NS	30	0	NS	NS	30	60
2003	0	40	55	0	NS	0	NS	95
2004	9	11	1	5	NS	0	NS	26
2005	0	0	3	0	NS	0	NS	3
2006	0	6	5	0	NS	0	NS	11
2007	NS	150	10	325	100	2	200	787
2008	0	0	62	535	455	9	215	1,276
2009	NS	130	70	100	NS	0	NS	375
2010	NS	125	3	6	NS	0	NS	134
2011	0	1000	6	2	100	6	NS	1,114
2012	300	350	NS	650	275	NS	0	1,575
2013	0	0	NS	25	0	NS	NS	25

Otolith collection for aging of spawners is essential to link back to specific egg plants and assess the success of the egg plant program. Variations in age at maturity occur with relative frequency in Kootenay Lake based on otolith analysis of Meadow Creek spawners but it may not be prudent to assume that Meadow Creek spawner data is representative of the age at maturity of South Arm tributary spawners until data are collected to confirm this. There is some evidence in nearby Kinbasket Reservoir that age at maturity has differed among tributaries within the same year, although the authors caution that more data is required to confirm this (Bray et al. 2013). The mechanisms affecting changes in age at maturity are not well enough understood that age at maturity can be inferred among other tributaries with confidence. Having age at maturity data from South Arm tributaries will also assist with comparing North Arm and South Arm habitats; at this time there are no data relating age at maturity with in-lake conditions during the rearing stage. It is possible that growing conditions during early stages of life affect age and size at maturity (Leifasbjorn et al. 2004).

Spawner size and fecundity

Very few data are collected on Kootenay Lake spawners, with the exception of those returning to Meadow Creek spawning channel. Meadow Creek kokanee spawners are generally small, similar to most kokanee found in large oligotrophic lakes in BC. The mean length of Meadow Creek kokanee was remarkably consistent prior to the nutrient restoration program but has since increased in variability. Since 1969 Kokanee spawner fork lengths have ranged in length from 195–282 mm with the mean length of females (223 mm) slightly smaller than of males (226 mm) (Fig 70). Length peaked in 2007 at 277 mm for females and 282 mm for males and declined in each of the following years until 2013. In 2013 size of spawners increased dramatically and females averaged 270 mm and males 276 mm in length. This represents an increase in annual average size from the second smallest on record in 2012 to the second largest on record in 2013.

Fecundity, related to size, also increased from an average of 180 eggs per female in 2012 to 285 eggs per female in 2013 (Fig. 70). The average from 1969-2013 was 261 eggs per female. The increase in fecundity was less than predicted by the annual relationship of average female kokanee spawner sizes plotted against the average fecundity for 45 years spanning from 1969 to 2013 (Fig 71). The linear equation formed by that relationship predicts about 385 eggs per 270 mm female compared to the average of 285 eggs per 270 mm female counted *in situ* at Meadow Creek spawning channel during the 2013 escapement. In Arrow Reservoir, a similar occurrence of lower than predicted fecundity was noted in 2013, 2006, and 1998 during years of rapid growth immediately following a period of slow growth and declining spawner sizes (Bassett et. al. 2015). The lower than predicted fecundity in Kootenay lake in 2013 occurred during a year of very rapid growth immediately following a period of declining spawner sizes, similar to what was noted in Arrow Reservoir.

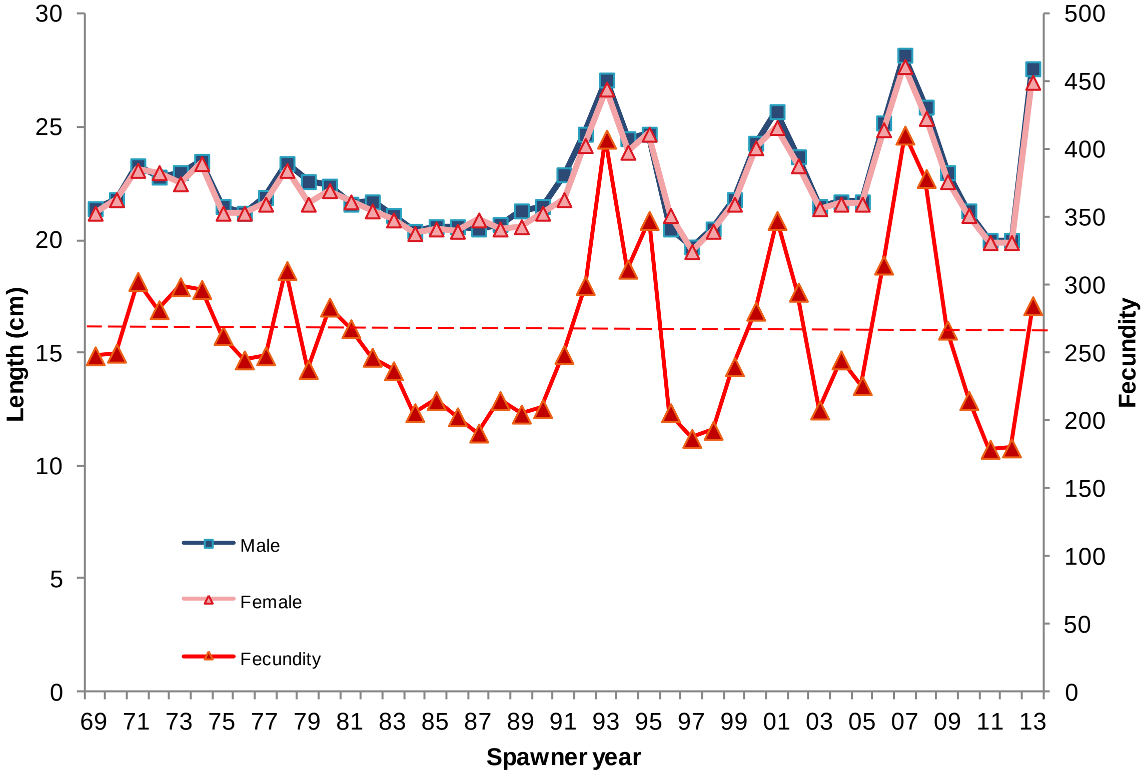


Figure 70. Mean length of Meadow Creek female and male kokanee spawners and mean fecundity, 1969–2013. Red dashed line illustrates average fecundity.

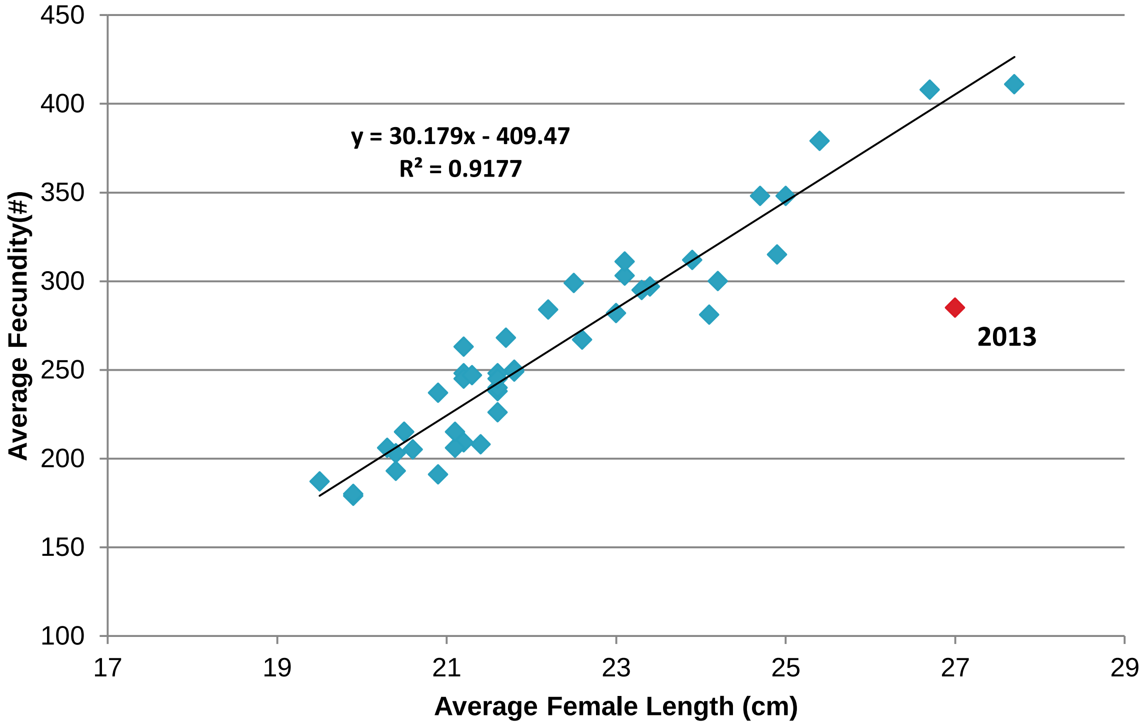


Figure 71. The relationship between annual average size of female kokanee spawners and average fecundity for years 1969-2013.

Meadow Creek kokanee fry production

Meadow Creek spawning channel is the largest contributor of kokanee fry to Kootenay Lake, so the management of this channel reflects strongly in the population. Since the nutrient restoration program began the number of spawners allowed in the channel has ranged from a maximum of 519,557 in 2012 to a minimum of 202,748 in 2013 (Appendix 8). The fry produced from Meadow Creek channel during the spring of 2013 was estimated at 13.77 million, up slightly from 2012 but still below the post fertilization average of 17.5 million (Fig. 72). Egg to fry survival was similar to other years as depicted in Figure 73.

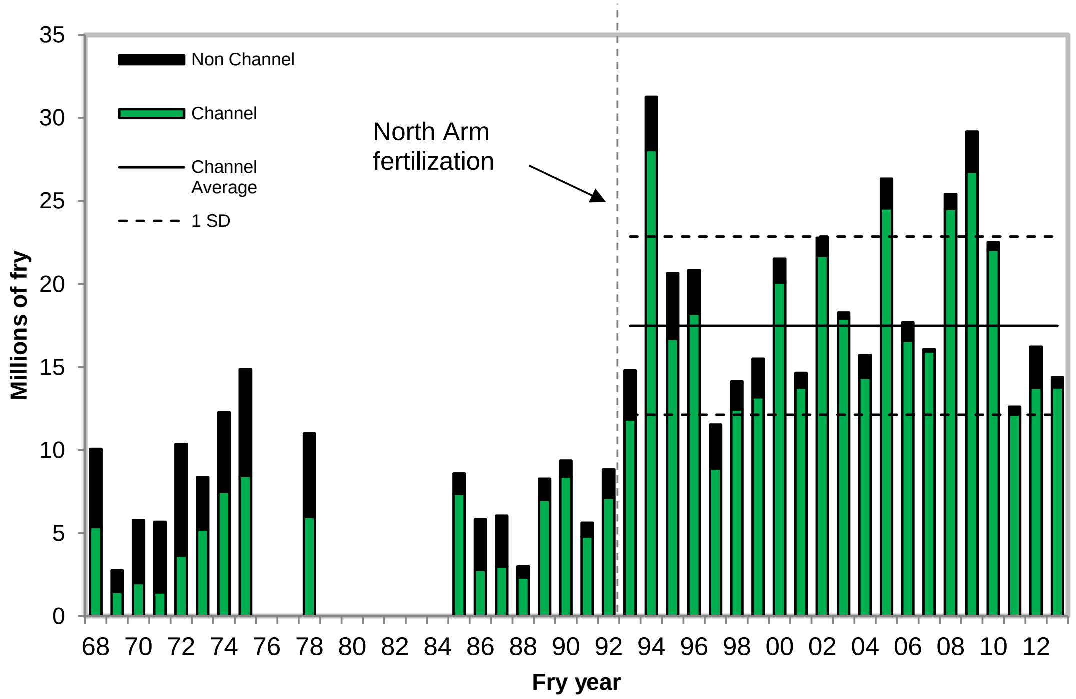


Figure 72. Meadow Creek kokanee fry production from the spawning channel and areas upstream and downstream of the channel, 1968–2013. No data for years without bars.

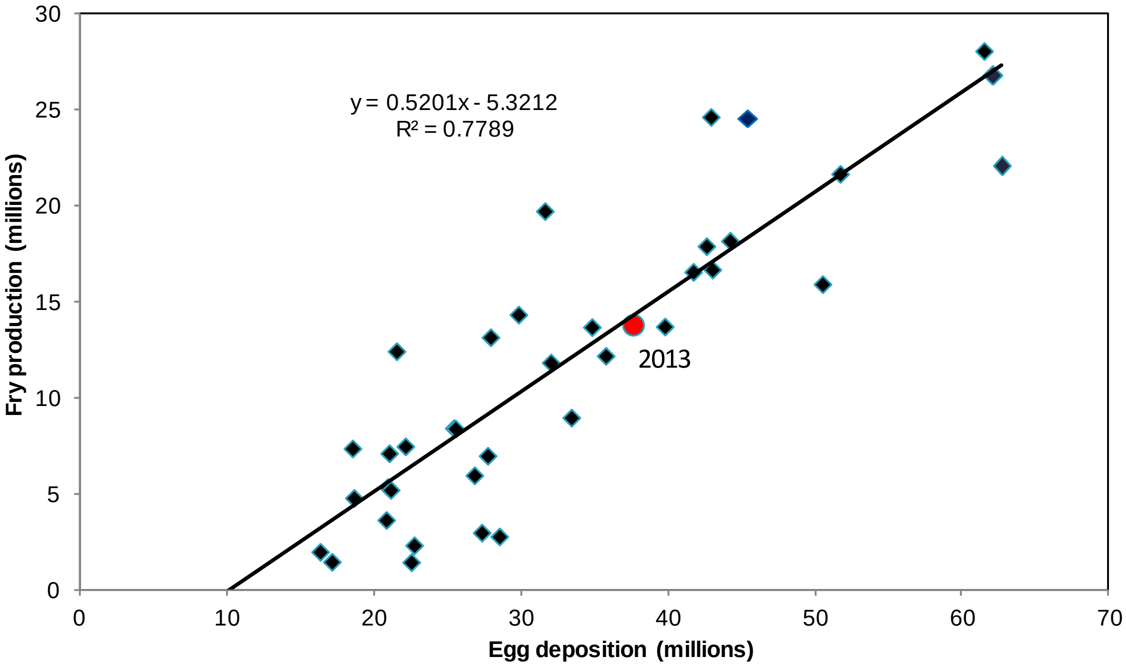


Figure 73. Meadow Creek spawning channel egg deposition versus fry production for years with available data, 1968–2013. Note: The red circle represents the 2013 fry out migration.

Trawl Catch Data

Trawl surveys have been carried out in early fall on Kootenay Lake for more than 20 years, and the catch has consistently been >99% kokanee. This affirms that virtually all fish recorded by the acoustic survey in the limnetic zone are kokanee. Since the South Arm nitrogen additions began in 2004, a second trawl survey was initiated annually in late spring. These surveys occurred while North and South arm fry populations were still segregated, so the surveys are intended to record fish distribution, abundance, and size information early in the growing season and as an index for both North and South arms. No trawling occurred in 2013 due to wide dispersal and low abundance of fry throughout the water column in the South Arm making trawling ineffective.

Fall sampling in 2013 included ten trawls in the North arm and nine trawls in the South arm catching a total of 796 kokanee and 1 pygmy whitefish. The South Arm catch included 130 fry and 1 age 1+. The North Arm catch included 641 fry, 18 age 1+, 3 age 2+, 3 age 3+ and 1 pygmy whitefish (Table 9, kokanee only).

Table 9. Kokanee catch statistics from spring and fall trawl surveys in 2013.

Survey time	**Section**	**Station**	**Hauls**	**age 0**	**age 1**	**age 2**	**age 3**	**Total**
Spring 2013	*No Trawling Conducted*							
Fall	North Arm	1 Johnson	3	54	3	0	0	57
Fall	North Arm	2 Shutty Bench	4	258	8	3	3	272
Fall	North Arm	4 Woodbury Cr	3	329	7	0	0	336
Fall	South Arm	5 Wilson Creek	3	41	0	0	0	41
Fall	South Arm	6 Rhino Point	3	71	1	0	0	72
Fall	South Arm	7 Redman Pt	3	18	0	0	0	18
Fall	North Arm	total	10	641	18	3	3	307
Fall	South Arm	total	9	130	1	0	0	152
Fall 2013	***Total lake***	***Total survey***	***19***	***771***	***19***	***3***	***3***	***796***
				97%	*2%*	*0.5%*	*0.5%*	*100%*

Length-at-age

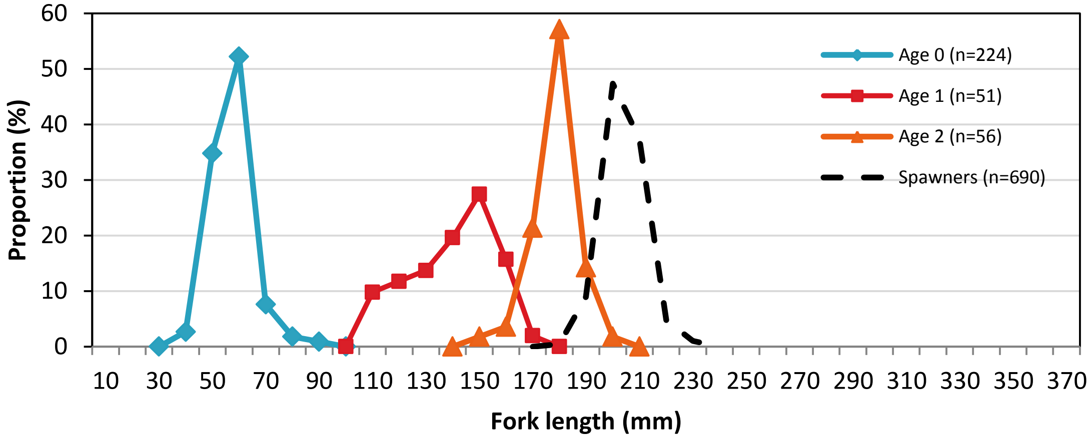
The lengths of trawl-caught fish and age composition (determined by a combination of scale aging and plotted length frequencies) provided age-specific length frequencies that were comparable among years (Fig. 74). Typically, there are separately observable modes which correspond to age classes, as was the case in 2011 (Fig. 74a), which can assist to verify the ageing of spawners and trawl captured fish. In 2013, similar to 2012, there was considerable overlap between the age 2 and 3+ (and 4+ in 2012) in-lake kokanee and with spawners. This may be due to variable growth and age at maturity in recent years, and the persistence of age 3 and 4+ fish holding over in-lake to spawn the following year. It should also be noted however that the sample size for the older age class fish has been low during the past two years which limits insight into length at age.

It is remarkable how widely spread the size distributions were between age 1+ and age 2+ in 2013, as there was a dramatic increase in size at age of 2+ and older fish and a decrease in size at age of 1+ fish. The age 1+ distribution was uni-modal in 2013, whereas typically they are clearly bi-modal as in 2012, or at least somewhat bi-modal as in 2011. In 2013, the fall trawl sampling produced mean length-at-age estimates of 57, 109, 246, and 262 mm for ages 0 - 3+ kokanee respectively (Table 10, Fig. 75). The mean length of spawners measured at Meadow Creek spawning channel was 273mm. Figure 75 illustrates the long term time-series for size at age from trawl caught kokanee and spawners. Age 2+ kokanee went from among the smallest on record in 2012 to the largest on record in 2013. While the sample size was exceptionally low at only 3 fish, the dramatic size increase does correspond with the increase in spawner size discussed previously. Age 1+ kokanee declined in size to the smallest on record, which is counter-intuitive given the expectation that growth should have increased under lower densities as it had for the older kokanee and spawners. We caution against using age 1+ growth as a metric of in-lake conditions though as historically there are often two size modes of 1+ fish and misrepresentation of either mode can skew the results.

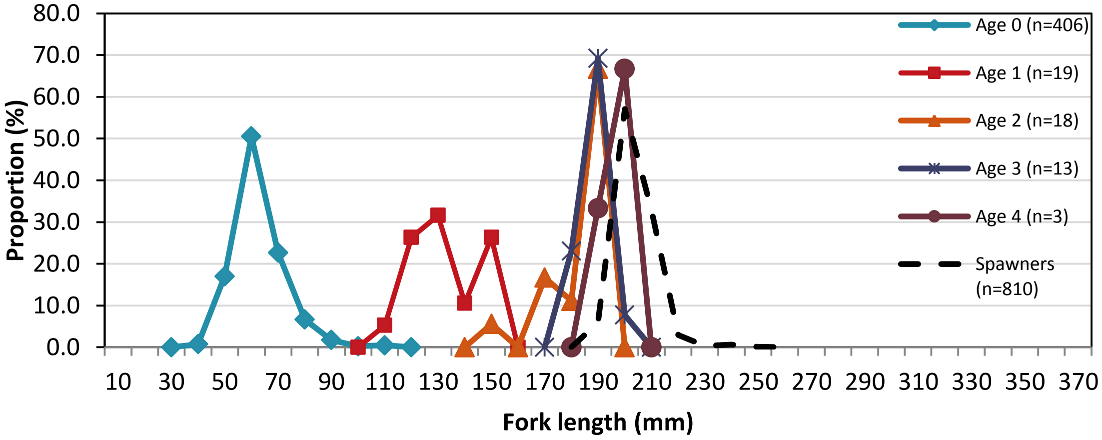
Table 10. Size statistics from trawl-captured kokanee during September survey in 2013 (No trawling occurred in spring 2013).

Survey time	**Basin**	**Station**	**age 0**	**age 1**	**age 2**	**age 3**
Sept 2013	North Arm	Avg. length (mm)	56	108	246	262
		Length range (mm)	38-85	90-126	231-256	239-276
		Standard deviation	9.3	9.3	13.4	20.3
		Sample size (n)	641	18	3	3
	South Arm	Avg. length (mm)	64	124	-	-
		Length range (mm)	47-88	-	-	-
		Standard deviation	7.7	-	-	-
		Sample size (n)	130	1	0	0
	Both Arms - total avg. length (mm)		*57*	*109*	*246*	*262*

a) 2011 trawl and spawners



b) 2012 trawl and spawners



c) 2013 trawl and spawners

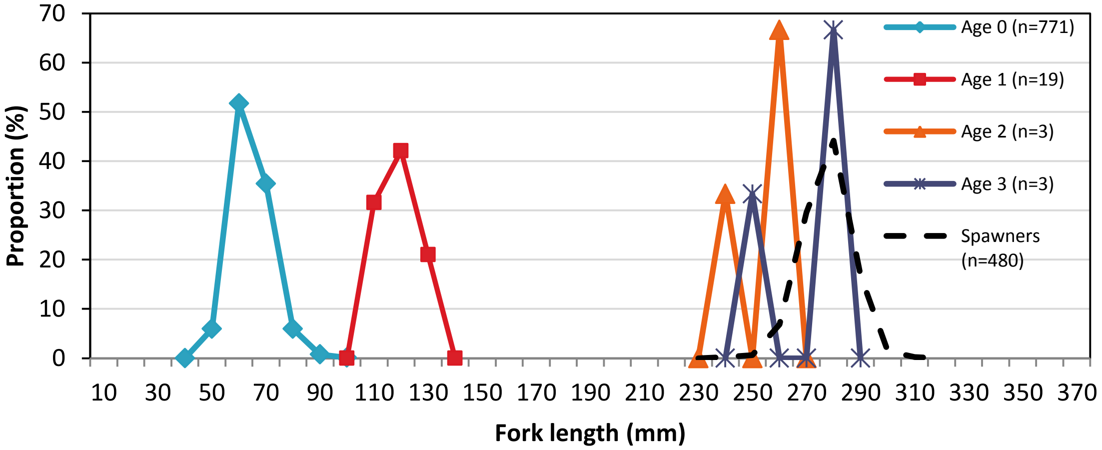


Figure 74. Kokanee length-frequency distribution by age from fall trawling in a) 2011 b) 2012, and c) 2013 and including spawner data from Meadow Creek.

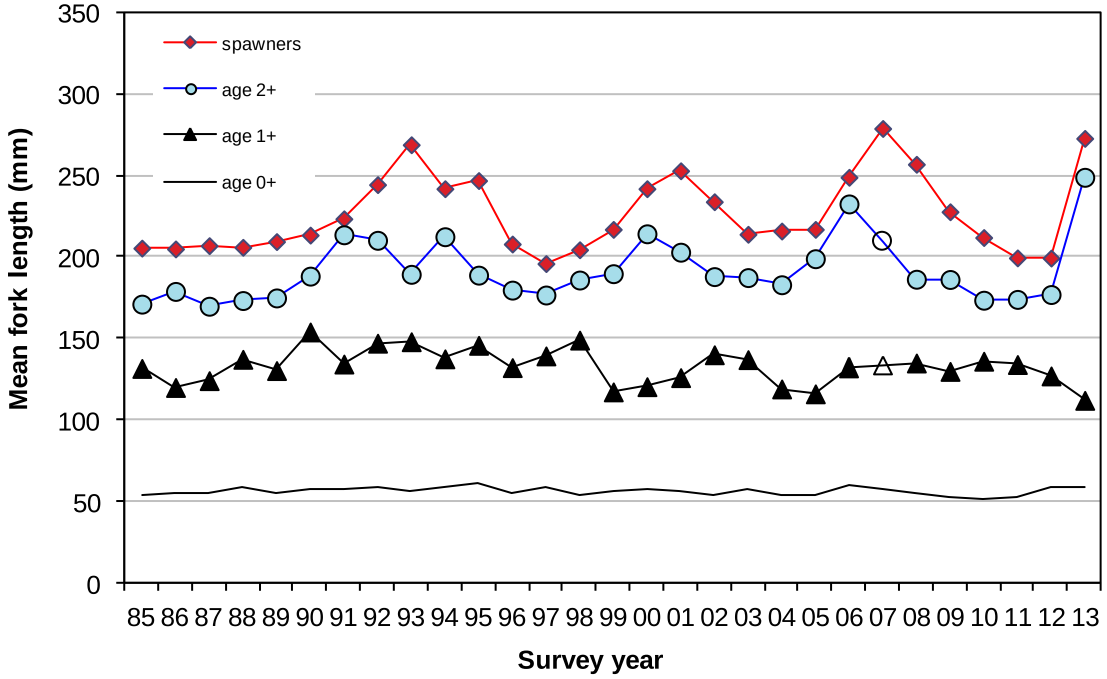


Figure 75. Trends in mean length-at-age for trawl-captured kokanee in Kootenay Lake, 1985–2013. Age 0, 1, and 2 kokanee lengths are adjusted to Oct 1st growth date. Length data for spawners were obtained from Meadow Creek kokanee. No trawling occurred in 2007. The average size of 2006 and 2008 age 0-2+ kokanee was used for 2007 data points (open symbols).

Trawl sampling coinciding with the spring/early summer acoustic surveys has not been conducted since 2011. Sample sizes during spring trawling have historically been low due to very low fry numbers in the South Arm (as indicated by spring acoustic surveys) and a fish layer that is not as well defined and vertically concentrated as it is in the fall. Limited trawl sampling time as a result of short nights and seasonal windy weather further exacerbates the issue. At the current low densities, we do not recommend that South Arm trawling effort be increased, as getting an adequate sample size would be time and cost prohibitive. Trawl data from the spring surveys from 2004-2011 were compared with that from fall surveys by Schindler et al. (2014). Trawl catch data were separated between North and South Arms and pooled due to low sample sizes by year in the spring. Although there is bias toward years of higher fry catch when pooling all years, the North and South Arms showed a distinct difference in fry-sized modes, suggesting that South Arm fry are larger.

Age-at-maturity

Kokanee in Meadow Creek usually mature after their third year (3+), as is common in many large-lake kokanee populations in BC. Remarkably, in 2013 the majority of kokanee aged from otoliths collected during the spawner return (n=30) were 4+ fish with only two kokanee at age 3+ and two at 5+. Otolith interpretations and a single mode of lengths from 440 un-aged spawners indicated a shift in dominant age-at-maturity to 4+ for the 2013 Meadow Creek escapement (Fig. 76). This is consistent with the hypothesis that reductions in growth rates in successive cohorts induce a shift to older age at maturity (Grover, 2005). Patterson et al. (2008) suggest maturation in kokanee begins from 10-16 months prior to spawning and that attaining a size threshold of 180-190 mm during fall was a good predictor of maturation the following year. The delayed maturation to 4+ of 2013 spawners in Kootenay Lake can be traced to the very small average size of age 2+ fish in 2011, which averaged only 174 mm by fall. It appears that while the majority of this cohort spawned as 3+ in 2012, a substantial component did not achieve the threshold size to begin maturation until they were age 3+ (i.e. fall of 2012) which delayed spawning until age 4+ (i.e., in 2013). The abundant 2010 fry cohort were also very small (177mm average) as age 2+ in the fall of 2012. Their small average size may have resulted in delayed maturation as they did not return in substantial numbers as 3+ in 2013, only making up ~7% of the return. This same scenario occurred in Arrow Lakes in 2013, where exceptionally small age 2+ fish (176mm and 173mm in Upper and Lower Arrow respectively by fall 2011) failed to spawn as age 3+ and the spawner age at maturity shifted to age 4+ in 2013 (Bassett et. al. 2015).

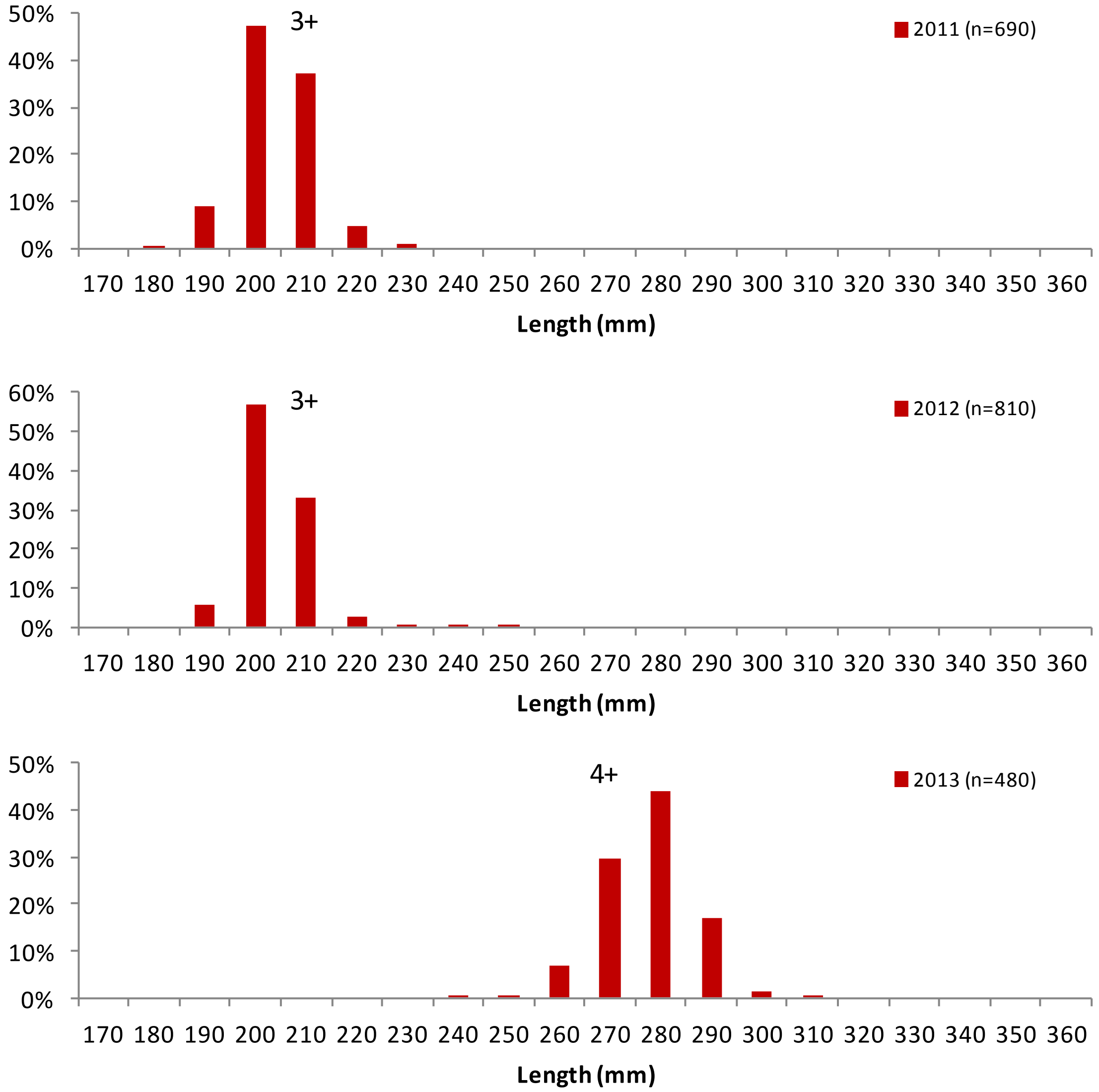


Figure 76. Percent length frequency of kokanee spawners returning to Meadow Creek from 2011–2013.

Hydroacoustic abundance estimates and trends

Hydroacoustic and trawl surveys of the limnetic zone have been conducted using standard methods since 1991, and comparable manual echo counts date back to 1985. These hydroacoustic and trawl survey data provide evidence of the positive impact of lake fertilization on the kokanee population in Kootenay Lake. In the late 1980s and early 1990s, prior to lake fertilization, fall surveys indicated 6–13 million kokanee in the lake (Fig. 77). By 1994, two years after the start of lake fertilization, the population reached 35 million kokanee. This increase was mainly due to rapid population growth at the onset of fertilization (i.e., a classic density-growth response to more favourable in-lake conditions), which resulted in a peak of both fecundity and total egg deposition at Meadow Creek in 1993 (Appendix 8; Figs. 70 & 72). The population fluctuated below that peak until 2009 but remained larger than in the pre-fertilization period.

In 2009 and 2010, the population was the largest since fertilization began (2009=47.1 million, 2010=37.8 million) as a result of strong escapements and fecund spawners from 2007–2009. Hydroacoustic abundance estimates of kokanee decreased substantially in 2011 and 2012 to a total kokanee population of 22.8 and 15.6 million respectively. Total kokanee abundance increased marginally to 18.0 million (16.0–20.0) in 2013 due to an increase in fry numbers.

Until 2009, the post fertilization average fall abundance of ages 1-3+ was 6.2 million with a peak of 11.6 million in 1996 (Fig. 78). The 2009 estimate of 15.9 million 1-3+ was 37% higher than the 1996 peak abundance. Remarkably, the 2010 age 1-3+ population estimate was similarly high at 15.4 million. The dramatic increase in 1-3+ abundance in 2009 and 2010 suggests excellent survival among all ages during this period, but in particular from 2008 fry to 2009 age 1+. In 2011 the age 1-3+ population decreased by ~50% to 7.6 million, and then declined further in 2012 to only 2.4 million. This rapid decline signaled a sharp reversal in survival, in particular for fry to age 1+, given that the age 0+ populations remained relatively high (in particular 2010 fry). The age 1-3+ estimate for 2013 declined further to 1.1 million, the lowest recorded population for these age classes since the nutrient restoration program began. Complete fall kokanee density and abundance statistics are provided in Appendices 5, 6, and 7.

The Meadow Creek spawning channel produces most of the fry for Kootenay Lake, and accordingly there is a strong relationship between spring fry production at Meadow Creek and the fall acoustic in-lake fry estimate (R^2=0.84) (Fig. 79). This relationship suggests that fry survival rates over the summer period have been relatively consistent from year to year (1990–2013), although two years (2000 and 2005) were considered outliers and not included in the regression model due to abnormally poor survival during the summer.

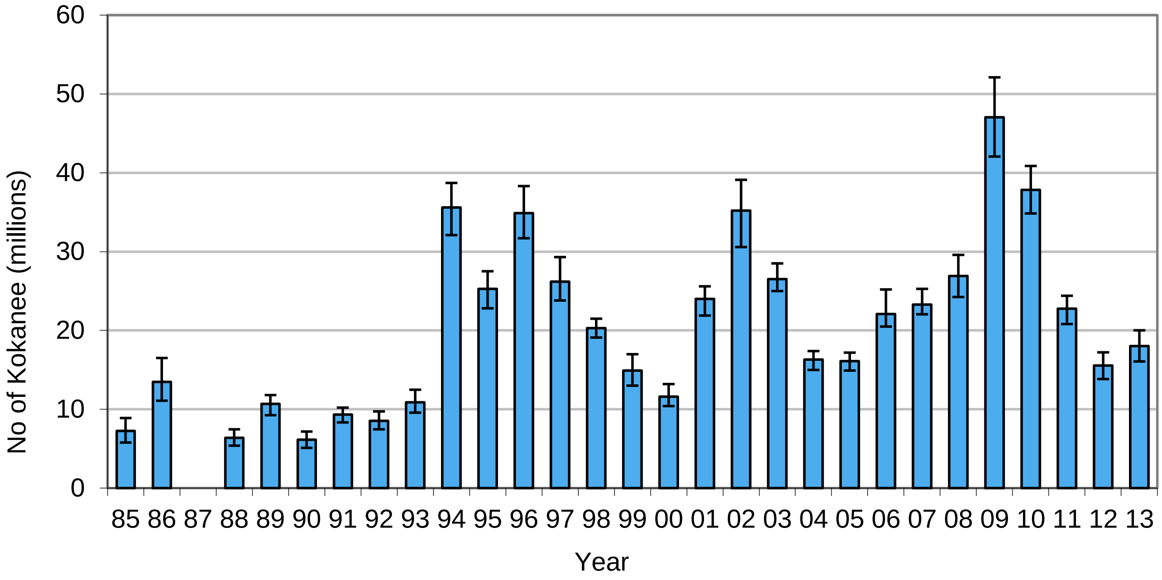


Figure 77. Kootenay Lake kokanee abundance (all ages) based on fall hydroacoustic surveys.

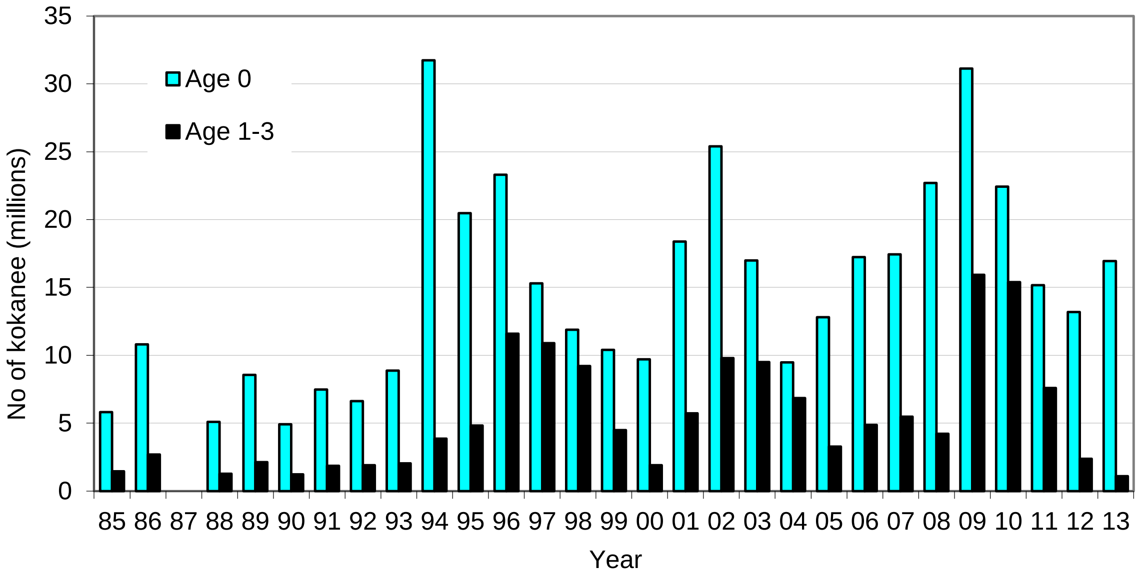


Figure 78. Kootenay Lake age 0+ and ages 1-3+ kokanee abundances based on fall hydroacoustic surveys.

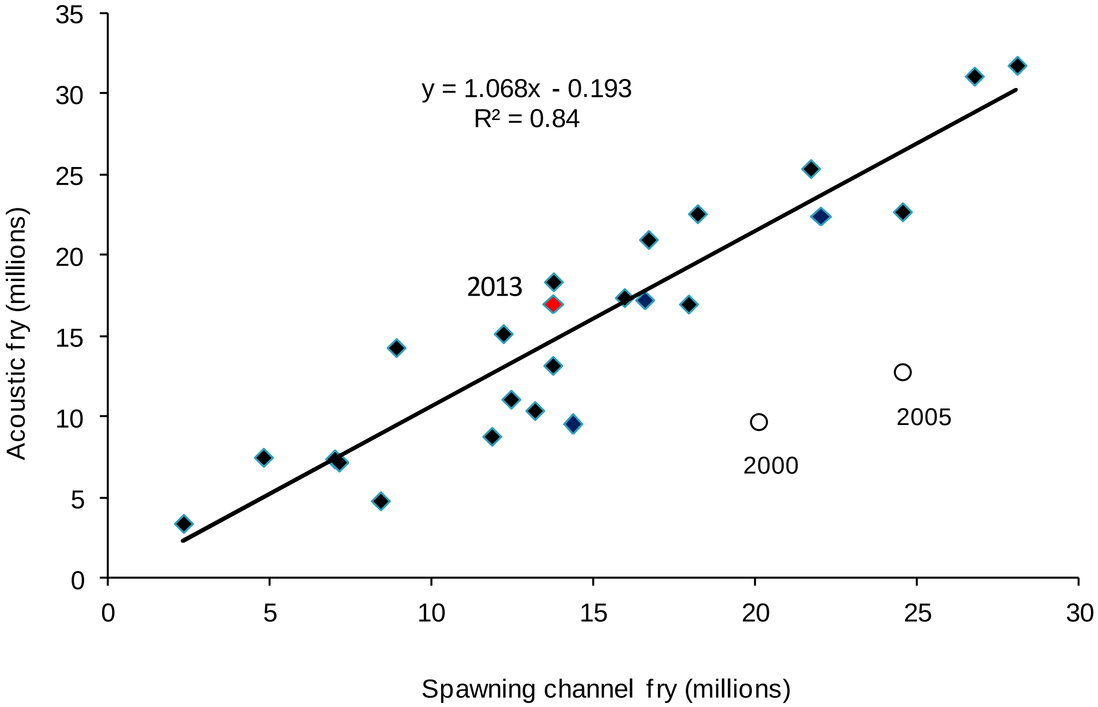


Figure 79. Relationship between kokanee fry produced from the Meadow Creek spawning channel and estimated fry from fall hydroacoustic surveys (1988–2013). Note: Years 2000 and 2005 removed, as considered outliers.

South Arm fry population

The late spring/early summer hydroacoustic surveys were initiated primarily to estimate fry abundance originating from South Arm spawning streams prior to the fry mixing with North Arm fish. Over the last ten years, early season South Arm fry estimates have ranged from 1.4–6.5 million (Table 11) with 2009–2011 being far higher than previous years, similar to the trend of increased abundance noted for the North Arm. Statistical bounds on the South Arm estimates are fairly wide, particularly in 2004, due to low densities, patchy distribution, and few survey transects (n=8) in the South Arm.

Table 11. Early summer fry estimates for the South Arm of Kootenay Lake during the South Arm nutrient addition period, 2004-2013.

Year	Survey dates	Fry MLE[1] (95% CI) (millions)
2004	June 13-16	3.85 (0.76 – 6.75)
2005	July 8-10	1.41 (0.90 – 1.95)
2006	June 26-28	2.39 (0.67 – 3.98)
2007	July 4-7	3.12 (1.61 – 4.49)
2008	July 5-6	2.37 (0.84 – 3.92)
2009	June 26-28	6.42 (4.89 – 8.08)
2010	July 12-15	5.42 (4.45 – 6.74)
2011	July 5-8	6.49 (5.48 – 7.49)
2012	July 17-20	3.11 (2.53 – 3.68)
2013	July 6-8	3.33 (2.68 – 4.07)

[1] MLE = maximum likelihood estimate

Early season kokanee abundance in the South Arm is higher than would be expected solely from the egg plants, suggesting there must be other significant sources of fry production (assuming the North Arm fry have not yet dispersed into the South Arm). In 2009 and to a lesser degree in 2010, the data indicated relatively large numbers of kokanee fry at transects #17 and #18 in early season sampling (Schindler et al. 2013). Based on the time of year and location, these fish were most likely of southern BC tributary or Idaho origin, including any kokanee that were entrained from Kookanusa Reservoir. The South Arm fry population distribution in July 2013 was spread fairly evenly across transects (Fig. 80), similar to the previous 2 years.

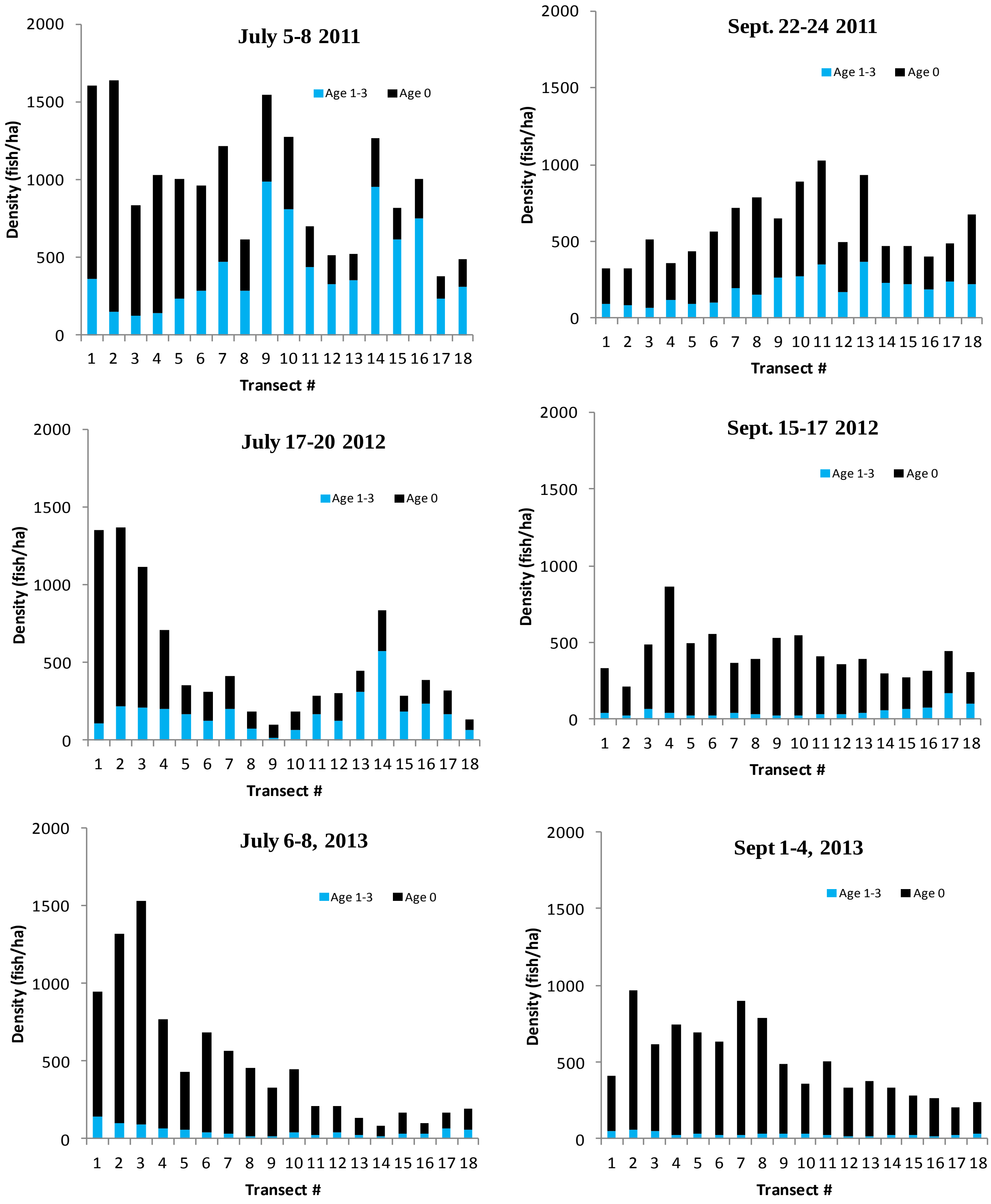


Figure 80. Longitudinal density distributions for age 0+ and ages 1-3+ kokanee in Kootenay Lake during July and September 2011-2013. Note: Transects are in order from North to South with #1–10 representing the North Arm and #11–18 representing the South Arm.

In-lake distribution

Comparisons of the two hydroacoustic surveys conducted each year indicate changes in the seasonal longitudinal distribution of kokanee in response to lake fertilization. In early summer, fry have typically been highly skewed to the north end of the lake, since most kokanee production is from Meadow Creek and the Lardeau River. By the end of summer, the fry tend to disperse more evenly throughout the lake, as illustrated by comparing July and September fry distributions for all years except 2005 (Schindler et al. 2013). The 2013 longitudinal fry distribution followed a similar pattern of southward movement over the summer, demonstrated by a more even distribution throughout the lake by fall, although dispersal of fish to the South Arm wasn't as pronounced as other years (Fig. 80).

Unlike fry, age 1-3+ distributions are not expected to be affected by proximity to spawning areas in early season sampling, nor in late season sampling which occurs after mature fish have left to spawn. In order to investigate if the onset of South Arm fertilization may have affected distribution patterns through spatial changes to lower trophic level productivity, fall age 1-3+ transect densities were averaged by arm and compared before and after 2004. No noticeable pattern was observed, with densities higher in the South Arm 58% the years prior to South Arm fertilization (1992-2003), and 50% of years since (2004-13). North Arm densities were higher 33% of years prior to South Arm fertilization and 30% of years since, and the remaining years were approximately even. In 2013, average age 1-3+ transect densities were higher in the North Arm during both the spring and fall surveys, in contrast to 2011 and 2012 when densities were higher in the South Arm during both spring and fall surveys (Fig 80). Age 1-3+ kokanee were concentrated towards the north end of the North Arm in the spring, and by fall were spread more evenly although the highest densities were still found at the top of the North Arm.

Kokanee biomass estimates

The in-lake kokanee biomass in Kootenay Lake was estimated using mean weights and abundances of all age groups present determined from trawl and hydroacoustic surveys (see Appendix 56 for details). Prior to nutrient additions to the North Arm (1985–1991), the average kokanee biomass in Kootenay Lake was about 3.5 kg/ha (not including spawners). With nutrient additions (1992–2013), the biomass of in-lake kokanee has increased almost threefold to an average of 10.0 kg/ha (Fig. 81; Appendix 7b). In 2010, the in-lake biomass reached a peak of 18.5 kg/ha before declining to near pre-fertilization levels of only 3.1 kg/ha in 2013 due to the very low abundance of age 1-3+, and a high proportion of small size age 1+ as determined by trawl sampling.

Spawner biomass was calculated by applying average weights from fish in Meadow Creek spawning channel to the combined escapement estimate from Meadow Creek and Lardeau River. Due to the strong in-lake biomass in 2010, which was attributed to the abundant age 2+ kokanee, the spawner biomass increased from 2.0 kg/ha in 2010 to 3.6 kg/ha in 2011. Escapements in 2012 consisted of less abundant but similar-sized fish to 2011, resulting in a drop in spawner biomass to 2.5 kg/ha, which was lower than the post-fertilization average of

3.4 kg/ha but still above the pre-fertilization average of 1.8 kg/ha. In 2013, the number of spawning kokanee decreased from the previous year but the size increased resulting in an increase of biomass to 2.9 kg/ha (Appendix 7c).

As fall acoustic surveys occur once spawners have left the lake, the in-lake and spawner biomass were summed to estimate a total kokanee biomass in Kootenay Lake of 6.0 kg/ha in 2013, down from 6.9 kg/ha in 2012 and far below the peak of 20.8 kg/ha in 2009. The before- and after-treatment average total biomass was estimated at 5.3 and 13.4 kg/ha, respectively.

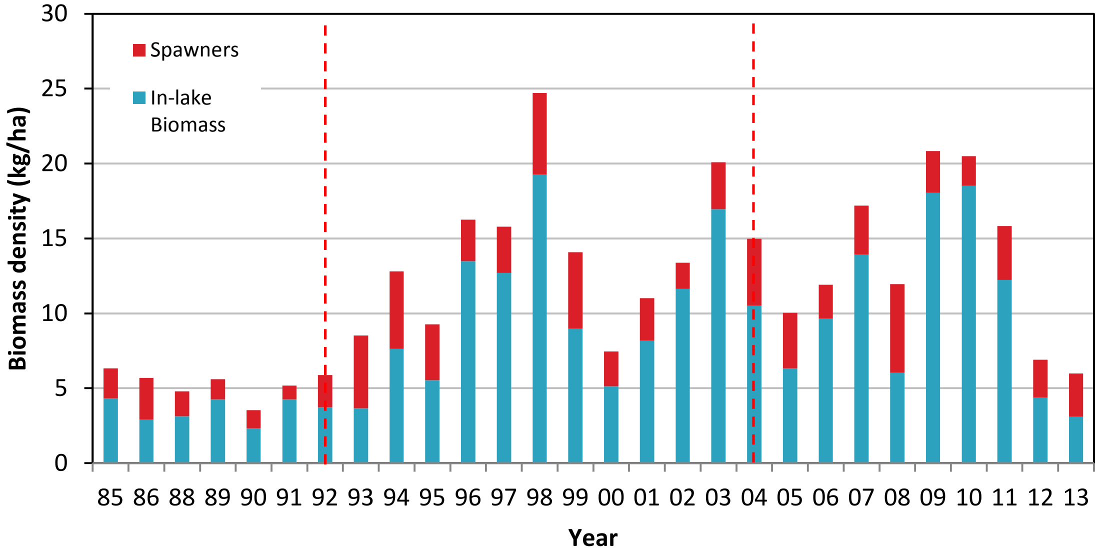


Figure 81. Trends in biomass (kg/ha) for Kootenay Lake based on acoustic and trawl surveys, 1985–2013. The dotted lines indicate the start of nutrient additions to the North Arm in 1992 and South Arm in 2004.

Fry-to-adult survival rates

Two separate estimates of fry to adult survival have been calculated and presented using the Meadow Creek long-term data set for total fry production and adults returning. As age at maturity has historically been dominant age 3+, calculation of fry to adult survival previously reported on has assumed age 3+ at return all years. We continued applying this assumption in calculating the survival trend presented as ‘assumes 3+ spawners’ in Figure 82.

However, given the shift to age 4+ spawners in 2013, we have also calculated and presented fry to adult survival for each fry cohort based on adult return age proportions from otolith analysis. This method combines all retuning spawners, from age 2-5+, for each fry year presented, and is presented as ‘corrected to age at return’ in Figure 82.

The post fertilization average was the same for both methods of calculating survival at ~4.1%. The survival rate trends of both calculation methods are remarkable similar (Figure 82), suggesting that the previously standard method, which assumes age 3+ at maturity, was adequate although clearly the estimate for 2009 fry using this method is not reliable given the shift to age 4+ spawners in 2013. The fry to adult survival, corrected for age at return, for the 2009 fry cohort was below average at 3.34%, and declined from the above average estimate for the 2008 fry year of 5.14%. The 2010 fry survival rates were not presented in Figure 82 due to the assumption that a sizeable component of this cohort is still expected to return as age 4+ in 2014. However, it is expected that there will be a sharp decrease in survival for 2010 fry given the strong cohort size (22.5 million fry) and the very low numbers that returned as age 3+ to date (~13,500).

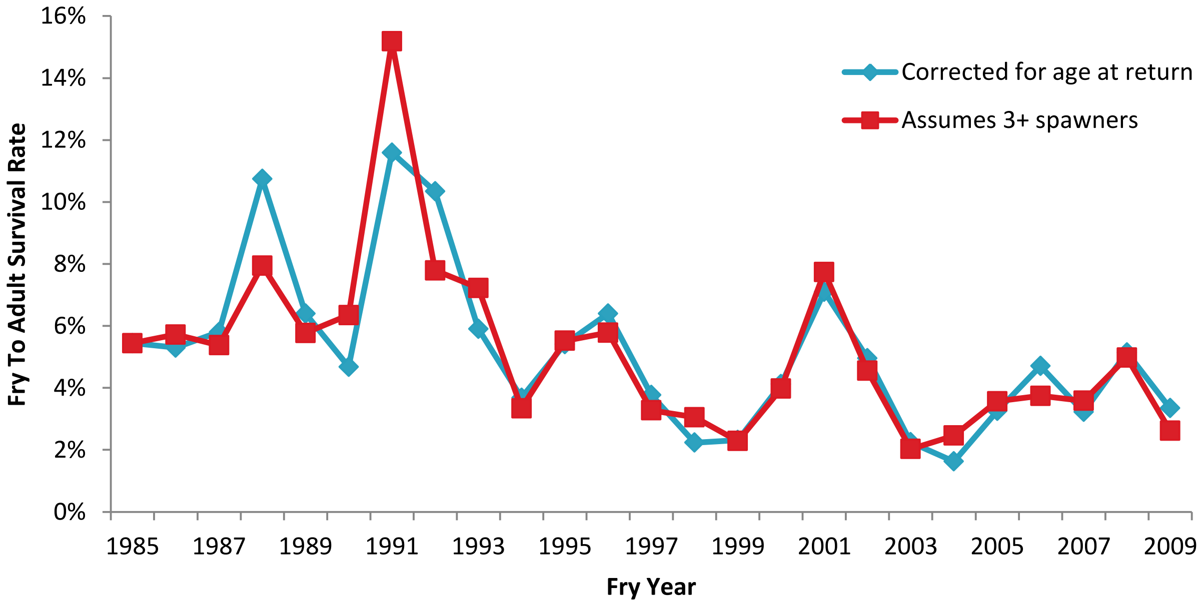


Figure 82. Meadow Creek Kokanee fry-to-adult survival rate by fry year.

Kokanee/predator relationship

Piscivory is known to have top-down effects on prey fish populations, including fish communities where kokanee act as the main prey source of larger predators (Baldwin and Polacek 2002, Beauchamp et al. 1995). Accordingly, it is likely that the Gerrard rainbow trout, bull trout, and other piscivores have a pronounced effect on the kokanee population in Kootenay Lake. The peak Gerrard spawner count, an index of predator abundance, increased remarkably reaching a record high of 1068 in 2012 (Fig. 83). The Gerrard peak spawner count of 750 in 2013 remained well above the post fertilization average of 461 fish and was also higher than any other return prior to 2010.

Figure 84 compares the Gerrard population index with kokanee biomass and illustrates how the dramatic increase in Gerrards follows the peak in kokanee biomass in the years 2009 and 2010, allowing for a one- or two-year lag. Notably, the unprecedented Gerrard counts in 2011 and 2012 assumedly contributed substantially to the dramatic decline in kokanee biomass in 2012 and 2013. The next few years are expected to provide greater insight to the kokanee/predator relationship and how the low kokanee densities will impact the condition and survival of predators.

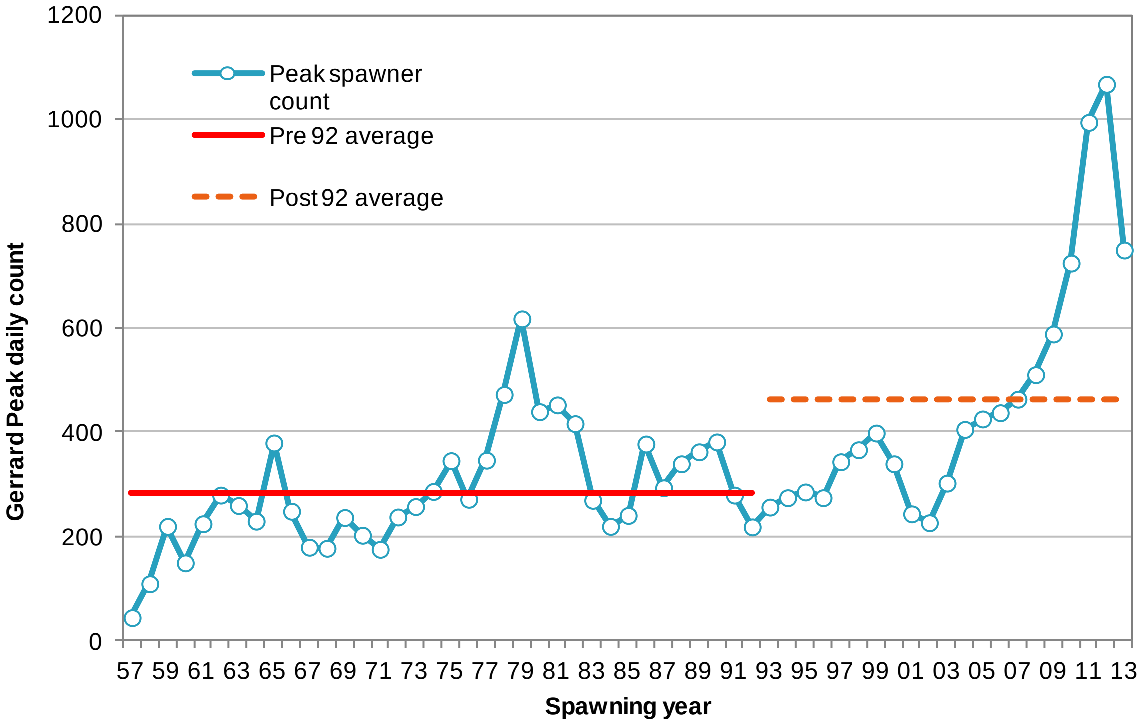


Figure 83. Trends in Gerrard rainbow trout peak spawner numbers during 1957–2013. The solid horizontal line represents the average of 284 from 1957–1992 (pre-fertilization), and the dashed line represents the average of 461 from 1993–2013 (post-fertilization, North Arm). Note: 2004 was the onset of the South Arm fertilization program.

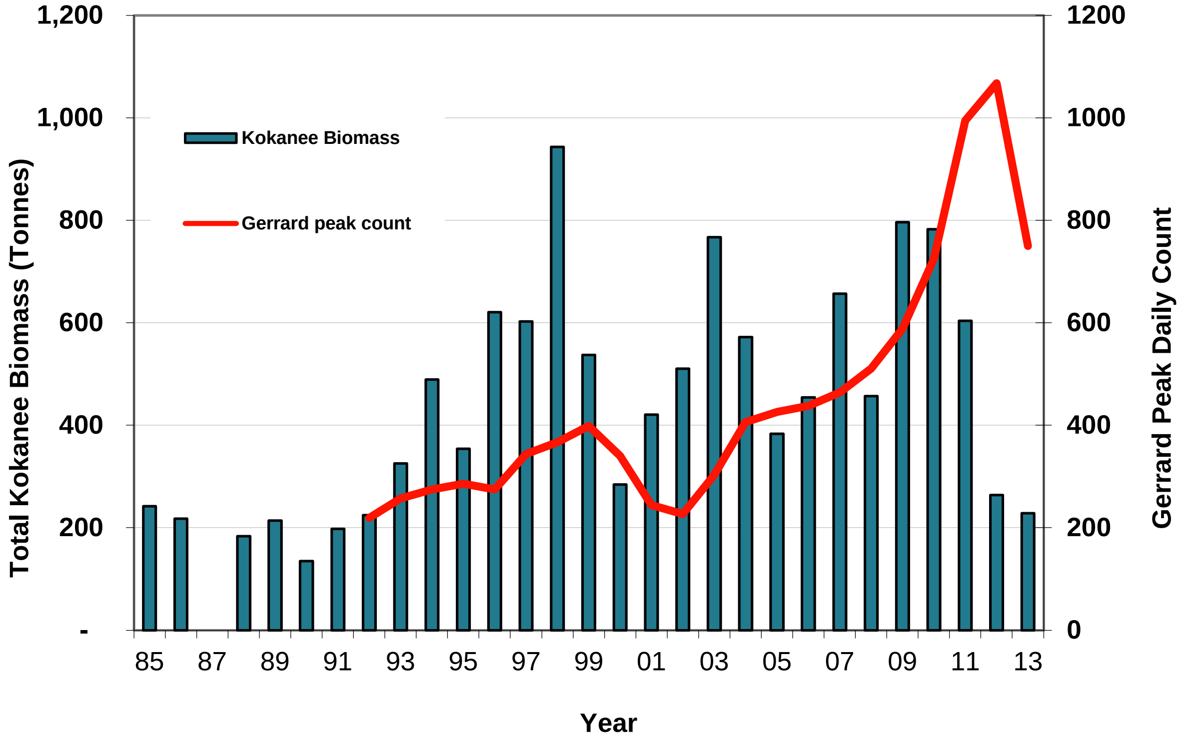


Figure 84. Comparison of trends in total kokanee biomass (kg/ha) in Kootenay Lake with peak spawner counts for rainbow trout in Lardeau River at Gerrard, 1992-2013.

Kokanee Summary

In the late 2000's peaks in both spawner size (2006-08) and abundance of kokanee (2008-10) occurred due to a combination of favourable survival and growth conditions, likely enhanced by the onset of South Arm fertilization at a time when abundance of kokanee was low in 2004. This peak in kokanee abundance coincided with three years of channel fry production in excess of 20 million, which remarkably sustained exceptional survival rates to older age classes, in particular the 2008 and 2009 fry years. Coinciding with this period, the Gerrard rainbow trout numbers were building, yet survival was excellent to older age classes. This lead to two consecutive years (2009 and 2010) of the highest age 1-3+ populations ever recorded (>15 million vs previous peaks of 10-12 million). At this point, a density dependent growth response resulted in kokanee size declining rapidly; age 2+ and spawner size declined to among the smallest on record during 2010-12. The extent to which size declined, and the shift in age at maturity to predominantly age 4+ in 2013 (and possibly 2014), is unprecedented in the time series, and is a sign that capacity may have been exceeded at some point in the life cycle of the 2009 and possibly 2010 fry cohorts.

Following the peak in 2010, kokanee survival decreased and the population began to decline sharply, as has been the case after each previous peak in abundance in the time-series. This decline coincided with back to back years with abnormally cold and wet spring seasons. In 2011, seasonal spring air temperature was the lowest since the onset of fertilization in 1992 (Fig. 6). Summer improved slightly yet remained below average, and fall temperatures were again well below average. These low air (and accordingly water) temperatures assumedly contributed to poor zooplankton production suggested by the low 2011 *Daphnia* abundance (Fig. 52). In 2012, spring air temperatures were again well below average and among the coldest since fertilization (Fig. 6). The spring of 2012 was exceptionally wet (Fig. 7), and June precipitation was highest over the 1992-2014 time period (data not shown). Kokanee productivity and survival declined severely in nearby Arrow Reservoir during this time as well (Bassett et al. 2015). Dramatic declines in kokanee abundance were observed in Kinbasket and Revelstoke reservoirs in 2011 and 2012 (Sebastian and Weir 2013) and Okanagan Lake spawner returns and in-lake abundance/biomass declined in 2012 (MFLNRO data on file). These systems are all remarkably different from each other and Kootenay Lake in many ways (e.g. relative predator abundance), which suggests that perhaps regional climatic driver(s) were unfavourable to kokanee production/survival in 2011 and 2012.

The dramatic decline of age 1-3+ numbers in Kootenay Lake by 2012 was not entirely unexpected given the extent of the recent peak and likelihood that climatic drivers negatively affected kokanee productivity. In 2013, the kokanee population increased marginally due to an increase in fry numbers but 1-3+ and spawner numbers continued to decline. Size at age of adult kokanee increased substantially, with the exception of 1+ kokanee, but not enough to increase biomass by offsetting the decreasing numbers. The increased fecundity of the larger spawners did not offset the decline in the number of spawners and egg deposition decreased from 2012.

Part of the decline in spawner numbers may be attributed to a delay in age at maturation from 3+ to 4+ exhibited by some kokanee resulting in the 2009 fry cohort contributing the majority of spawners over two different years (2012 and 2013). The 2010 fry year had not contributed spawners to any sizeable degree as of 2013. It is likely that the main cause for the delay in maturation to 4+ is the small size-at-age of this cohort in its early years (Patterson et al. 2008). The slow growth during early life followed by very good growth in the year or two prior to spawning may have contributed to a lower average fecundity for their average size (relative fecundity), being that fecundity is determined during early stages of oogenesis (Campbell et al. 2006). The abundant 2010 fry cohort were still very small as age 2+ in the fall of 2012, so are expected to return as age 4+ in 2014, and the lack of age 3+ spawners from this cohort in 2013 suggests this may be the case.

The failure of kokanee survival to improve in 2013 regardless of low densities, adequate zooplankton resources, and normal climatic conditions is somewhat unusual. The exceptionally high number of Gerrard rainbow trout, and bull trout numbers (Andrusak, 2014), in recent years have undoubtedly exerted substantial grazing pressure on kokanee. The current imbalance between predator and prey evident in figure 84 is a major cause for concern and a reduction in predator numbers either through natural processes or harvest is likely required before kokanee survival improves and abundance increases to normal levels.

Recommendations

1) Review fry production targets given recent evidence that the lake may have been pushed beyond capacity after consecutive years of very high fry production. The extent to which this drives extreme fluctuations in the kokanee population and whether that is desirable should be considered.
2) Continue egg plants in South Arm tributaries when possible except discontinue egg plants in Boulder creek. Also, monitor Boundary Creek for escapement and discontinue egg plants if no response is seen in the next couple of years. Since egg plants were postponed due to IHN at Meadow Creek there may be an opportunity to evaluate egg plant success, as there will be at least two years without any egg plants in the southern tributaries.
3) Calculating survival from planted egg to adult as an evaluation of the egg plant program, especially with the recent shift of age at maturity noted in Meadow creek fish, would require otolith collection for aging data. If spawner returns become substantial enough to collect a reasonable sample size (preferably from carcasses) this option should be considered, although at this time it does not appear to be possible.
4) Investigate piscivore (Gerrard rainbow trout, bull trout, sturgeon, and burbot) dynamics and how they may be affecting growth and survival in the kokanee population. Consider options to promote recovery of the kokanee population given evidence that survival is not increasing at current low densities while piscivore numbers remain high.

SUMMARY

In the North Arm, the total weight of fertilizer applied in 2013 was 33 tonnes of phosphorus and 208 tonnes of nitrogen. In the South Arm, 258 tonnes of nitrogen were added. An adaptive management strategy was taken, where weekly loading was adjusted based on physical limnology, water chemistry and phytoplankton results to achieve optimal algal production to move up the food chain to *Daphnia*.

Total dissolved phosphorus ranged from below the reportable detection limit (2 µg/L) to 6.8 µg/L. Dissolved inorganic nitrogen collected from epilimnetic integrated samples ranged from 42.7 µg/L to 172.1 µg/L and reached nadir in the summer, this seasonal trend corresponds with phytoplankton uptake and use during summer stratification. The annual mean of total phosphorus (4.99 µg/L) increased marginally from the previous year, and was not significantly different than the 1992-2012 pooled average of 4.87 µg/L.

Total nitrogen in 2013 (193 µg/L) was significantly higher than the 1992–2012 mean (180 µg/L) (Fig. 17). Dissolved inorganic nitrogen (DIN) in 2013 (114 µg/L) was slightly lower than in 2012 but not significantly different from the 1992-2012 pooled mean of 88 µg/L. The seasonal trend of DIN was typical of previous years where high spring values were followed by a summer decrease and a slight rebound in the fall.

Abundance and biomass of phytoplankton in integrated epilimnetic samples was dominated by chryso-cryptophytes and bacillariophytes. Chryso-cryptophytes were highest in the late spring and early summer, whereas bacillariophyte abundance peaked in the summer. The trend of decreased chryso-cryptophytes into the summer coincided with increased zooplankton, suggesting grazing on phytoplankton.

Zooplankton density in 2013 was significantly higher than the pre and post nutrient addition long-term averages. Copepods were the main contributor to the overall zooplankton population in the spring, while cladocerans, particularly *Daphnia* sp. appearing in August, peaking in September, and maintaining a population through November. *Daphnia* biomass was significantly higher than in previous years, particularly in the North Arm.

Mysis diluviana annual biomass was below the pre and post nutrient addition long-term averages. Average biomass was higher in the South Arm than the North Arm in deep sites and immature and mature developmental stages contributed the most to overall biomass.

In 2013, the kokanee population increased marginally from 2012 due to an increase in fry numbers but 1-3+ and spawner numbers continued to decline. After a few years of close to average fry production but a population decreasing to well below average, indicates a period of poor survival and low recruitment into the adult age classes.

Size at age of adult kokanee increased substantially, with the exception of 1+ kokanee, but not enough to offset the decreasing numbers resulting in a decrease in biomass similar to pre-nutrient restoration levels. The increased fecundity of the larger spawners did not offset the decline in the number of spawners and egg deposition decreased from 2012. It is important to note that age of maturity, normally 3+, changed to 4+ in 2013, therefore the spawner return in 2013 is a small remnant of the same cohort as the spawners from 2012.

The failure of kokanee survival to improve in 2013 regardless of low kokanee densities, adequate zooplankton resources, and normal climatic conditions is somewhat unusual. The exceptionally high Gerrard rainbow trout, and bull trout numbers (Andrusak, 2014), in recent years have undoubtedly exerted substantial grazing pressure on kokanee. The imbalance between predator and prey needs to be addressed. A reduction in predator numbers either through natural processes, or increased harvest is likely required before kokanee survival improves and abundance increases to the nutrient restoration program average.

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APPENDICES

Appendix 1. Kootenay Lake participants, activities, and affiliation for 2013 studies.

Contribution	Personnel	Affiliation
Project co-ordination, management and scientific liaison	Eva Schindler	Resource Management, MoFLNRO[1], Nelson
Report compilation	Eva Schindler Marley Bassett	Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson
Report review	Dale Sebastian Ken Ashley	British Columbia Conservation Foundation B C Institute of Technology Rivers Institute
Fertilizer schedule, loading	Eva Schindler Ken Ashley Wilf Doering	Resource Management, MoFLNRO, Nelson B C Institute of Technology Rivers Institute Agrium, Kamloops
Fertilizer application	Western Pacific Marine Eva Schindler Gary Munro Les Fleck	Western Pacific Marine, Balfour Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson Crystal Springs Contracting
Physical limnology, water chemistry, phytoplankton, zooplankton, mysid sampling	Don Miller and staff Eva Schindler Marley Bassett Albert Chirico Tom Roos Dave Heagy Chris Price	Kootenay Wildlife Services Ltd. Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson Environmental Sustainability Division, MoE[2], Nelson BC Parks, MoE BC Parks, MoE BC Parks, MoE
Physical limnology, water sampling data analysis and reporting	Eva Schindler Marley Bassett	Resource Management, MoFLNRO, Nelson
Primary production sampling	Shannon Harris Allison Hebert Petra Wypkiss Eva Schindler Les Fleck Greg Andrusak	Environmental Sustainability Division, MoE, Vancouver Environmental Sustainability Division, MoE, Vancouver British Columbia Conservation Foundation Resource Management, MoFLNRO, Nelson Crystal Springs Consulting Redfish Consulting Ltd.
Primary productivity analysis and reporting	Shannon Harris	Environmental Sustainability Division, MoE, Vancouver
Chlorophyll *a* analysis	Allison Hebert Shannon Harris Petra Wykpiss	Environmental Sustainability Division, MoE, Vancouver Environmental Sustainability Division, MoE, Vancouver British Columbia Conservation Foundation
Phytoplankton sample analysis	Dr. John Stockner	Eco-Logic Ltd.
Zooplankton and mysid sample analysis and reporting	Dr. Lidija Vidmanic	Limno-Lab Ltd.
Kokanee acoustic sampling	Tyler Weir David Johner	Fish and Wildlife, MoFLNRO, Victoria Fish and Wildlife, MoFLNRO, Victoria

Kokanee trawling	Don Miller and staff	Kootenay Wildlife Services Ltd.
Kokanee analysis and reporting	Tyler Weir David Johner Dale Sebastian	Fish and Wildlife, MoFLNRO, Victoria Fish and Wildlife, MoFLNRO, Victoria British Columbia Conservation Foundation
South Arm tributary adult kokanee enumeration	Les Fleck Gary Munro Eva Schindler Marley Bassett Albert Chirico	Crystal Springs Contracting Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson Environmental Sustainability Division, MoE, Nelson
Kokanee hydroacoustics and analysis	Tyler Weir David Johner Dale Sebastian	Fish and Wildlife, MoFLNRO, Victoria Fish and Wildlife, MoFLNRO, Victoria British Columbia Conservation Foundation
Meadow Creek Spawning Channel operation and support	Murray Pearson Matt Neufeld	Resource Management, MoFLNRO, Nelson
Kokanee otolith analyses	Carol Lidstone	Birkenhead Scale Analyses
Kokanee scale analyses	Bob Land Andrew Schellenberg	Environmental Sustainability Division, MoE, Vancouver
Gerrard spawner enumeration and support	Jessica Spencer Matt Neufeld Jeff Burrows	Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson
Regional support	Jeff Burrows	Resource Management, MoFLNRO, Nelson
FWCP Technical Committee	Jeff Burrows Tyler Weir Alf Leake James Crossman	Resource Management, MoFLNRO, Nelson Fish and Wildlife, MoFLNRO, Victoria BC Hydro, Vancouver BC Hydro, Castlegar
FWCP Board	Paul Rasmussen David Tesch Patrice Rother Doug Johnson Rick Morley Grant Trower Dave White Joe Nicholas James Pepper	Resource Management, MoFLNRO, Nelson Environmental Sustainability Division, MoE, Victoria BC Hydro, Vancouver BC Hydro, Castlegar Public Representative Public Representative Public Representative First Nations Representative First Nations Representative
FWCP Policy Committee	Marc Zacharias Rebecca Reid Edi Thome	MoE, Victoria Fisheries and Oceans Canada BC Hydro, Burnaby
Administration	Trevor Oussoren Lorraine Ens Eva Schindler Sue Ireland Charlie Holderman Barb Waters Anne Reichert Julie Lawrence Elaine Perepolkin Disa Westerhaug	FWCP[3] FWCP MoFLNRO Kootenai Tribe of Idaho Kootenai Tribe of Idaho British Columbia Conservation Foundation Regional Program and Administrative Support, MoE, Nelson Corporate Services Branch, MoFLNRO, Nelson

[1] Ministry of Forests, Lands and Natural Resource Operations
[2] Ministry of Environment
[3] Fish and Wildlife Compensation Program

Appendix 2. Sampling activities – Kootenay Lake, 2013.

Parameter sampled	**Sampling frequency**	**Locations**	**Sampling technique**
Temperature, dissolved oxygen, conductivity	Monthly, April to November	KLF 1-8	SeaBird profile from surface to bottom
Transparency	Monthly, April to November (and June 18th)	KLF 1-8	Secchi disk (without viewing chamber)
	Twice monthly, July and August	KLF 2 & KLF 6	
Epilimnion Water Chemistry Turbidity, pH, TP, TN, NO_3, NO_2, TIC, TDP, OP, TOC, alkalinity, silica	Monthly, April to November	KLF 1-8	Integrated sampling tube at 0 – 20m
TP, TN, NO_3, NO_2,TDP, OP, silica	June 18th	KLF 1-8	
Turbidity, TP, TN, NO_3, NO_2, TDP, OP	Twice monthly, July and August	KLF 2 & KLF 6	
Total metals	June and September	KLF 1-8 *KLF 8 omitted from bottom sampling	Integrated sampling tube at 0 – 20m and *discrete sample 5 m off the bottom
Discrete Epilimnion Water Chemistry TP, NO_3, NO_2, TDP, OP	Monthly, June to September	KLF 2 & KLF 6	Discrete samples at 2 m, 5 m, 10 m, 15 m and 20 m
Hypolimnion Water Chemistry Turbidity, pH, TP, TN, NO_3, NO_2, TIC, TDP, OP, TOC, alkalinity, silica	Monthly, May to October	KLF 1-7	Discrete samples 5 m off the bottom
Epilimnion Chlorophyll *a*	Monthly, April to November	KLF 1-8	Integrated sampling tube at 0 – 20m
	June 18th	KLF 1-8	
	Twice monthly, July and August	KLF 2 & KLF 6	
Discrete Epilimnion Chlorophyll *a*	Monthly, June to September	KLF 2 & KLF 6	Discrete samples at 2 m, 5 m, 10 m, 15 m and 20 m
Epilimnion Phytoplankton	Monthly, April to November	KLF 1-8	Integrated sampling tube at 0 – 20m
	June 18th	KLF 1-8	
	Twice monthly, July and August	KLF 2 & KLF 6	

Discrete Epilimnion Phytoplankton	Monthly, June to September	KLF 2 & KLF 6	Discrete samples at 2 m, 5 m, 10 m, 15 m and 20 m
Primary Production	Monthly, June to September	KLF 2 & KLF 6	
Macrozooplankton	Monthly, April to November	KLF 1-8	3 oblique Clarke-Bumpus net hauls (3 minutes each) from 40–0 m with 150 µm net mesh
Mysids	Monthly, April to November	KLF 1-8	3 replicate hauls with mysid net, two deep (1 m off the bottom) and one shallow (25 m)
Kokanee acoustic sampling	2 surveys, July and September	18 transects	Standard MoFLNRO Simrad and Biosonics hydroacoustic procedures
Kokanee trawling	Early season (June/July) and Late season (usually September) trawl series	KLF 1-7 KLF 3 omitted	Standard MoFLNRO trawl series using oblique hauls at specified transects
Adult kokanee enumeration	Fall spawning period at	Meadow Creek, the Lardeau River, and selected South Arm tributaries to Kootenay Lake	Standard MoFLNRO, Region 4 procedures

Appendix 3. Equipment and data processing specifications.

Echosounder Specifications and Field Settings

Category	Parameter	Value
Echosounder	Manufacturer	Simrad EK60
Transceiver	Frequency	120 kHz
	Max power	100 W
	Pulse duration	0.256 ms
	Band width	8.71 kHz
	Absorption coefficient	4.11 dBKm
Transducer	Type	split-beam
	Depth of face	1.0 m
	Orientation, survey method	vertical, mobile, tow foil
	Sv, TS transducer gain	27.0 dB
	Angle sensitivity	23.0
	nominal beam angle	7.0 deg
	Data collection threshold	-70 dB
	Ping rate	2 – 5 pps

Data Processing Specifications: SONAR 5 software version 6.0.1

Data conversion	Amplitude/ SED thresholds	-70 dB (40 Log R TVG)
	Sv, TS gain (correction)	-26.65 dB from field calibration
Single target filter	analysis threshold[1]	-70 to -26 dB (44 1dB bins)
	Min echo length	0.7 – 1.3
	Max phase deviation	0.30
Fish tracking	Minimum no. echoes	2
	Max range change	0.20 m
	Max ping gap	1
Density determination	Integration method	20 log r density (total) from Sv/Ts
	Echo counting method[2]	40 log r density based on SED
	Fish size distributions	From in situ single echo detections

[1] Lower Threshold varied with survey from -61 to -58dB depending on interference from mysids.

[2] Note: echo counting was the main method used for determining fish densities in 2013.

Appendix 4. Love’s (1977) empirical relation of fish length to acoustic target strength.

Aspect Dorsal: $TS = 19.1 \log_{10} (L) – 0.9 \log_{10} (F^1) – 62$

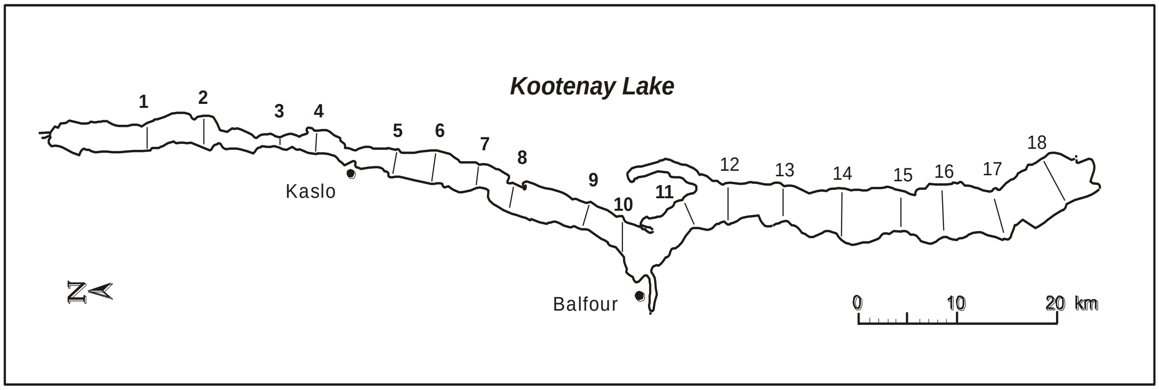
Where: TS=target strength in decibels (dB), L=length in cm and F=frequency in KHz=120 KHz

Target strength	Fish length range (mm)		Target strength	Fish length range (mm)	
(dB)	Min	Max	(dB)	Min	Max
-26	961		-44	110	123
-27	852	960	-45	97	109
-28	755	851	-46	86	96
-29	669	754	-47	76	85
-30	593	668	-48	68	75
-31	526	592	-49	60	67
-32	466	525	-50	53	59
-33	413	465	-51	47	52
-34	366	412	-52	42	46
-35	325	365	-53	37	41
-36	288	324	-54	33	36
-37	255	287	-55	29	32
-38	226	254	-56	26	28
-39	201	225	-57	23	25
-40	178	200	-58	20	22
-41	158	177	-59	18	19
-42	140	157	-60	16	17
-43	124	139	-61	14	15
			-62	13	13

Appendix 5. Transect fish densities (number.ha-1) in Kootenay Lake in 2013.

Transect Number	**July 2013**			**Sept. 2013**		
	All Ages	**Age 0+**	**Age 1-3+**	**All Ages**	**Age 0+**	**Age 1-3+**

1	942	801	141	412	365	47
2	1317	1220	97	967	910	57
3	1524	1430	94	611	563	48
4	764	701	63	741	718	23
5	431	373	57	696	662	34
6	687	648	39	636	609	26
7	568	534	34	901	876	24
8	456	437	19	788	757	31
9	330	310	19	484	454	30
10	446	407	40	363	329	33
11	212	188	24	507	482	25
12	212	174	38	330	314	16
13	132	107	25	372	355	17
14	80	62	18	334	311	23
15	165	130	36	279	255	24
16	99	70	29	261	244	16
17	164	98	65	205	176	29
18	197	136	61	241	205	35



Appendix 6. Maximum likelihood population estimates and bounds for (a) all ages of kokanee and (b) ages 1-3 kokanee in Kootenay Lake in July 2013.

a) Statistics for kokanee of all ages (>–61 dB) two zones (Zone 1=TR 1-03; Zone 2=TR 04-18)

Zone	Depth	N	Density	Std. Error	Area	Stratum Pop.	Statistic[1]	Abundance
1	3-5	3	39.8	5.6	5320	211608		
1	5-10	3	615.7	96.9	5320	3275483		
1	10-15	3	403.7	50.4	5320	2147464		
1	15-20	3	131.2	28.7	5320	697794		
1	20-25	3	28.3	4.8	5267	149050		
1	25-30	3	17.8	4.8	5211	92589	LB=	14,947,114
1	30-35	3	6.8	2.7	5138	34991	MLE=	17,577,634
1	35-40	3	8.0	3.4	5052	40574	UB=	20,007,521
1	40-45	3	5.9	2.7	4965	29344		
1	45-50	3	4.0	0.9	4878	19436		
2	3-5	15	1.6	1.1	32880	54031		
2	5-10	15	57.8	17.2	32880	1900666		
2	10-15	15	111.4	26.2	32880	3662356		
2	15-20	15	91.8	12.0	32880	3019175		
2	20-25	15	41.2	6.6	32649	1345920		
2	25-30	15	14.0	2.1	32431	454335		
2	30-35	15	5.4	0.9	32132	174789		
2	35-40	15	2.6	0.6	31852	81256		
2	40-45	15	2.2	0.7	31632	69777		
2	45-50	15	1.4	0.5	31406	44157		

b) Statistics for age 1-3+ kokanee (>–45 dB); two zones (Zone 1=TR 1-03, Zone 2=TR 04-18.)

Zone	Depth	N	Density	Std. Error	Area	Stratum Pop.	Statistic[1]	Abundance
1	3-5	3	11.7	11.7	5320	62482		
1	5-10	3	16.9	5.2	5320	89819		
1	10-15	3	40.2	15.1	5320	214054		
1	15-20	3	27.1	6.2	5320	143989		
1	20-25	3	7.5	1.5	5267	39329		
1	25-30	3	3.8	1.1	5211	19622		
1	30-35	3	1.3	0.3	5138	6582		
1	35-40	3	1.3	0.6	5052	6367		
1	40-45	3	0.6	0.5	4965	3029	LB=	1,507,368
1	45-50	3	0.3	0.2	4878	1358	MLE=	1,820,217
2	5-10	15	2.4	1.1	32880	79602	UB=	2,141,531
2	10-15	15	6.3	1.9	32880	206677		
2	15-20	15	12.9	1.8	32880	424825		
2	20-25	15	9.0	2.0	32649	295085		
2	25-30	15	4.5	0.8	32431	146658		
2	30-35	15	1.9	0.4	32132	59470		
2	35-40	15	0.4	0.1	31852	11709		
2	40-45	15	0.2	0.1	31632	7792		
2	45-50	15	0.2	0.1	31406	5839		

[1] MLE = maximum likelihood estimate, LB = lower bound, and UB = upper bound

Appendix 6 cont. Maximum likelihood population estimates and bounds for (c) all ages of kokanee and (d) ages 1-3 kokanee in Kootenay Lake in Sept 2013.

c) Statistics for kokanee of all ages (>–61 dB); two zones (Zone 1=TR 1-10; Zone 2=TR 11-18)

Zone	Depth	N	Density	Std. Error	Area	Stratum Pop.	Statistic[1]	Abundance
1	3-5	11	3.6	2	20090	71740		
1	5-10	11	17.7	6	20090	354658		
1	10-15	11	17.2	6	20090	345740		
1	15-20	11	145.0	22	20090	2912553		
1	20-25	11	307.4	36	19905	6118493		
1	25-30	11	111.9	14	19731	2208720	LB=	16,078,114
1	30-35	11	27.5	9	19468	535581	MLE=	18,037,040
1	35-40	11	6.5	3	19191	123902	UB=	20,030,637
1	40-45	11	5.9	4	18983	112712		
1	45-50	11	3.3	2	18771	61151		
2	5-10	7	6	2	18110	117573		
2	10-15	7	8	2	18110	137429		
2	15-20	7	69	16	18110	1257952		
2	20-25	7	141	13	18012	2537808		
2	25-30	7	46	6	17911	826639		
2	30-35	7	12	2	17803	219805		
2	35-40	7	2	1	17713	42667		
2	40-45	7	2	1	17614	34608		
2	45-50	7	1	0	17513	22907		

d) Statistics for age 1-3+ kokanee (>–45 dB); one zone (Zone 1=TR 1-18)

Zone	Depth	N	Density	Std. Error	Area	Stratum Pop.	Statistic[1]	Abundance
1	10-15	18	2	0	38200	76101		
1	15-20	18	2	0	38200	72359		
1	20-25	18	8	1	37916	311595	LB=	955,257
1	25-30	18	12	1	37642	443321	MLE=	1,103,869
1	30-35	18	4	1	37271	151120	UB=	1,289,116
1	35-40	18	1	0	36903	26747		
1	40-45	18	1	0	36596	23676		

Appendix 7. Preliminary estimates of kokanee biomass for Kootenay Lake

a) Estimated number of fish at each age based on Fall acoustic abundance, trawl proportions, and mean weights by year and age from trawl samples.

	Estimated number of fish				**Mean weight (g)**			
Year	**Age 0+**	**Age 1+**	**Age 2+**	**Age 3+**	**Age 0+**	**Age 1+**	**Age 2+**	**Age 3+**
1985	3,630,000	1,334,103	2,016,667	279,231	1.6	24.9	53.5	66.0
1986	11,603,512	648,799	1,023,105	224,584	1.9	17.9	60.4	69.3
1988	3,400,660	1,685,283	1,294,057	-	2.2	26.6	52.2	
1989	7,423,643	1,368,605	1,700,388	207,364	1.6	25.5	59.9	68.3
1990	4,808,922	732,788	480,892	137,398	2.2	39.9	75.4	89.2
1991	7,479,751	930,124	775,104	155,021	2.1	29.7	127.9	130.8
1992	7,212,801	390,618	908,413	18,168	2.1	36.3	120.6	180.9
1993	8,790,000	1,218,451	460,634	430,915	1.5	36.5	76.4	108.9
1994	31,780,000	2,510,286	1,287,886	21,829	2.0	31.0	114.1	134.0
1995	21,000,000	3,721,029	572,466	6,505	2.0	34.2	74.4	138.4
1996	22,600,000	6,181,282	5,956,053	162,665	1.4	21.4	57.2	62.8
1997	14,270,000	5,807,355	5,840,165	262,479	1.7	25.0	50.5	77.4
1998	8,400,000	2,248,680	8,012,903	538,416	1.4	36.8	73.4	97.4
1999	10,360,000	2,050,323	2,489,677	-	2.1	33.3	101.4	
2000	9,690,000	636,667	1,273,333	-	2.0	32.2	123.0	
2001	18,380,000	4,967,368	752,632	-	2.4	35.9	119.2	
2002	25,430,000	9,091,528	542,778	135,694	1.8	37.0	84.9	111.4
2003	17,049,000	5,263,848	4,187,152	-	3.4	39.9	90.9	
2004	9,450,000	3,692,578	2,782,813	374,609	2.5	23.1	90.6	109.3
2005	12,830,000	1,703,125	1,021,875	545,000	1.7	18.7	110.8	137.7
2006	17,230,000	3,933,462	936,538	-	3.3	35.8	183.4	
2007[1]	17,859,000	3,736,000	1,401,000	350,000	*3.3*	*35.8*	*183.4*	*235.0*
2008	22,644,000	3,827,896	445,104	-	2.3	35.5	93.6	
2009	31,130,000	14,398,400	1,653,900	101,900	2.0	33.1	94.0	
2010	22,443,000	11,157,400	4,075,800	152,800	1.5	34.0	68.3	96.8
2011	15,162,366	3,622,974	3,978,167	-	1.9	35.5	77.9	
2012[2]	13,197,000	851,057	806,264	716,679	2.7	28.9	79.7	58.7
2013	16,933,171	838,940	132,464	132,464	2.6	16.7	228.5	231.2

[1] no trawling in 2007; applied approximate proportion by age from two previous years to the age 1 2 and 3 fish. Based on density, the growth was likely similar to 2006 so applied 2006 mean weights by age. Estimates are italicized. The mean weight of age 3 was assumed to be the same as mean weight of spawners in 2007.

[2] Three 4+ kokanee were included in the Age 3+ sample.

b) Calculation of in-lake biomass (metric tons) and biomass density ($kg\cdot ha^{-1}$) of kokanee in Kootenay Lake in September of 2013.

	Biomass (metric tons)					**Biomass Density ($kg\cdot ha^{-1}$)**				
Year	**Age 0+**	**Age 1+**	**Age 2+**	**Age 3+**	**Total**	**Age 0+**	**Age1+**	**Age2+**	**Age 3+**	**Total**
1985	6	33	108	18	165	0.16	0.87	2.82	0.48	4.3
1986	22	12	62	16	111	0.58	0.30	1.62	0.41	2.9

1988	7	45	68	-	120	0.19	1.18	1.77	-	3.1
1989	12	35	102	14	163	0.31	0.91	2.67	0.37	4.3
1990	11	29	36	12	88	0.28	0.76	0.95	0.32	2.3
1991	16	28	99	20	163	0.42	0.72	2.59	0.53	4.3
1992	15	14	110	3	142	0.40	0.37	2.87	0.09	3.7
1993	14	44	35	47	140	0.35	1.16	0.92	1.23	3.7
1994	64	78	147	3	291	1.66	2.04	3.85	0.08	7.6
1995	41	127	43	1	212	1.07	3.33	1.11	0.02	5.5
1996	32	132	341	10	515	0.83	3.46	8.92	0.27	13.5
1997	24	145	295	20	485	0.64	3.80	7.72	0.53	12.7
1998	12	83	588	52	735	0.31	2.17	15.40	1.37	19.2
1999	22	68	252	-	343	0.57	1.79	6.61	-	9.0
2000	19	21	157	-	196	0.50	0.54	4.10	-	5.1
2001	44	178	90	-	312	1.15	4.67	2.35	-	8.2
2002	47	336	46	15	444	1.22	8.81	1.21	0.40	11.6
2003	57	210	381	-	648	1.50	5.50	9.96	-	17.0
2004	24	85	252	41	402	0.62	2.23	6.60	1.07	10.5
2005	21	32	113	75	242	0.56	0.83	2.96	1.96	6.3
2006	56	141	172	-	369	1.47	3.69	4.50	-	9.7
2007[1]	*58*	*134*	*257*	*82*	*531*	*1.52*	*3.50*	*6.73*	*2.15*	*13.9*
2008	53	136	42	-	230	1.38	3.56	1.09	-	6.0
2009	62	477	155		694	1.62	12.48	4.07		18.2
2010	35	379	279	15	707	0.90	9.93	7.29	0.39	18.5
2011	28	129	310	-	467	0.74	3.37	8.11	-	12.2
2012[2]	36	25	64	42	167	0.94	0.64	1.68	1.1	4.4
2013	44	14	30	31	110	1.16	0.37	0.79	0.80	3.1
Pre	12	30	79	13	135	0.3	0.8	2.1	0.4	3.5
Fert	37	136	189	20	381	1.0	3.6	4.9	0.5	10.0

[1] Note: 2007 biomass estimates are based on assumptions from table above

[2] Note: Three 4+ kokanee were included in the Age 3+ sample

c) Calculation of kokanee spawner biomass (metric tons) and biomass density (kg·ha^{-1}) in Kootenay Lake. Note: bottom rows compare average biomass during pre-fertilization (1985-91) and fertilization years (1992-2013).

Year	**Total Spawners (no)**	**Mean Weight (g)**	**Spawner Biomass (tonnes)**	**Spawners (kg·ha^{-1})**	**In-lake (kg·ha^{-1})**	**Total (kg·ha^{-1})**
1985	901,100[1]	85	76.6[1]	2.0[1]	4.3	6.3[1]
1986	1,197,600	89	106.6	2.8	2.9	5.7
1988	657,900	97	63.5	1.7	3.1	4.8
1989	483,000	107	51.5	1.3	4.3	5.6
1990	436,607	107	46.8	1.2	2.3	3.5
1991	277,088	126	34.8	0.9	4.3	5.2
1992	520,903	159	82.6	2.2	3.7	5.9
1993	848,959	218	185.2	4.8	3.7	8.5
1994	1,253,000	158	198.2	5.2	7.6	12.8
1995	855,745	167	142.6	3.7	5.5	9.3
1996	1,181,718	89	105.7	2.8	13.5	16.2
1997	1,444,227	82	118.1	3.1	12.7	15.8
1998	2,198,000	95	208.5	5.5	19.2	24.7
1999	1,730,720	113	194.9	5.1	9.0	14.1
2000	563,956	156	88.1	2.3	5.1	7.4
2001	591,308	184	108.8	2.8	8.2	11.0
2002	464,000	144	66.6	1.7	11.6	13.4
2003	1,100,501	108	119.1	3.1	17.0	20.1
2004	1,526,125	112	170.4	4.5	10.5	15.0
2005	1,269,028	112	142.1	3.7	6.3	10.0
2006	478,307	180	86.1	2.3	9.7	11.9
2007[1]	534,073	236	125.8	3.3	13.9	17.2
2008	1,349,325	168	226.7	5.9	6.0	12.0
2009	907,839	118	107	2.8	18.0	20.8
2010	826,788	91	75.5	2.0	18.5	20.5
2011	1,764,100	78	137.4	3.6	12.2	15.8
2012	1,255,843	77	96.6	2.5	4.4	6.9
2013	453,592	241	109.5	2.9	3.1	6.0
Pre	658,883	102	63.3	1.7	3.5	5.2
Fert	1,050,821	140	131.6	3.4	10.0	13.4

*In-lake biomass assumptions outlined in tables above.

[1] 1985 spawner estimate does not include Lardeau spawners (not counted)

Appendix 8. Summary of Production statistics for Meadow Creek spawning channel, 1985-2013.

Spawning year	Spawner counts[1] (no.)	Mean Fecundity (egg no.)	Egg Retention[2] (egg no.)	Females[2] (%)	Egg Deposition[3] (millions)	Fry emigration[4] (millions)	Egg-to-fry survival (%)
1985	287,252	215			28.47	7.37	39.8
1986	256,410	203			27.29	2.78	9.8
1987	236,062	191			22.72	2.98	10.9
1988	291,895	215			27.69	2.32	10.2
1989	230,000	205			25.48	6.99	25.2
1990	203,197	209			18.56	8.41	33.0
1991	168,775	249			20.95	4.79	25.8
1992	253,545	300			32.01	7.13	34.0
1993	291,368	408			61.46	11.85	37.0
1994	300,000	312			43.05	28.07	45.7
1995	302,063	348			44.20	16.69	38.8
1996	371,000	206			33.43	18.20	41.2
1997	352,093	187			21.46	8.89	26.9
1998	336,636	193			27.82	12.44	59.3
1999	353,674	240			31.62	13.17	47.4
2000	250,056	281			34.82	20.10	62.5
2001	303,808	348			51.80	13.75	39.4
2002	302,500	295	7	49	42.59	21.69	41.9
2003	358,782	208	10	43	29.76	17.92	42.1
2004	514,791	245	16	34	42.91	14.35	48.2
2005	463,614	226	11	38	41.70	24.56	57.2
2006	331,194	315	11	50	50.50	16.58	39.7
2007	245,991	411	11	47	45.50	15.94	31.6
2008	437,236	379	17	36	62.22	24.53	53.9
2009	506,035	267	19	50	62.74	26.75	43.0
2010	452,530	214	14	44	35.74	22.05	35.2
2011	485,128	179	15	47	39.76	12.22	34.2
2012	519,557	180	13	43	37.68	13.73	34.5
2013	165,748	285	8	44	20.27	13.77	36.6

[1] Refers only to fish in the spawning channel and does not include fish above and below channel or fish removed by FFSBC during egg takes.

[2] Derived by sampling at spawning channel

[3] Potential egg deposition based on number of adults in channel x (fecundity – retention) x % females. Note, there were green females returned to channel some years so these are deducted from channel before applying % females and then added to determine total females (Calculations are more complex than suggested by this table).

[4] Fry emigration from spring time sampling does not include non-channel production which is estimated separately based on a 5% egg-to-fry survival rate.