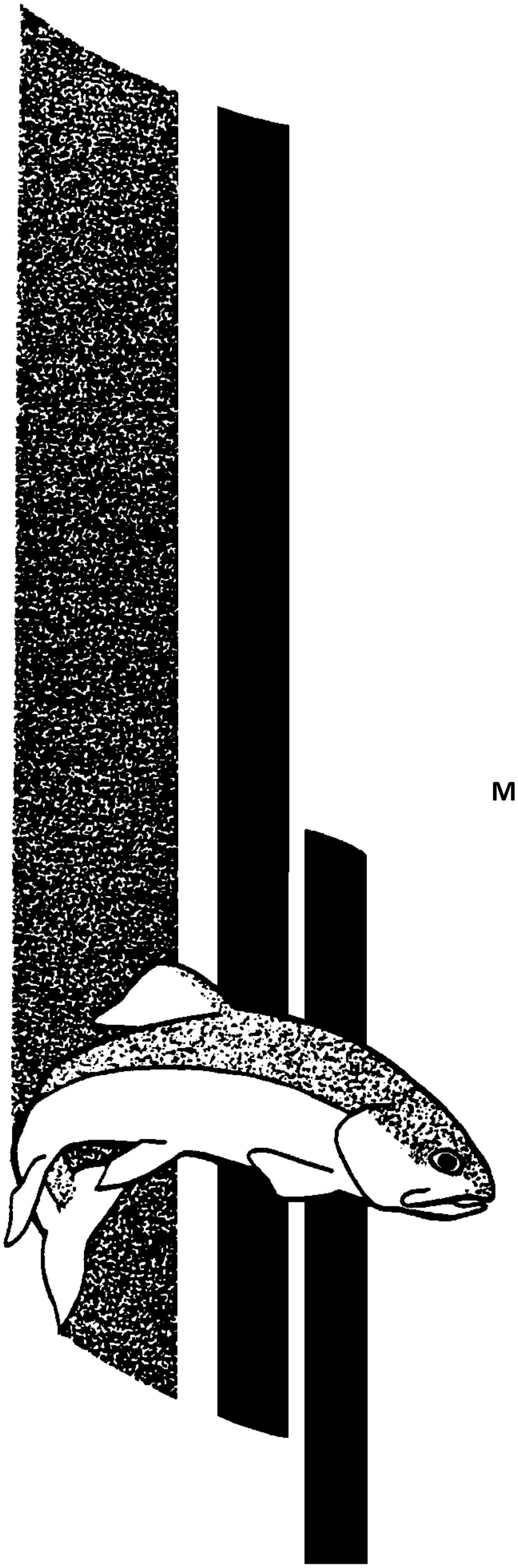

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NORTH ARM AND SOUTH ARM
2014 AND 2015 REPORT

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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 2014 and 2015.

EXECUTIVE SUMMARY

This report summarizes results from the 23rd year (2014) and 24th year (2015) of nitrogen and phosphorus additions to the North Arm of Kootenay Lake and 11th year (2014) and 12th year (2015) 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 km^2 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 2014 and 2015 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. In 2014, total dissolved phosphorus (TDP) collected from epilimnetic integrated samples ranged from below the reportable detection limit (2 µg/L) to 9.6 µg/L, and in 2015 ranged from below the reportable detection limit (2 µg/L) to 9.6 µg/L. Dissolved inorganic nitrogen (NO_2-N+NO_3-N+NH_3-N) collected from epilimnetic integrated samples in 2014 ranged from 53.4 µg/L to 209.0 µg/L, and in 2015 ranged from 53.6µg/L to 218.0 µg/L and in both years 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 in both 2014 and 2015. In 2014, chryso-cryptophytes were highest in the late spring; whereas, bacillariophyte abundance peaked in the summer. In 2015, Chryso-cryptophytes were highest in June in the South Arm; whereas, bacillariophyte abundance peaked in July. In the North Arm, the chryso-cryptophyte mean in 2015 was significantly lower than the long term 1992-2013 mean and bacillariophyte biovolume was significantly lower in 2014 compared to the 1992-2013 mean. In the South Arm, the 2014 and 2015 means were not significantly different from the long term 1992-2013 mean.

The zooplankton population in 2014 and 2015 was significantly higher than the pre and post nutrient addition long-term averages. A pattern of high results has been observed since 2013. *Daphnia* biomass was lower in the North and West Arms in 2014 relative to 2013, but higher in the South Arm. The mean biomass in 2015 increased in all Arms from 2014 to 2015. A record high zooplankton biomass was observed in the South Arm in 2015.

Mysis diluviana (mysid) 2014 and 2015 densities were below the long-term 1993-2015 average. In 2014 mysid densities in the North Arm were slightly above the long term average (1993-2015), but were below the South Arm average. In 2015, mysid densities in the North Arm were marginally below the average, and in the South Arm, marginally above the long term mean. In both 2014 and 2015, the West Arm densities were marginally below the long term West Arm average.

The main Lake kokanee population continued to face challenging circumstances in Kootenay Lake through 2014 and 2015, failing to recover to post nutrient restoration norms for growth, abundance, and survival. Mature kokanee demonstrated a significant growth response to low densities, where spawner fork lengths increased to a new historic high. Size at age data were limited for in-lake age 2+ kokanee, while age 1+ kokanee length increased slightly from a record low in 2013 yet remained among the smallest on record. Age 0+ abundance remained similar from 2011-2015, slightly below the nutrient restoration era average. However, the age 1-3+ kokanee population remained exceptionally low through 2014 and 2015, 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 to record lows in 2014 and 2015. Kokanee spawner abundance continued to decline to the lowest on record for both Meadow Creek and Lardeau River in 2015. Survival trends indicate exceptional survival from egg to fall fry in 2014 and 2015, however survival from fall fry to age 1+ remained very low, similar to 2012 and 2013.

Gerrard Rainbow spawner abundance was exceptionally high from 2009-13, then began declining in 2014 and fell to among the lowest on record by 2015. Regardless, predator numbers are still thought to be high and top down pressure continues to be the likley mechanism inhibiting kokanee population recovery.

TABLE OF CONTENTS

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 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 population 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 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 a greater contribution by the nanoplankton and microplankton (>20.0 µm) fractions (Stockner 1987). Microplankton are considered too large to be edible by most zooplankton.

The central strategy of 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 (percent by weight N-P_2O_5-K_2O), and phosphorus as ammonium polyphosphate, 10-34-0 (N-P_2O_5-K_2O), 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-P_2O_5-K_2O) 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 intentionally introduced into Kootenay Lake in 1949 by Provincial Fish and Game staff in a misguided attempt to increase growth rates of juvenile Gerard trout.

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. 1999a). The initial response of North Arm kokanee to nutrient additions was very positive. Kokanee escapements to the North Arm's Lardeau River and Meadow Creek systems exceeded 1 million fish.

There was a deliberate reduction in nutrient loading from 1997–2000 to confirm the hypothesis that nutrient additions were responsible for increasing the kokanee numbers through a bottom-up effect. Kokanee numbers and zooplankton biomass declined with the reduced nutrient loading (Schindler et al. 2009). This clear cause-and-effect relationship enabled fisheries managers to secure long-term funding and adjust the annual nutrient loading back to the 1992 nutrient loading inputs 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; Bassett et al. 2016).

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. 1999a; Thompson 1999; Wright 2002; Schindler et al. 2007a, 2009, 2010, 2011, 2013, 2014b; Bassett et al. 2016). 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 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 genetically distinct West Arm stock of kokanee (Redfish Consulting Ltd. 2002). Furthermore, the South Arm kokanee, another 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 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 Koocanusa 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 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 in conjunction with the South Arm fertilization experiment (Sebastian et al. 2010; Ericksen et al. 2009). In 2014, the IHN (Infectious hematopoietic necrosis) virus was detected in the spawning adults at the source of eggs, Meadow Creek Spawning Channel (MCSC). Because of disease prevention protocol at the hatchery, eyed eggs were not available for planting. Additionally, MCSC escapement was not high enough to offer surplus eggs in 2014 and 2015.

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 livestock 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).

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 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).

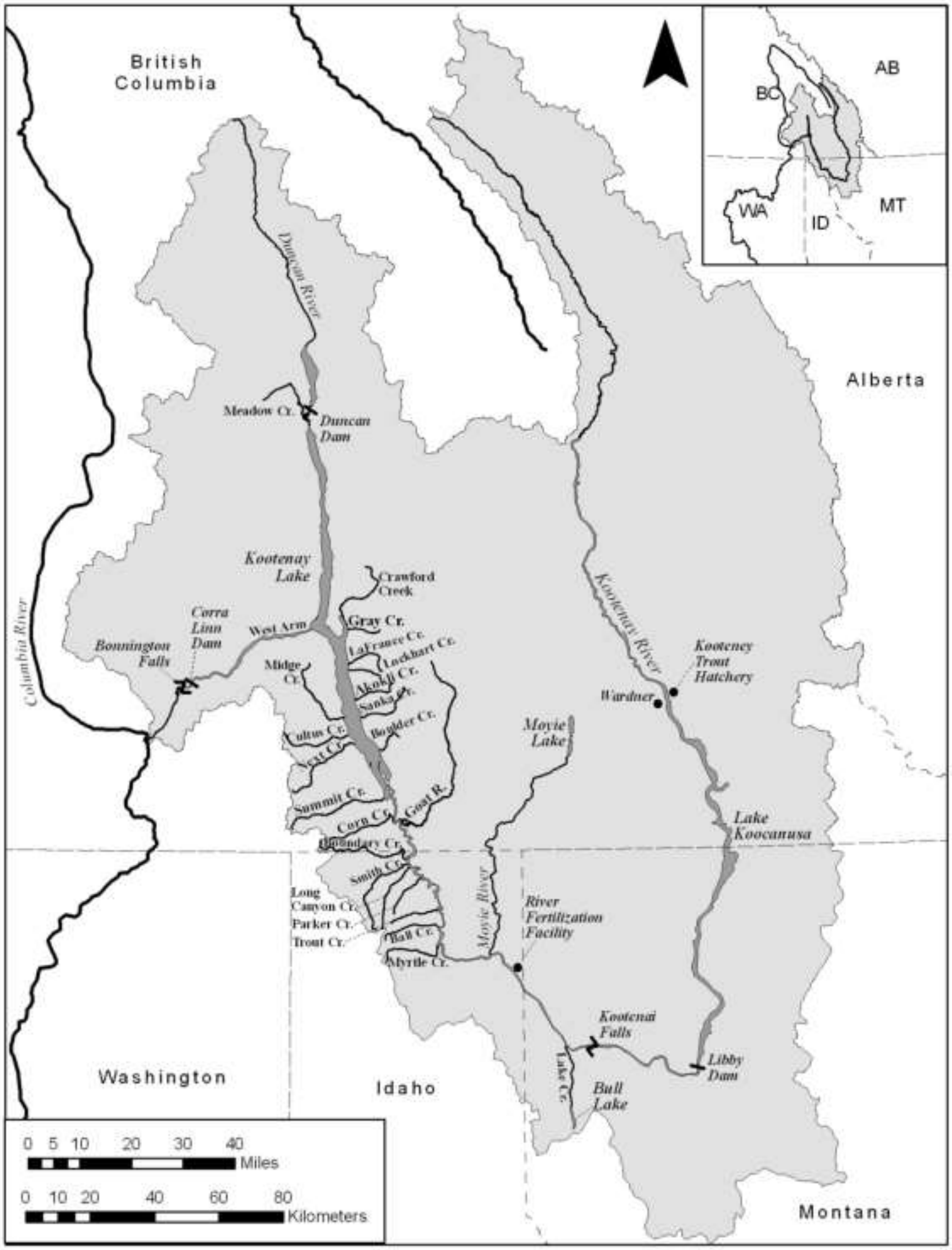


Figure 1. Map of the Kootenay River Basin in British Columbia, Montana, and Idaho showing South Arm tributaries (adapted from Ericksen et al. 2009).

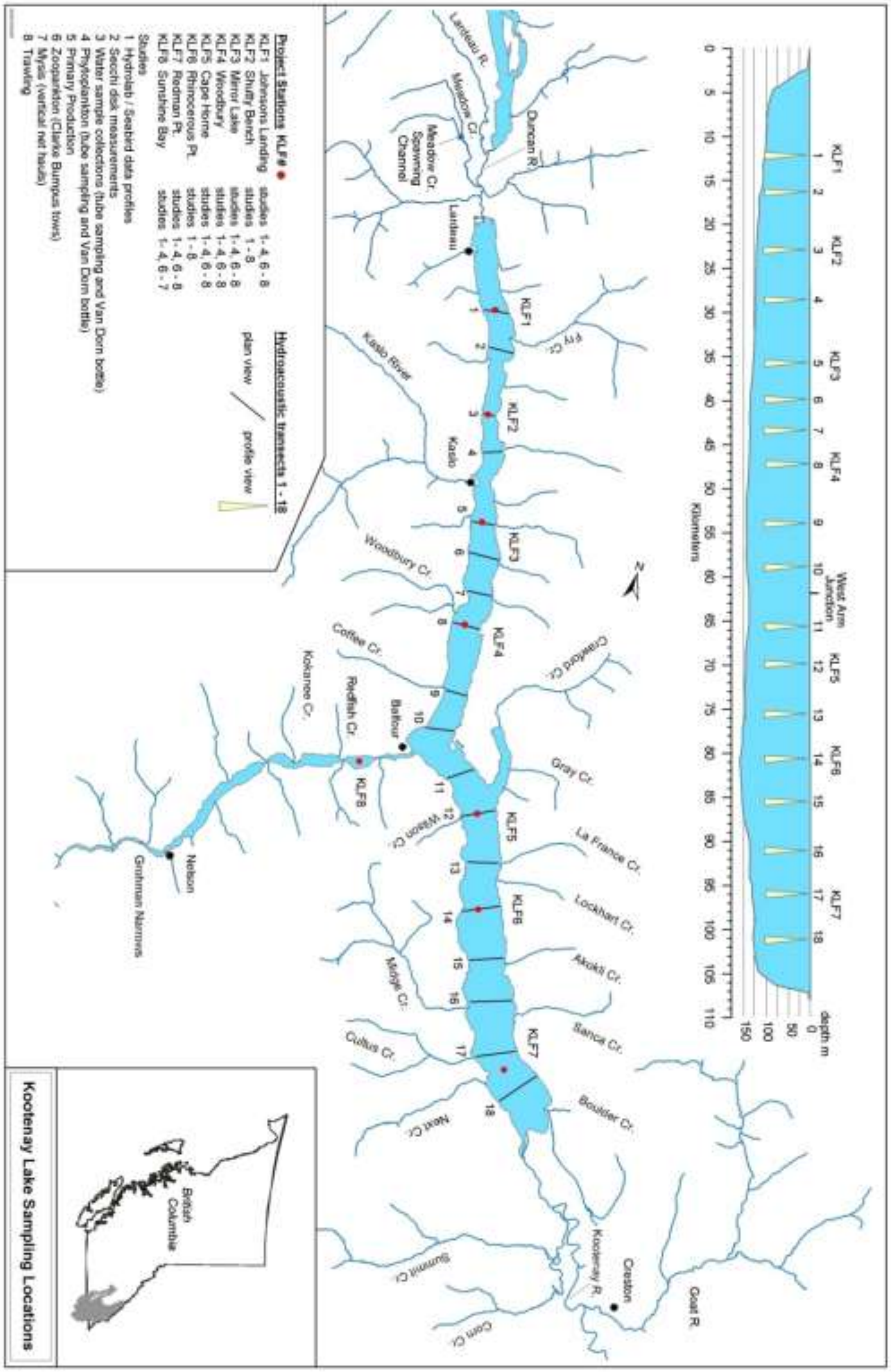


Figure 2. Kootenay Lake, British Columbia, sampling station sites.

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 2014 and 2015, 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, 2014b and Bassett et al. 2016. Personnel contributing to the program in 2014 and 2015 are listed in Appendix 1a and 1b respectively. The sampling activities are listed in Appendix 2.

Objectives

The overall objective of the nutrient restoration program is to promote primary productivity by additions of nutrient additions. The result of higher productivity is efficient transfer of nutrients up the food web from zooplankton to Kokanee. Kokanee are the primary food source for the two apex piscivores in Kootenay Lake, the Gerrard rainbow trout and bull trout. One of the Kootenay Lake fish priorities as laid out in the FWCP Large Lakes Action plan is "Province of BC's highest sport fishery priority is the Gerrard rainbow trout, followed by bull trout, and there is a desire to increase the in-lake population of large fish to support a world class recreational fishery." FWCP, 2012). Further objectives of large lakes management as discussed in the FWCP large lakes action plan is to for; 1. Conservation – Ensure a productive and diverse aquatic ecosystem, 2. Conservation – Improve the status of species of conservation concern, and 3. Sustainable Use – Maintain or improve opportunities for sustainable use (FWCP, 2012).

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 2015 are listed in Table 1.

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. In 2015, a temporary weigh restriction of 60 tonnes on the MV Balfour was applied for the first 6 weeks of the season.

The total weight of fertilizer applied in 2014 was 26.3 tonnes of phosphorus and 206 tonnes of nitrogen (Fig. 3). Applications started on May 2nd and continued weekly until September 11th. Only nitrogen was added for 7 weeks; July 3rd to Aug 7th and Aug 28th. 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 early May to 10.9:1 in late August, early September. 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 2015, the total weight of fertilizer applied was 32.1 tonnes of phosphorus and 213 tonnes of nitrogen (Table 1). Applications started on May 1st and continued weekly until September 15th, with the exception of cancelling a week on July 9th. 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 early May to 10.9:1 in late July to September. Phosphorus loading ranged from 0 to 22.8 mg/m^2 and nitrogen loading ranged from 0 to 112.9 mg/m^2. In 2015, a temporary weight restriction of 60 tonnes on the MV Balfour was applied for the first 10 weeks of the season.

South Arm

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 drove onto the ferry, and nutrients were applied to the lake via two dispensing diffusers located at the stern of the vessel. The weight restriction on the ferry is 70 tonnes of fertilizer. 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 17.5 km (Fig. 2). In previous reports the distance of nutrient addition in the South Arm was reported at 12.5

km, the zone has been confirmed to be a distance of 17.5km. Fertilizer load was distributed with one half released on the departing trip and one half on the return trip. In 2015, a temporary weigh restriction of 60 tonnes on the MV Balfour was applied for the first 6 weeks of the season.

In 2014 and 2015, the previously used strategy of adding only nitrogen to the South Am was maintained. In total in 2014, 247 tonnes of nitrogen were added in the form of urea-ammonium nitrate (28-0-0: N-P2O5-K2O; % by weight) (Table 1). Additions occurred at weekly intervals from May 30th to August 29th at a loading rate of 85.9 mg/m^2, except on July 4th, July 25th and August 1st when the loading rate was 43, 46.6 and 46.6 mg/m^2 (respectively) (Fig. 4). In 2015, a total of 267 tonnes of nitrogen were added, beginning on May 29th and ending on September 11th, 2015. The loading rate was lower at the beginning of the season due to temporary weight restrictions on the ferry, the first 6 weeks of loading was 73.7 mg/m^2 (Fig. 4). The 7th week was cancelled, the 8th week was 43 mg/m^2 and the last 8 weeks loading were 85.9 mg/m^2 (Fig. 4).

Table 1. Total tonnes of phosphorus and nitrogen (from liquid agricultural fertilizer) dispensed into the North Arm of Kootenay Lake, 1992–2015, and tonnes of nitrogen to the South Arm, 2004–2015.

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
2014	26.3	206	247
2015	32.1	213	267

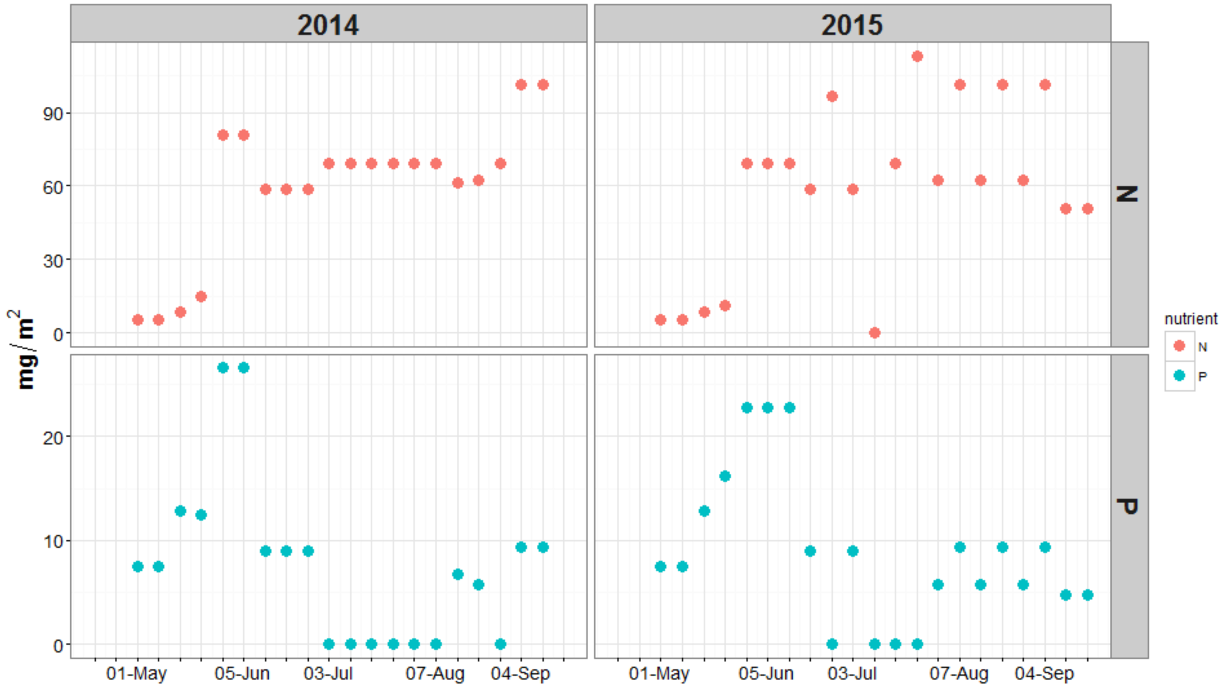


Figure 3. Weekly nitrogen (N) and phosphorus (P) inputs (mg/m^2) from fertilizer to the North Arm, May through September, 2014 and 2015.

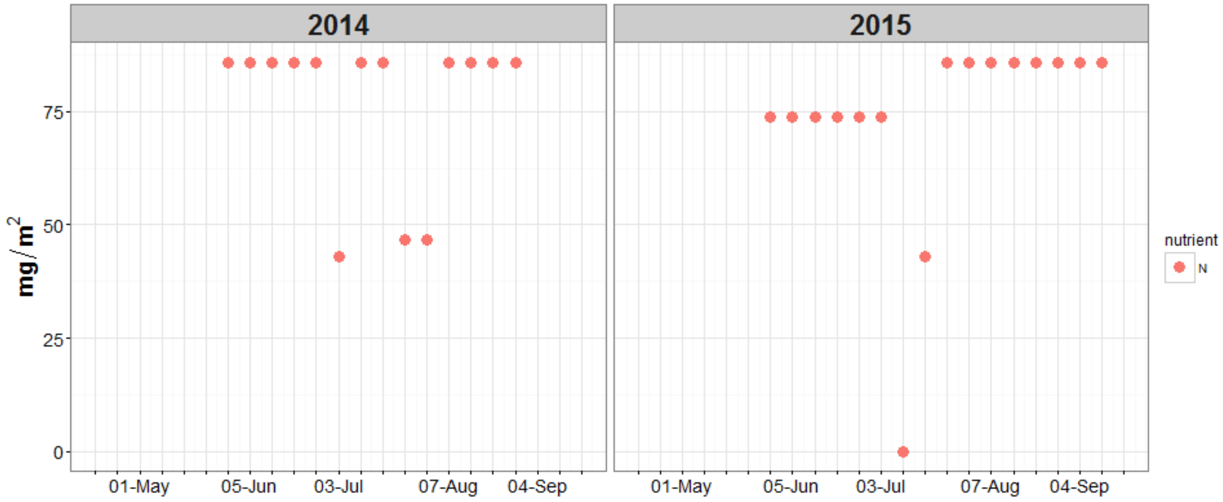


Figure 4. Weekly nitrogen (N) inputs (mg/m^2) from fertilizer to the South Arm, May through September, 2014 and 2015.

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)	UTM NAD 83 Zone 11 N	E
KLF 1	E216949	Kootenay Lake at Johnson's Landing	100	5545282	507185
KLF 2	E216950	Kootenay Lake at Kembell Creek	120	5536157	507641
KLF 3	E216951	Kootenay Lake at Bjerkeness Creek	120	5524429	508278
KLF 4	E216952	Kootenay Lake at Hendricks Creek	135	5512528	507820
KLF 5	E216953	Kootenay Lake at Crawford Bay	140	5492123	511773
KLF 6	E216954	Kootenay Lake at Rhinoceros Point	150	5480843	514101
KLF 7	E218832	Kootenay Lake at Redman Point	125	5464171	519001
KLF 8	E252949	Kootenay Lake – West Arm (sunshine Bay)	35	5495866	499072

Vertical profiles of temperature, specific conductivity and oxygen 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. Technical issues with the instrument resulted in lack of temperature, specific conductivity and oxygen for 2014 for the July-November casts. Temperature data, in 2014 is reported as April-June, as well as temperature data from the hydroacoustic survey in October (TR1 and TR18 only; Appendix 3). For graphing purposes, temperature profiles for KLF 2 and TR1 represent the North Arm and KLF 6 and TR18 represents the South Arm. Water transparency was measured at each station using a standard 20-cm Secchi disc (without a viewing chamber).

Long term temperature and precipitation trends were reported for the time series 1992-2015. Water temperature at 2 m was extracted from the profile data for the years 1992-2015, 2m depth was chosen to capture a depth in the epilimnion unaffected by surface noise on the profile data. Missing data in this dataset are summarized in Appendix 3. Air temperature and precipitation recorded from a weather station in Nelson (name: NELSON NE, Lat=49.59, long=-117.21, elevation=570m) was used to as an index of climate on Kootenay Lake. Annual values by seasons (spring= Apr–Jun, summer= Jul–Sep, and fall= Oct–Nov and winter=Jan-Mar and Dec) are presented. Data available online at http://climate.weather.gc.ca/)

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 1–7 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 until March 31st, 2015, after samples were shipped and analyzed by ALS Global in Burnaby, BC.

Water samples were analyzed for turbidity, pH, total phosphorus (TP), total dissolved phosphorus (TDP), orthophosphate (OP), total nitrogen, nitrate and nitrite, silica, alkalinity, and total organic carbon (TOC). 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. On June 1st, 2015, the water chemistry analyst lab changed from Maxxam to ALS. The switch in labs was not apparent in the data.

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 6. Samples were obtained from depths of 2, 5, 10, 15, and 20 m for analysis of OP, TP, TDP, DIN, Chl *a*, and phytoplankton taxonomy (described below).

Physical and water chemistry data were analyzed with the statistics software R (ver. 3.1.3). Analysis of variance (ANOVA) tests were performed to compare group mean differences. Multiple comparisons of means were also performed (Tukey's Contrasts), 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. Statistical significance was taken at a level of $p < 0.05$.

Phytoplankton

Phytoplankton samples were collected from the 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 are described above. Lugol's iodine solution was added immediately after collection and samples were couriered to West Vancouver for processing by Eco-Logic Ltd.

The 2014 and 2015 integrated and discrete samples were analyzed as follows: Phytoplankton enumeration was typically performed within 5 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 appears in Appendix 1 from Stockner (2009) in Schindler et al. (2009).

In 2014, the sample bottle for the West Arm (KLF 8) broke in transit; therefore there is no West Arm July data. Phytoplankton results were plotted and analyzed with the statistics software R with R Studio (R ver. 3.1.3 and R studio ver. 0.98.1103). Analysis of variance (ANOVA) tests were performed to compare group mean differences. Multiple comparisons of means were also performed (Tukey's Contrasts), 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. For consistency in comparison, the second monthly samples in June - August (Jun_2, Jul_2 and Aug_2) were omitted from this analysis. Yearly comparisons were made for both the North and South Arm, between a pooled mean from1992-2013, 2014 and 2015. Again, for consistency in comparison, the second monthly samples in June - August (Jun_2, Jul_2 and Aug_2) were omitted from this analysis, as were the West Arm results. The three groups analysed are; total phytoplankton biomass, bacillariophyte biomass and chryso-cryptophyte biomass. Statistical significance was taken at a level of $p < 0.05$.

Zooplankton

Samples have been collected monthly at four stations (KLF 2, 4, 6 and 7) 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.

At each of the stations, three replicate oblique tows were made. The net had 153-µm mesh and was raised from a depth of 40 m to the surface 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 a flow meter on the Clarke-Bumpus sampler. The net and flow meter were calibrated in a flume at the Civil Engineering Department at the University of British Columbia.

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 and biomass (estimated from empirical length-weight regressions, McCauley 1984). 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 2007-2014. From 2004-2014 mysid samples were collected from station KLF 8 located in the West Arm. 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, 210 µm 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 have been enumerated for 50 years. Enumeration methods are described in detail by Redfish Consulting Ltd. (1999) and 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 ground estimates were also made of kokanee numbers in Meadow Creek downstream of the channel. In years of high spawner numbers, some fish were manually passed upstream of the channel through 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; see Redfish Consulting Ltd. (1999) for detailed fry enumeration methods. Age at maturity was determined from spawner samples using otolith interpretation methods described by Casselman (1990).

Lardeau River spawners were enumerated irregularly beginning in 1964 then annually since 1979 (with the exception of 1985). Due to the high cost of enumerating the Lardeau River via helicopter, only a single peak count estimate was conducted historically to provide an estimate useful for understanding population trends. The peak of spawning was reasonably well known based on the daily count information of nearby Meadow Creek. In 2014 multiple flights on the lower Duncan River occurred under a separate project which also informed peak timing for the Lardeau flight. In 2015 three flights of the entire Lardeau occurred to determine a peak count estimate. These data are not considered valid to provide a statistical estimate of absolute abundance for the Lardeau River, but are rather an index of abundance to help inform total North Arm escapement trends.

South Arm spawning streams in BC were assessed by experienced fisheries personnel that conducted bank counts of areas accessible to spawning kokanee, or conducted spot counts only at pre-determined sites along the stream. The spot check sites and reaches are presented in Appendix 4. These index sites have changed minimally over the course of the time series. The surveys occurred approximately every week from late August to the end of September. The index streams included Crawford, Grey, Lockhart, LaFrance, Akokli, Boulder, and Summit creeks and Goat River. In 2014, the first count was on Aug 29th and the last count was on Sep 24th (number of counts per stream varied). In 2015, the first count was on Sep 10th and the last count was Sep 24th (all streams were counted three times). 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

South Arm Tributaries

The term ‘eyed-egg’ plants refer to plants of eggs that were developed at a hatchery to the eyed life stage. Eyed-egg plants in South Arm tributaries took place in BC from 2005-2012 and in Idaho from 1997-2012. Assumedly, progeny from the egg plants in 2012 were still rearing in the lake as 1+ and 2+ during 2014 and 2015. No collection of kokanee eggs for stocking South Arm tributaries took place in 2013 due to the detection of infectious hematopoietic necrosis virus (IHN) in Meadow Creek spawning stock in 2013. Eggs were not collected in 2014 and 2015 due to the low escapement.

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

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 ground 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. Placement of eggs was done by pouring the eggs in water into the pipe semi buried into the substrate. As the pipe filled with eggs it was gradually pulled 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 later years (2008-2013), an alternate method was used to plant a portion of the eggs in the South Arm Kootenay Lake tributaries. Perforated tubes (~20 cm long) were filled with 30,000–35,000 eyed eggs per tube, placed in a trench in the substrate, and weighted with rocks and then covered with gravel.

Meadow Creek Spawning Channel

In the fall of 2015, 477,500 eyed-eggs (collected from Hill Creek spawning channel on Arrow Reservoir) were planted into Meadow Creek spawning channel in an attempt to bolster low kokanee abundance. The top 150 m of the spawning channel was reserved for the artificial redds. This allowed for separate enumeration of fry to evaluate the success of plants. Artificial redds were created along 15 transects within the spawning channel and three different methods used to bury the eggs in order to reduce risk of any one method failing:

1) Wooden box method – Spades were used to dig a depression in the gravel to a depth of about 20 cm below water level inside an open-bottom plywood box (approximately 0.5 m x 1.5 m) held on top of the substrate perpendicular to the current. Eyed eggs were spread among the crevices in the excavated area and gently covered with a layer of gravel before the box was removed. Approximately 150,000 eggs (30%) were buried in Transects 1 to 3 by this method.
2) PVC pipe method - Placement of eggs was done by pouring the eggs in water into a pipe semi buried into the substrate. As the pipe filled with eggs it was gradually pulled 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. Approximately 50,000 eggs (10%) were buried in Transect 4 by this method.

3) Perforated tubes - Tubes (~50 cm long) were filled with approximately 5,600 eyed eggs per tube, placed in a trench in the substrate, and covered with gravel. Redds were developed by digging a trench 25-30cm below water level and perpendicular to the current. Tubes were weighted with rocks and covered with gravel from the spawning channel. For five tubes on Transect 6 the method was modified by adding gravel to the inside of the tubes along with the eggs before they were buried to test performance of eggs with gravel. Approximately 300,000 eggs (60%) were buried in Transects 5-15 using the perforated tube method.

Trawl and Hydroacoustic Sampling

Two night time hydroacoustic and trawl surveys were conducted on Kootenay Lake in 2014 during the nights of June 24–27 and September 24-26 and in 2015 on June 18-22 and September 15-17. 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, 2004–2015.

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	-	-
2014*	June	24-26	-	-
2015*	June	18-22	-	-

*No early summer trawling due to low densities and poorly defined fish layer.

Trawl Surveys

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. Fall trawl surveys typically consisted of three stepped-oblique trawls (oriented west, center, and east) at each of six stations, KLF 1, 2, and 4-7 (Fig. 2). Each trawl consisted of 5 layers at eight-minutes each ranging from 20-45 m depth to capture a representative sample of fish from each depth strata. When excessive fry were captured in the first two trawls at any station the third trawl at that site was not conducted, as was the case for KLF 1 in 2014, where only 2 trawls occurred. All three trawls at each of the 6 sites were conducted in 2015. Trawl gear consisted of an opening and closing 5 x 5 m beam trawl, 20 m long with 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. An exception to the standard methodology and equipment occurred in 2015, when the usual trawl vessel experienced mechanical issues and was unable to complete Woodbury Station (KLF 4). Instead, a 7 x 3 m beam trawl (depth by width), 21 m long with graduated mesh size (6-92 mm stretched), was towed utilizing the same methodology but covering 20 – 33 m depths in two thirty minute layers. While the depth range trawled was less than the standard range, the majority of the fish layer was sampled as very low densities of fish were observed in the acoustic data below 33 m. This increased the effort and total catch at Woodbury Station, although still maintained the oblique trawl method (i.e., approximately the entire fish layer was sampled equally), which is important for determining age structure among the age 1-3+ Kokanee. The methods were adapted at Woodbury station in this fashion partly due to the different trawl net opening size, but also in an attempt to increase the total sample size for biological statistics given the very low catch rate at other stations in 2015.

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., it was concluded that trawling was unlikely to be successful at other locations in the South Arm where acoustic densities were even lower). During the 2014 and 2015 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) in Appendix 5.

Hydroacoustics

Acoustic data for each survey were collected at 18 standard 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 6). 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 approximately 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). 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. A stochastic simulation (a Monte Carlo method) approach approximated 95% confidence. For each depth stratum 30,000 random realizations of normal distribution were calculated with a mean being the stratum mean and the standard deviation being the standard error of the population mean estimate. The 0.05 and 0.95 quantiles were taken as the 95% confidence intervals. Simulations were done in the statistical programming environment R (R Core Team, 2014). Bounds were produced for the entire fish population, fry sized 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 10 for biomass calculations and results.

Kokanee Survival

Meadow Creek Spring Fry to Adult Survival

Kokanee fry to adult (spawner) survival rates were estimated using the Meadow Creek long-term data set for total fry production and adults returning. Fry production data 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 were 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 have been 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 also calculated and presented fry to adult survival for each fry cohort based on adult return age proportions from otolith analysis. No attempt was 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.

North Arm Egg to Fall Fry Survival

Egg deposition estimates were calculated by applying the annual sex ratio and fecundity data from Meadow Creek Spawning Channel to both Meadow Creek and Lardeau spawner counts for a combined total North Arm egg deposition. Survival rates to fall fry were calculated using the acoustic age 0+ estimates. For the purpose of this analysis, total Meadow Creek egg deposition was used (channel and non-channel).

Fall Fry to 1+ Survival

Fall fry to 1+ survival estimates were determined using acoustic and trawl derived age specific estimates. Note that the age 1+ estimates (found in Appendix 9) may be less robust than the age 0+ estimates, and are susceptible to an undetermined degree of trawl bias. These estimates are not considered robust statistical estimates of age 1+ abundance; however we believe they adequately represent the trend in age 1+ abundance allowing for evaluation of survival trends.

RESULTS

Physical Limnology

Temperature

West Arm

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 in 2014 and 2015 were fairly uniform from surface to bottom, although more stratification was observed in summer months. Peak temperature was observed on August 5th, 2014 and on July 27th in 2015 (Table 4).

Table 4. Seasonal mean and standard deviation (SD) of temperatures (^{o}C) in the West Arm (KLF 8) taken at 0–35 m depths, 2014 and 2015. Seabird malfunction Jul-Nov in 2014.

Month	2014			2015		
Category	Date	Mean	SD	Date	Mean	SD
Apr	2014-04-07	4.87	0.20	2015-04-07	5.47	0.29
May	2014-05-12	6.55	0.25	2015-05-04	8.24	0.37
Jun	2014-06-04	10.45	0.26	2015-06-01	11.87	0.28
Jun#2	2014-06-23	12.59	0.35	2015-06-15	14.69	0.37
Jul				2015-06-29	17.36	0.34
Aug				2015-07-27	18.42	0.46
Sep				2015-08-28	18.03	0.14
Oct				2015-09-28	14.77	0.26
Nov				2015-10-26	13.02	0.04

Main Lake

In 2014, the main body of Kootenay Lake (stations KLF 1–7) began warming in May with a thermocline developing in June at KLF 2. Hypolimnetic temperatures remained at 4–6 ^{o}C throughout the year (Fig. 5).

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).

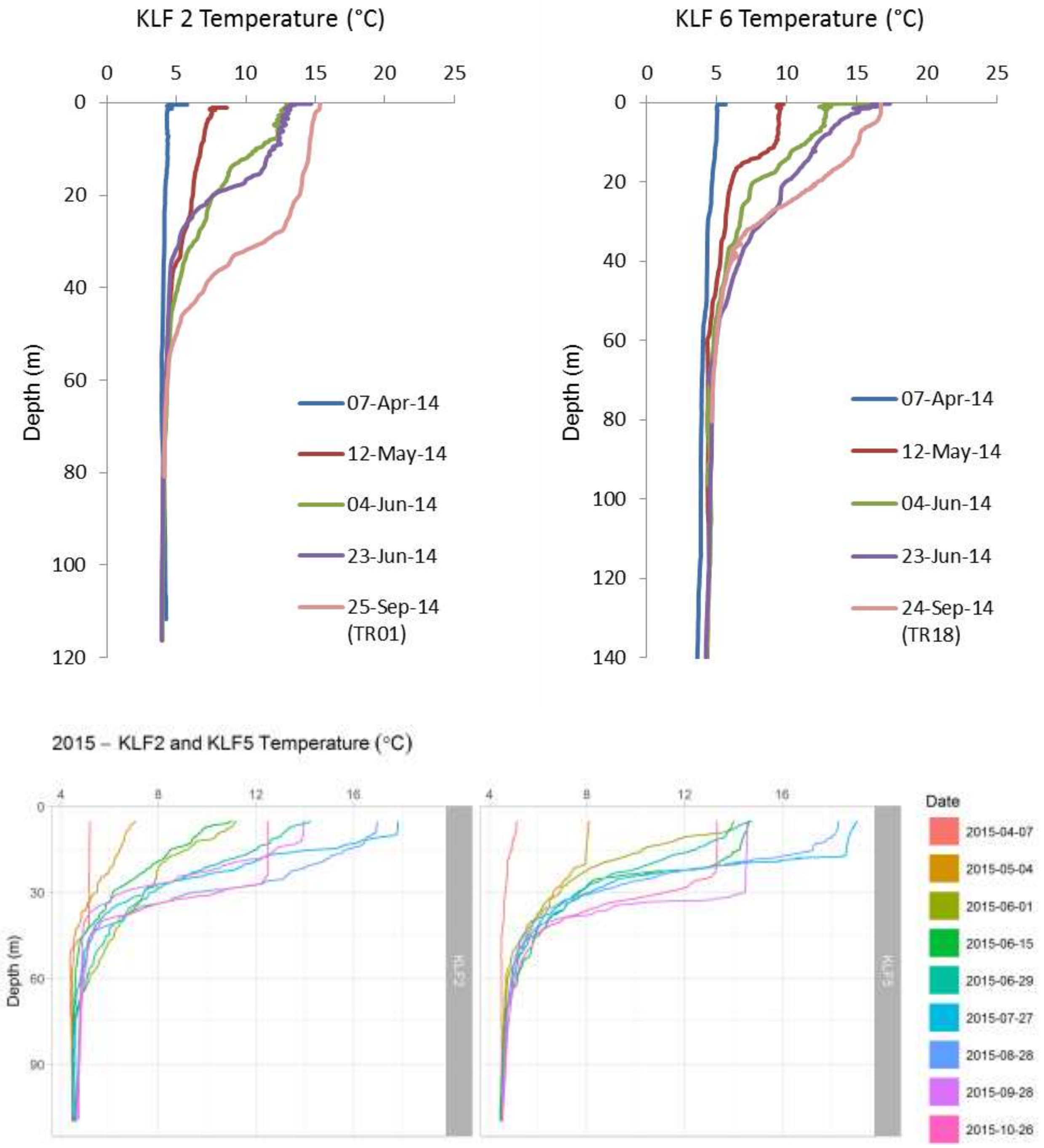


Figure 5. Temperature profiles at a North Arm station (KLF2) and a South Arm station (KLF6 - 2014; KLF5 - 2015), April to October, 2014 and 2015.

Dissolved Oxygen

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 2014 and in 2015 oxygen ranged between 5-10 mg/L, was consistent through the water column, and typical of an orthograde profile. Nutrient enrichment has had no detectable effect on hypolimnetic oxygen concentrations.

Long term temperature and precipitation trends (1992-2015)

The seasonal water temperatures for both the North and South Arms were above the mean (Fig. 6). Generally in 2014, water temperatures were similar to the previous year (2013), aside from a decrease in the summer in the North Arm and an increase in the fall in the South Arm. In 2015, water temperatures were above the long term mean for both the North and South Arms for all seasons, with the exception of fall water temperatures in the South Arm.

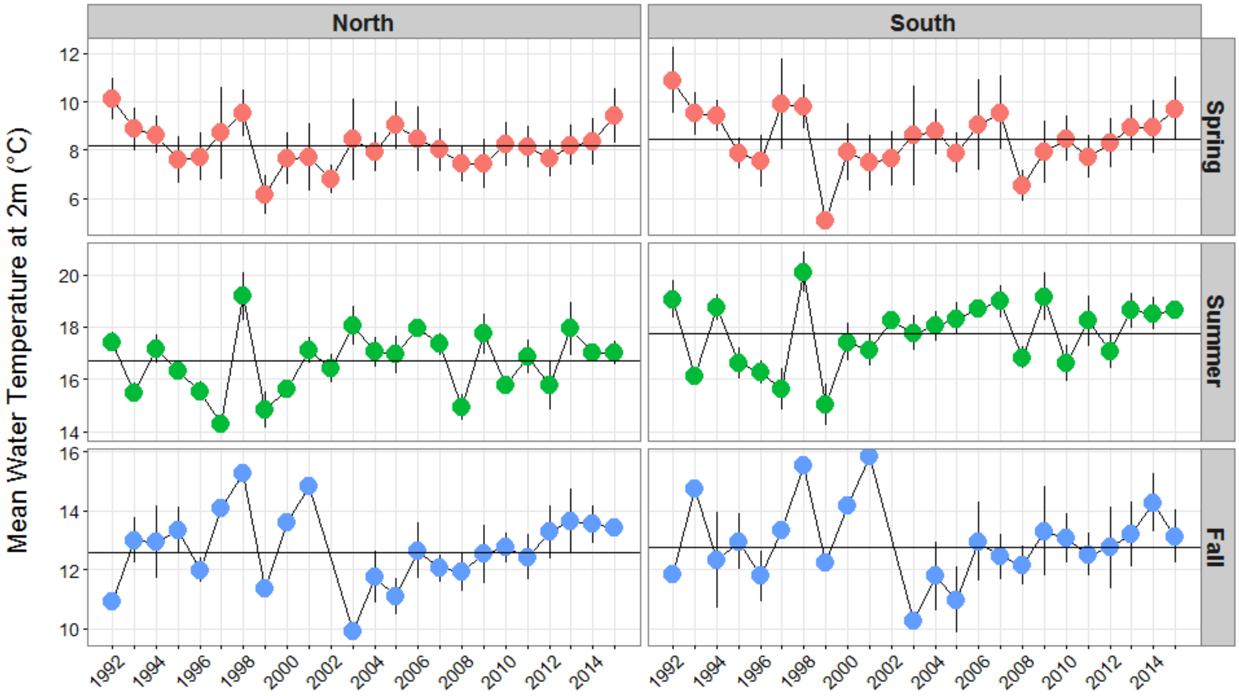


Figure 6. Annual mean water temperatures (°C) at 2m by Arm (North; KLF1-4 and South; KLF 5-7) and by season 1992-2015. Means ±SE.

For air temperatures in 2014, winter and spring temperatures were similar to the average from 1992-2015 while the summer temperature was higher than the long term mean (Fig. 7). The 2014 fall temperature however was substantially higher than the long term mean and was the highest in the 1992-2015 dataset. In summary, 2014 was a near average year for air temperatures, with the exception of higher than average summer and fall air temperatures. In 2015, winter air temperatures were higher than average, driven mostly by higher February and March temperatures. Similarly, spring air temperatures were above average, particularly in June. Fall air temperatures were also above average, while summer air temperatures were near average. In summary, 2015 was a warmer year on average relative to the long-term mean.

Precipitation in 2014 was similar to the long term 1992-2015 mean for all seasons (Fig. 8), with the exception of fall months where daily total precipitation was high. In 2015, precipitation was more variable relative to the long term mean; winter and fall were above the average, whereas spring and summer daily precipitation was well below average.

In summary, the climatic conditions in 2014 were near average; whereas 2015 was a warmer year with lower than average precipitation.

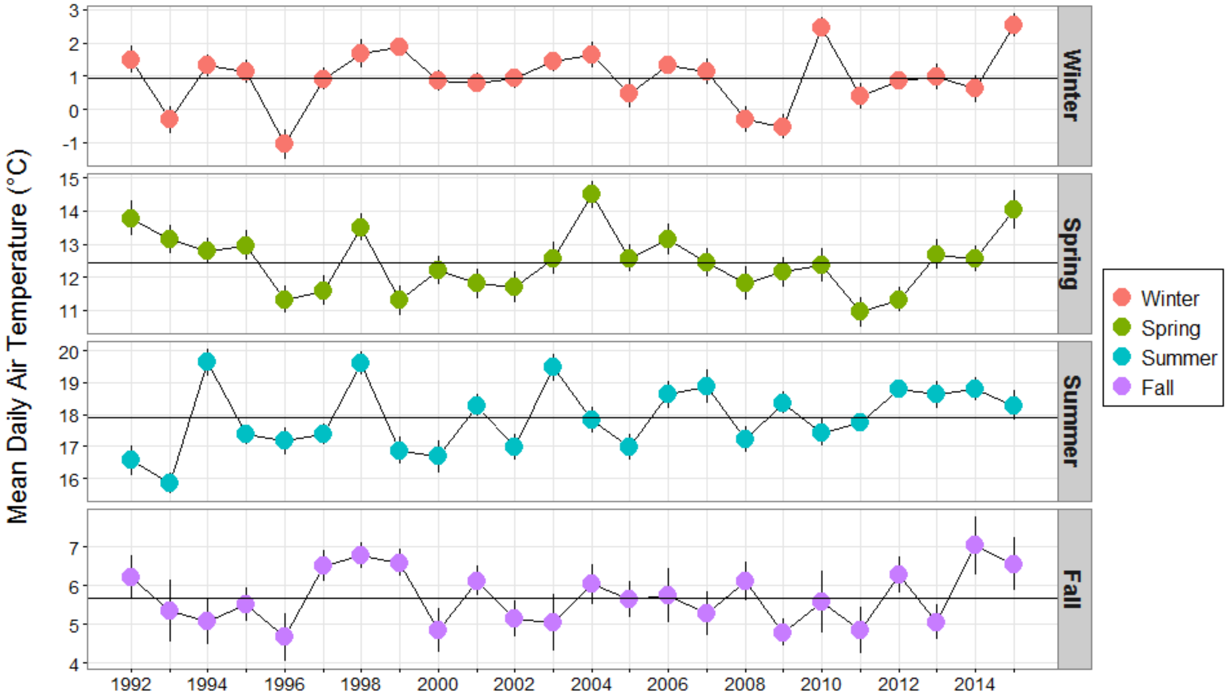


Figure 7. Annual daily mean air temperatures (°C) recorded at the Nelson city airport 1992-2015 by season. Note winter data is from Jan-Mar and Dec of that respective Year. Means ±SE.

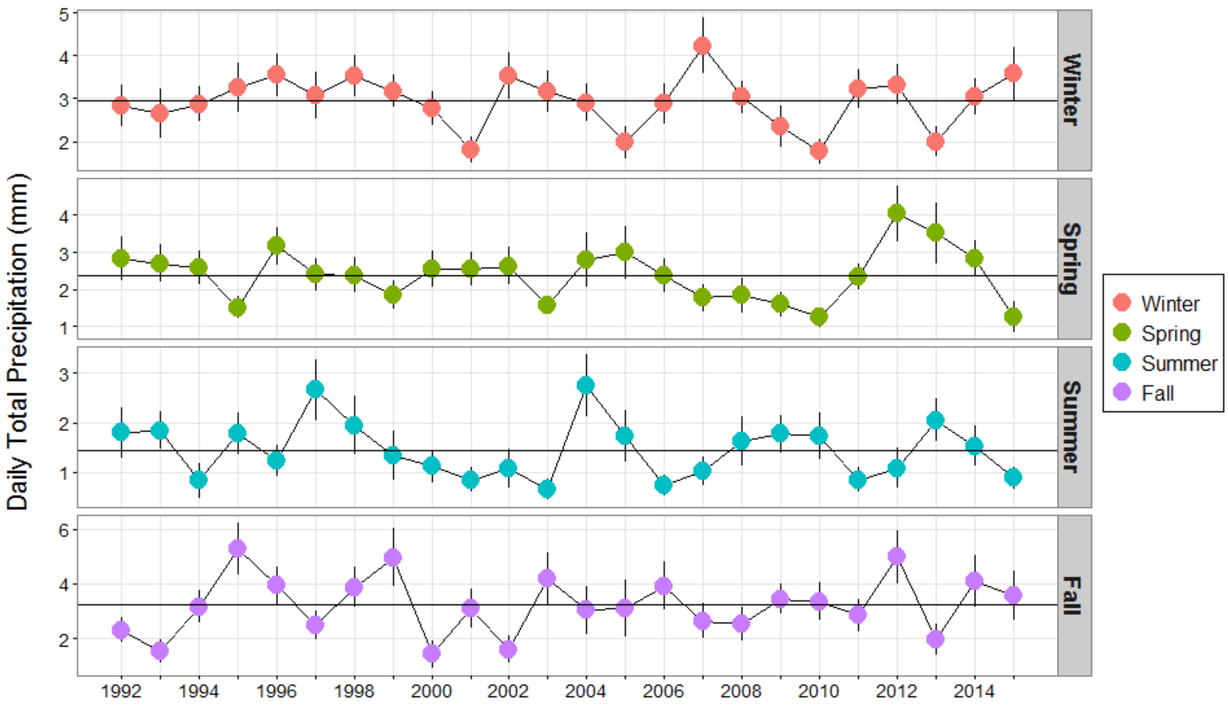


Figure 8. Seasonal total daily precipitation daily mean air temperatures (mm) recorded at the Nelson city airport 1992-2015 by season. Means ±SE.

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 2014 and 2015 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. 9). In 2014 and 2015, there were not significant differences in Arm means (Table 5). However, in both years there were significant differences in the season means, where the highest transparency was observed in the fall and lowest in the summer (Table 5). In 2014, there was a slight decrease in Secchi depths from 2013 in all Arms, and in 2015, Secchi depths were similar to 2014 (Fig. 10). Aside from slightly higher transparency in the North Arm, 2014 and 2015 annual Arm means were similar to the long term means (Fig 10).

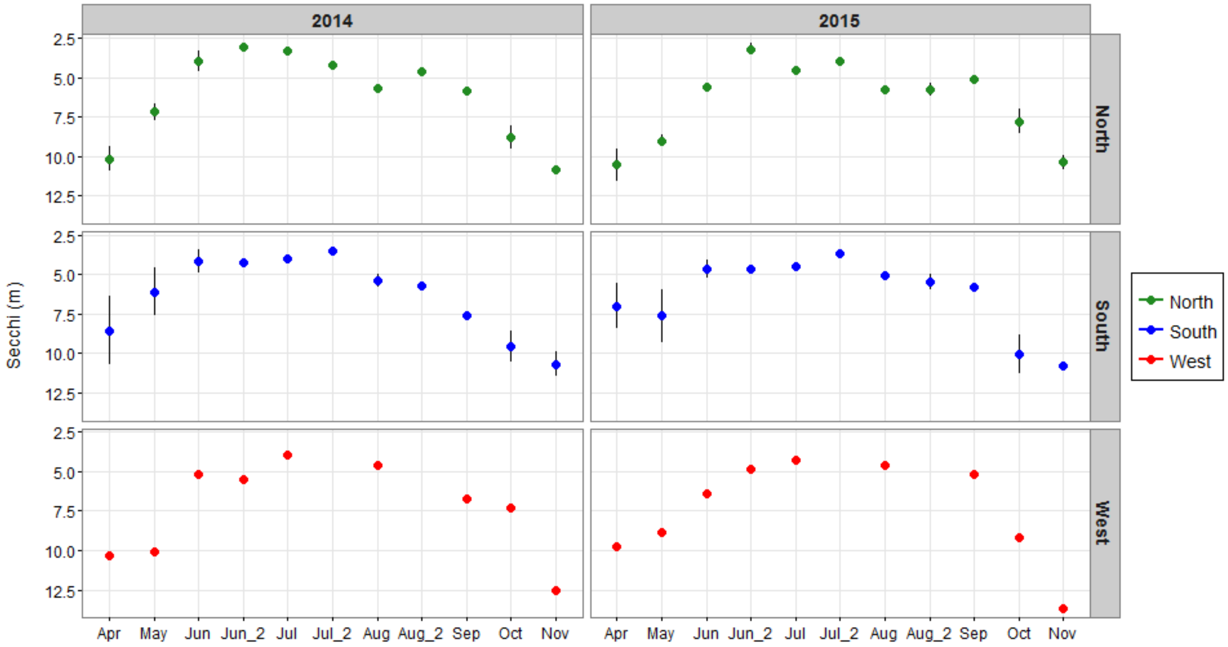


Figure 9. Secchi disc measurements (m), North (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November 2014 and 2015. Jul_2 and Aug_2 are stations KLF 2 and KLF 6 only. Note y axis is in reverse. Means ±SE.

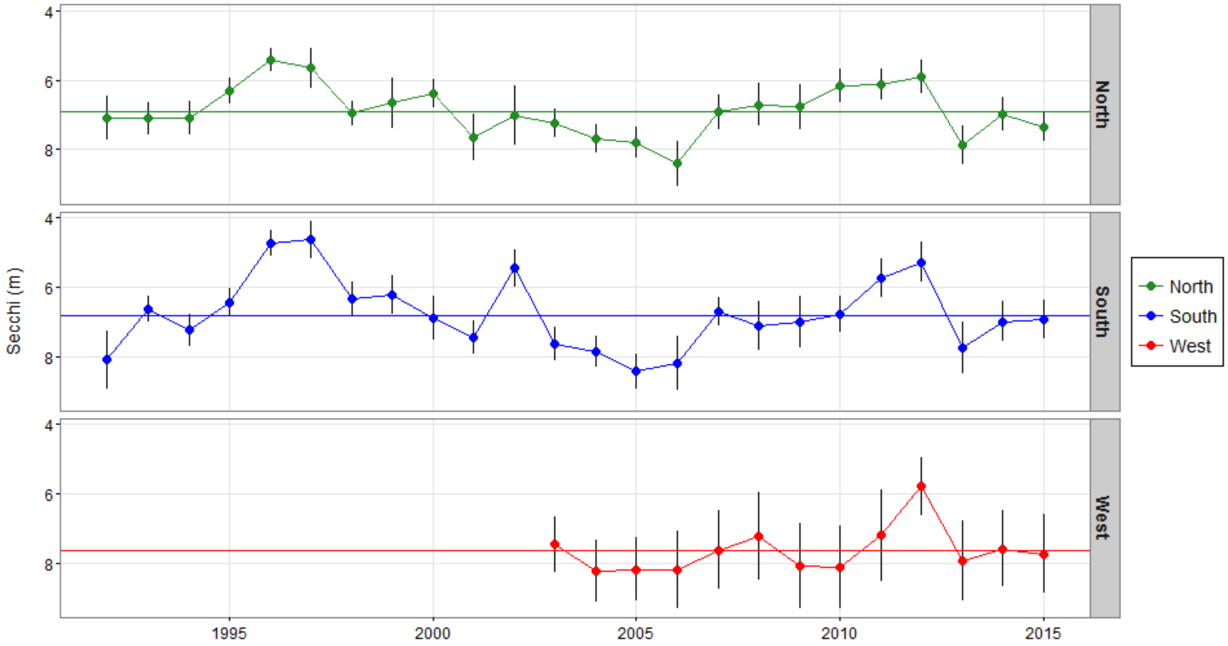


Figure 10. Annual Apr-Nov monthly mean of Secchi disc measurements (m) by Arm. Solid lines are the long-term means for North, South (1992-2015) and West (2004-2015) Arms. Note y axis is in reverse. Means ±SE.

Water Chemistry

Integrated Epilimnion

Table 5. Comparison of Arm means (North=KLF1-4, South=KLF5-7 and West=KLF8) and Season means (Spring=Apr-Jun, Summer=Jul-Sep and Fall=Oct-Nov), Jun_2, Jul_2 and Aug_2 were omitted from analysis. Letter denotes a significant difference at 0.05. * indicates parameter was logged prior to analysis.

		Arm			**Season**		
Parameter		**North**	**South**	**West**	**Spring**	**Summer**	**Fall**
Secchi	2014	6.97^{a}	7.00^{a}	7.58^{a}	6.96^{b}	5.25^{a}	9.93^{c}
m	2015	7.35^{a}	6.94^{a}	7.74^{a}	7.65^{b}	5.08^{a}	9.87^{c}
TP*	2014	3.52^{a}	3.86^{a}	3.39^{a}	3.82^{a}	3.83^{a}	3.04^{a}
µg/L	2015	3.94^{a}	4.96^{a}	4.95^{a}	5.637^{b}	4.43^{b}	2.72^{a}
TDP*	2014	3.35^{a}	3.52^{a}	3.46^{a}	3.77^{b}	3.56^{b}	2.73^{a}
µg/L	2015	2.50^{a}	2.74^{a}	2.38^{a}	3.40^{b}	2.03^{a}	2.16^{a}
OP*	2014	1.16^{a}	1.18^{a}	1.14^{a}	1.20^{a}	1.22^{a}	1.03^{a}
µg/L	2015	1.19^{a}	1.30^{a}	1.23^{a}	1.57^{b}	1.00^{a}	1.05^{ab}
TN*	2014	215.84^{a}	244.83^{b}	217.25^{ab}	229.83^{ab}	207.33^{a}	251.81^{b}
µg/L	2015	174.53^{a}	193.09^{a}	191.00^{a}	212.50^{b}	162.17^{a}	169.21^{a}
DIN	2014	117.53^{a}	139.13^{a}	117.94^{a}	160.58^{c}	93.34^{a}	121.84^{b}
µg/L	2015	114.18a	121.67^{a}	114.28^{a}	159.70^{c}	77.45^{a}	112.25^{b}
N:P	2014	38.42^{a}	43.69^{a}	40.29^{a}	48.83^{b}	27.84^{a}	47.52^{b}
DIN/TDP	2015	46.99^{a}	48.15^{a}	47.41^{a}	52.31^{b}	38.25^{a}	54.06^{b}
Turbidity	2014	0.37^{a}	0.40^{a}	0.37^{a}	0.38^{ab}	0.47^{b}	0.26^{a}
NTU	2015	0.38^{a}	0.39^{a}	0.36^{a}	0.32^{a}	0.50^{b}	0.30^{a}
Silica	2014	3.46^{a}	4.29^{b}	3.73^{ab}	4.90^{b}	3.14^{a}	3.14^{a}
mg/L	2015	2.92^{a}	3.21^{a}	3.06^{a}	4.65^{a}	1.78^{a}	1.90^{a}
pH	2014	7.89^{a}	7.96^{b}	7.97^{ab}	7.92^{a}	7.94^{a}	7.92^{a}
pH units	2015	8.03^{a}	8.11^{b}	8.10^{ab}	8.01^{a}	8.14^{b}	8.05^{a}
Alkalinity	2014	56.70^{a}	67.73^{b}	63.75^{b}	64.96^{b}	58.71^{a}	61.35^{b}
mg/L	2015	62.13^{a}	72.98^{b}	69.90^{b}	65.08^{a}	67.87^{a}	69.26^{a}
TOC*	2014	1.19^{a}	1.78^{b}	1.84^{ab}	1.28^{a}	1.80^{b}	1.36^{ab}
mg/L	2015	1.17^{a}	1.51^{b}	1.31^{ab}	1.24^{a}	1.44^{a}	1.23^{a}

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. Of the integrated samples in 2014, 5% of total phosphorus (TP), 9% of total dissolved phosphorus (TDP) and 54% of orthophosphate values were under the RDL. In 2015, 18% of total phosphorus (TP), 57% of total dissolved phosphorus (TDP) and 85% of orthophosphate values were under the RDL.

Total phosphorus varied minimally over the sampling season in 2014 (Fig. 11). There was no difference between the Arms, or between the seasons (Table. 5). All observations were under the water quality guidelines (10 µg/L) in 2014 (Fig 11). In 2015, there was not a significant difference between Arm means, however there was a seasonal expression; with the spring and summer means higher than the fall mean (Fig 11 and Table 5). A portion of the results for April and September in the West Arm were above water quality guidelines (Fig 11). Overall, the annual means for 2014 and 2015 were below the long term means, with the exception of the West Arm, where the 2015 mean was above the long term mean (Fig. 12).

Total dissolved phosphorus (TDP) also did not differ across Arms in 2014 or 2015 (Table 5). However, there was a seasonal expression where fall TDP was significantly lower than the spring and summer means in 2014, and in 2015 where spring TDP was significantly higher than summer and fall TDP means (Fig. 13 and Table 5). The 2014 mean was slightly up from the 2013 means for all Arms. 2015 saw a decrease from 2014 means (Fig. 14).

Orthophosphate in both years did not differ spatially across Arms (Table 5). In 2014 there was not a significant difference across seasons, however in 2015 the spring mean for orthophosphate was significantly higher than the summer mean (Table 5).

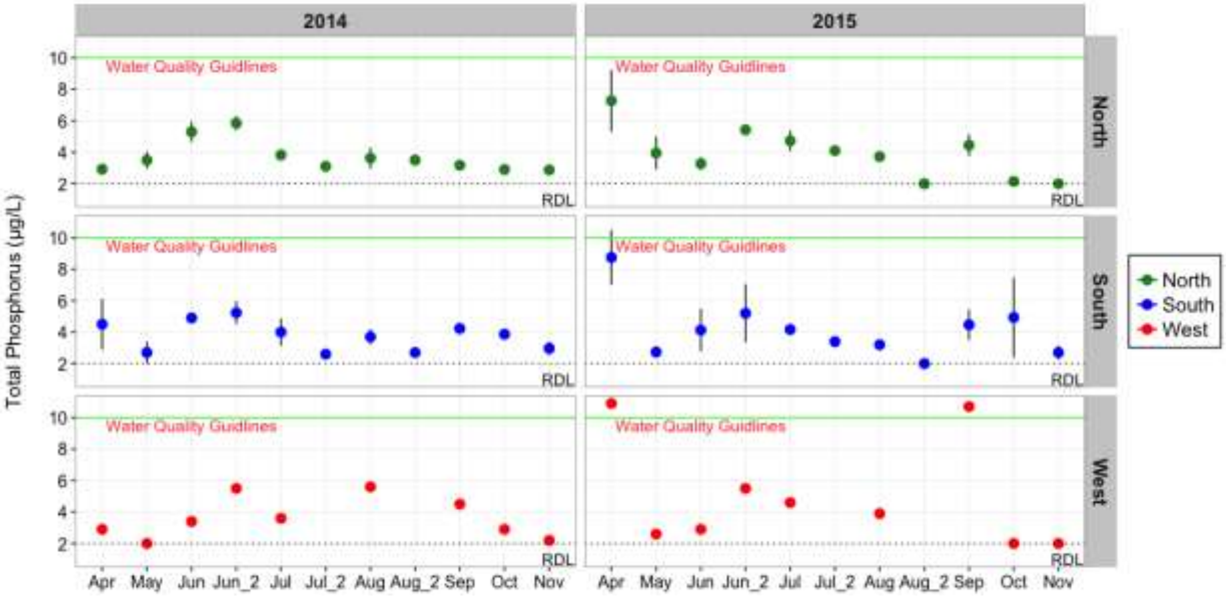


Figure 11. Total phosphorus (µg/L) North (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November 2014 and 2015. Jul_2 and Aug_2 are stations KLF 2 and KLF 6 only. Means ±SE.

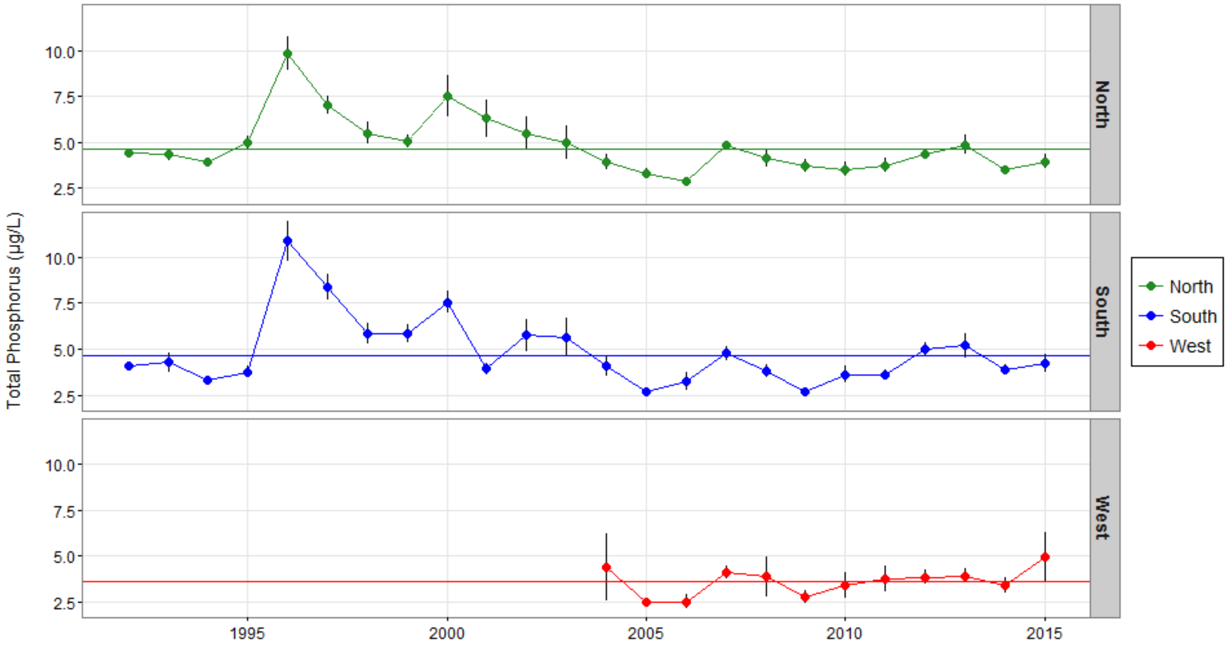


Figure 12. Annual Apr-Nov monthly mean of total phosphorus (µg/L) by Arm. Solid lines are the long-term means for North, South (1992-2015) and West (2004-2015) Arms.

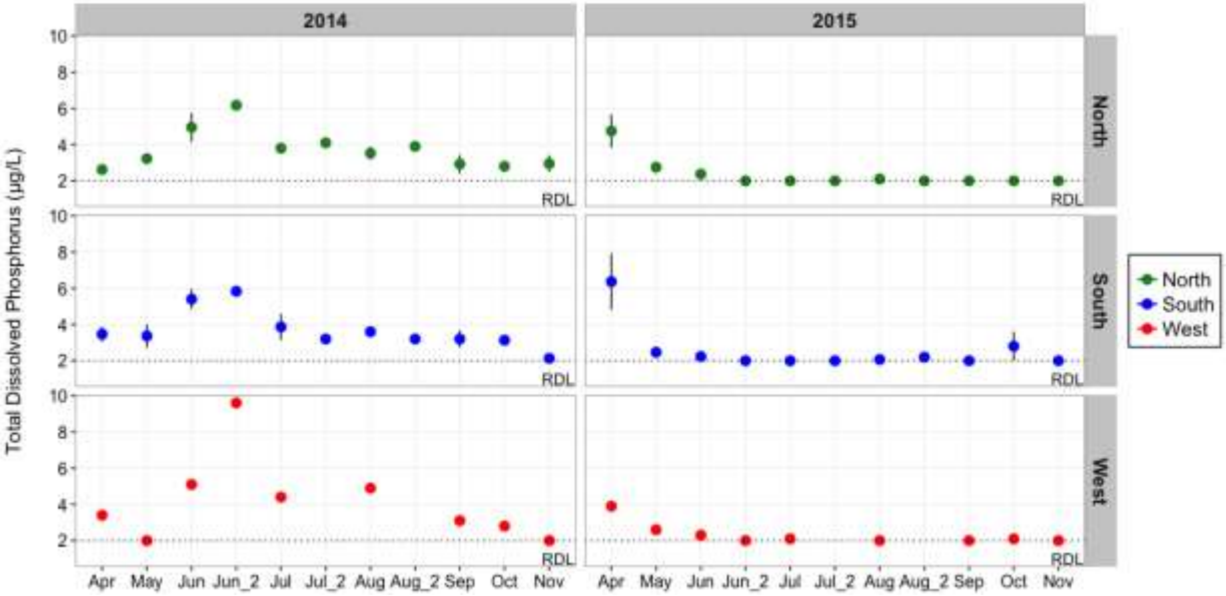


Figure 13. Total dissolved phosphorus (µg/L) North (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November 2014 and 2015. Jul_2 and Aug_2 are stations KLF 2 and KLF 6 only.

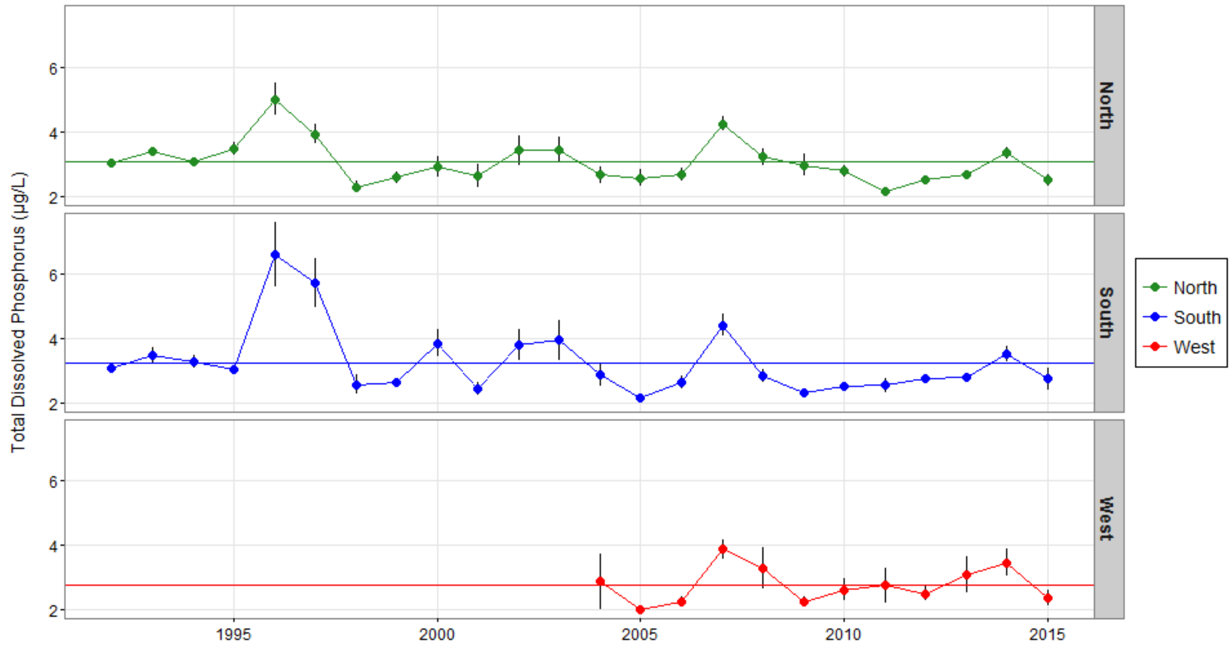


Figure 14. Annual Apr-Nov monthly mean of total dissolved phosphorus (µg/L) by Arm. Solid lines are the long-term means for North, South (1992-2015) and West (2004-2015) Arms.

Nitrogen

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

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 was not analyzed in 2008 to 2014; therefore, the dissolved inorganic nitrogen is represented by the nitrate and nitrite data plus an inferred ammonia value of 5 µg/L. In 2015, ammonia was again tested for and included in the dissolved inorganic nitrogen calculation.

Total nitrogen in Kootenay Lake in 2014 differed spatially and temporally (Fig. 15). Total Nitrogen in the North Arm was significantly lower than the South Arm, and seasonally, summer TN was lower than fall TN (Table 5). In 2015, TN did not differ across Arms (Table 5), however there was a significant difference in the spring mean to the rest of the sampling season, where the highest TN results were observed in the spring. In 2014 there was a slight increase from 2013 in TN, whereas in 2015 the annual mean was similar to the long term means for each Arm (Fig. 16).

Dissolved inorganic nitrogen in 2014 started highest in the spring, became lowest in the summer, and then increased again into the fall, a trend that was observed across seasons again in 2015 (Fig. 17 and Table 5). There was not a difference between the Arms for either 2014 or 2015. Dissolved inorganic nitrogen in 2014 increased slightly from 2013, whereas in 2015 a slight decrease from 2014 was observed in all Arms (Fig. 18). Both years were above the long term means for each Arm, however sampling methodology changed in 2004 which minimized water sampling from below the thermocline where nitrogen richer water occurs. The integrated samples were collected from 0-30 metres up to 2004 and since then were collected from 0-20 metres. This also coincides with the depth at which the long-term phytoplankton data was collected.

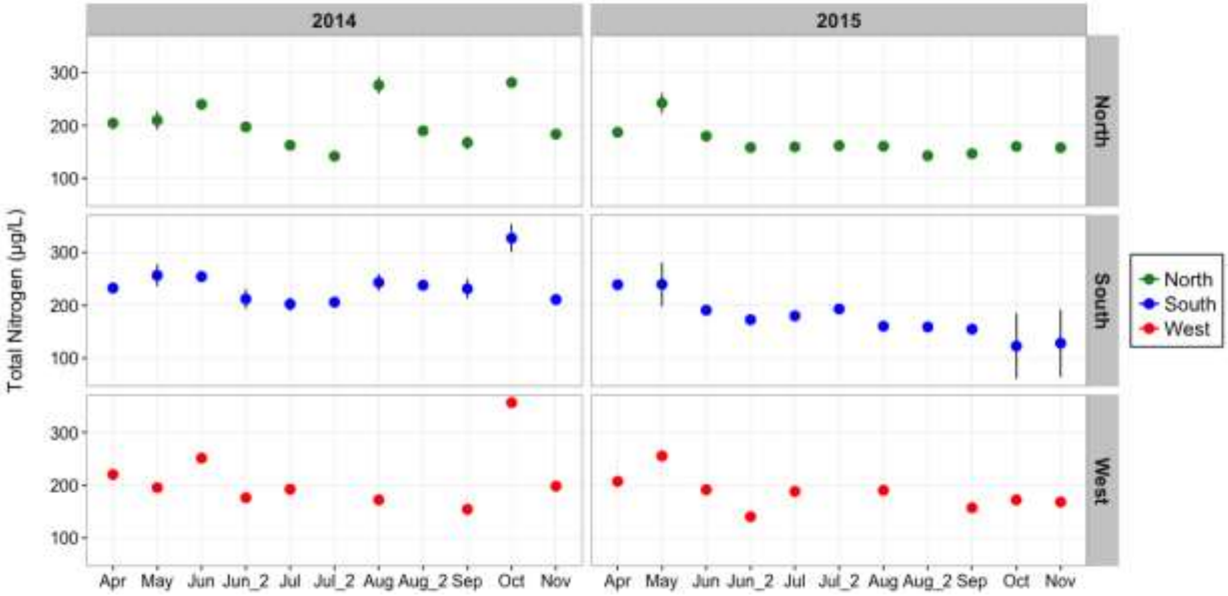


Figure 15. Total nitrogen (µg/L) North (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November 2014 and 2015. Jul_2 and Aug_2 are stations KLF 2 and KLF 6 only.

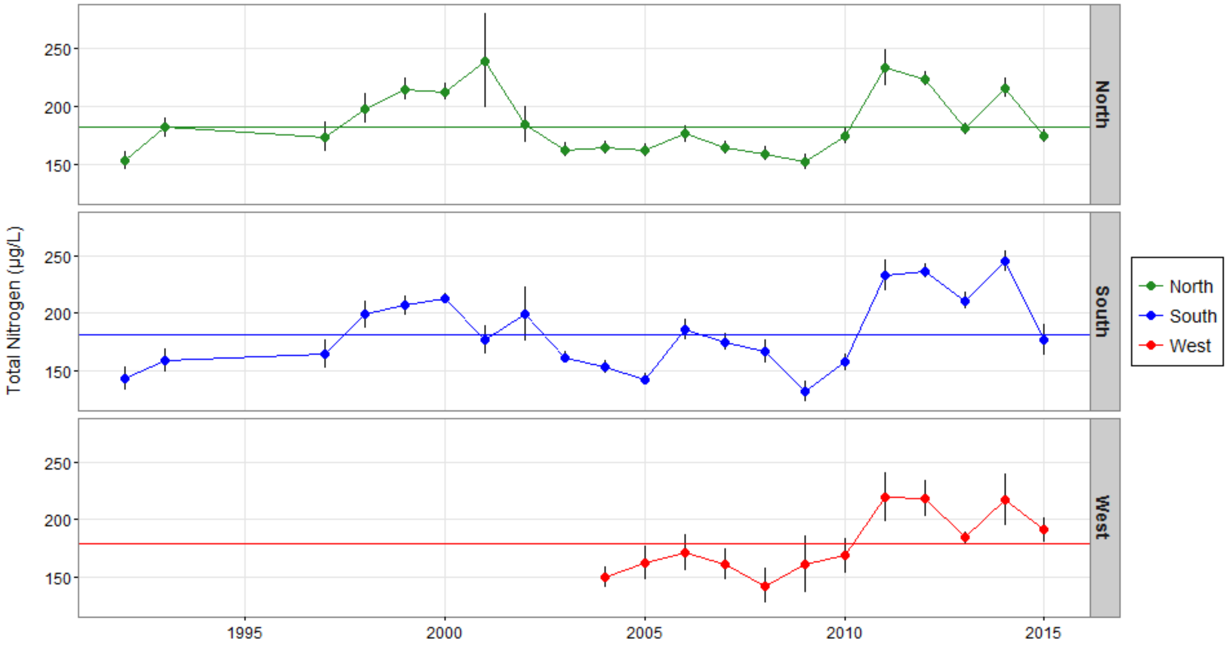


Figure 16. Annual Apr-Nov monthly mean of total nitrogen (µg/L) by Arm. Solid lines are the long-term means for North, South (1992-2015) and West (2004-2015) Arms.

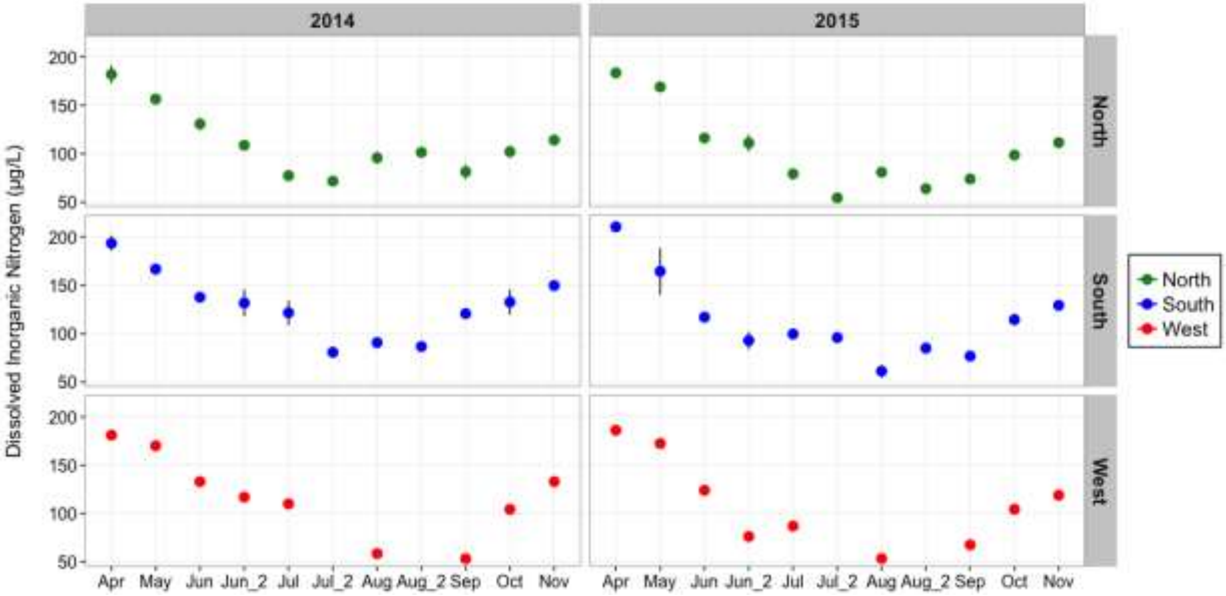


Figure 17. Dissolved inorganic nitrogen (µg/L) North (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November 2014 and 2015. Jul_2 and Aug_2 are stations KLF 2 and KLF 6 only.

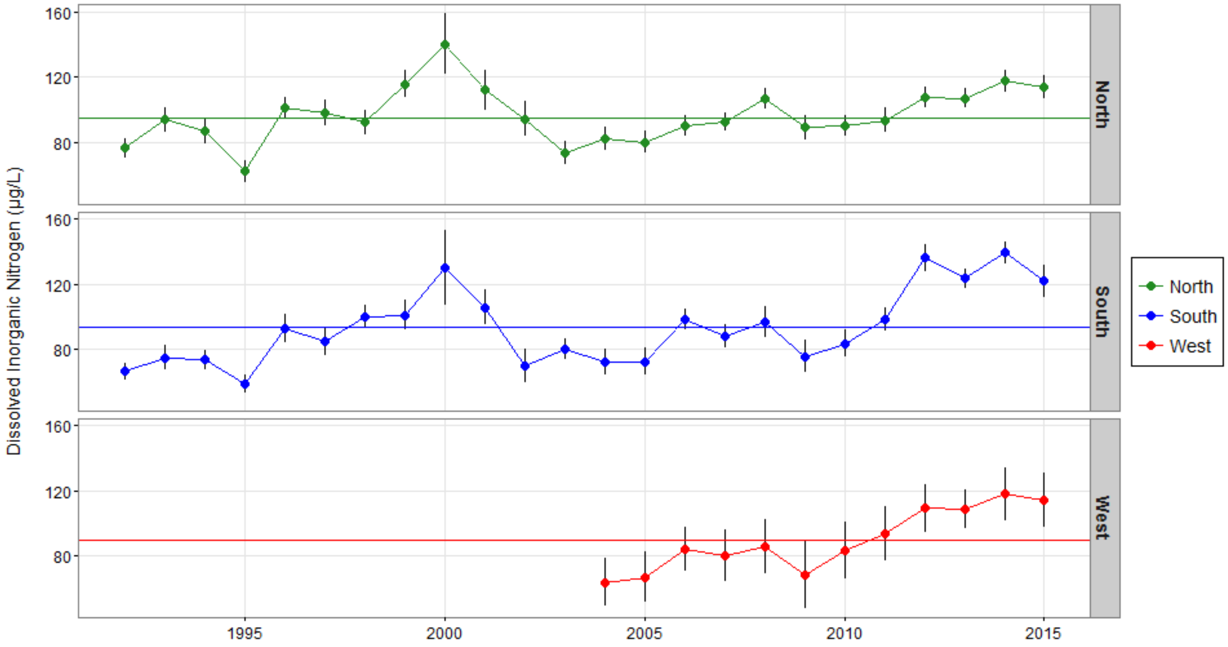


Figure 18. Annual Apr-Nov monthly mean of dissolved nitrogen (µg/L) by Arm. Solid lines are the long-term means for North, South (1992-2015) and West (2004-2015) Arms.

Nitrogen:Phosphorus Ratio

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 < 14:1 (weight:weight) is indicative of nitrogen limitation, and a ratio >14:1 is indicative of phosphorus limitation (Koerselman and Meuleman, 1996).

The N:P ratios in 2014 and 2015 did not differ between Arms (Fig. 19 and Table 5). For both 2014 and 2015 the N:P ratio was lowest in the summer, which follows the trend observed in DIN. The N:P ratio stayed above nitrogen limitation for both 2014 and 2015. The annual mean of N:P in 2014 was slightly higher than the long terms for each Arm, and increased in 2015 from 2014 (Fig. 20).

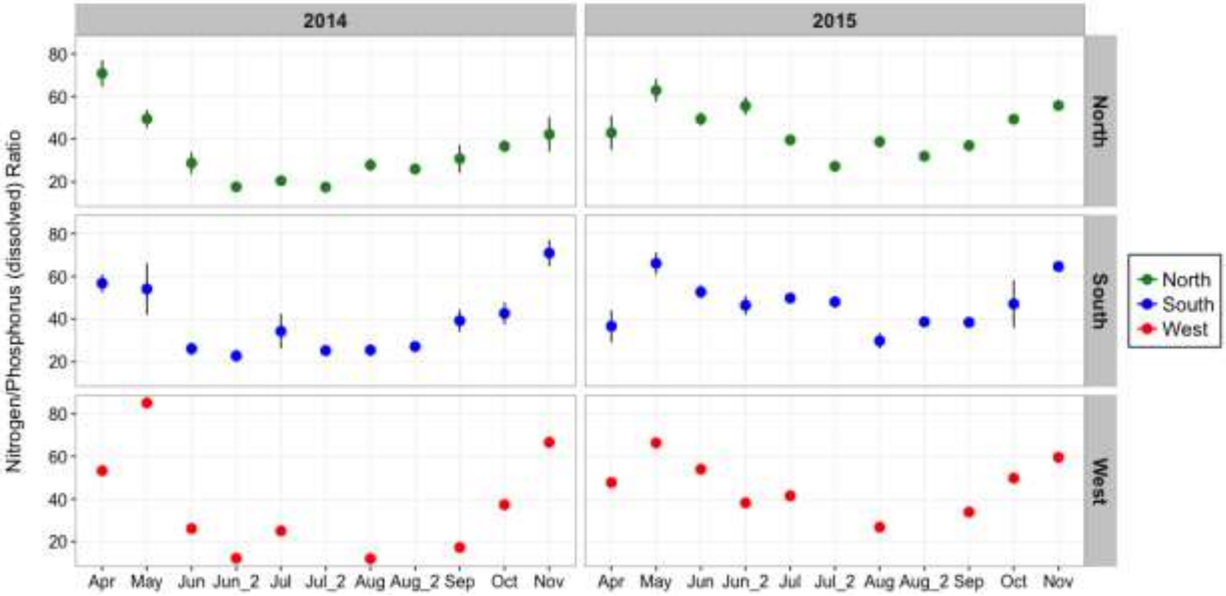


Figure 19. Nitrogen:Phosphorus ratio (dissolved), North (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November 2014 and 2015. Jul_2 and Aug_2 are stations KLF 2 and KLF 6 only.

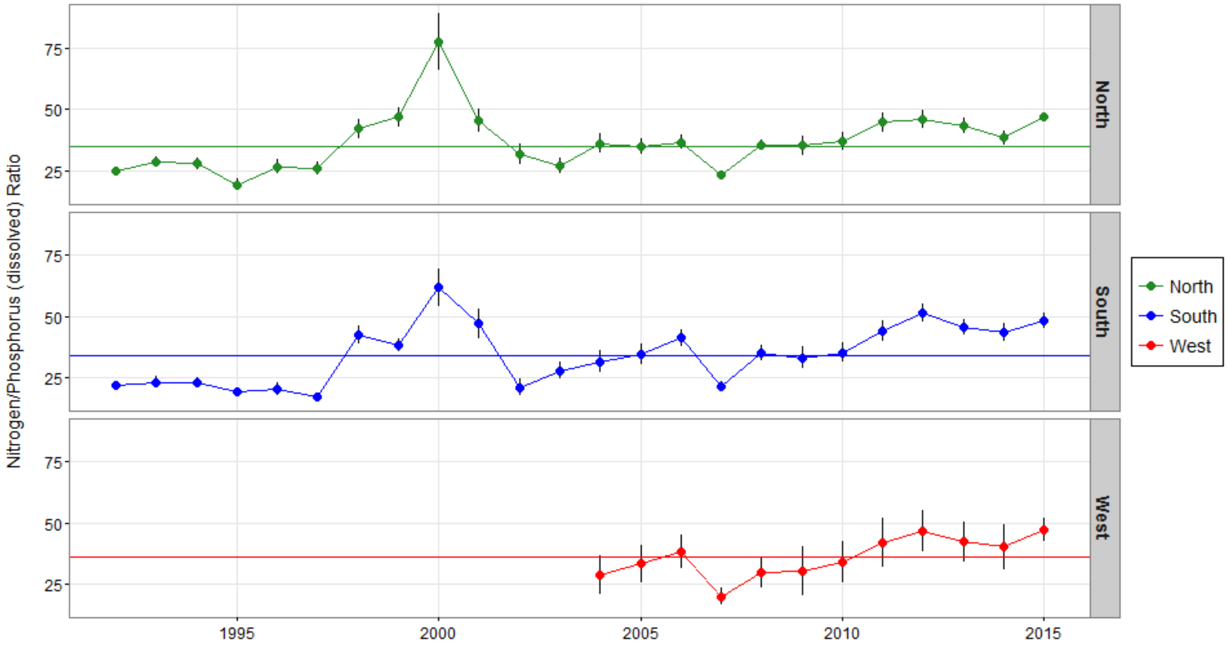


Figure 20. Annual Apr-Nov monthly mean of Nitrogen:Phosphorus ratio (dissolved) by Arm. Solid lines are the long-term means for North, South (1992-2015) and West (2004-2015) Arms.

Turbidity, Silica, Alkalinity, pH and Carbon

Turbidity is caused by suspended particles (e.g., fine particulate matter), plankton, and other small organisms (Wetzel and Likens, 2000). In both 2014 and 2015, turbidity did not differ across Arms (Fig. 20 and Table 5). There was, however a seasonal expression in 2014 where the summer mean of 0.47 NTU was significantly higher than the fall mean of 0.26 NTU (Table 5). In 2015, the summer mean (0.50 NTU) was significantly higher than spring and fall means (Table 5). Turbidity in all Arms was marginally lower than the long term means for each Arm for both years (Fig. 21).

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. In 2014, silica remained above 0.5 mg/L, the concentration at which it is considered limiting for diatoms (Wetzel 2001). In 2014, silica was significantly different across seasons, where spring was the highest. There was no seasonal expression in 2015 (Fig. 22 and Table 5). Silica results did however increase moving north up the main body of the lake (KLF1- KLF7), aside from the summer of 2015 (Fig. 23). In 2014, silica was significantly higher in the South Arm, whereas in 2015, there was no difference across the Arms (Table 5). The annual silica mean in 2014 was similar to the previous years, however a decrease in 2015 from 2014 was observed across all Arms (Fig. 24).

The pH was different between the North and South Arms in both 2014 and 2015 (Fig. 25 and (Table 5). There was not a seasonal expression in 2014, however in 2015 the spring and summer means were higher than the fall mean (Table 5). The annual mean in 2014 was similar to the long term means for each Arm, while in 2015 mean pH increased and was slightly higher than the previous year and the long term mean (Fig. 26). Overall, pH in Kootenay Lake indicated slightly alkaline conditions and results were consistent with values observed since 1997, with the exception of 2005. It is not apparent why pH was lower in 2005.

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 2014, Alkalinity changed seasonally, where the summer mean was significantly lower than the spring and fall means (Fig. 27 and Table 5). In 2015, there was no seasonal expression. In both 2014 and 2015, alkalinity in the North Arm was significantly higher than the South and West Arm alkalinity means (Table 5). Interestingly, alkalinity increased moving north up the lake (Fig. 28). This trend has also been observed in previous years (Bassett et al., 2016). Alkalinity increased in 2015 from 2014 and was higher than the long term means of both Arms (Fig. 29).

Total organic carbon (TOC) includes both dissolved and particulate organic carbon (Wetzel, 2001). Dissolved carbon dioxide and bicarbonate (both forms of inorganic carbon) are the major sources of inorganic carbon for photosynthesis in freshwater systems. Utilization of inorganic carbon provides the foundation for much of the organic productivity in an ecosystem. In 2014 and 2015, the North Arm TOC was significantly higher than the South Arm mean (Fig. 30 and Table 5). In 2014, the summer mean was higher than the spring mean, however in 2015, there was no seasonal expression (Table 5). The North Arm TOC means in 2014 were slightly below the long term mean (1997-2015), whereas in the South and West Arms, 2014 was slightly above, and 2015 slightly below the Arm means (Fig. 31).

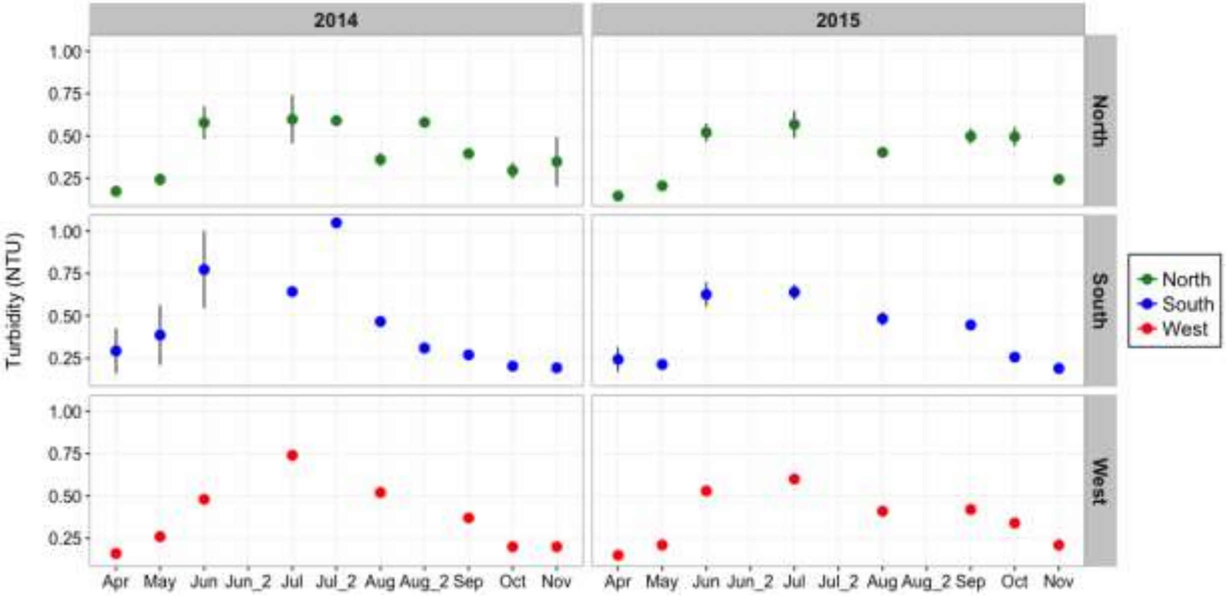


Figure 20. Turbidity (NTU), North (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November 2014 and 2015. Jul_2 and Aug_2 are stations KLF 2 and KLF 6 only.

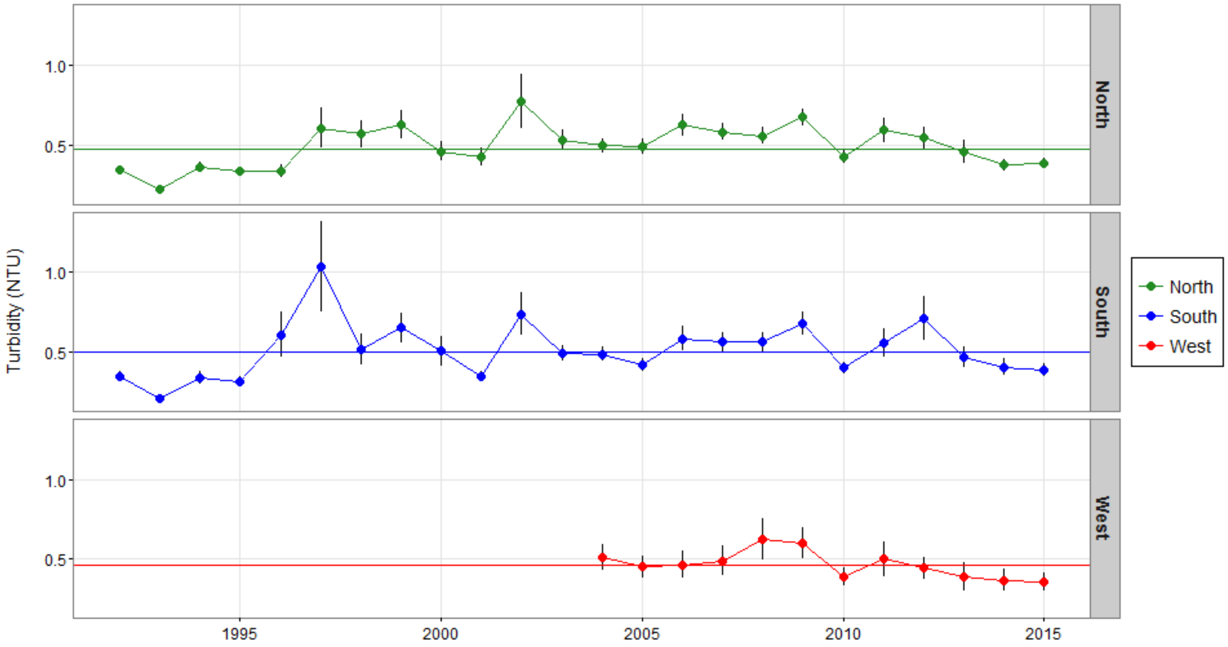


Figure 21. Annual Apr-Nov monthly mean of turbidity (NTU) by Arm. Solid lines are the long-term means for North, South (1992-2015) and West (2004-2015) Arms.

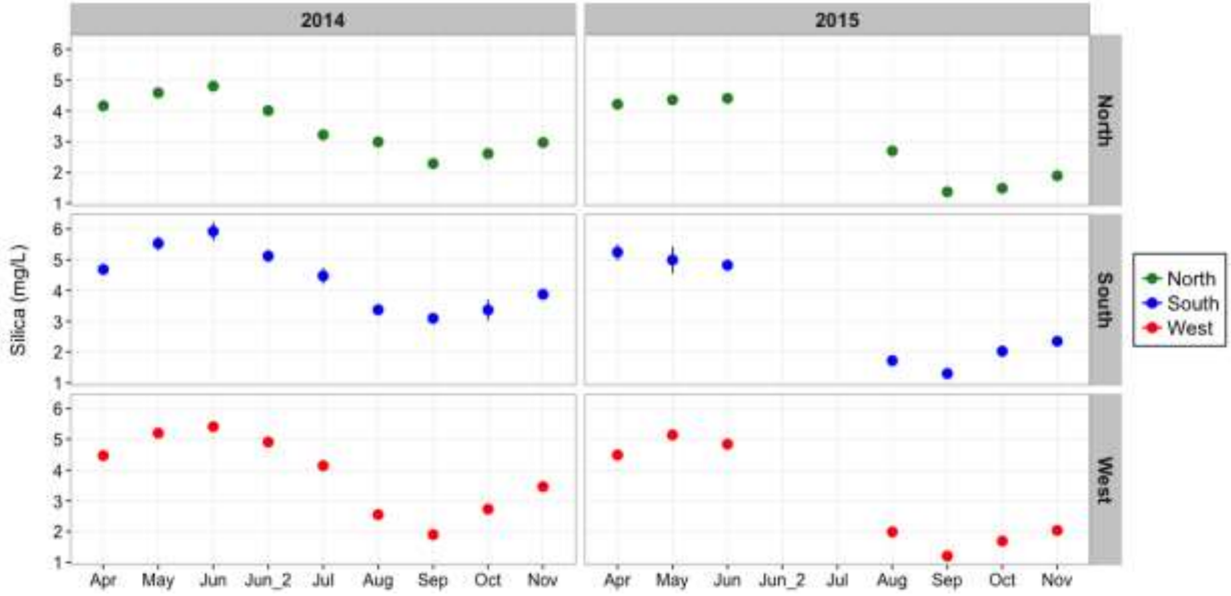


Figure 22. Silica (mg/L), North (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November 2014 and 2015.

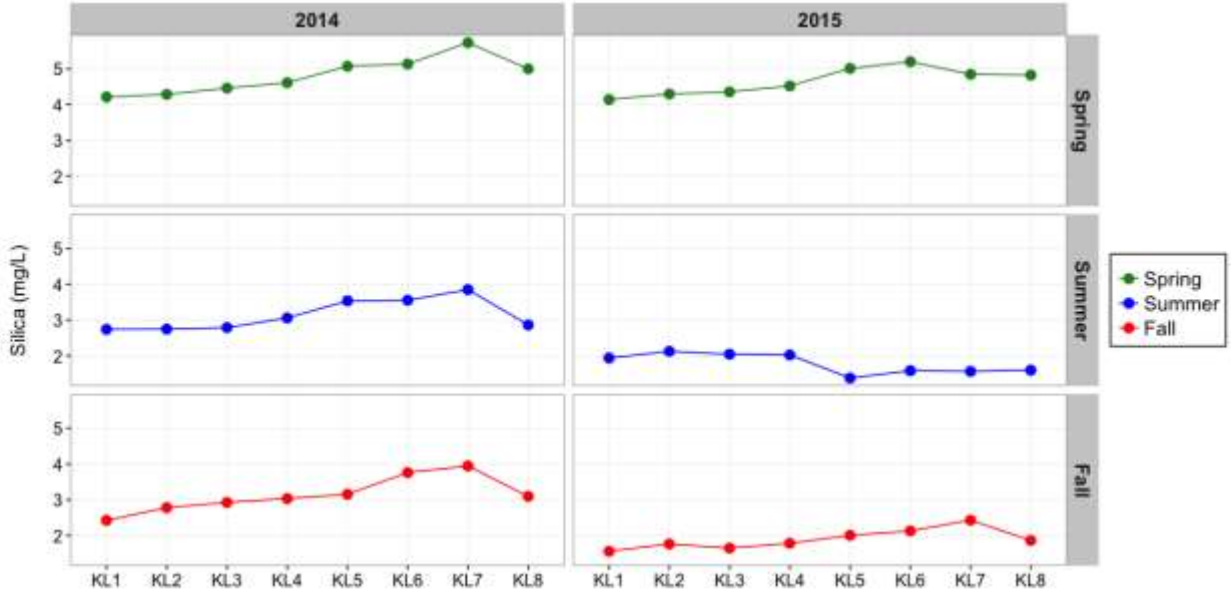


Figure 23. Silica, spring, summer and fall by station KLF 1-8, 2014 and 2015

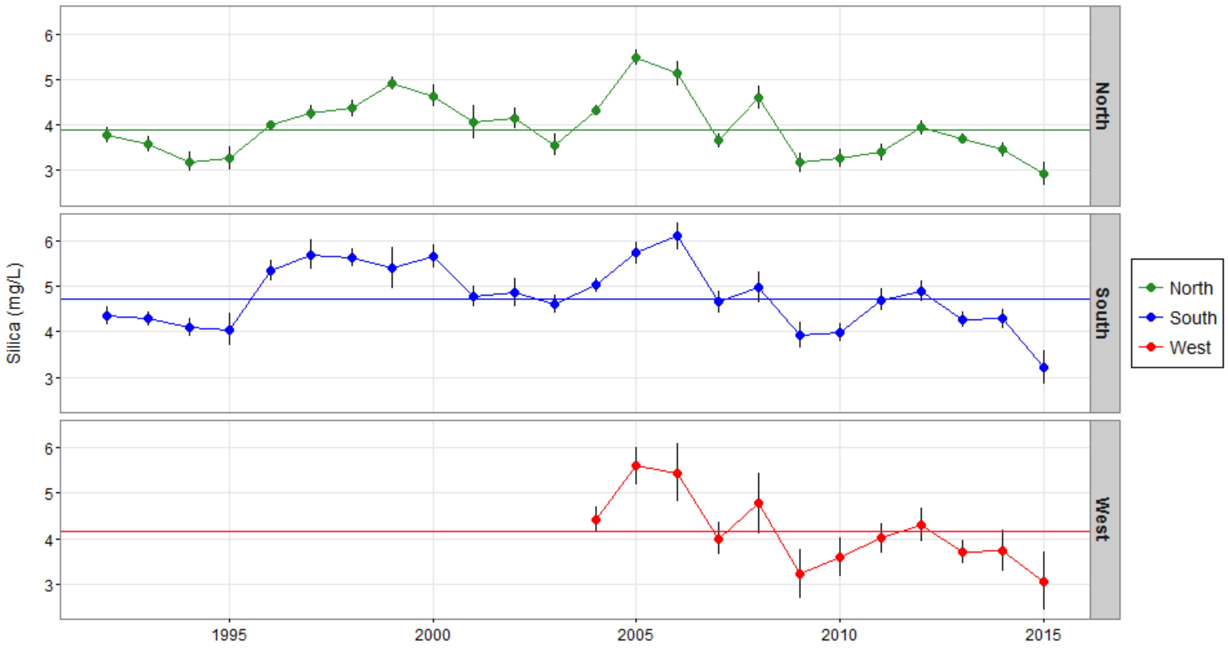


Figure 24. Annual Apr-Nov monthly mean of silica (mg/L) by Arm. Solid lines are the long-term means for North, South (1992-2015) and West (2004-2015) Arms.

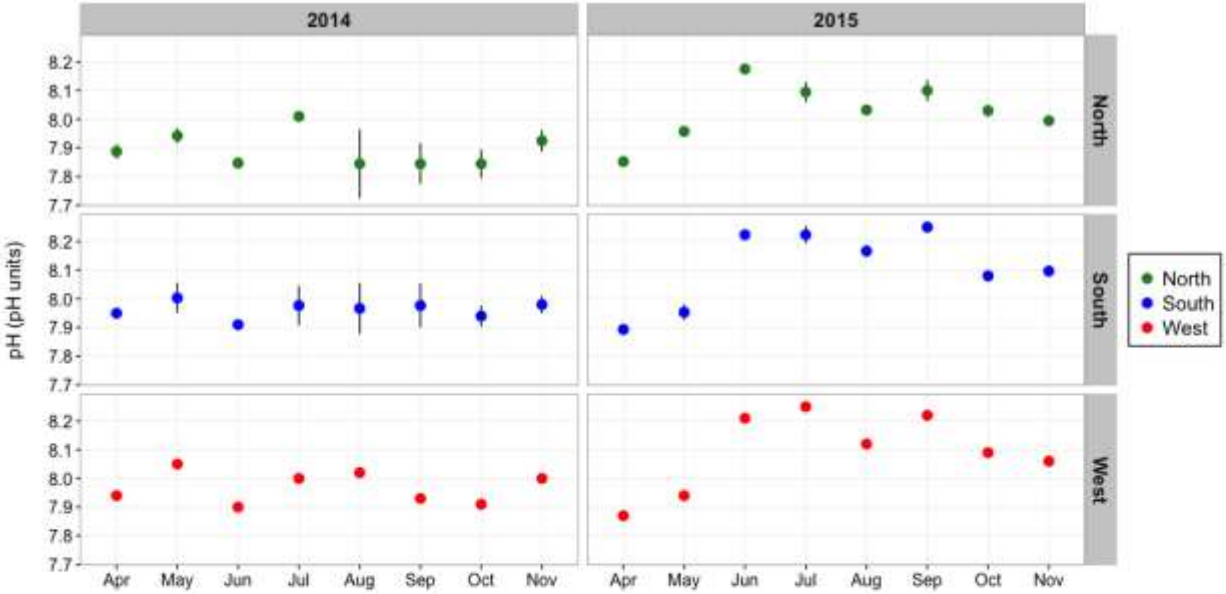


Figure 25. ph (pH units) (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November, 2014 and 2015

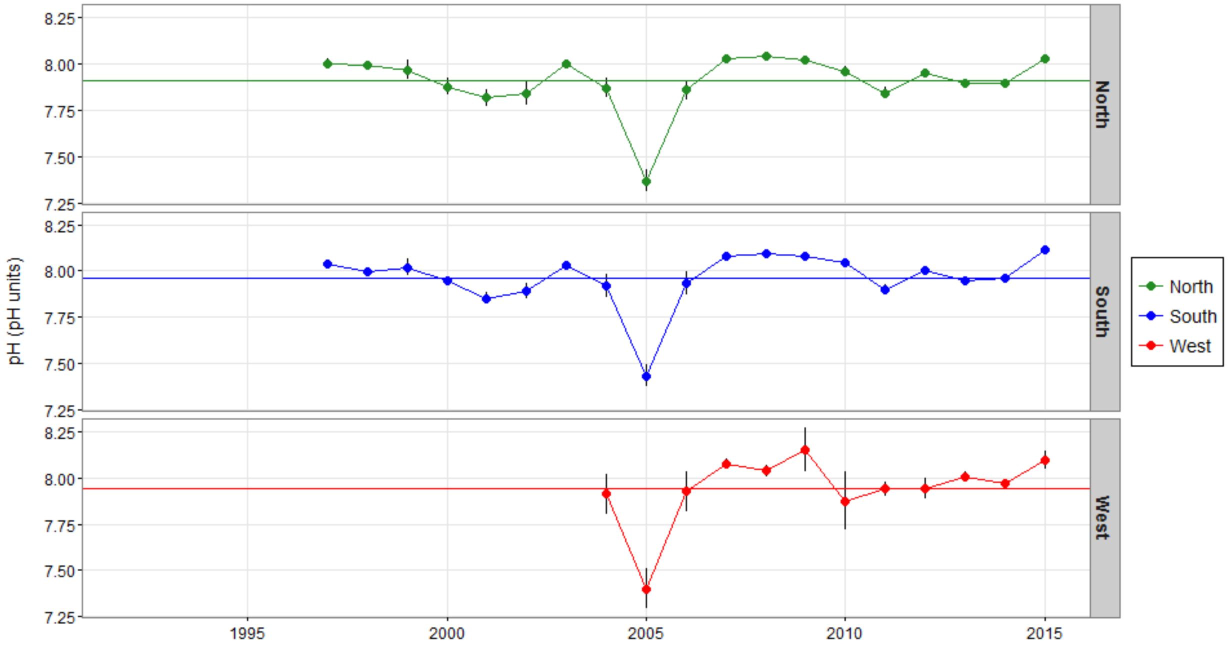


Figure 26. Annual Apr-Nov monthly mean of pH (pH units) by Arm. Solid lines are the long-term means for North, South (1992-2015) and West (2004-2015) Arms.

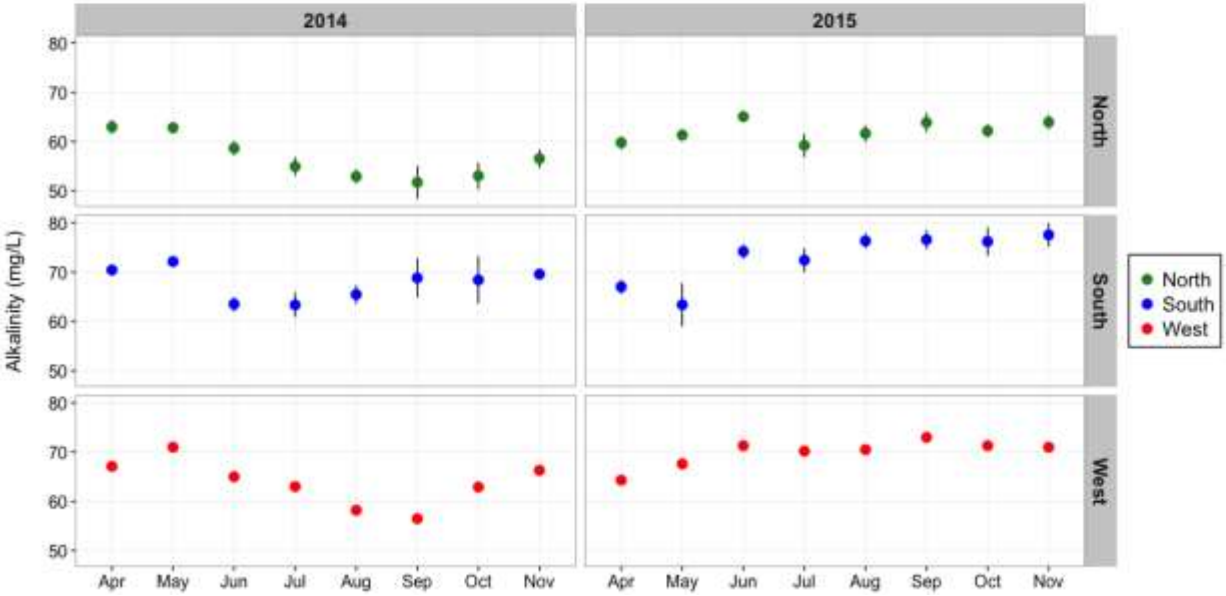


Figure 27. Alkalinity (mg/L), (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November, 2014 and 2015.

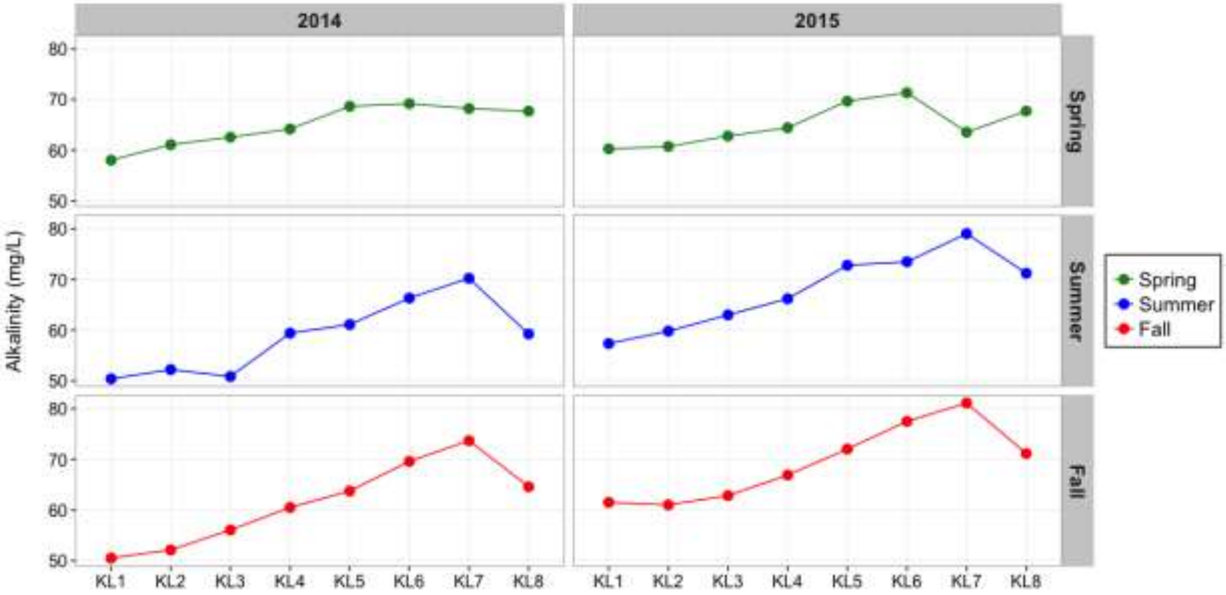


Figure 28. Alkalinity (mg/L), spring, summer and fall by station KLF 1-8, 2014 and 2015.

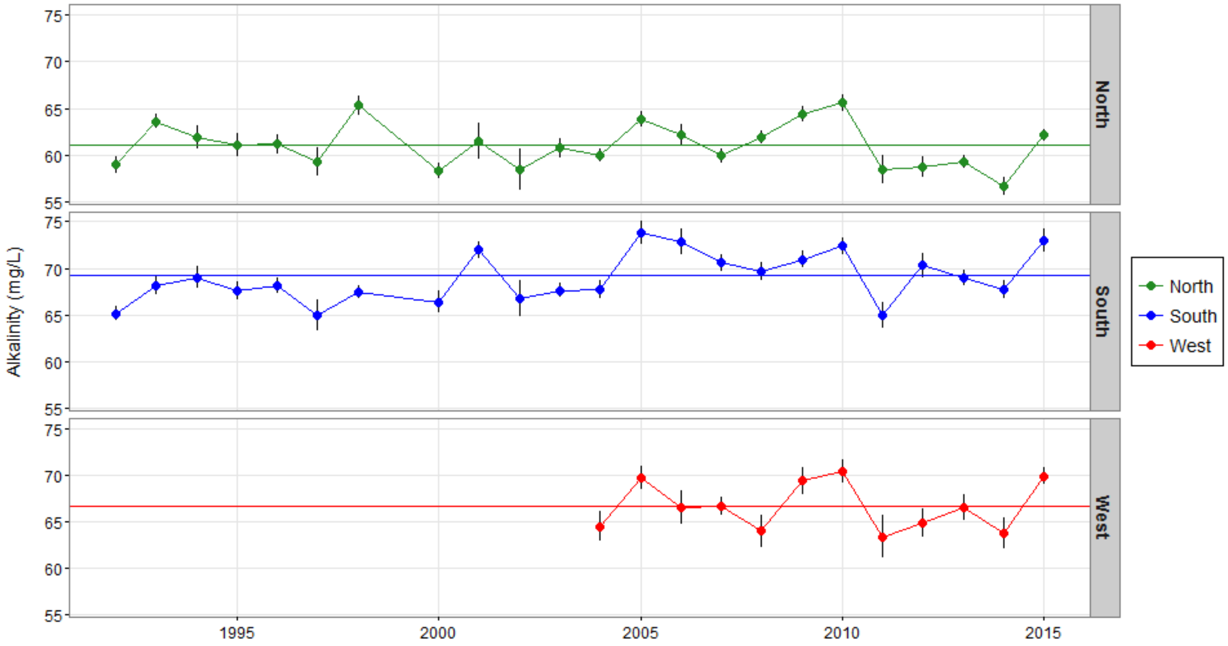


Figure 29. Annual Apr-Nov monthly mean of alkalinity (mg/L) by Arm. Solid lines are the long-term means for North, South (1992-2015) and West (2004-2015) Arms.

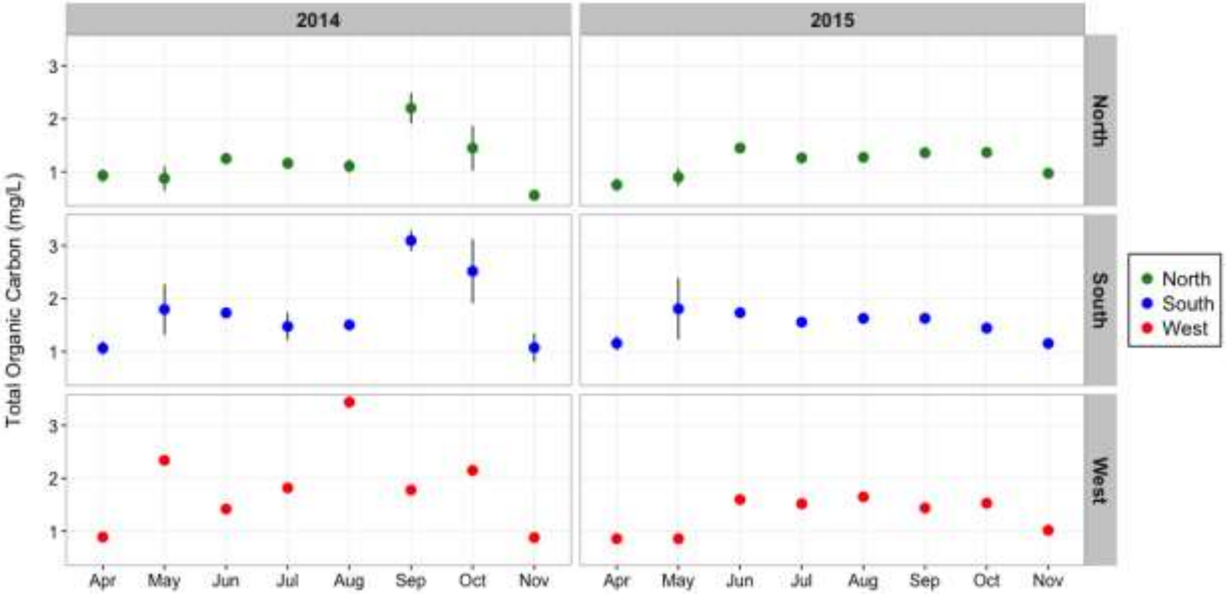


Figure 30. Total organic carbon (mg/L), (KLF 1-4), South (KLF 5-7) and West (KLF 8) Arm, April to November, 2014 and 2015.

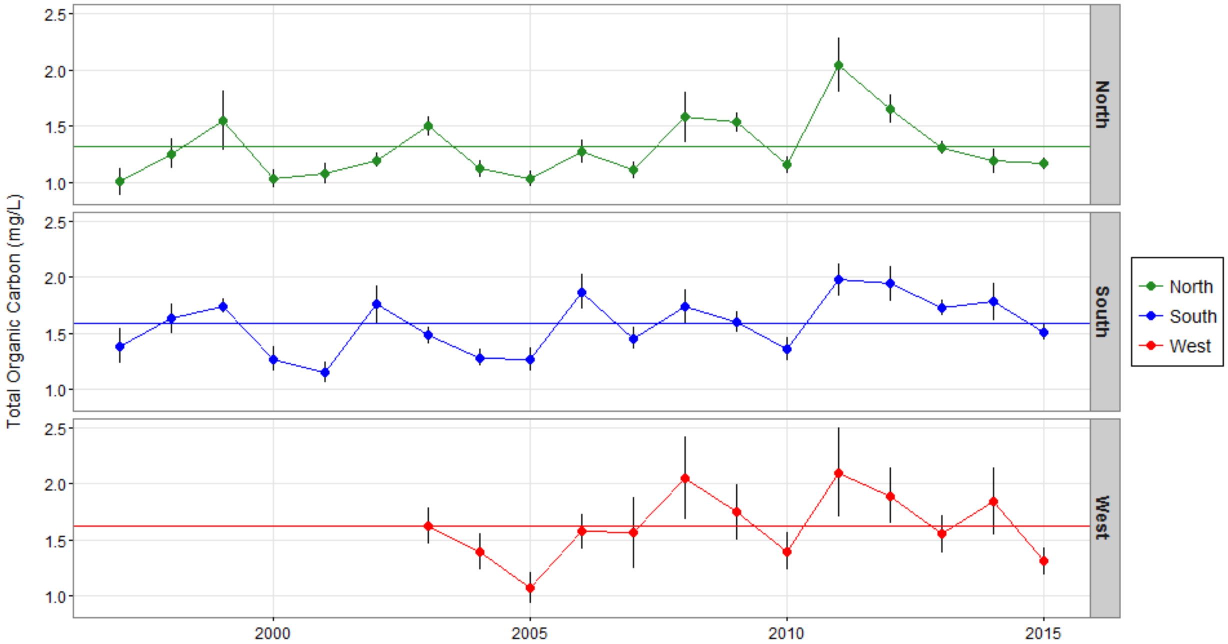


Figure 31. Annual Apr-Nov monthly mean of Total organic carbon (mg/L) by Arm. Solid lines are the long-term means for North, South (1997-2015) and West (2004-2015) Arms.

Discrete epilimnion sampling: chemistry

2014

Total phosphorus

In 2014, total phosphorus (TP) ranged from 3.1 to 11.5 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, although at KLF 2 high values at 2 m (September) and 2 and 5 m (June) were observed. At station KLF 6 in the South Arm, higher values between 5 and 20m were observed in August (Fig. 32).

Total dissolved phosphorus

Total dissolved phosphorus (TDP) ranged from the RDL (2 µg/L) to 10.0 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 5 m at KLF 2 in June (Fig. 32).

Dissolved inorganic nitrogen

Dissolved inorganic nitrogen (DIN) ranged from 48–186 µg/L and increased down the epilimnion, a trend that became more pronounced as the season progressed (Fig. 32). Higher concentrations were observed in June and August at station KLF 2, whereas at station KLF 6 high DIN values were observed in June and September (Fig. 32).

Nitrogen:Phosphorus Ratio

The ratio of N:P increased as depth increased in the epilimnion (Fig. 32), particularly at station KLF 6. At station KLF 2, this increasing trend was most pronounced in June and August. At station KLF 6, this trend was most pronounced in September. There was nitrogen limitation near the surface in June and July at station KLF 2, and in July and August at KLF 6.

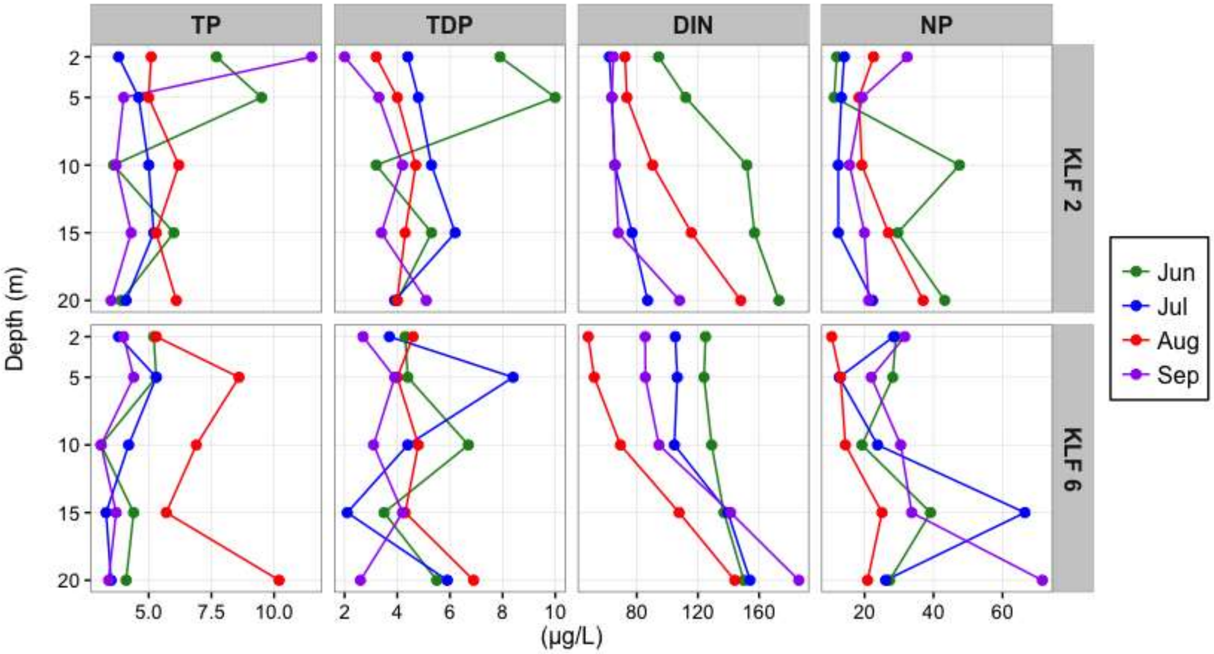


Figure 32. Discrete depth profiles of the North Arm (KLF 2) and the South Arm (KLF 6), June - September 2014. Note x scale changes by parameter.

2015

Total phosphorus

In 2015, total phosphorus (TP) ranged from the RDL (2 µg/L) to 7.2 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 June where a higher value was observed at 10m at station KLF2 (Fig. 33).

Total dissolved phosphorus

Total dissolved phosphorus (TDP) ranged from the RDL (2 µg/L) to 2.3 µg/L (Fig. 33). Due to a lab request error, there were no results for TDP in June for both Stations KLF 2 and KLF 6. At KLF2 and KLF6, July and September results were 2 µg/L.

Higher TDP results were observed in the August sampling period.

Dissolved inorganic nitrogen

Dissolved inorganic nitrogen (DIN) ranged from 54–231 µg/L and gradually increased down the epilimnion (Fig. 33). A high DIN result was observed at 5 m in June at KLF 6 (Fig. 33). KLF 2 and KLF 6 both had highest DIN results in in June.

Nitrogen:Phosphorus Ratio

The ratio of N:P (DIN/TDP) increased as the depth increased in the epilimnion at KLF 2 or was fairly consistent through the epilimnion at KLF 6 (Fig. 33). Due to a lab request error, there were no results for TDP in June for both Stations KLF 2 and KLF 6; subsequently there are no NP results for June. The NP ratio ranged from 26.3 to 60.2; minimum N:P ratios were observed in July for KLF 2, whereas minimum NP rations were observed in August for station KLF 6.

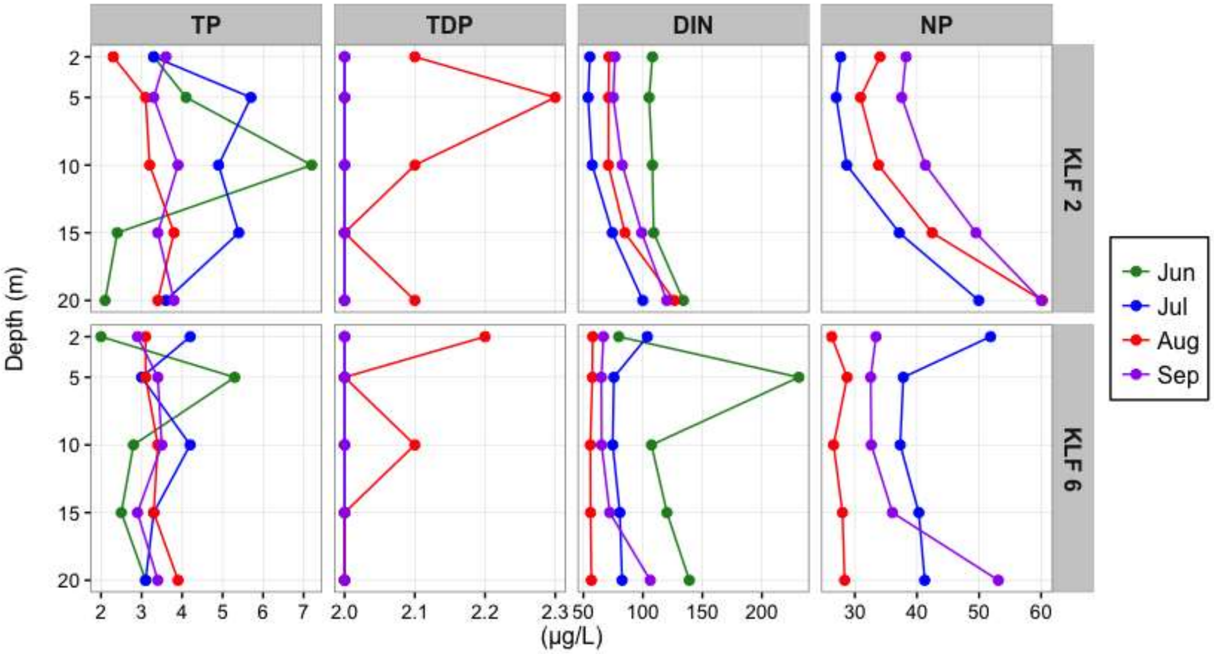


Figure 33. Discrete depth profiles of the North Arm (KLF 2) and the South Arm (KLF 6), June - September 2015. Note x scale changes by parameter.

Hypolimnion

Phosphorus

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. Of the hypolimnetic samples, 21% of total phosphorus (TP), 19% of total dissolved phosphorus (TDP) and 12% of orthophosphate values were under the RDL in 2014. In 2015, 21% of total phosphorus (TP), 31% of total dissolved phosphorus (TDP) and 37% of orthophosphate values were under the RDL.

The mean for hypolimnetic total phosphorus (TP) in 2014 for the North Arm was 2.79 µg/L, and ranged from the RDL (2 µg/L) to 5.10 µg/L (Fig. 34). In the South Arm, the 2014 mean was 3.64 µg/L and ranged from the RDL (2 µg/L) to 5.70 µg/L. For the North Arm in 2015, the minimum result was the RDL (2 µg/L), the maximum was 3.60 µg/L, and the average was 2.42 µg/L; in the South Arm, the hypolimnetic TP average was 3.19, and ranged from 2.20 to 4.70 µg/L.

The mean for total dissolved phosphorus (TDP) in 2014 for the North Arm was 2.65 µg/L, and ranged from the RDL (2 µg/L) to 4.80 µg/L (Fig. 35). For the South Arm in 2014, the mean was 3.31 µg/L, and ranged from the RDL (2 µg/L) to 4.90. In 2015, the North Arm TDP mean was 2.35 µg/L and ranged from the RDL (2 µg/L) to 3.80 µg/L, whereas the South Arm mean was 3.06 and ranged from the RDL (2 µg/L) to 4.20 µg/L.

The mean of hypolimnetic orthophosphate (OP) was 1.62 µg/L for the North Arm and 2.54 µg/L for the South Arm in 2014 (data not shown). The North Arm ranged from the RDL (1 µg/L) to 4.10 µg/L. In the South Arm OP ranged from 1.50 to 3.70 µg/L. In 2015, the North Arm mean was 1.21 µg/L, the South Arm mean was 2.19 µg/L, and OP ranged from the RDL (1 µg/L) to 1.9 µg/L and from the RDL (1 µg/L) to 3.20 µg/L; North and South, respectively.

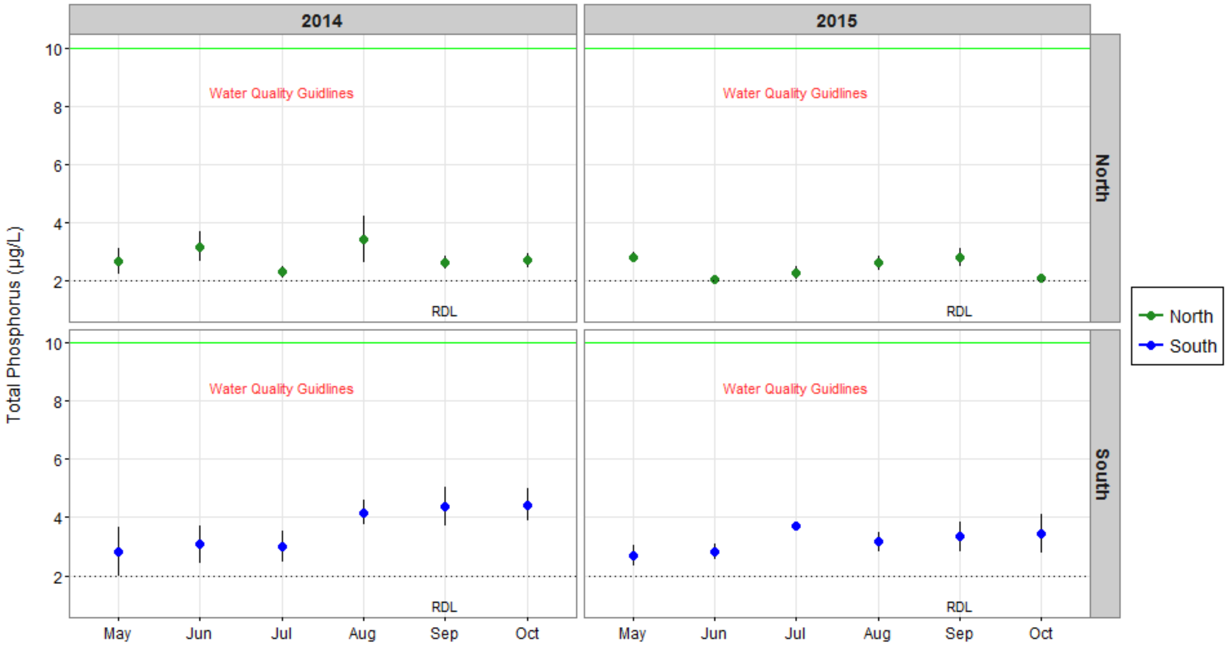


Figure 34. Total phosphorus (µg/L) North (KLF 1-4) and South (KLF 5-7) Arm, May to October 2014 and 2015. Means ±SE.

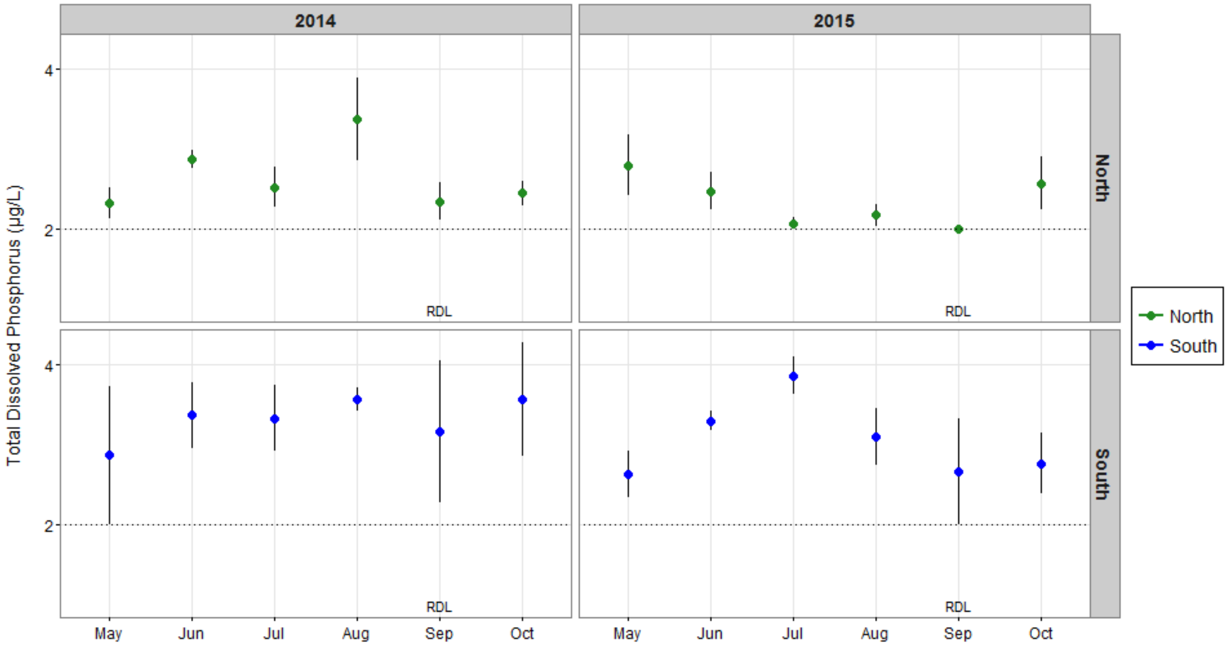


Figure 35. Total dissolved phosphorus (µg/L) North (KLF 1-4) and South (KLF 5-7) Arm, May to October 2014 and 2015. Means ±SE.

Nitrogen

In 2014, the mean for hypolimnetic total nitrogen (TN) in the North Arm was 296 µg/L, and ranged from 242 to 392 µg/L (Fig. 36). In the South Arm, the mean was 322 µg/L, and ranged from 203 to 451 µg/L. In 2014, the highest observations were observed in October. In 2015, the North Arm mean was 269 µg/L and ranged from 240 to 318 µg/L, whereas the South Arm mean was 266 µg/L and ranged from 245 to 320 µg/L.

In 2014, the mean dissolved inorganic nitrogen (DIN) was 216 µg/L (201 to 236 µg/L) in the North Arm, and the mean in the South Arm was 226 µg/L (205 to 245 µg/L) (Fig. 37). The North Arm mean in 2015 was 239 µg/L, and ranged from 218 to 253 µg/L. In the South Arm in 2015, the mean was 230 µg/L and ranged from 108 (a low nitrate result in June) to 269 µg/L.

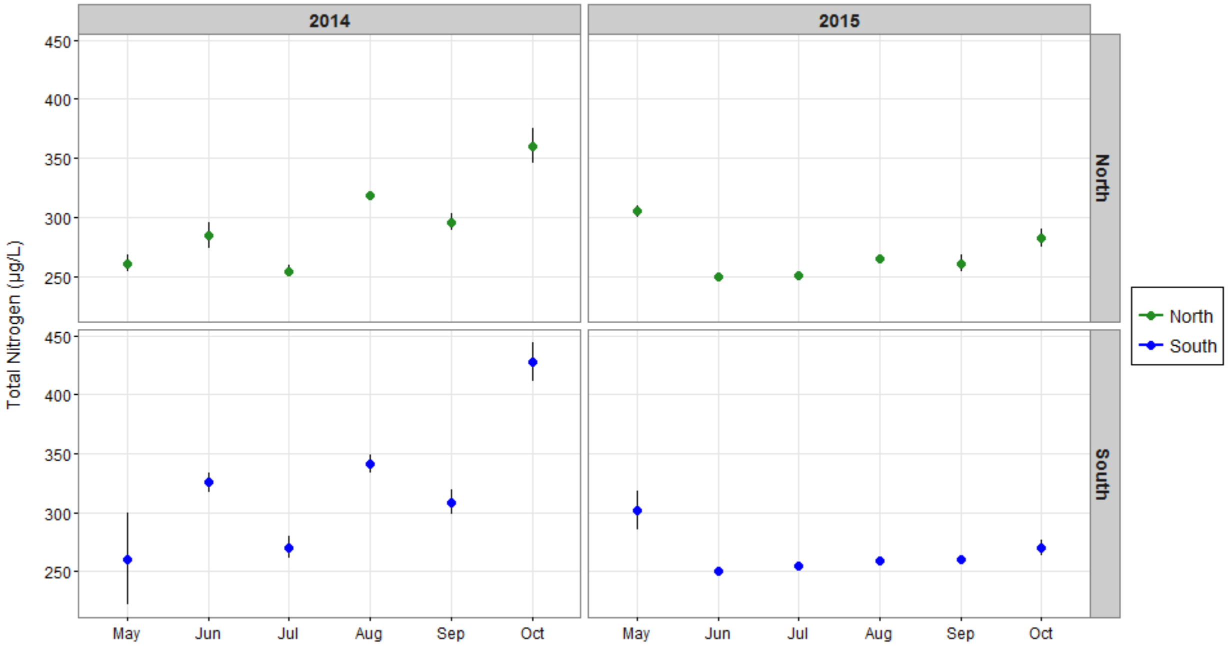


Figure 36. Total nitrogen (µg/L) North (KLF 1-4) and South (KLF 5-7) Arm, May to October 2014 and 2015. Means ±SE.

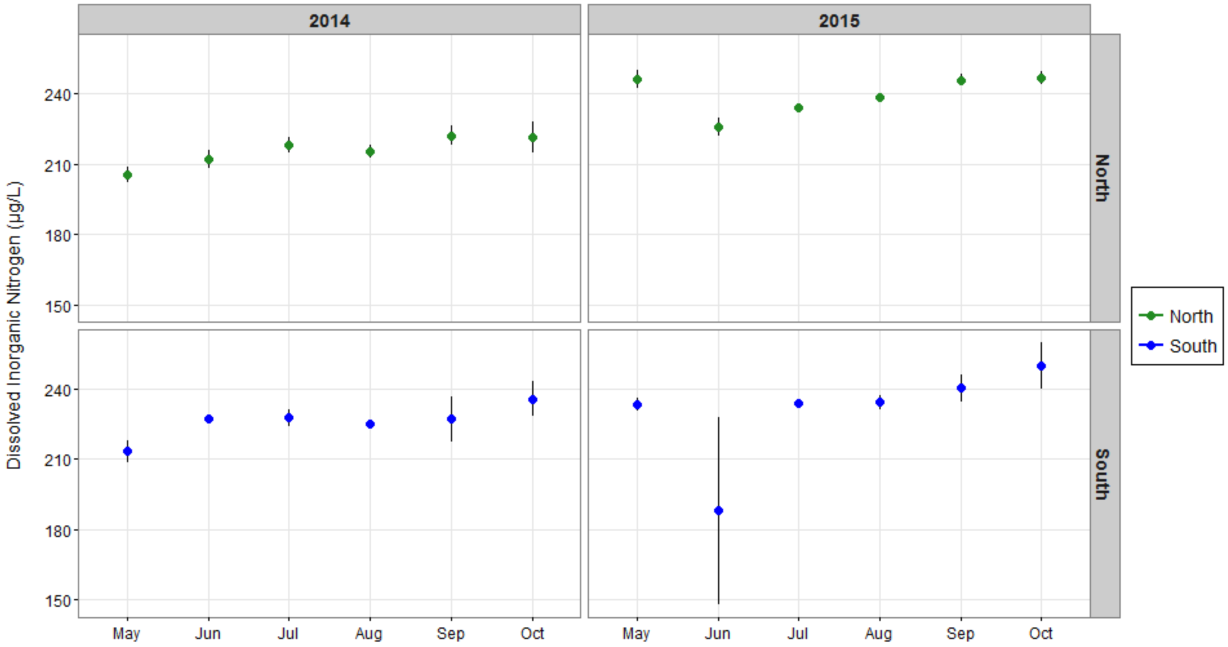


Figure 37. Dissolved inorganic nitrogen (µg/L) North (KLF 1-4) and South (KLF 5-7) Arm, May to October 2014 and 2015. Means ±SE.

Turbidity, Silica, Alkalinity, pH and Carbon

The mean turbidity in 2014 for the North Arm was 0.19 NTU and ranged from 0.11 to 0.34 NTU (Fig. 38). For the South Arm in 2014, the mean was 0.20 NTU and ranged from 0.12 to 0.33 NTU. In 2015, the North Arm mean was 0.21 NTU and ranged from 0.1 to 0.36 NTU, whereas the South Arm mean was 0.18 NTU and ranged from 0.11 to 0.29 NTU.

Silica in 2014 averaged 5.52 mg/L for the North Arm (ranging from 5.07 to 6.09 mg/L), and averaged 5.87 in the South Arm (ranging from 5.48 to 6.54 mg/L) (Fig. 39). In 2015, the North Arm mean was 5.87, the South Arm mean was 5.94, and these ranged from 5.61 to 6.20 mg/L and 5.29 to 6.93 mg/L , North and South respectively.

Alkalinity in the hypolimnetic samples in 2014 ranged from 70.5 to 77.3 mg/L in the North Arm, and 74.8 to 79.8 mg/L in the South Arm. The North Arm mean was 73.2 mg/L and South Arm mean was 77.3 mg/L (Fig. 40). In 2015, the North Arm mean was 76.9 mg/L and ranged from 73.3 to 82.9 mg/L, whereas the South Arm mean was 79.8 mg/L and ranged from 75.3 to 85.7 mg/L.

Hypolimnetic pH results in 2014 ranged from 7.8 to 8.1 pH units in both the North and South Arms (Fig. 41). The mean in the North Arm was 7.9, and 8.0 in the South Arm. In 2015, North Arm pH was 7.9 (ranging from 7.6 to 8.1 pH units), and South Arm pH mean was 8.0 (ranging from 7.8 to 8.2 pH units).

The mean for hypolimnetic total organic carbon (TOC) in 2014 for the North Arm was 1.45 mg/L and ranged from 0.54 to 3.13 mg/L (Fig. 42). For the South Arm in 2014, the mean was 1.71 mg/L and ranged from 0.66 to 3.05 mg/L. The minimum result in 2015 for the North Arm was 0.74 mg/L, the maximum was 1.60 mg/L, and the average was 1.25 mg/L; for the South Arm, TOC average was 1.28 mg/L, and ranged from 0.69 to 1.51 mg/L.

The total inorganic carbon (TIC) mean for the North and South Arms (in 2014) were 17.0 and 18.0 mg/L respectively, and ranged from 10.6 to 19.8 mg/L in the North Arm and 11.8 to 20.1 mg/L in the South Arm (data not shown). In 2015, the North Arm TIC average was 17.3 mg/L and ranged from 14.5 to 20.1 mg/L, whereas in the South Arm the average was 16.7 mg/L and ranged from 15.7 to 19.3 mg/L.

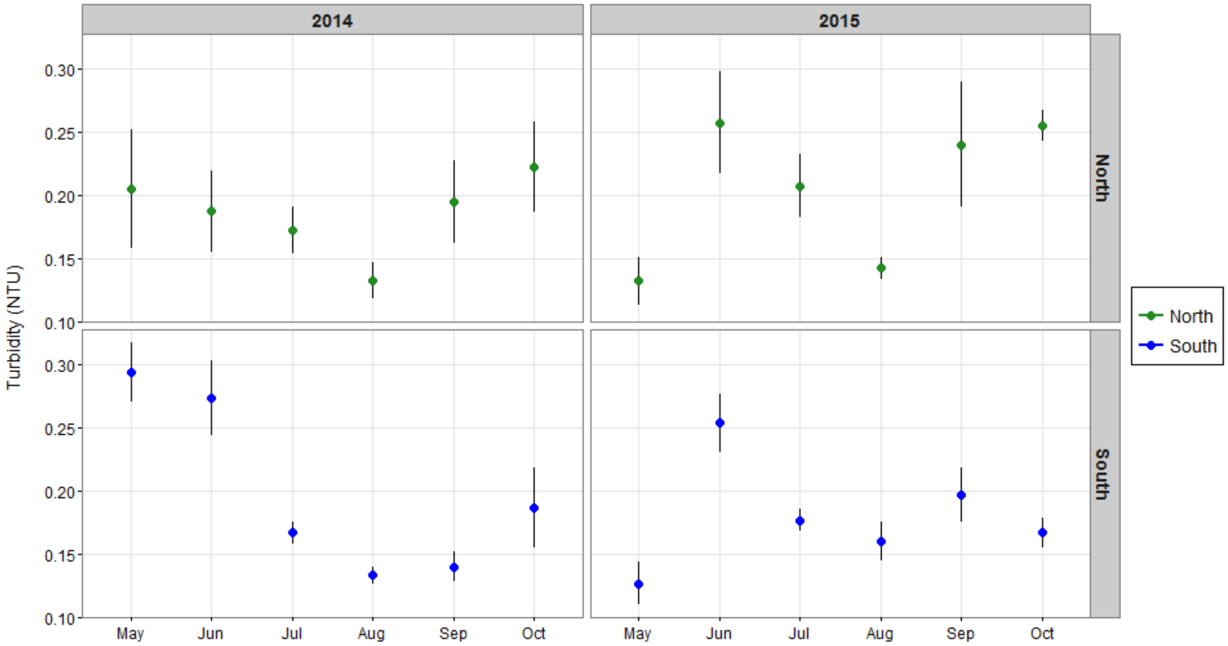


Figure 38. Turbidity (NTU) North (KLF 1-4) and South (KLF 5-7) Arm, May to October 2014 and 2015. Means ±SE.

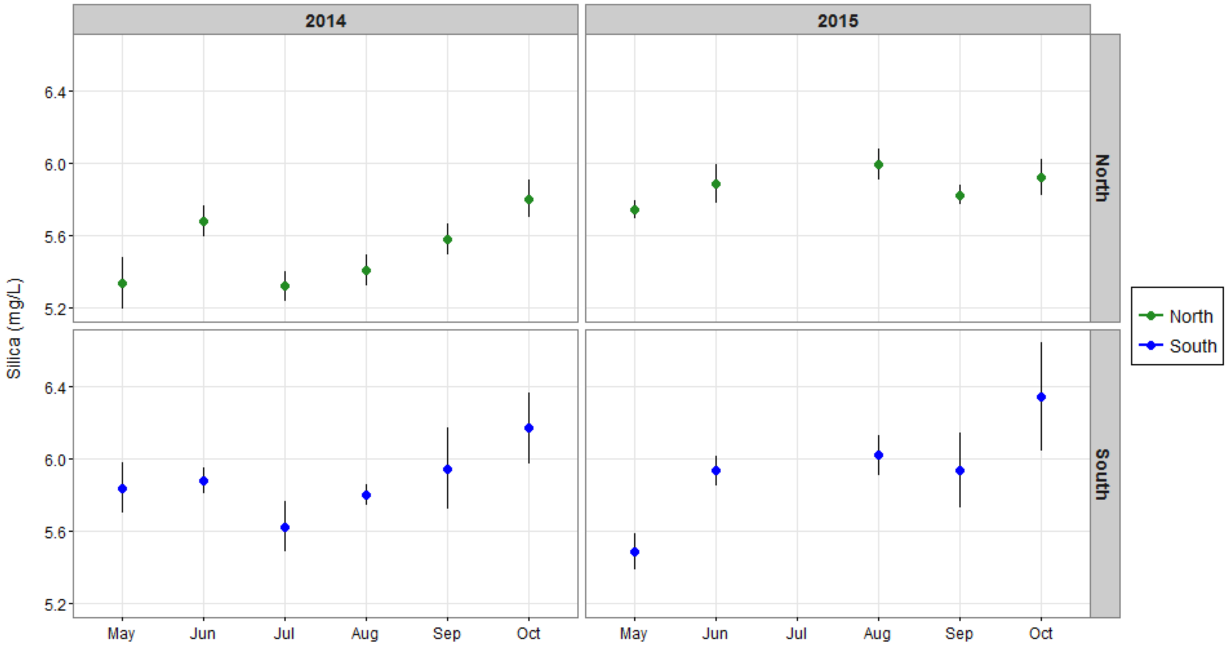


Figure 39. Silica (mg/L) North (KLF 1-4) and South (KLF 5-7) Arm, May to October 2014 and 2015. Means ±SE.

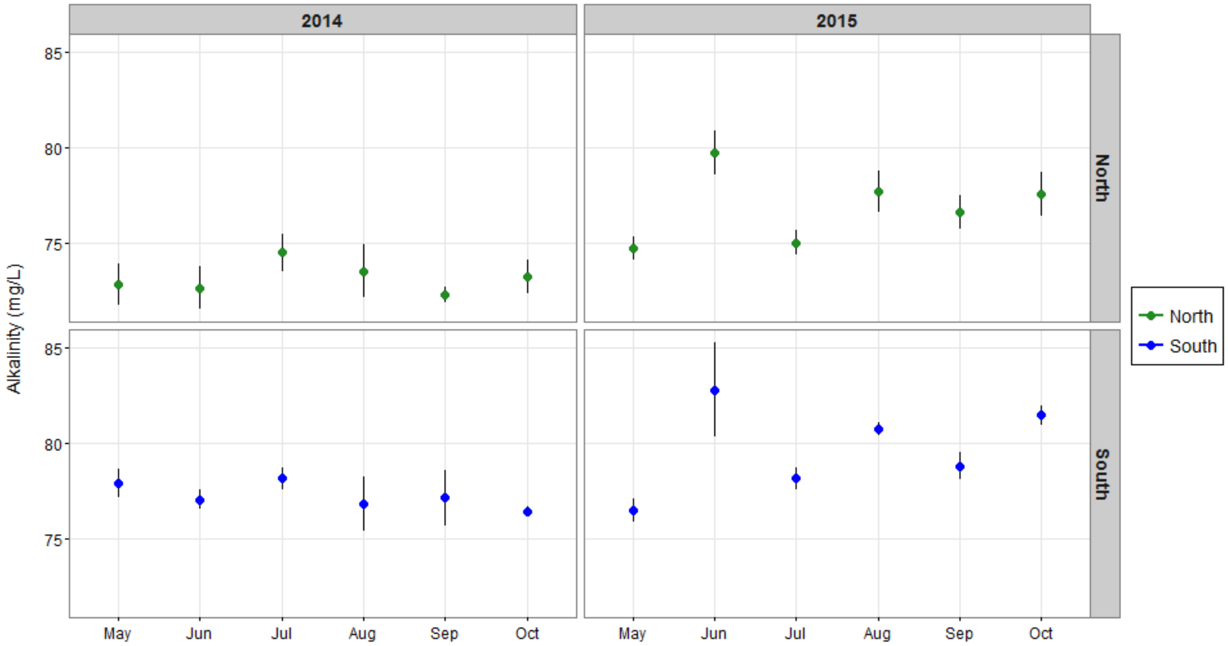


Figure 40. Alkalinity (mg/L) North (KLF 1-4) and South (KLF 5-7) Arm, May to October 2014 and 2015. Means ±SE.

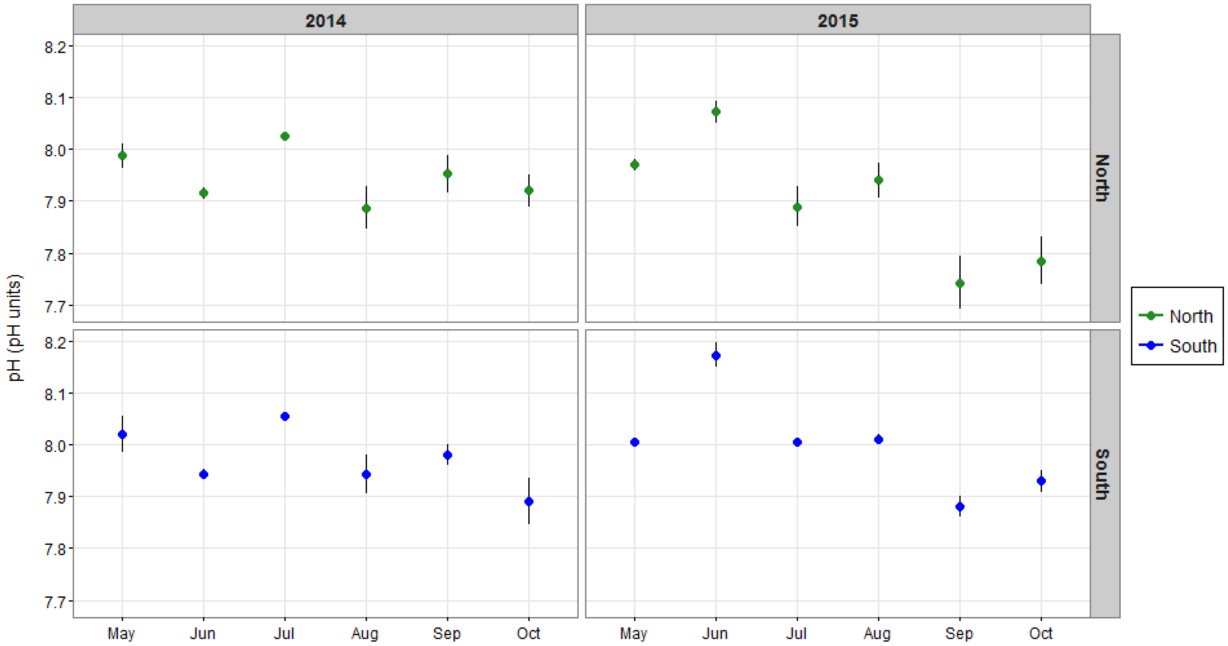


Figure 41. pH (pH units) North (KLF 1-4) and South (KLF 5-7) Arm, May to October 2014 and 2015. Means ±SE.

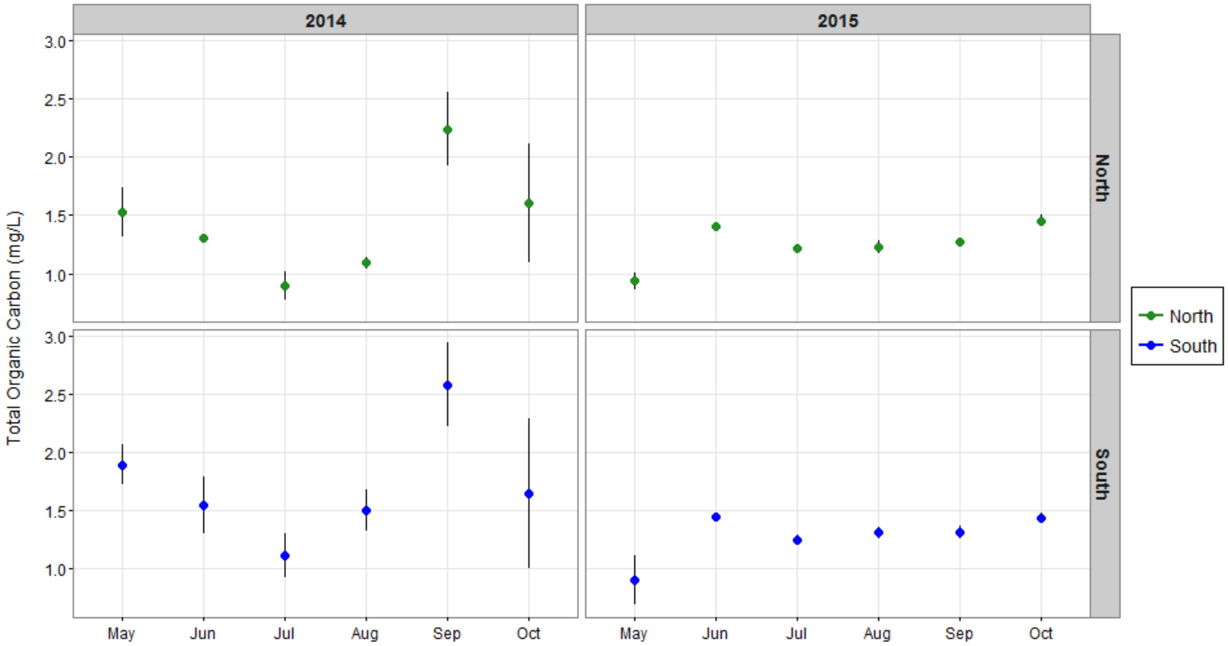


Figure 42. Total organic carbon (mg/L) North (KLF 1-4) and South (KLF 5-7) Arm, May to October 2014 and 2015. Means ±SE.

Phytoplankton

2014

Integrated Epilimnion

Class Abundance

Comparisons of arms and seasons were done and are summarized in Table 6. The results by class for each sampling period are shown in Figure 43. The total abundance of phytoplankton did not differ significantly between the North, South and West Arms. There was however a significant difference when comparing seasons of total phytoplankton abundance, where the summer mean was significantly higher than the spring and fall means. Total abundance peaked in July, largely contributed by high bacillariophyte counts.

Bacillariophytes (aka diatoms) also did not differ across arms, and the summer mean was significantly higher than the spring and fall. Bacillariophytes are the predominant class, so it is not surprising that total abundance and bacillariophyte abundance have the same temporal and spatial trends. In late June, *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.*

Chlorophytes did not differ across arms, and were highest in the summer when 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 did differentiate across the lake in 2014 where there was a significant difference the North Arm and South Arm, South Arm Chryso-Cryptophytes being higher. Temporally, the mean for Chryso-Cryptophytes was higher in spring than the rest of the sampling season. 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 did not differ by arm, but temporally the fall mean was significantly higher than the summer mean. Fall abundance was strongly driven by high counts of the species *Merismopedia sp.* observed in the November results. Throughout the rest of the season, *Merismopedia sp.* and *synechococcus* species dominated cyanophyte abundance.
The abundance of dinophytes did not differ across arms or show a seasonal trend, and throughout the season the dominant species was *Gymnodinium*.

Class Biomass

Comparisons of arms and seasons were made, and are again summarized in Table 6. The results of phytoplankton biomass by class for each sampling period are shown in Figure 44. Total phytoplankton biomass did not change significantly across arms, there was however a seasonal expression where total biomass was significantly higher in the summer.

Bacillariophytes (diatoms) also did not differ across arms, and were significantly higher in the summer, peaking in July in both the North and South Arms. This was due to high biomass of the species *Cyclotella stelligera.* As the KL 8 sample bottle broke in transit there is no West Arm July data. During the summer months for all Arms, the dominant bacillariophyte species was *Fragilaria crotonensis.*

Chlorophytes were significantly higher in the South Arm compared to the North Arm, however there was not a seasonal expression for Chlorophytes in 2014. High amounts of Chlorophytes were observed in May, July and Sept in the South Arm.

Chryso-Cryptophytes were high in biomass from May through the end of August, and peaked on June 18th. The species that contributed the most to that peak were *Cryptomonas and Dinobryon.*

Cyanophytes were varied minimally throughout the sampling season, with the exception of high biomass observed in mid-July, which was largely from high *microcystis, Limnothrix redekei* and *synechococcus* species.

There was not a spatial or temporal change in dinophytes in 2014, and throughout the season the dominant species was *Gymnodinium*.

Table 6. Comparison of Arm means (North=KLF1-4, South=KLF5-7 and West=KLF8) and Season means (Spring=Apr-Jun, Summer=Jul-Sep and Fall=Oct-Nov) for 2014. Jun_2, Jul_2 and Aug_2 were omitted from analysis. Letter denotes a significant difference between means at 0.05.

		Arm			**Season**		
		North	**South**	**West**	**Spring**	**Summer**	**Fall**
Abundance (cells/ml)	Total Phytoplankton	3163^{a}	3650^{a}	2653^{a}	2781^{a}	4821^{b}	1962^{a}
	Bacillariophyte	1626^{a}	1609^{a}	1035^{a}	721^{a}	3193^{b}	543^{a}
	Chlorophyte	215^{a}	282^{a}	216^{a}	213^{a}	312^{b}	184^{a}
	Chryso-& Cryptophyte	1050^{a}	1473^{b}	1156^{ab}	1567^{b}	1079^{a}	915^{a}
	Cyanophyte	252^{a}	263^{a}	230^{a}	255^{ab}	217^{a}	303^{b}
	Dinophyte	21^{a}	24^{a}	16^{a}	25^{a}	20^{a}	18^{a}
Biomass (mm3/L)	Total Phytoplankton	0.3660^{a}	0.4482^{a}	0.3258^{a}	0.3194^{a}	0.6010^{b}	0.2187^{a}
	Bacillariophyte	0.1901^{a}	0.2013^{a}	0.1342^{a}	0.0846^{a}	0.3967^{b}	0.0567^{a}
	Chlorophyte	0.0278^{a}	0.0491^{b}	0.0288^{ab}	0.0309^{a}	0.0499^{a}	0.0251^{a}
	Chryso-& Cryptophyte	0.1176^{a}	0.1654^{b}	0.1366^{ab}	0.1754^{b}	0.1208^{a}	0.1063^{a}
	Cyanophyte	0.0156^{a}	0.0139^{a}	0.0139^{a}	0.0116^{a}	0.0174^{a}	0.0159^{a}
	Dinophyte	0.0150^{a}	0.0193^{a}	0.0123^{a}	0.0169^{a}	0.0161^{a}	0.0157^{a}

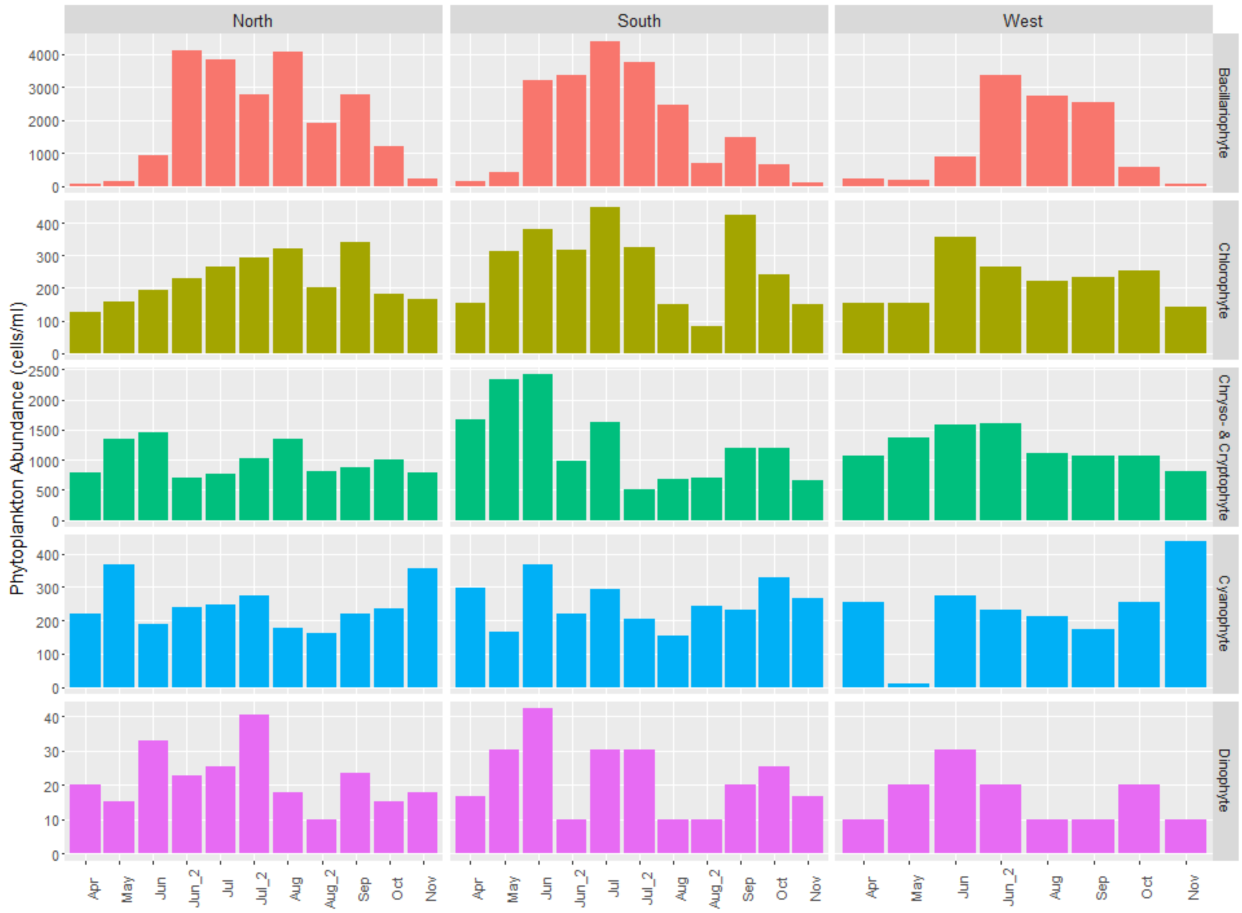


Figure 43. Phytoplankton monthly mean by group (Bacillariophyte, Chlorophyte, Chryso-& Cryptophyte, Cyanophyte and Dinophyte) abundance (cells/ml) by Arm; North (KL 1-4), South (KL 5-7) and West (KL 8) Kootenay Lake. April to November, 2014. Only KL2 and KL6 sampled on Jul_2 and Aug_2. Note axis changes by class.

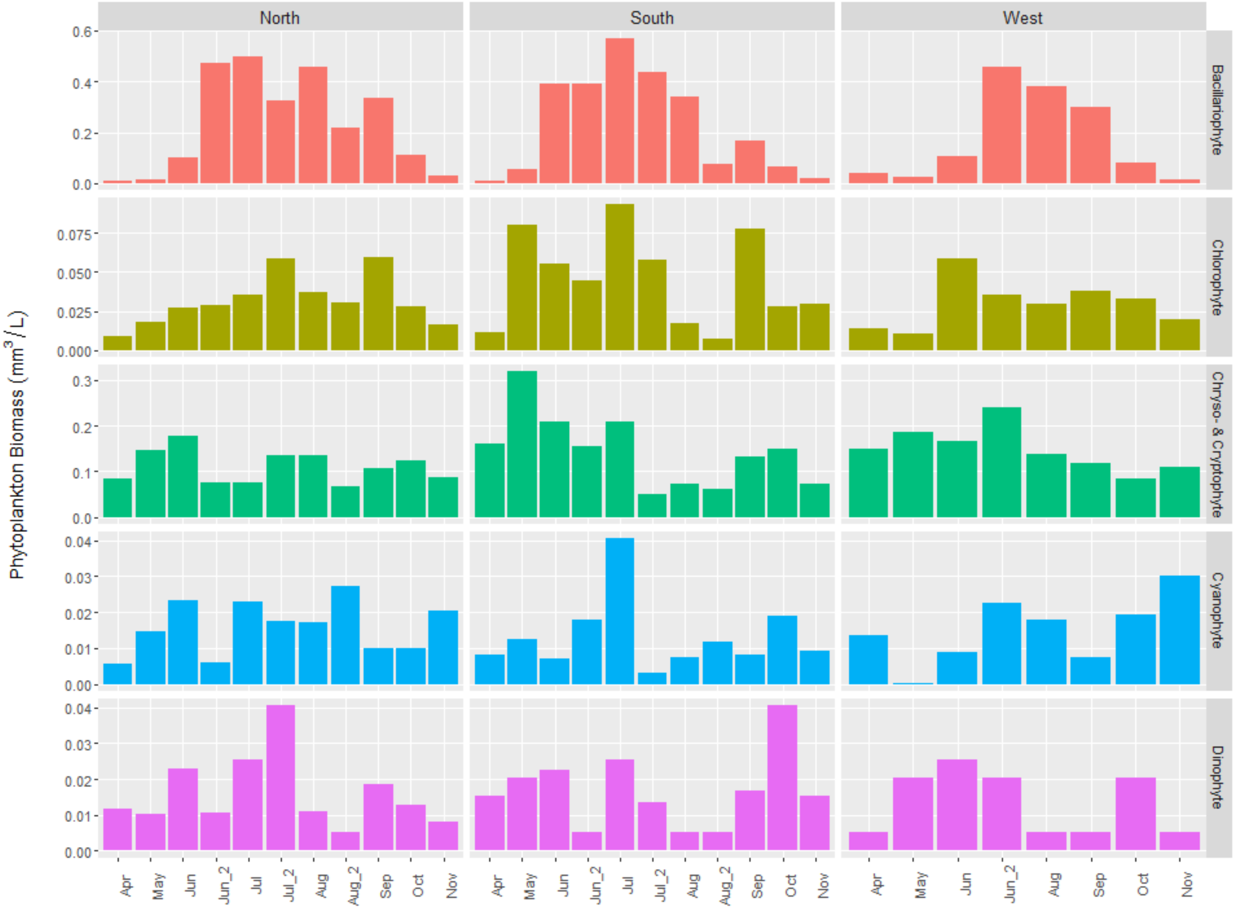


Figure 44. Phytoplankton monthly mean by group (Bacillariophyte, Chlorophyte, Chryso-& Cryptophyte, Cyanophyte and Dinophyte) biomass (mm^3/L) by Arm; North (KL 1-4), South (KL 5-7) and West (KL 8) Kootenay Lake. April to November, 2014. Only KL2 and KL6 sampled on Jul_2 and Aug_2. Note axis changes by class.

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. 45). 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, where inedible abundance in 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 (Fig. 46). The peak occurred on July 15 with bacillariophytes dominated by *Fragilaria crotonensis.* The same species contributed the most to the peak of inedible phytoplankton biomass in the West Arm, which occurred on June18. Biomass of edible phytoplankton was highest in June. The group that dominated the edible fraction of biomass in the lake were the Chryso-Cryptophytes, specifically the species *Cryptomonas* and *Dinobryon.*

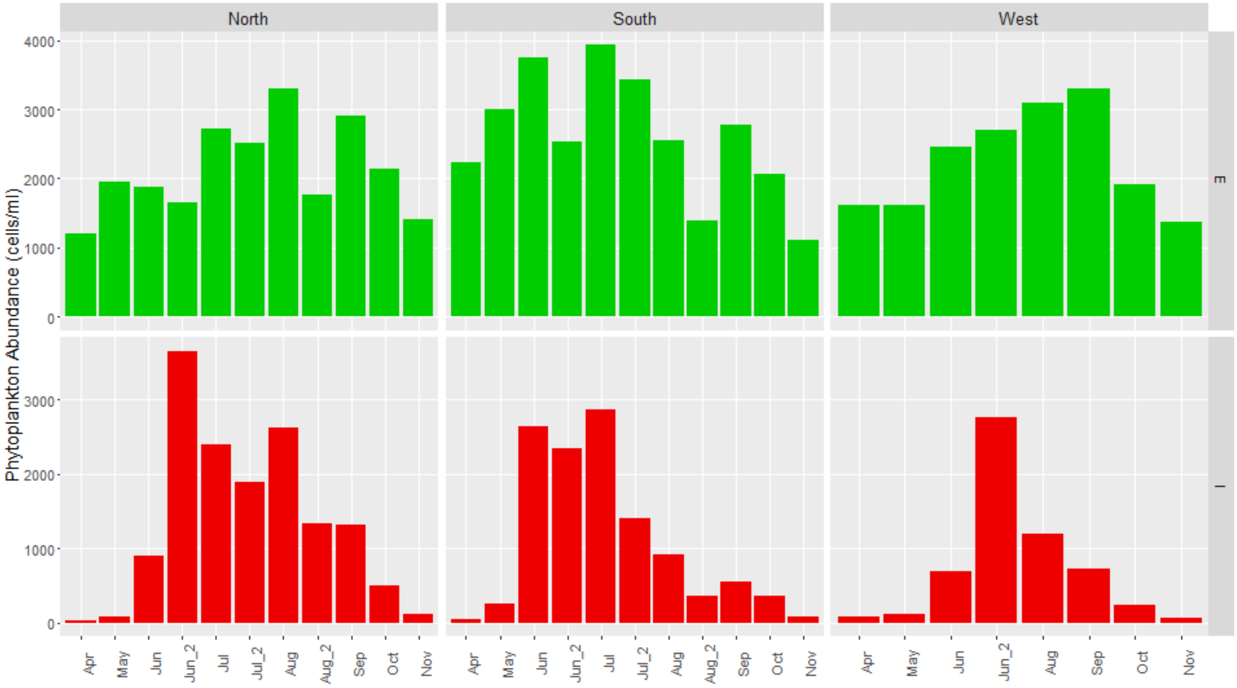


Figure 45. Abundance (cells/ml) monthly mean of edible (E - green) and inedible (I - red) phytoplankton by Arm; North (KL 1-4), South (KL 5-7) and West (KL 8) Kootenay Lake. April to November, 2014. Only KL2 and KL6 sampled on Jul_2 and Aug_2.

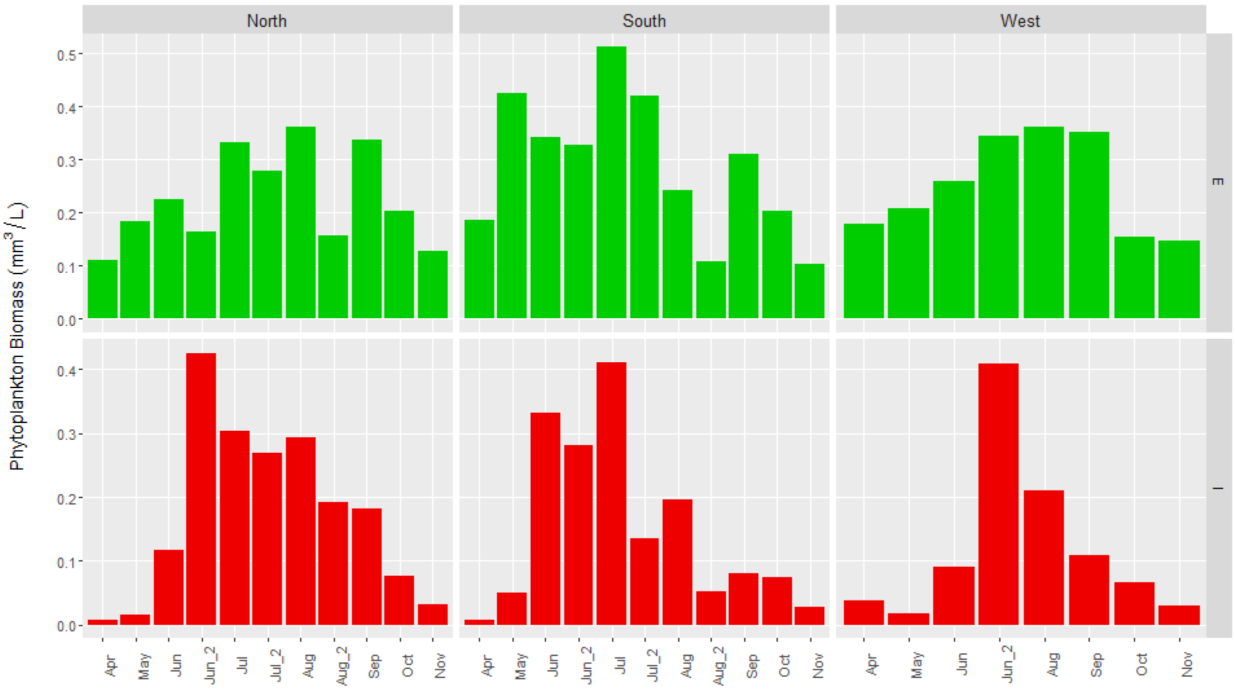


Figure 46. Biomass (mm^3/L) monthly mean of edible (E - green) and inedible (I - red) phytoplankton by Arm; North (KL 1-4), South (KL 5-7) and West (KL 8) Kootenay Lake. April to November, 2014. Only KL2 and KL6 sampled on Jul_2 and Aug_2.

Discrete Epilimnion

Class Abundance

The discrete samples were collected at 2 stations; KLF2 in the North Arm, and KLF6 in the South Arm, and at depths of 2,5,10, 15 and 20 m. Profile abundance of phytoplankton is shown in Figure 47. Bacillariophytes were highest in July at the surface depths (2 and 5 m) at KLF6. Chlorophyte abundance did not vary much across depths, seasons or stations. The minimum Chlorophyte abundance result was 60.82 cells/ml reported at 5 m at KLF6 in September, whereas the maximum was reported at 425.75 cells/ml at KLF2 in June, also at 5 m. Chryso-Cryptophytes were high in June at KLF2, peaking at 2 m at 3831.74 cells/ml. Cyanophytes peaked in September for the 5 m result at KLF2 (608.21 cells/ml). Dinophytes ranged minimally over the discrete samples; the maximum was reported at 101.37 cells/ml at KLF6 in June at 10 m, whereas approx. 78% of the other dinophytes samples were at or below an abundance of 20.28 cells/ml.

Class Biomass

Profile biomass of phytoplankton is shown in Figure 48. Bacillariophytes were highest in July at the surface depths (2 and 5 m) at KLF6, the peak of which was 0.8111 mm^3/L at 2m. Low

Bacillariophyte results occurred in June and September particularly at KLF 6. Chlorophyte biomass ranged from 0.0035 mm^3/L (KLF6 September at 15m) to 0.1348 mm^3/L (KLF2 in June at 2 m). Chlorophyte biomass was influenced by the large celled species *Planctosphaeria*. Chryso-Cryptophytes were high in June at KLF2 at surface depths, peaking at 0.5911 mm^3/L at 2m. The sample at KLF6 in July at 2m was also high at 0.4205 mm^3/L. Cyanophyte biomass is low relative to the other classes. Results ranged from 0.0012 mm^3/L (KLF2 June at 20 m) to 0.0637 mm^3/L (KLF6 July at 10 m). Dinophytes peaked at station KLF2 in September at 5 m (0.1419 mm3/L), with approximately 81 % of the other dinophytes samples were at or below a biomass of 0.0203 mm3/L.

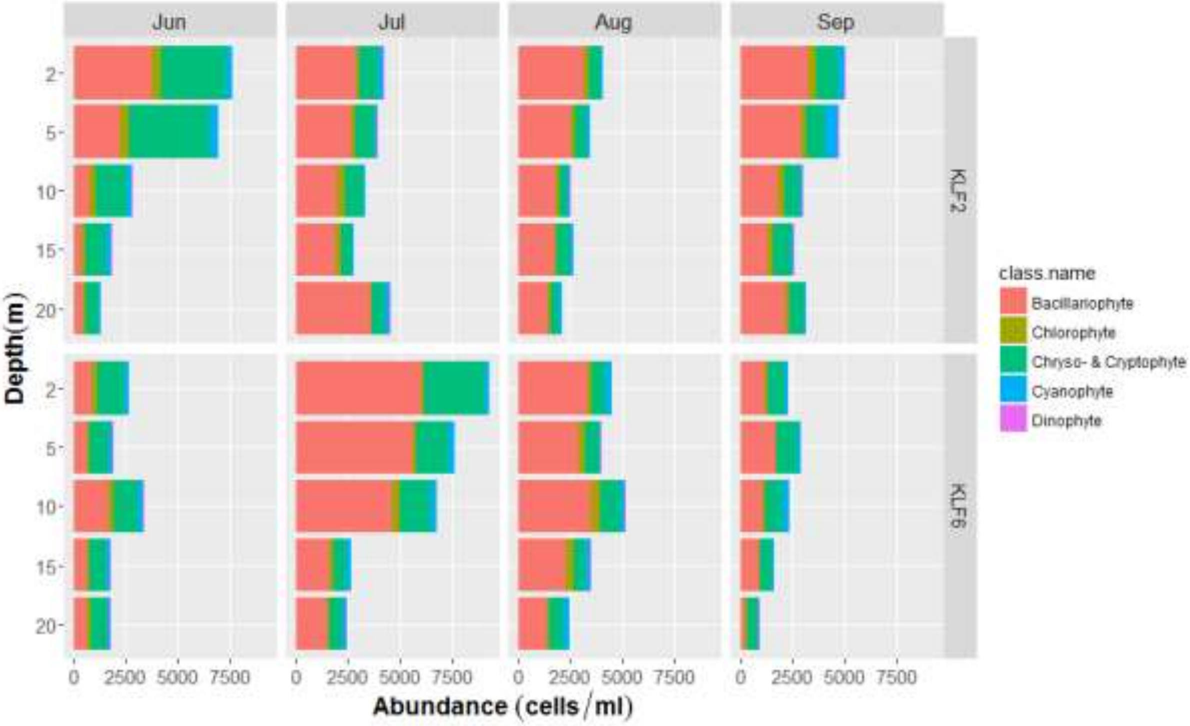


Figure 47. Discrete depth profiles of the North Arm (KLF 2) and the South Arm (KLF 6), June - September 2014 of phytoplankton abundance (cells/ml) by class name.

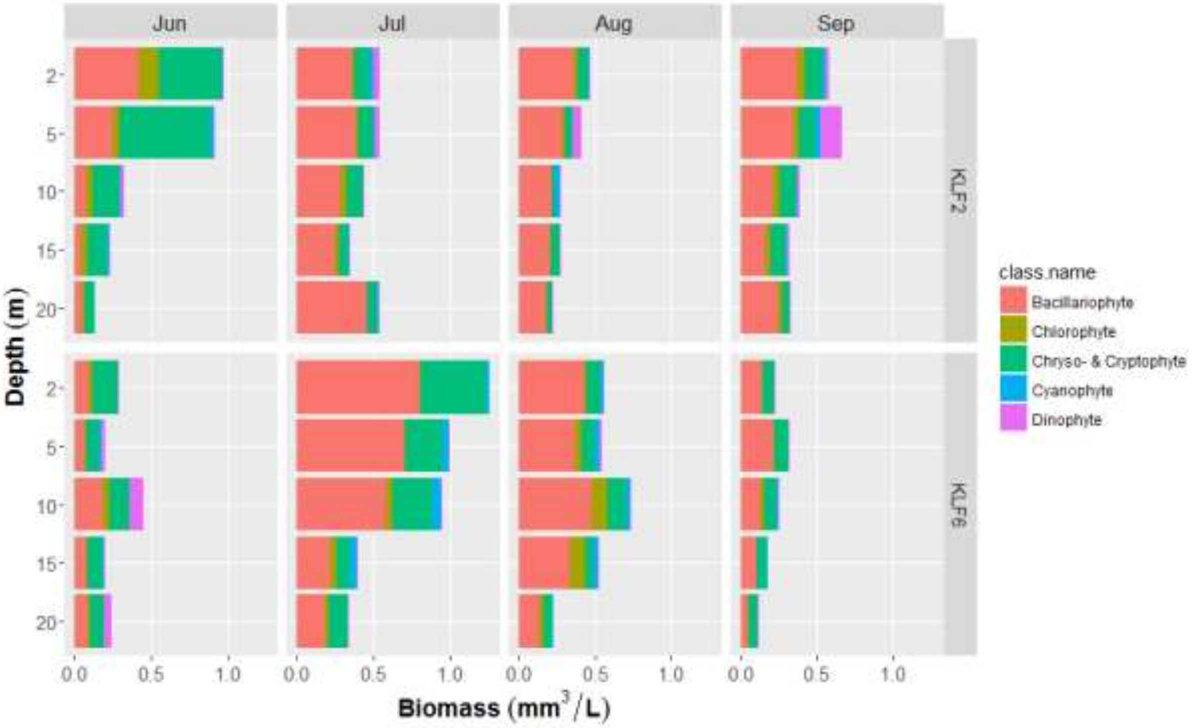


Figure 48. Discrete depth profiles of the North Arm (KLF 2) and the South Arm (KLF 6), June - September 2014 of phytoplankton biomass (mm^3/L) by class name.

Edible and Inedible

The abundance (cells/ml) of edible phytoplankton for discrete samples was highest in July at station KLF6 at 6741.04 cells/ml for the 2m sample (Fig. 49). The species that largely contributed to the high edible counts was the edible diatom *Cyclotella stelligera.* The abundance of inedible phytoplankton was highest in June at station KLF2 at 3629.02 cells/ml, also for the 2m sample. Inedible abundance was also in July at KLF2 at 20m, and at KLF 6 in the 2, 5 and 10m samples. These high inedible samples were from large contributions of the inedible diatoms *Asterionella formosa* and *Fragilaria crotonensis.*

Biomass of the discrete phytoplankton samples are shown in Figure 50. Edible phytoplankton biomass was highest in July at KLF6 (0.8940 mm^3/L) for the 2m sample. The 5 and 10m samples were also high in edible phytoplankton biomass; these high results were largely influenced by high *Cyclotella stelligera* and *Dinobryon sp* counts in the samples. Inedible phytoplankton was highest at 2m in the June KLF2 sample, largely from *Asterionella formosa* counts in the sample.

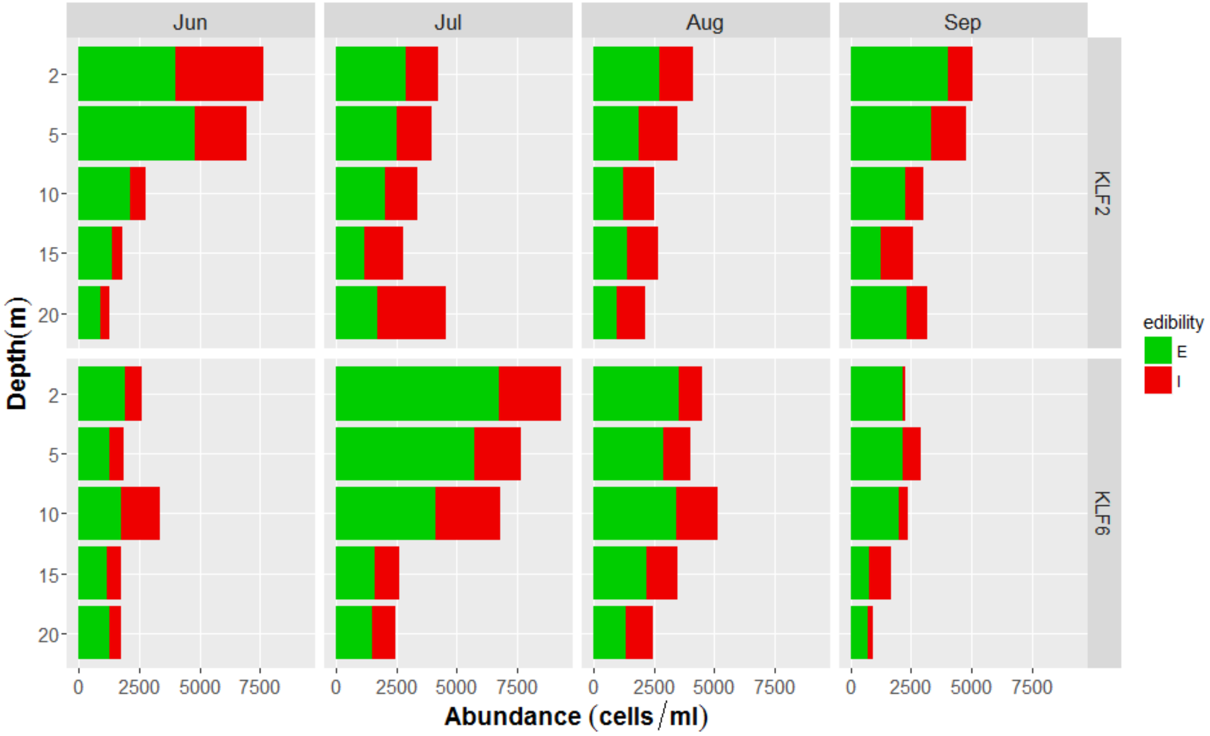


Figure 49. Discrete depth profiles of the North Arm (KLF 2) and the South Arm (KLF 6), June - September 2014 of phytoplankton abundance (cells/ml) by edibility.

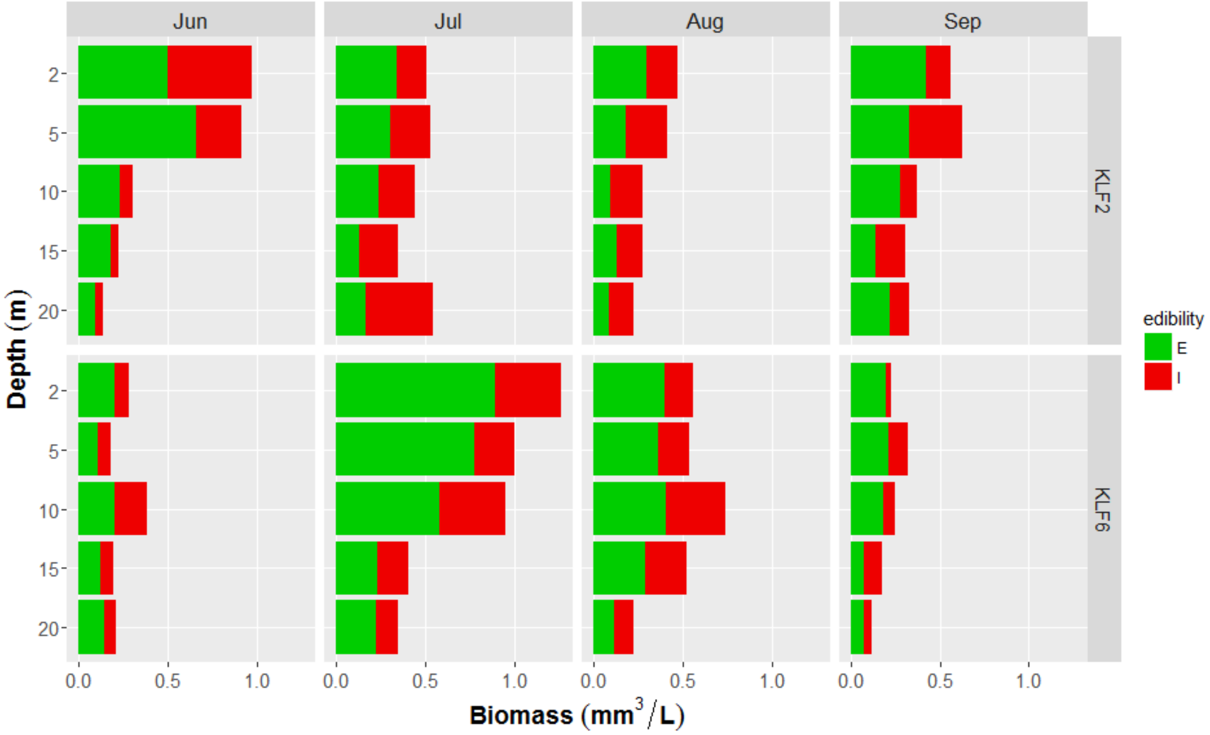


Figure 50. Discrete depth profiles of the North Arm (KLF 2) and the South Arm (KLF 6), June - September 2014 of phytoplankton biomass (mm^3/L) by edibility.

2015

Integrated Epilimnion

Class Abundance

Comparisons of arms and seasons were done and are summarized in Table 7. The results by class for each sampling period are shown in Figure 51. There was not a significant difference between the Arms for total abundance, however the summer mean was significantly higher than the spring and fall means.

Bacillariophytes peaked in July in the North Arm; this was largely from the species *Asterionella formosa* and *Cyclotella glomerata* observed at KLF 2. There was not a spatial expression across Arms, however the summer mean was significantly higher than the spring and fall means.

There was not a significant difference noted across arms in in 2015 for Chlorophytes abundance, however, seasonally, the spring mean was significantly higher than the summer mean. Chlorophytes peaked in June in the South Arm, and in late June in the West Arm, both due to large contributions of the species *Chlorella.*

Chryso-Cryptophyte abundance peaked in June in the South Arm, largely due to species *Chroomonas acuta* and *Dinobryon sp.* Cyanophtyes peaked in July in the North Arm due to species *Microcystis sp.* and *Planktothrix agardhii*, largely at KLF2. There was not a significant difference between arm means, however seasonally, the summer Chryso-Cryptophyte mean was significantly lower than the spring and fall means.

Dinophtyes peaked in late June; *Gymnodinium* species contribute to the majority of dinophyte abundance throughout the season, including this peak. There was no seasonal or spatial trend in dinophyte means in 2015.

Class Biomass

Biomass of phytoplankton by groups is shown in figure 52 and comparisons of arms and seasons were done and are summarized in Table 7. Total biomass in 2015 did not differ across arms, however seasonally the summer mean was significantly higher than the spring and fall means.

Bacillariophytes peaked in July in the North Arm; this was largely from the species *Asterionella formosa* and *Cyclotella stelligera* observed at KLF 2. There was not a spatial expression across Arms, however the summer mean was significantly higher than the spring and fall means.

Chlorophytes peaked in late July in the South Arm, and in late June in the West Arm; in both Arms large contributions of the species *Euglena* were a factor. There was no seasonal or spatial trend in chlorophytes means in 2015.

Chryso-Cryptophytes peaked in June in the South and West Arms, largely from the species *Dinobryon* species. Chryso-Cryptophytes were not significantly different across arms, however seasonally, the spring mean was significantly higher than the summer mean.

Cyanophtye biomass peaked in July in the North Arm due to species *Microcystis sp.* and *Planktothrix agardhii*, largely at KLF2. There was no seasonal or spatial trend in cyanophyte means in 2015.

Dinophtye biomass fluctuated throughout the sampling season, though the peak was observed in September in the West Arm with high biomass of the species *Ceratium*; the rest of the season was primarily *Gymnodinium* species. There was no seasonal or spatial trend in dinophyte means in 2015.

Table 7. Comparison of Arm means (North=KLF1-4, South=KLF5-7 and West=KLF8) and Season means (Spring=Apr-Jun, Summer=Jul-Sep and Fall=Oct-Nov) for 2015. Jun_2, Jul_2 and Aug_2 were omitted from analysis. Letter denotes a significant difference between means at 0.05.

		Arm			**Season**		
		North	**South**	**West**	**Spring**	**Summer**	**Fall**
Abundance (cells/ml)	Total Phytoplankton	3147^{a}	3566^{a}	2741^{a}	2161^{a}	5356^{b}	1735^{a}
	Bacillariophyte	2149^{a}	2500^{a}	1831^{a}	882^{a}	4616^{b}	716^{a}
	Chlorophyte	148^{a}	146^{a}	139^{a}	175^{b}	125^{a}	134^{ab}
	Chryso-& Cryptophyte	609^{a}	717^{a}	593^{a}	867^{b}	392^{a}	701^{b}
	Cyanophyte	245^{a}	185^{a}	160^{a}	217^{a}	236^{a}	165^{a}
	Dinophyte	21^{a}	21^{a}	18^{a}	22^{a}	18^{a}	15^{a}
Biomass (mm^3/L)	Total Phytoplankton	0.3982^{a}	0.4136^{a}	0.3444^{a}	0.2541^{a}	0.6429^{b}	0.2436^{a}
	Bacillariophyte	0.2389^{a}	0.2771^{a}	0.2090^{a}	0.1025^{a}	0.4830^{b}	0.1198^{a}
	Chlorophyte	0.0269^{a}	0.0238^{a}	0.0239^{a}	0.0242^{a}	0.0277^{a}	0.0237^{a}
	Chryso-& Cryptophyte	0.0647^{a}	0.0752^{a}	0.0658^{a}	0.0973^{b}	0.0368^{a}	0.0739^{ab}
	Cyanophyte	0.0528^{a}	0.0194^{a}	0.0263^{a}	0.0140^{a}	0.0831^{a}	0.0079^{a}
	Dinophyte	0.0212^{a}	0.0197^{a}	0.0195^{a}	0.0176^{a}	0.0237^{a}	0.0195^{a}

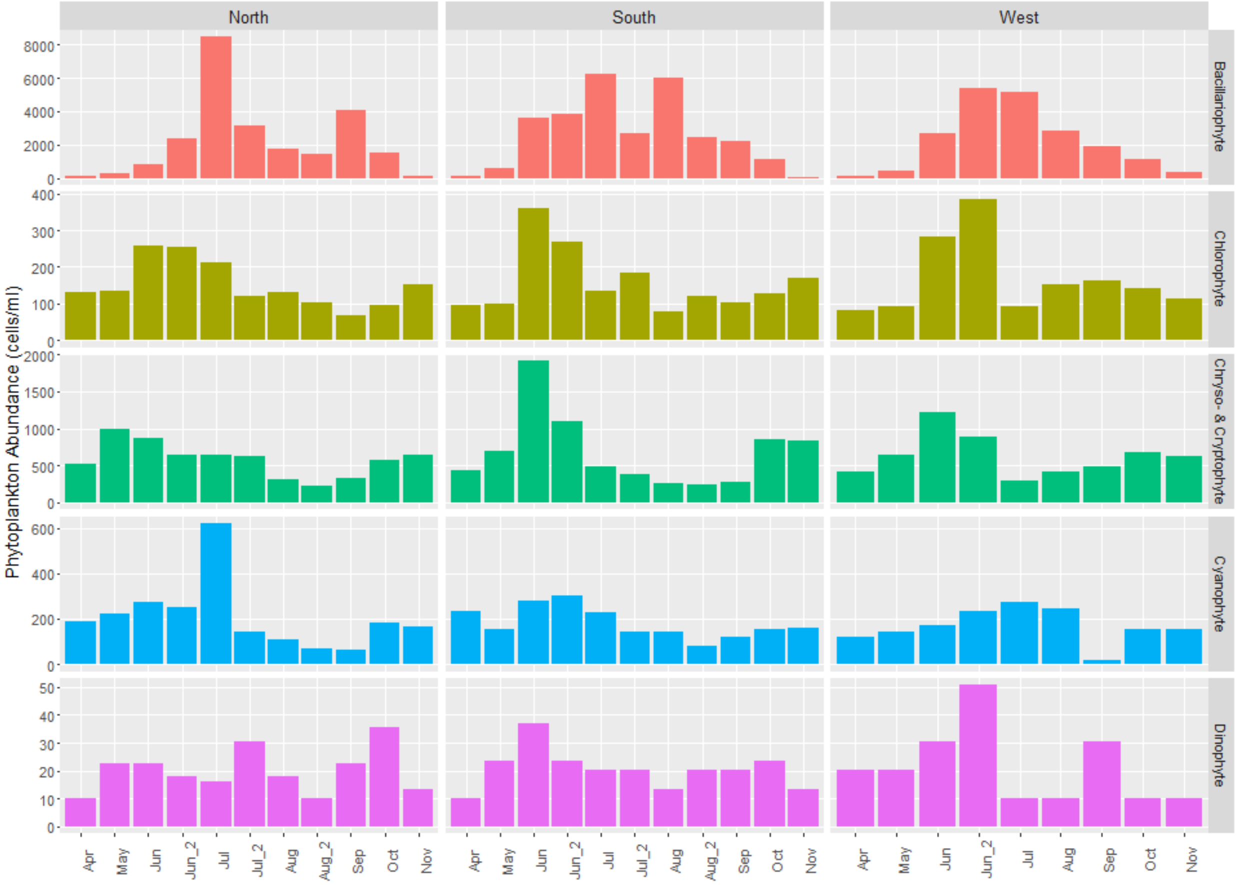


Figure 51. Phytoplankton monthly mean by group (Bacillariophyte, Chlorophyte, Chryso-& Cryptophyte, Cyanophyte and Dinophyte) abundance (cells/ml) by Arm; North (KL 1-4), South (KL 5-7) and West (KL 8) Kootenay Lake. April to November, 2015. Only KL2 and KL6 sampled on Jul_2 and Aug_2. Note axis changes by class.

Figure 52. Phytoplankton monthly mean by group (Bacillariophyte, Chlorophyte, Chryso-& Cryptophyte, Cyanophyte and Dinophyte) biomass (mm^3/L) by Arm; North (KL 1-4), South (KL 5-7) and West (KL 8) Kootenay Lake. April to November, 2015. Only KL2 and KL6 sampled on Jul_2 and Aug_2. Note axis changes by class.

Edible and Inedible

The abundance of edible phytoplankton was not significantly different between the North, South and West Arms. Seasonally, the summer mean of edible phytoplankton abundance was significantly higher than the spring and fall means. The Jun_2, Jul_2 and Aug_2 were omitted from this analysis. Edible phytoplankton abundance peaked in July in the North Arm, August in the South Arm, and in late June in the West Arm (Fig. 53). All high counts of edible phytoplankton abundance were the edible diatoms *Cyclotella stelligera* and *Cyclotella glomerata.* Inedible phytoplankton in 2015 did not differ across arms, but was significantly higher in the summer, (Jun_2, Jul_2 and Aug_2 were omitted from this analysis). Inedible phytoplankton abundance peaked in 2015 in the North Arm in the July results (Fig. 53), this was largely from high counts of the inedible diatom, *Asterionella formosa*.

Biomass of edible and inedible phytoplankton is shown in Figure 54. Edible biomass peaked in July in the North Arm, August in the South Arm and in late June in the West Arm, the species that contributed to these peaks were the edible diatom, *Cyclotella stelligera*. Inedible phytoplankton biomass peaked in July in the North Arm, due to high counts of the cyanophyte *Planktothrix agardhii*.

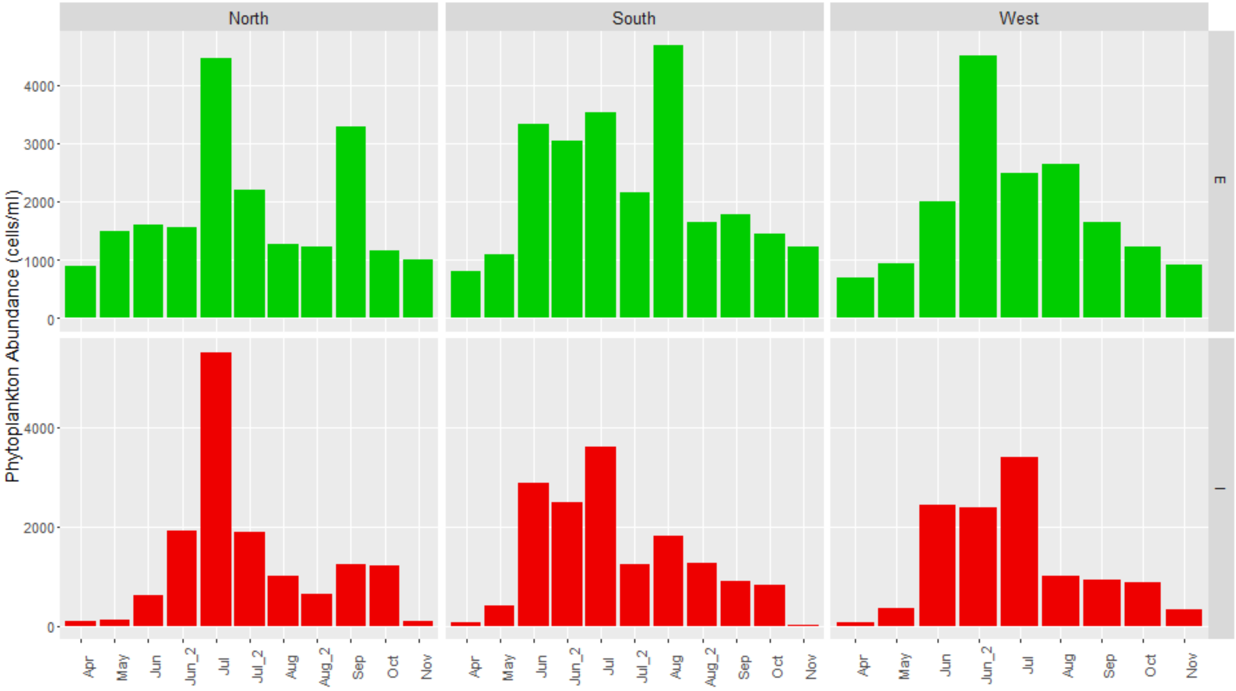


Figure 53. Abundance (cells/ml) monthly mean of edible (E) and inedible (I) phytoplankton by Arm; North (KL 1-4), South (KL 5-7) and West (KL 8) Kootenay Lake. April to November, 2015. Only KL2 and KL6 sampled on Jul_2 and Aug_2.

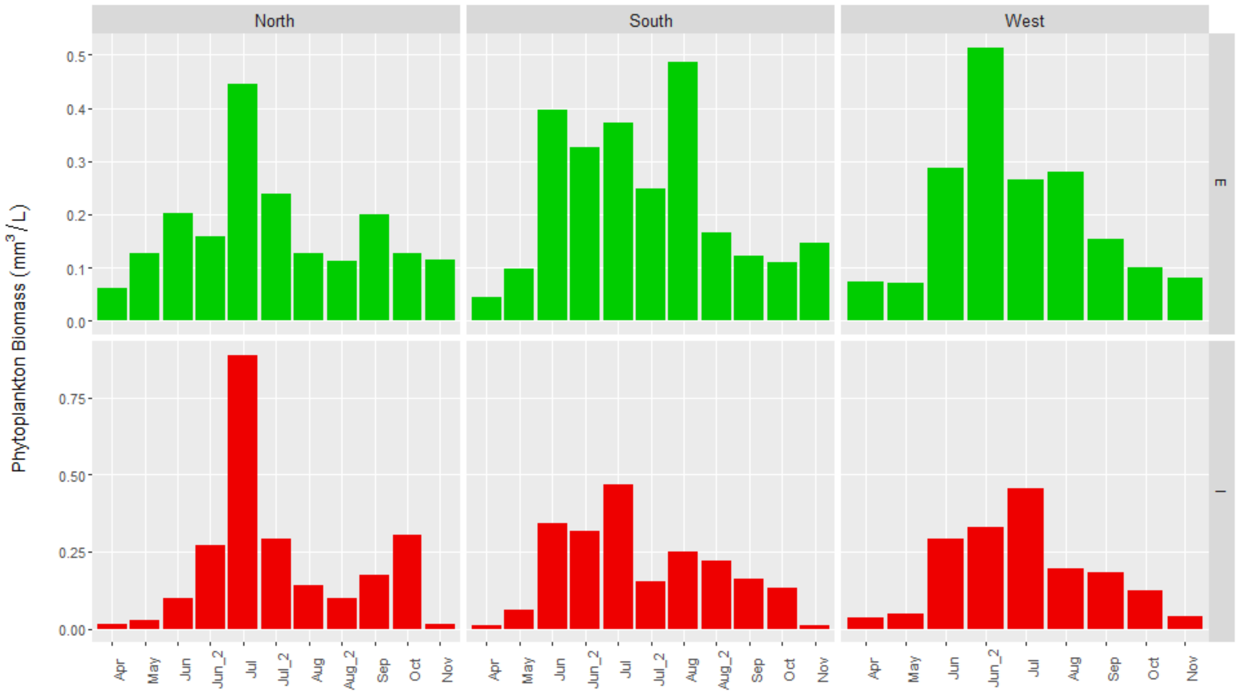


Figure 54. Biomass (mm^3/L) monthly mean of edible (E) and inedible (I) phytoplankton by Arm; North (KL 1-4), South (KL 5-7) and West (KL 8) Kootenay Lake. April to November, 2015. Only KL2 and KL6 sampled on Jul_2 and Aug_2.

Discrete Epilimnion

Class Abundance

Profile abundance of phytoplankton is shown in Figure 55. Bacillariophytes were highest in July at KLF2 and KLF6; the highest results were at KLF6 in July at 20 m and 5 m (7197.19 and 7176.91 cells/ml). Chlorophyte abundance did not vary much across depths, seasons or stations; the minimum Chlorophyte abundance result was 30.42 cells/ml reported at KLF6 in September at 20 m, whereas the maximum was reported at 324.4 cells/ml at KLF6 in September at 2 m. Aside from Bacillariophytes, Chryso-Cryptophytes contribute the highest to total abundance; the Chryso-Cryptophyte peak was observed at KLF 6 in June at 1307.65 cells/ml at the 10 m depth. Cyanophytes peaked at station KLF2 in July for the 15 m sample (679.16 cells/ml). Dinophytes ranged minimally over the discrete samples; the maximum was reported at 81.10 cells/ml at KLF6 in June at 2 m, whereas approximately 82% of the other dinophyte samples were at or below an abundance of 20.28 cells/ml.

Class Biomass

Profile biomass of phytoplankton is shown in Figure 56. The highest bacillariophyte result (1.2745 mm^3/L) was observed at KLF6 in June at 2 m, while low bacillariophyte results occurred in June and September for KLF2 and in September at station KLF6. Chlorophyte biomass ranged from 0.0061 mm^3/L (KLF6 September at 20 m) to 0.1425 mm^3/L (KLF2 in June at 15 m); this chlorophyte biomass high result was influenced by the large-celled species *Euglena*. Chryso-Cryptophytes were highest in June and July at varying depths, the peak of these was observed at KLF6 in June at 10 m (0.2285 mm^3/L). Cyanophyte biomass is low relative to the other classes, where results ranged from 0.0002 mm^3/L (KLF2 September at 10 m) to 0.3893 mm^3/L (KLF2 July at 15 m). Dinophytes peaked at station KLF6 in June at 10 m (0.1404 mm^3/L), whereas approximately 77 % of the other dinophyte samples were at or below a biomass of 0.0203 mm^3/L.

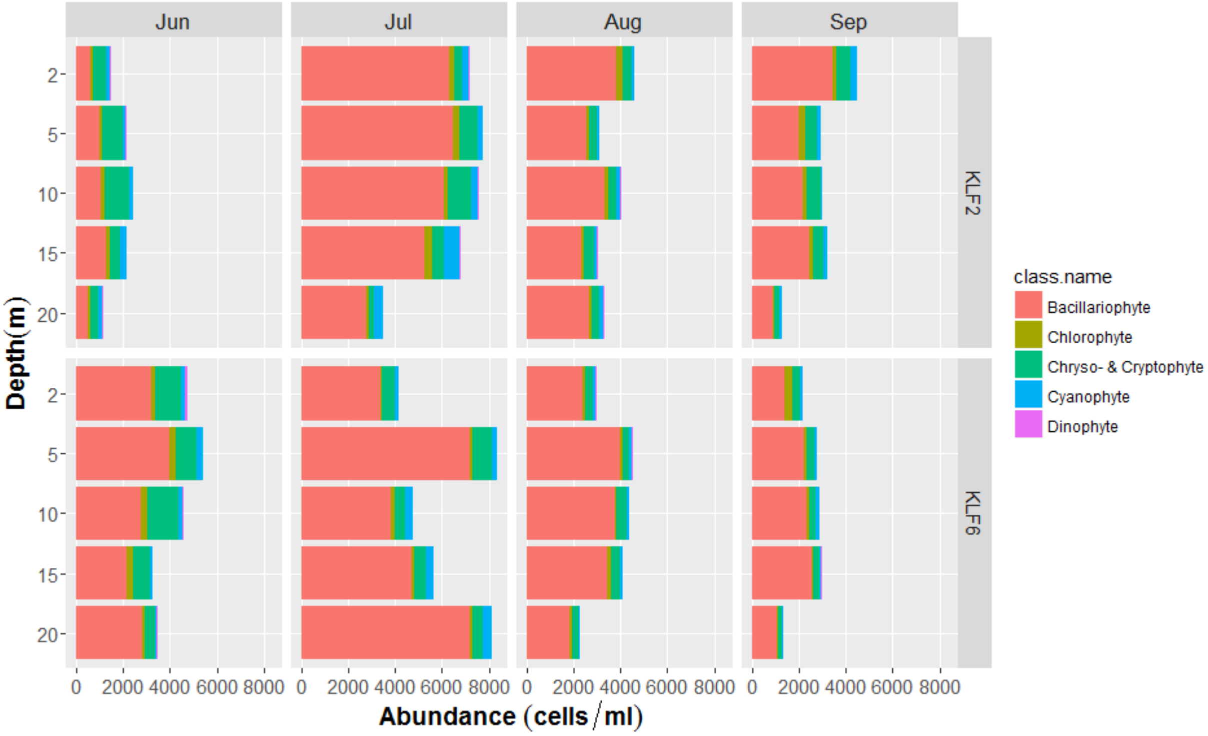


Figure 55. Discrete depth profiles of the North Arm (KLF 2) and the South Arm (KLF 6), June - September 2015 of phytoplankton abundance (cells/ml) by class name.

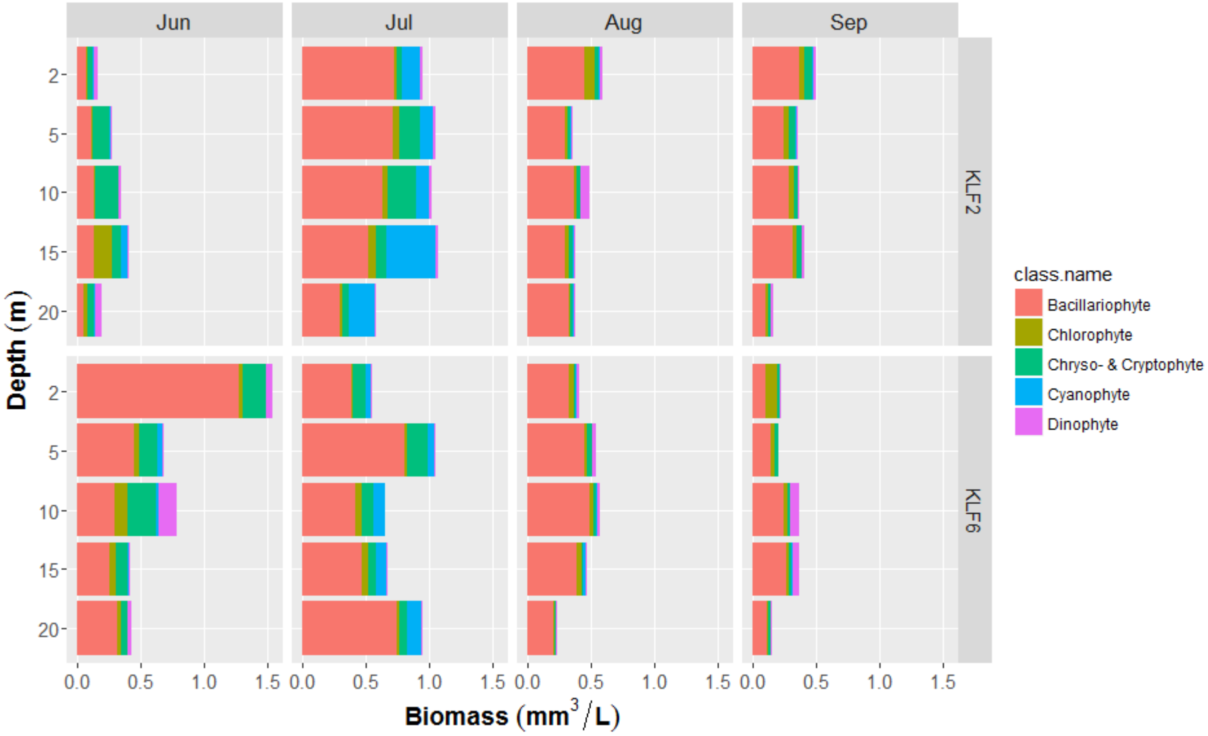


Figure 56. Discrete depth profiles of the North Arm (KLF 2) and the South Arm (KLF 6), June - September 2015 of phytoplankton biomass (mm^3/L) by class name.

Edible and Inedible

Discrete samples were collected at 2 stations; KLF2 in the North Arm and KLF6 in the South Arm, and at depths of 2, 5, 10, 15 and 20m. The abundance (cells/ml) of edible phytoplankton was highest in July and August, and peaked at KLF6 in Jul at 5m (Figure 57). The species that largely contributed to the high edible counts was the edible diatom *Cyclotella stelligera.* The abundance of inedible phytoplankton was highest in July, particularly at station KLF 2. Peak inedible abundance was observed at KLF2 in July at 5m due to large contributions from the inedible diatoms *Asterionella formosa* and *Fragilaria crotonensis.*

Biomass of the discrete phytoplankton samples are shown in Figure 58. Edible phytoplankton biomass was higher in July for both KLF 2 and KLF 6, with the peak of edible biomass observed at 5 m in July at KLF 6, and as was the case for abundance, was largely from the edible diatom *Cyclotella stelligera.* Inedible phytoplankton was also highest in July, although the peak biomass single result was observed in June at 2 m at KLF 6 due to contributions from the species *Stephanodiscus*.

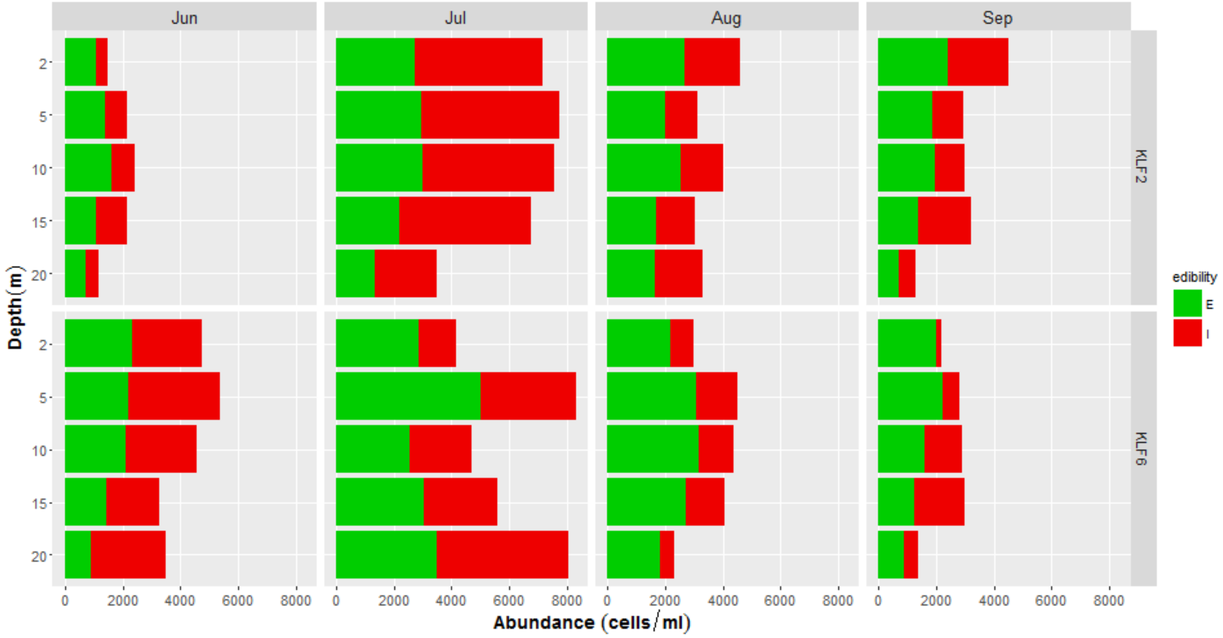


Figure 57. Discrete depth profiles of the North Arm (KLF 2) and the South Arm (KLF 6), June - September 2015 of phytoplankton abundance (cells/ml).

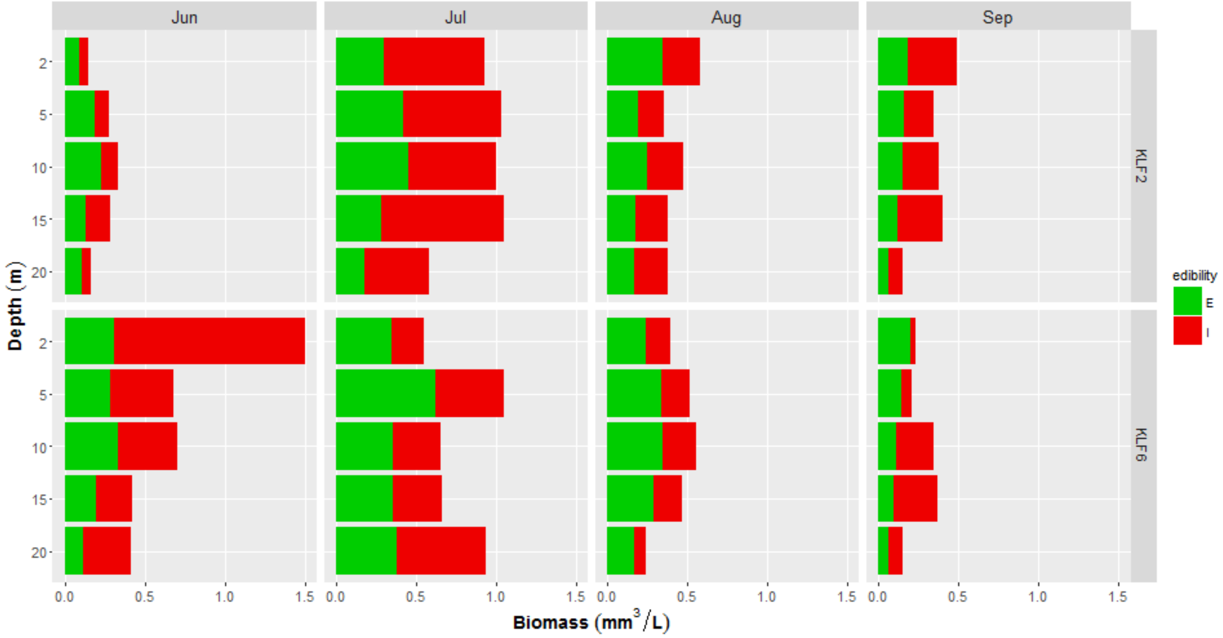


Figure 58. Discrete depth profiles of the North Arm (KLF 2) and the South Arm (KLF 6), June - September 2015 of phytoplankton biomass (mm^3/L).

Comparisons amongst years

Yearly comparisons were made for both the North and South Arm. Total phytoplankton was analysed, as were two other classes (bacillariophytes and chryso-cryptophytes).

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.

Total phytoplankton biomass, all classes combined (bacillariophyte, chlorophyte, chryso-& cryptophyte, cyanophyte and dinophyte), increased marginally in the North Arm from 2014 to 2015, and decreased marginally between years in the South Arm (Fig. 59). However, there was not a significant difference between the yearly comparison means (1992-2013 mean vs. 2014 and 2015) for both the North and South Arm (Table 8).

Bacillariophyte biomass increased in 2015 from 2014 in both the North and South Arms (Fig. 60). However, in the North Arm the only significant difference between means was between the 1992-2013 mean and the 2014 mean (2014 bacillariophyte biomass was lower, Table 8). In the South Arm, there were no significant differences between means observed (Table 8). The bacillariophyte biomass in 2002 was driven from high volumes of the netplankton species *Tabellaria* in the September and October samples in the South Arm.

Chryso-cryptophytes decreased in 2015 from the previous year, in both the North and South Arms (Fig. 61). In the North Arm, the 2015 mean was significantly lower than the 1992-2013 mean. In the South Arm, the 2014 Chryso-Cryptophyte mean was significantly higher than the pooled 1992-2013 mean as well as the 2015 mean (Table 8).

Table 8. Monthly (Apr-Nov) mean of phytoplankton (mm^3/L) of yearly comparisons (1992-2013; 2014 and 2015). Letters denotes significant differences in yearly comparisons, for each Arm.

Units=mm^3/L		**1992-2013**	**2014**	**2015**
Total Phytoplankton	North	0.5801^{a}	0.3660^{a}	0.3962^{a}
	South	0.4231^{a}	0.4482^{a}	0.4117^{a}
Bacillariophyte	North	0.3749^{b}	0.1901^{a}	0.2389^{ab}
	South	0.2794^{a}	0.2013^{a}	0.2771^{a}
Chryso-Cryptophytes	North	0.1439^{b}	0.1176^{ab}	0.0647^{a}
	South	0.1088^{a}	0.1654^{b}	0.0754^{a}

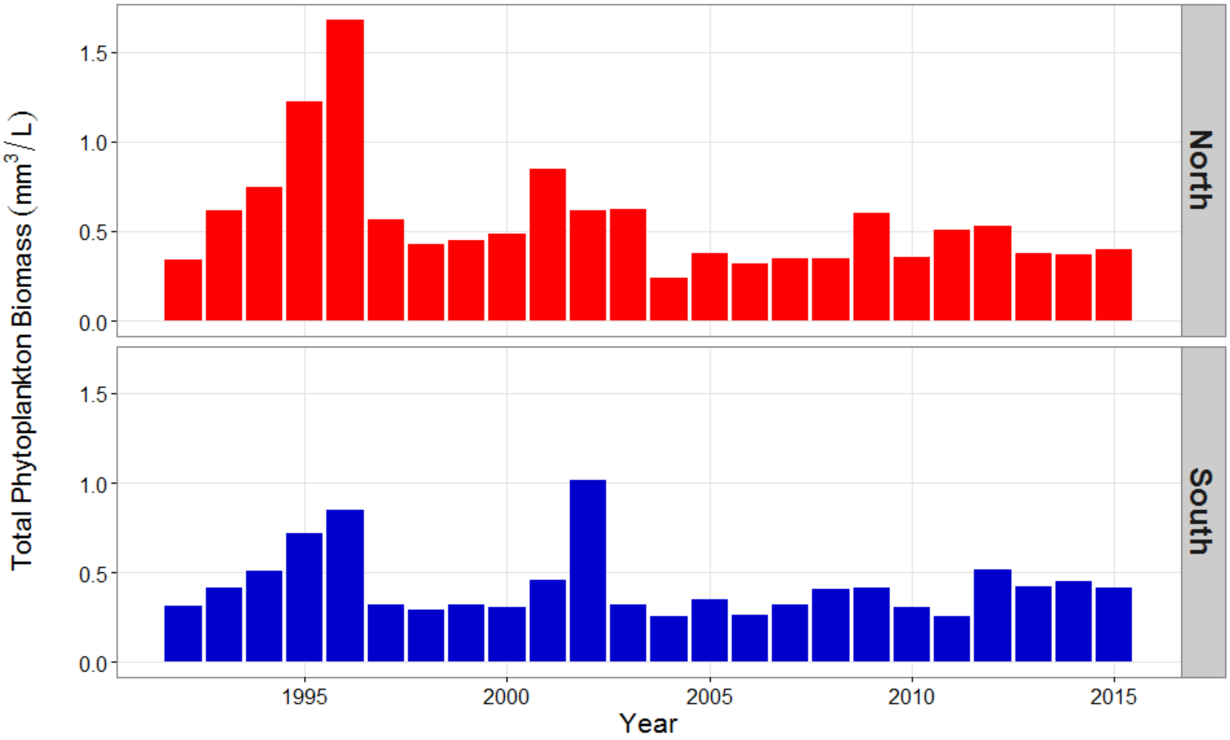


Figure 59. Average monthly total phytoplankton biomass by Arm (North Arm (KLF1-4) and South Arm (KLF 5-7), 1992 to 2015.

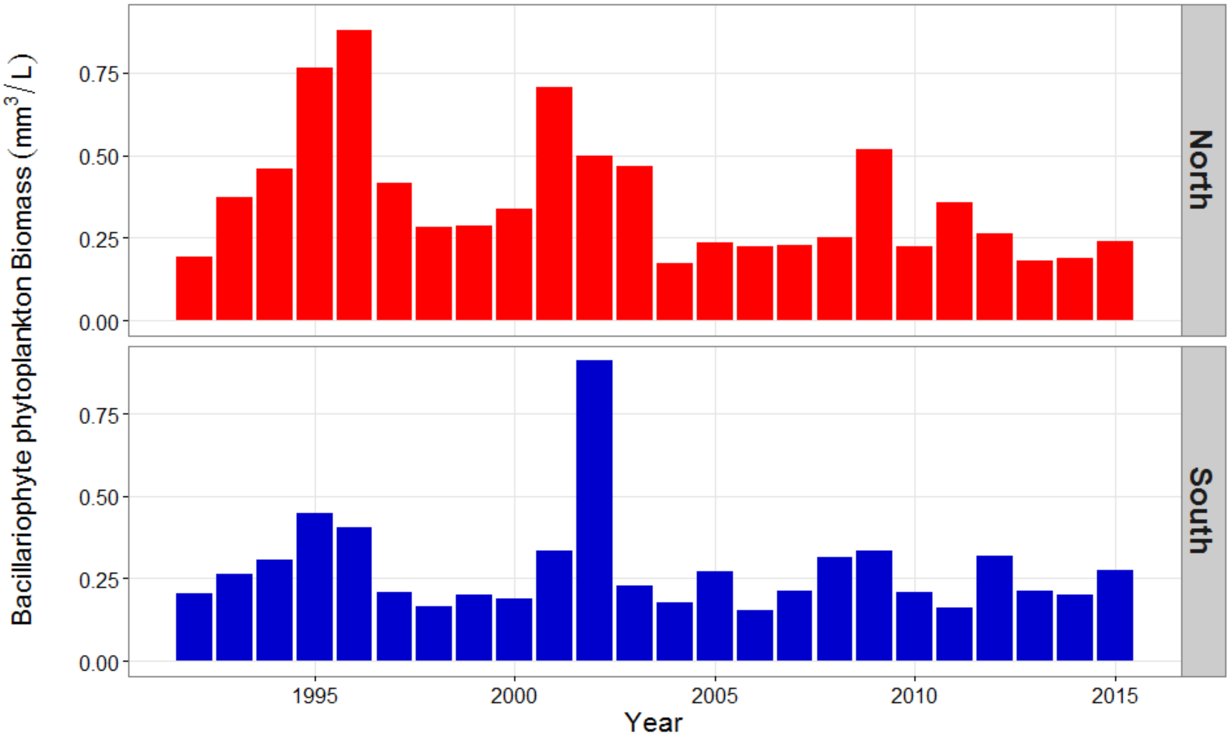


Figure 60. Average monthly bacillariophyte phytoplankton biomass by Arm (North Arm (KLF1-4) and South Arm (KLF 5-7), 1992 to 2015.

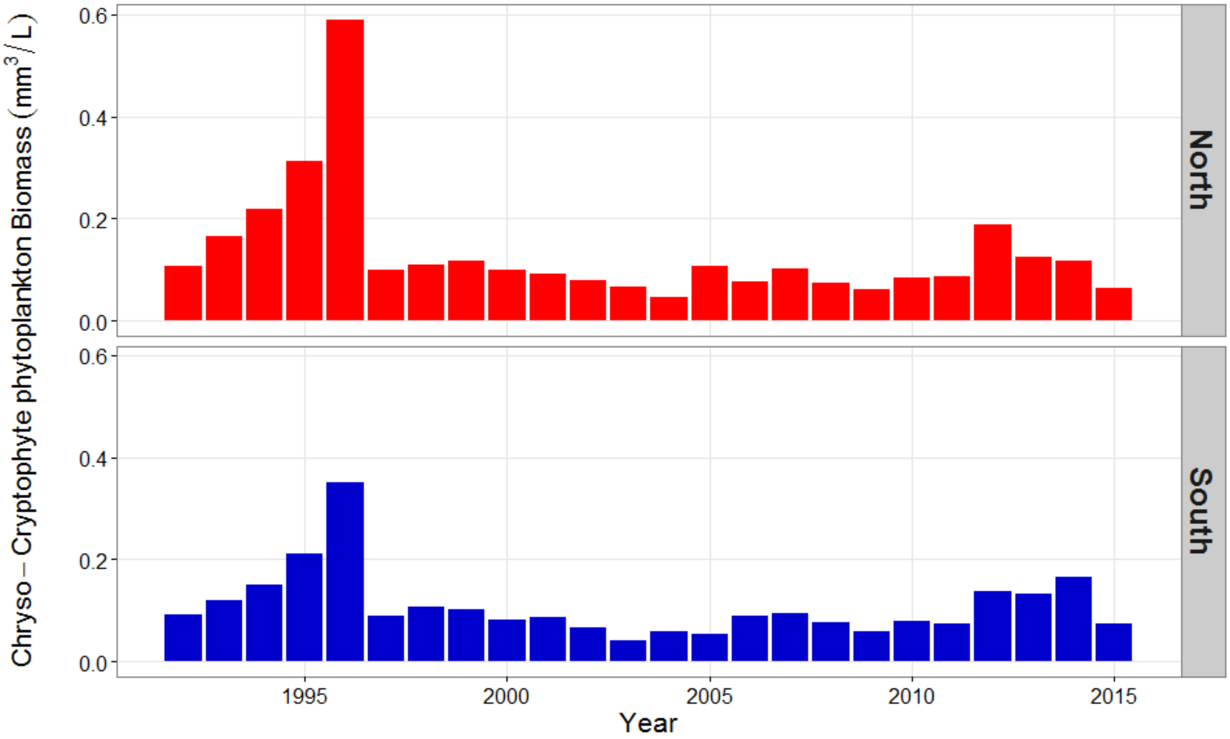


Figure 61. Average monthly Chryso-& Cryptophyte phytoplankton biomass by Arm (North Arm (KLF1-4) and South Arm (KLF 5-7), 1992 to 2015.

Zooplankton

Species

Twenty species of macrozooplankton were identified in samples over the course of the 2014 study and twenty-two over the course of the 2015 study, 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 2014 and 2015 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 brachyurum (Liéven). The rare cladoceran species *Acroperus harpae* (Baird) was seen at KL8 (May 2014, July 2015) and KL7 (July 2015), and one copepod *Macrocyclops sp*. (Claus) was seen in July 2015 at stations KLF8 and KLF7.

Density

As with previous years, copepods dominated the percentage of average zooplankton density in all arms of Kootenay Lake in 2014 and 2015, with *Daphnia* sp. and cladocerans other than *Daphnia* making up the remainder. In all arms of Kootenay Lake the proportion of copepod density declined or remained stable from 2014 to 2015, while the proportion of *Daphnia* sp. increased and cladocerans other than *Daphnia* decreased in proportion. In the North Arm, 89% (2014) and 84% (2015) of all average zooplankton were copepods, while *Daphnia* sp. increased from 7% to 14% and cladocerans other than *Daphnia* decreased from 4% to 2% between 2014 and 2015 (Fig.62). In the South Arm 87% (2014) and 84% (2015) of all average zooplankton were copepods, while *Daphnia* sp. increased from 8% to 12% and cladocerans other than *Daphnia* sp. decreased from 5% to 4% between 2014 and 2015. Similarly, in the West Arm copepods composed 80-81% of all average zooplankton density, while *Daphnia* sp. increased from 14% to 16% and cladocerans other than *Daphnia* sp. decreased from 6% to 3% between 2014 and 2015.

The average zooplankton density amongst all stations increased in 2015 to 33.37 individuals/L from 31.19 individuals/L in 2014 (Fig. 63 - West Arm results not included in the calculation). In the North Arm, from 2014 to 2015 the annual average density of copepods increased from 22.74 to 25.98 individuals/L, *Daphnia* sp. increased from 1.76 to 4.16 individuals/L, and cladocerans other than *Daphnia* sp. decreased from 1.10 to 0.66 individuals/L (Fig. 64). In the South Arm, between 2014 and 2015 the annual average density of copepods decreased from 33.55 to 30.85 individuals/L, while *Daphnia* sp. increased from 3.10 to 4.47 individuals/L, and cladocerans other than *Daphnia* sp. decreased from 1.99 to 1.46 individuals/L. In the West Arm, between 2014 and 2015 the annual average density of copepods increased from 19.14 to 20.23 individuals/L, while *Daphnia* sp. increased from 3.30 to 4.01 individuals/L, and cladocerans other than *Daphnia* sp. decreased from 1.42 to 0.87 individuals/L.

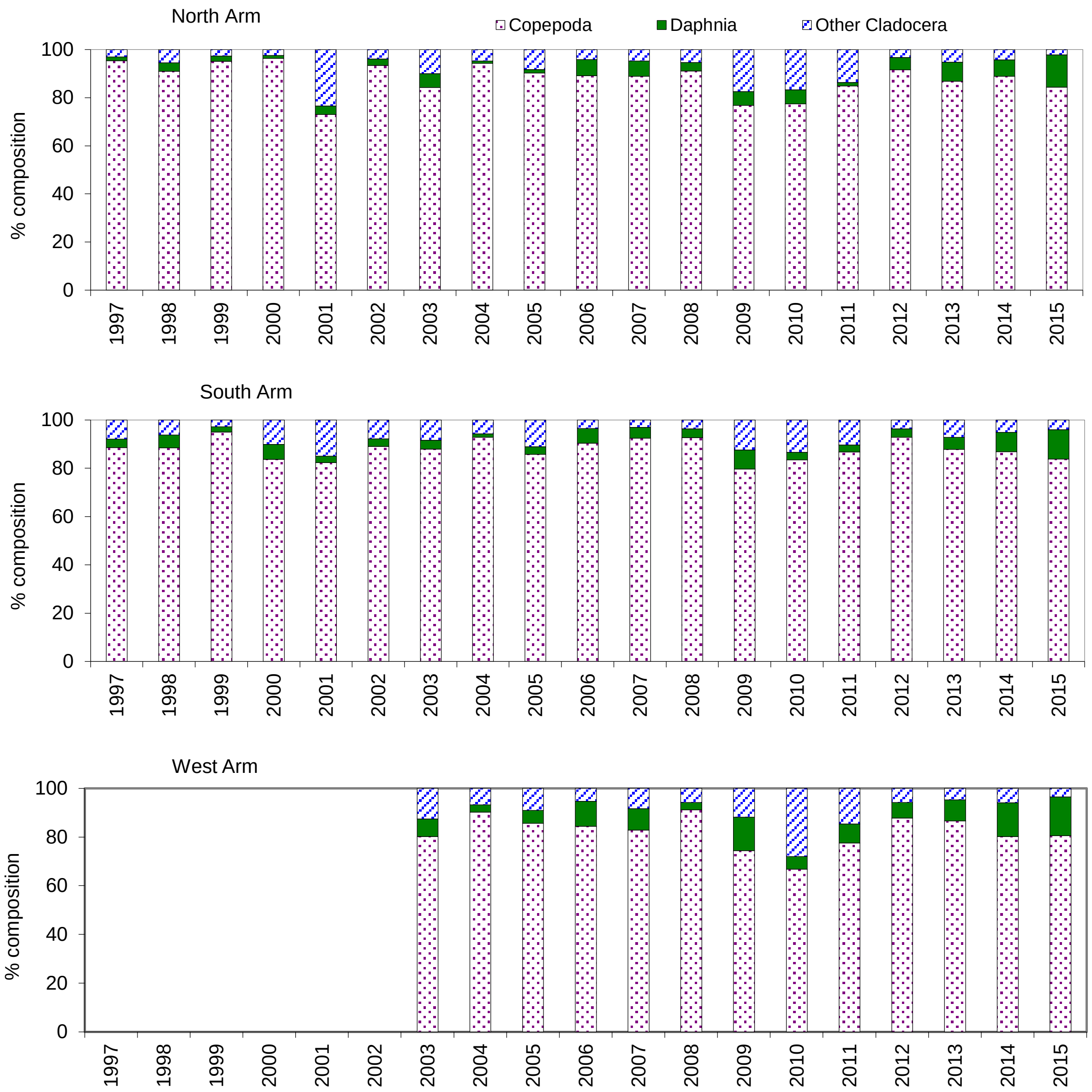


Figure 62. Seasonal composition of zooplankton as a percentage of average density in the North, South and West Arms of Kootenay Lake, 1997 to 2015.

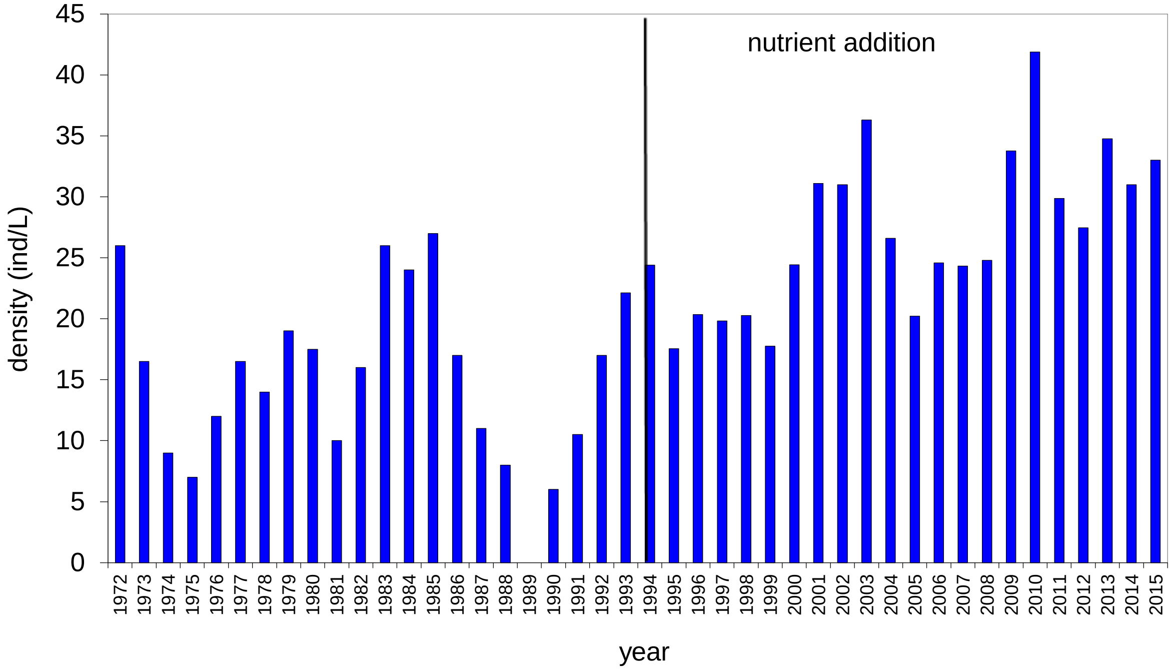


Figure 63. Average whole lake zooplankton density, 1972 to 2015. Note: 1972 to 1991 data collected from near present station KLF 5 and 1992 to 2015 data calculated as whole-lake average (West Arm data not included).

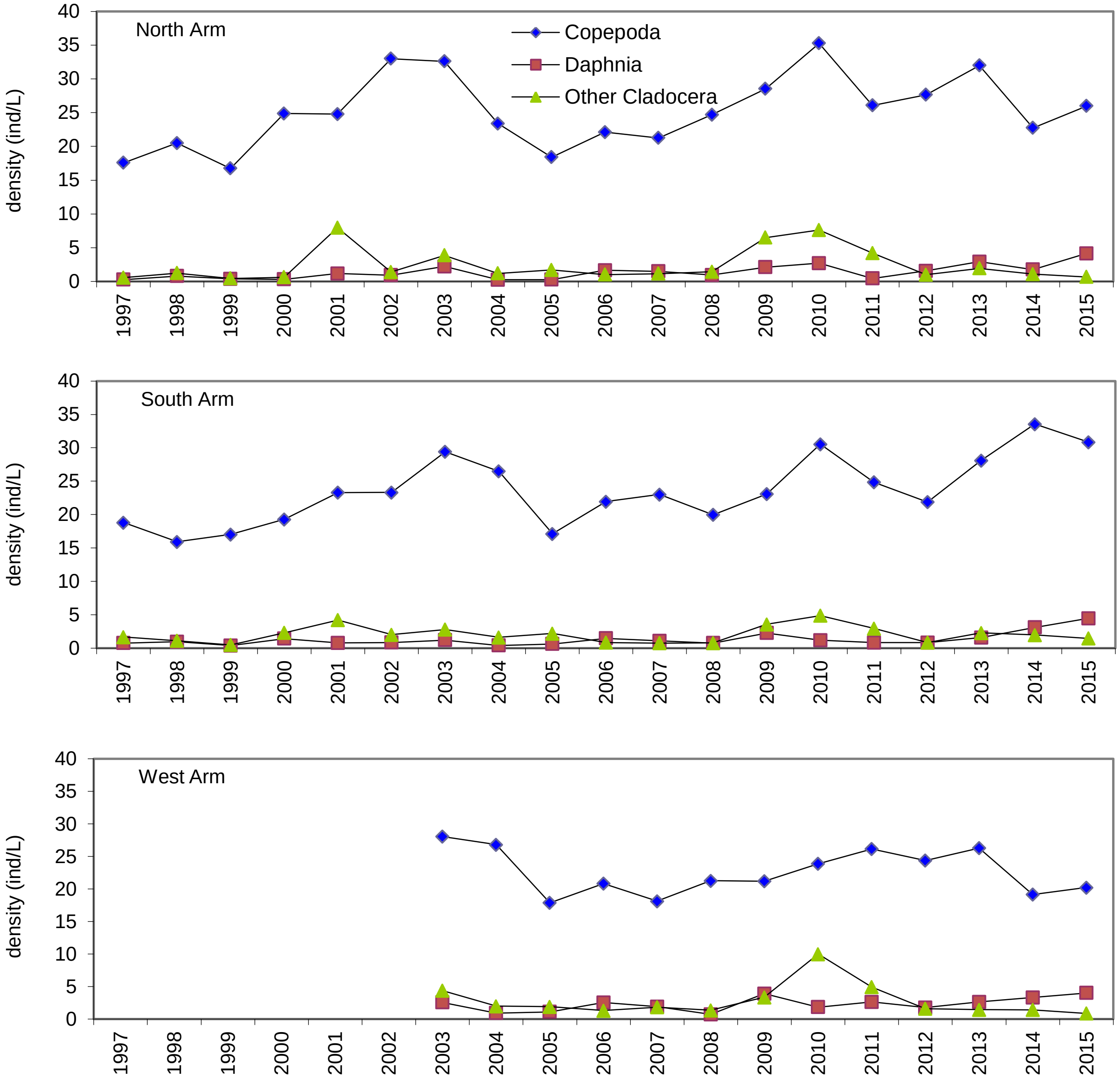


Figure 64. Seasonal average density of zooplankton in Kootenay Lake, North, South and West Arms, 1997 to 2015.

Biomass

Trends for composition of zooplankton as percentage of biomass matched density trends in all arms of Kootenay Lake, as the percentage of biomass for *Daphnia sp.* increased, while biomass for copepods and cladocerans other than *Daphnia sp.* decreased between 2014 and 2015. In the North Arm, the average zooplankton biomass increased from 55% to 73% for *Daphnia sp.* between 2014 and 2015, while copepods decreased from 43% to 26% and cladocerans other than *Daphnia sp.* decreased from 2% to 1% (Fig. 65). In the South Arm, the composition was similar with average zooplankton biomass increasing from 61% to 72% for *Daphnia sp.* between 2014 and 2015, while copepods decreased from 36% to 26% and cladocerans other than *Daphnia sp.* decreased from 3% to 2%. In the West Arm, the average zooplankton biomass increased from 69% to 78% for *Daphnia sp.* between 2014 and 2015, while copepods decreased from 29% to 21% and cladocerans other than *Daphnia sp.* decreased from 3% to 1%.

The 2014-2015 biomass percentage trends were again reflected in the seasonal average biomass results. In the North Arm, seasonal average zooplankton biomass increased from 53.47 to 107.59ug/L for *Daphnia sp.* between, while copepods decreased from 41.28 to 37.66ug/L and cladocerans other than *Daphnia sp.* decreased from 2.39 to 1.43ug/L (Fig. 66). In the South Arm, seasonal average zooplankton biomass increased from 92.93 to 148.81ug/L for *Daphnia sp.*, while copepods decreased from 55.68 to 52.61ug/L and cladocerans other than *Daphnia sp.* decreased from 4.94 to 4.05ug/L. In the West Arm, the seasonal zooplankton biomass increased from 72.20 to 114.77ug/L for *Daphnia sp.*, while copepods increased slightly from 30.02 to 30.30ug/L, and cladocerans other than *Daphnia sp.* decreased from 2.74 to 1.60ug/L.

The average zooplankton biomass amongst all stations (West Arm results not included in the calculation) increased in 2015 to 171.87 ug/L from 121.31 ug/L in 2014.

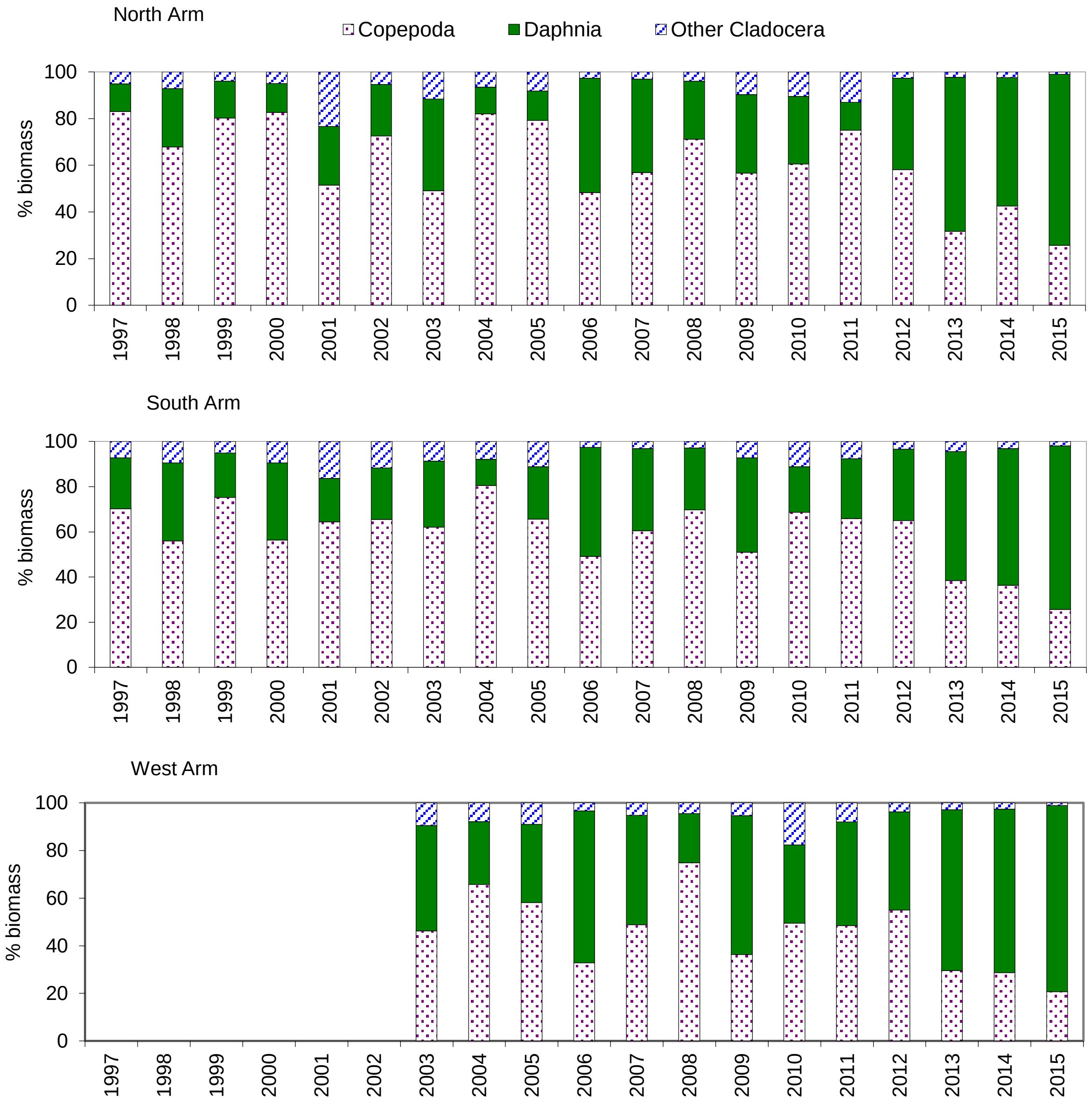


Figure 65. Seasonal composition of zooplankton as a percentage of average biomass in the North, South and West Arms of Kootenay Lake, 1997 to 2015.

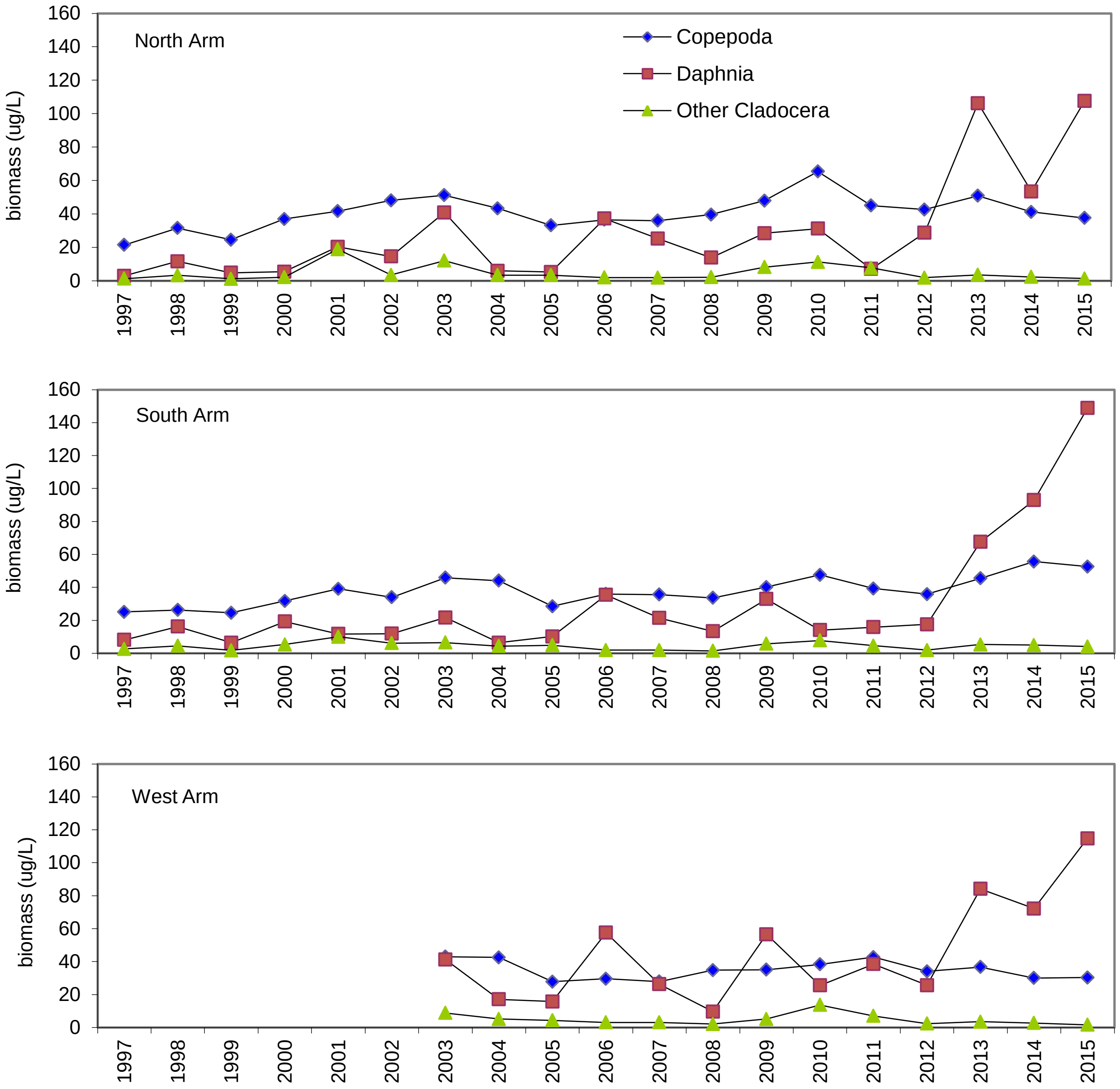
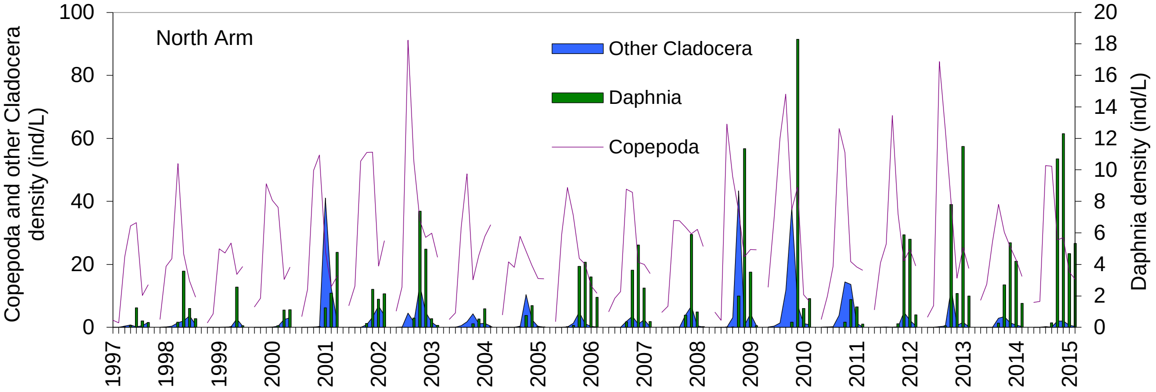


Figure 66. Seasonal average biomass of zooplankton in Kootenay Lake, North, South and West Arms, 1997 to 2015.

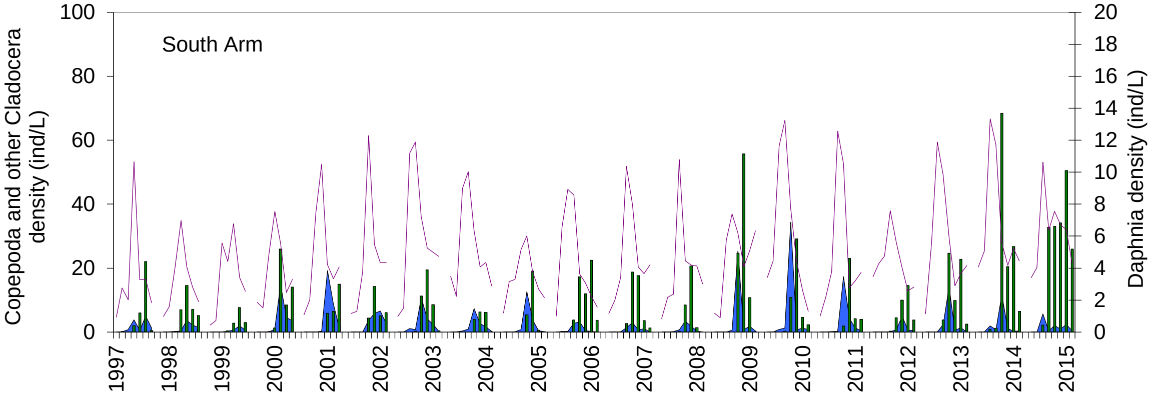
Seasonal and lake patterns

Copepods were the main contributor to the overall zooplankton population in the spring with *Daphnia* appearing in summer, peaking in fall and maintaining a population through November. This pattern occurred in the North, South and West Arms in 2015 with first appearing of *Daphnia* in April (2014) or June (2015), and reaching maximum density in August in the West Arm, September in the North Arm, and August (2014) or October (2015) in the South Arm (Fig. 67 for abundance and Fig. 68 for biomass). Copepods have been the main contributor to abundance during the sampling season (April to November 2014 and 2015) while the trend in biomass was dominated by *Daphnia* from August to October in 2014 and July through November in 2015. This is the typical trend observed throughout studied years.

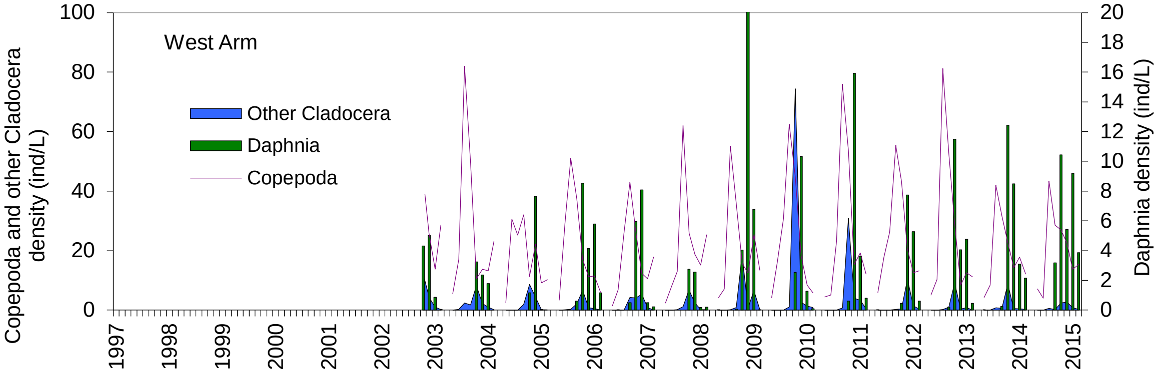
Total zooplankton density was considerably higher in the South Arm than in the North Arm for both 2014 and 2015. This is contrary to the traditional trend of zooplankton density being higher or similar in the North Arm compared to the South Arm for all years since 1998, with the exception of 2004 (Fig. 69). For the three years 2013-2015, total average zooplankton biomass in all three Arms of Kootenay Lake has been at record high levels: 2013 – 140.57 ug/L; 2014 – 119.27 ug/L, and 2015 – 168.72 ug/L (Fig. 70). This represents nearly a doubling of the long-term average (1997-2012) of 60.75 ug/L. During the 2013 and 2015 season, the appearance of very large *Daphnia* individuals accounted for larger increases of zooplankton biomass relative to the 2014 year. Of the three areas of the lake, total biomass was the highest in the South Arm in both 2014 and 2015; the only two years this has happened since the monitoring of the West Arm began in 2003 (Fig. 70).



a. Seasonal density of zooplankton in the North Arm of Kootenay Lake, 1997 to 2015.

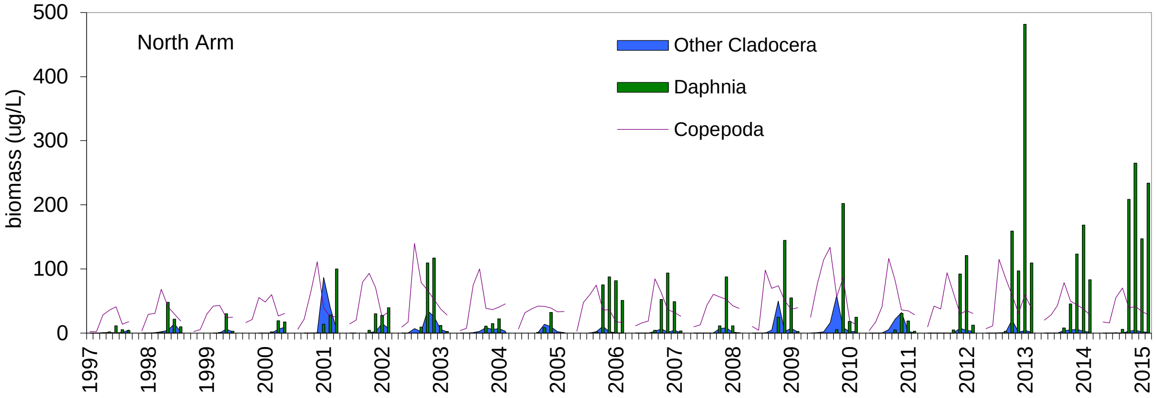


b. Seasonal density of zooplankton in the South Arm of Kootenay Lake, 1997 to 2015.

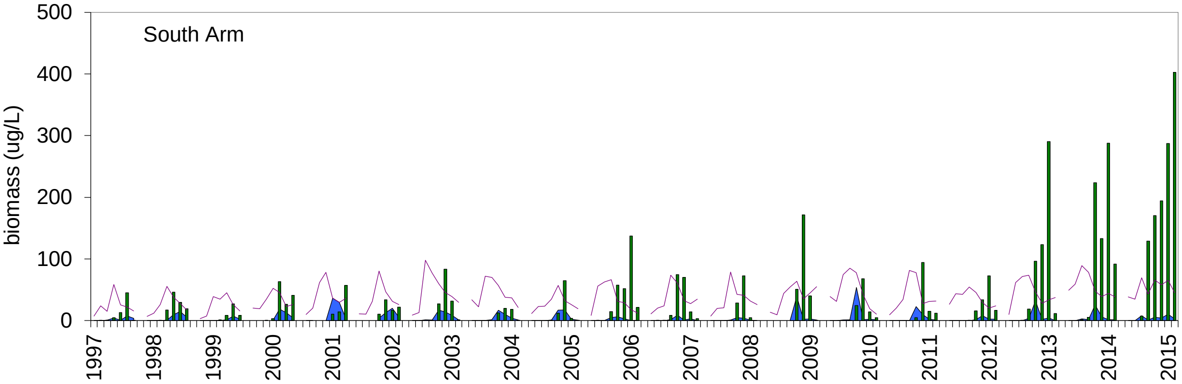


c. Seasonal density of zooplankton in the West Arm of Kootenay Lake, 1997 to 2015.

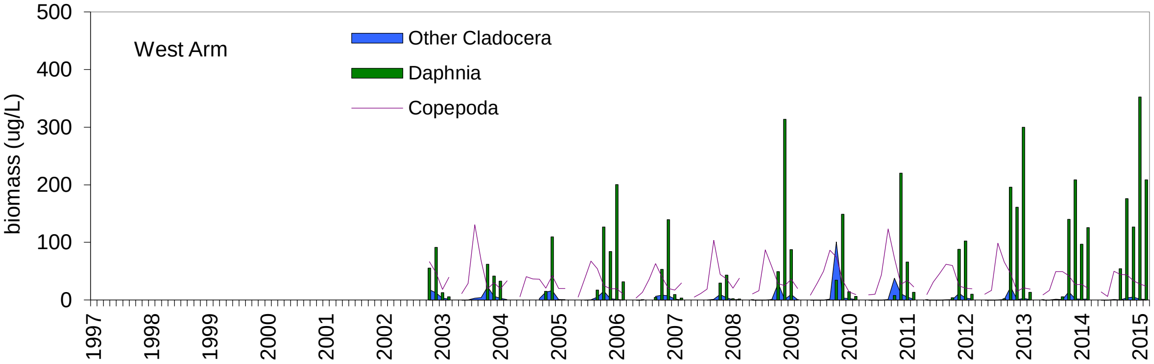
Figure 67. Zooplankton density in Kootenay Lake, 1997 to 2015.



a. Seasonal biomass of zooplankton in the North Arm of Kootenay Lake, 1997 to 2015.



b. Seasonal biomass of zooplankton in the South Arm of Kootenay Lake, 1997 to 2015.



c. Seasonal biomass of zooplankton in the West Arm of Kootenay Lake, 1997 to 2015.

Figure 68. Zooplankton biomass in Kootenay Lake, 1997 to 2015.

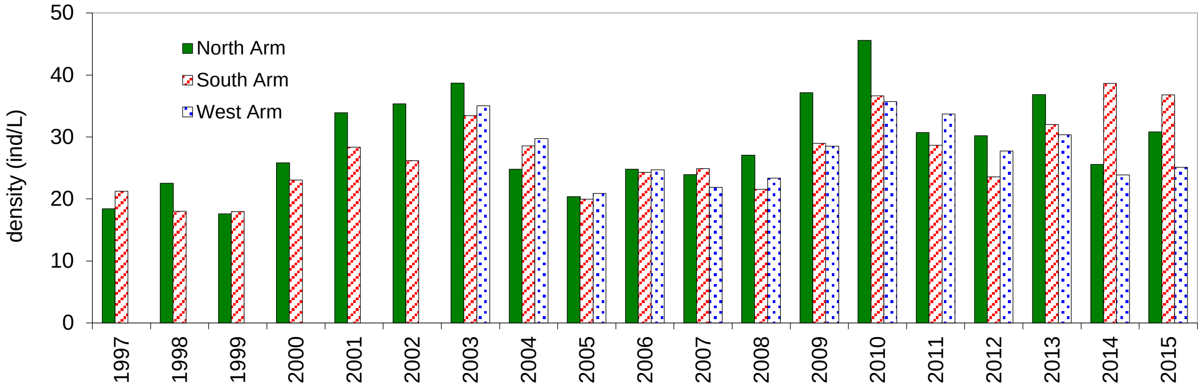


Figure 69. Seasonal average density of total zooplankton in North, South and West Arms, 1997 to 2015.

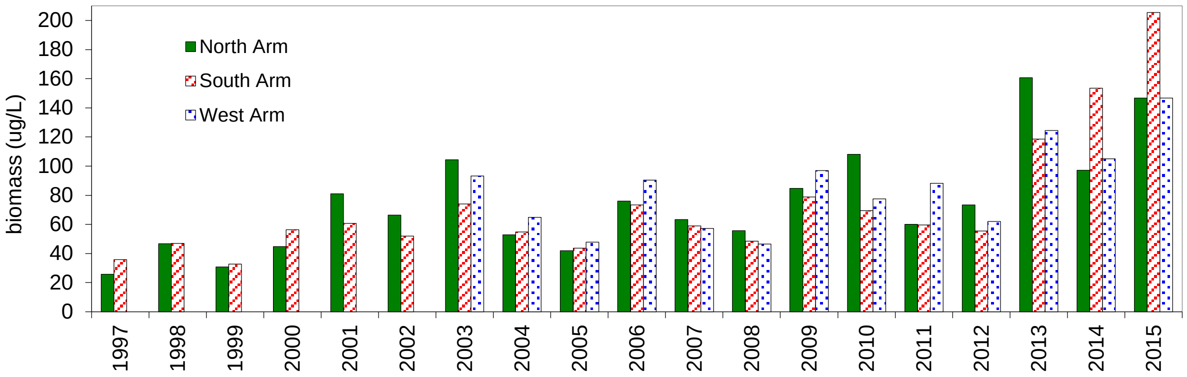


Figure 70. Seasonal average biomass of total zooplankton in North, South and West Arms, 1997 to 2015.

2014 and 2015 Monthly Results

Monthly results by Arm for densities and biomass are shown for 2014 and 2015; Figures 71 and 72; respectively. in When comparing densities amongst stations in the North Arm by month in 2014 and 2015, results tend to be similar among stations in the early and late parts of the season (Apr/May and Oct/Nov) when total zooplankton density are at their lowest numbers (Figs. 71 and 72). A temporary decline in zooplankton density in August at all stations can also be observed for all stations for both years (excluding KL4 for August 2014). By comparison, the results are quite variable between North Arm stations for the June, July, and September months that have higher zooplankton densities.

The South Arm density pattern is similar to the North Arm for the earliest and latest months (Apr and Nov), however 2014 has a different seasonal pattern than 2015 (Figs. 71 and 72). In 2014, South Arm stations' densities were similar, generally peaked earlier than North Arm stations, and declined through to the end of the season, whereas in 2015 South Arm stations' densities were quite variable and only had similar levels during a June peak, July decline, and coincidentally again in September. West Arm density patterns were similar for both 2014 and 2015, peaking in June, declining slightly in July before hitting a second peak in August, then declining throughout the rest of the season.

North Arm total biomass early-to-mid season results were similar among stations for both 2014 and 2015 as total biomass grew between April and August (Figs. 71 and 72). After August however, total biomass varied between stations and between years, growing to 129-329 ug/L in October before declining in November 2014, and growing to 213-413 ug/L in September before declining in October and rebounding to 98-391 ug/L in November 2015.

South Arm total biomass was again similar between stations from April to July for both years, but in 2014 swung wildly between 95-453 ug/L after peaking in August, and in 2015 peaked mildly in July-August before continuing to climb through to end of November to a range of 234-656 ug/L (Figs. 71 and 72). Station KL8 in the West Arm peaked slightly earlier (to 238 ug/L) in 2014 than 2015 (382 ug/L).

For all eight Kootenay Lake stations, fall 2014 biomass ranged between 70 and 450 ug/L, while fall 2015 biomass ranged between 98 and 656 ug/L (Figs. 71 and 72).

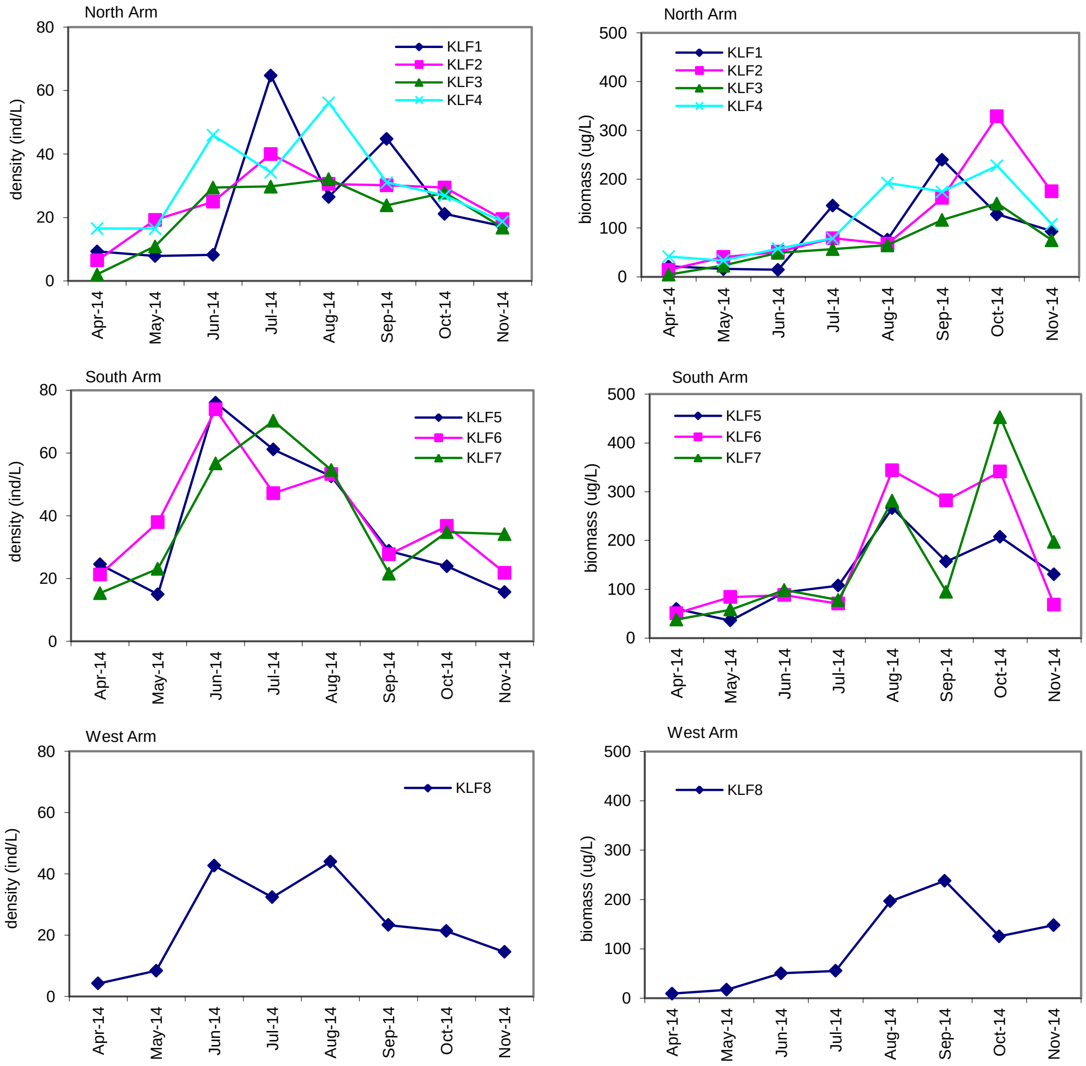


Figure 71. Total zooplankton density and biomass at each station, Kootenay Lake, April to November 2014.

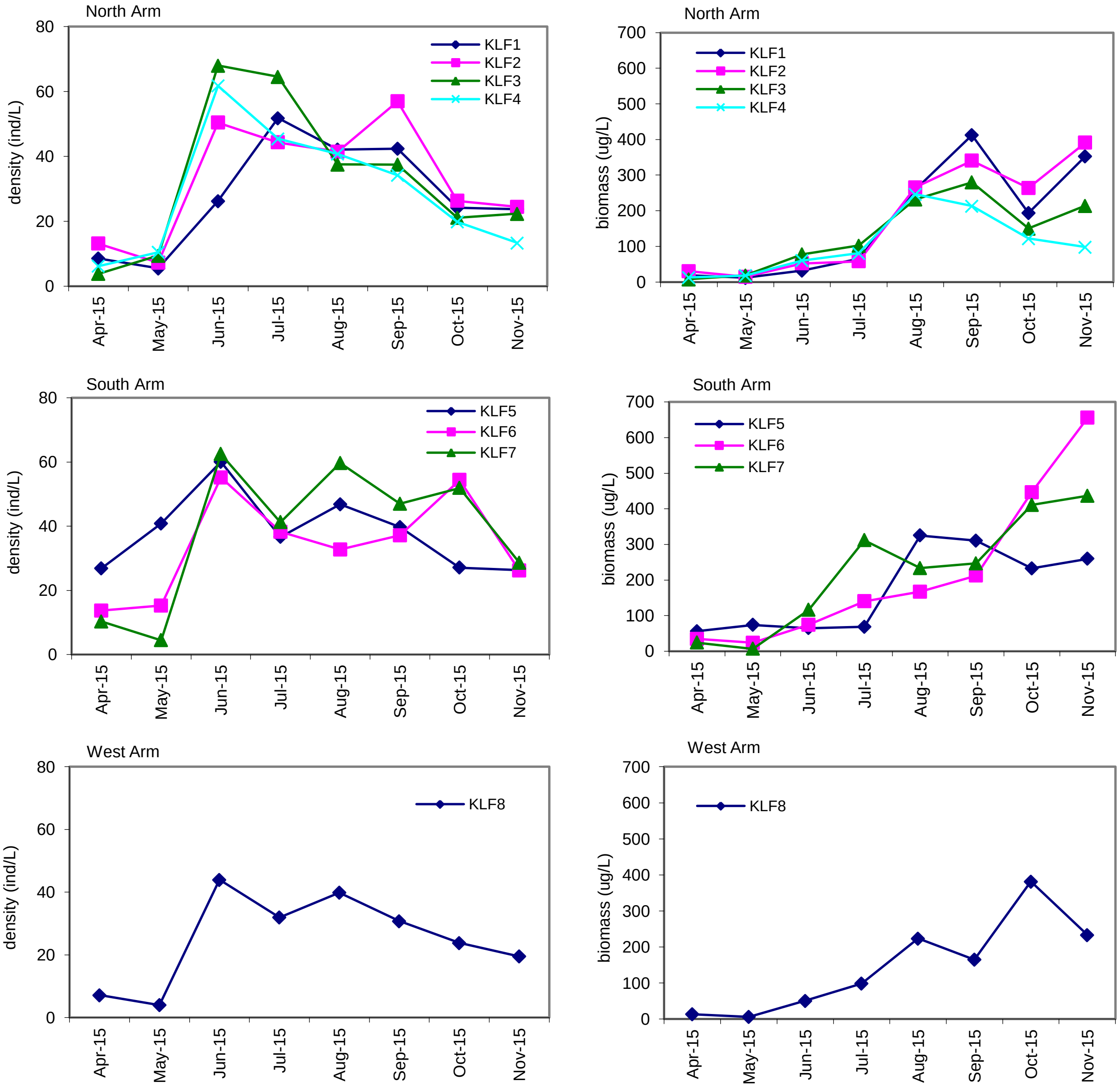


Figure 72. Total zooplankton density and biomass at each station, Kootenay Lake, April to November 2015.

Possible effects of drastic kokaneeh stock reduction

Large individuals of *Daphnia* dominated the zooplankton biomass in Kootenay Lake during the last few years (2013-2015), most likely as a consequence of a drastic kokanee stock reduction and lowered predation pressure (Fig. 82). In water bodies with a high number of planktivorous fish, predation pressure is high and large zooplankton – especially *Daphnia* as a favourite fish food – are consumed and removed from the zooplankton community, leaving a higher remaining proportion of smaller zooplankton. Reduction of planktivorous kokanee abundance most likley caused a shift from a high density of small zooplankton species to the domination of large *Daphnia* individuals that would otherwise be eaten. This would reflect a significant biomass increase, even if zooplankton abundance remained at the previous years' levels.

Mysis diluviana

Density

Densities and biomass of mysids have increased slightly in 2014-2015 over the 2013 year (Fig. 73). In the main lake, seasonal average mysid densities during the nutrient addition period (1992 through 2015) were lower than results from the late 1970s and the mid-1980s. 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 2014 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 (Fig. 73). The second highest density occurred in 2001, when nutrients were increased to the additions during the first five years of the program (1992-1996) (Table 1).

For deep sites, average densities were higher in the North Arm than the South Arm in 2014, a trend which was reversed in 2015 (Fig. 74). For shallow sites, average densities were higher in the South Arm for both years. The peak density in 2014 occurred in September at station KLF4 (704 ind/m2; Fig. 75), due mainly to an increased number of immature males and females (Fig. 76). The peak density in 2015 occurred in August at station KLF6 (390 ind/m2; Fig. 75), due also to an increased number of immature males and females (Fig. 77).

In the West Arm, peak density occurred in July in the 2014 season, one month later than in all previous studied years (2004 through 2013) (Fig. 77). The main contributor to total density was the immature male and female developmental stages. In 2015, peak density occurred in June, the same month as in all previous studied years. Here too the main contributors to total density were the immature male and female developmental stages.

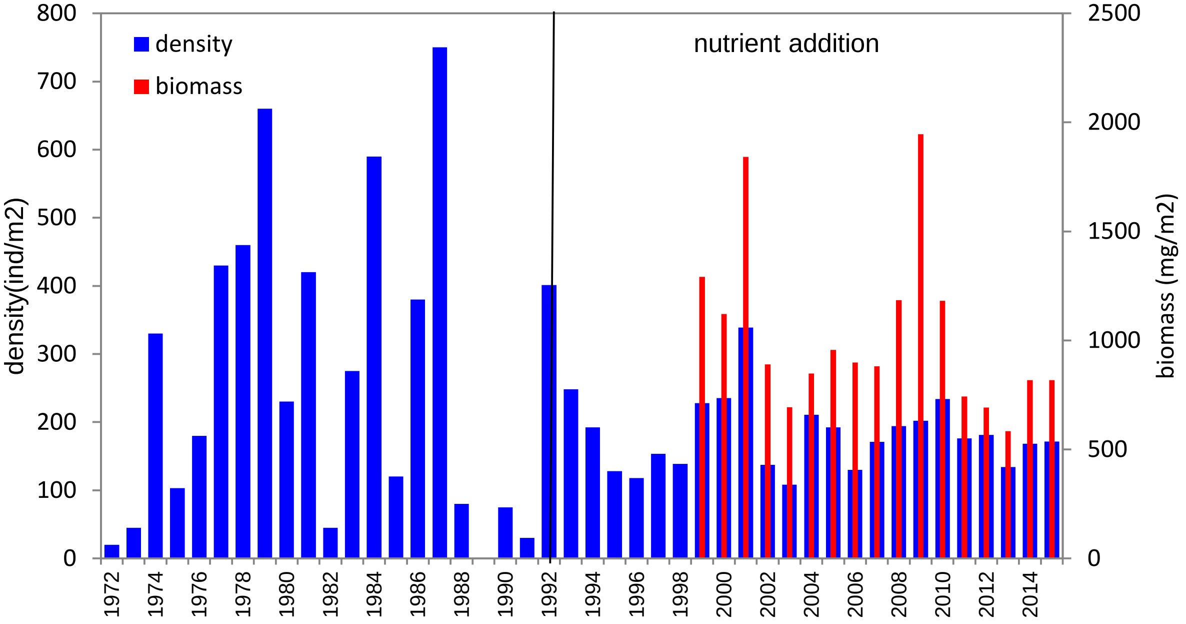


Figure 73. Annual average density and biomass of Mysis diluviana in Kootenay Lake, 1972 to 2015 (North and South Arm, deep sites only).

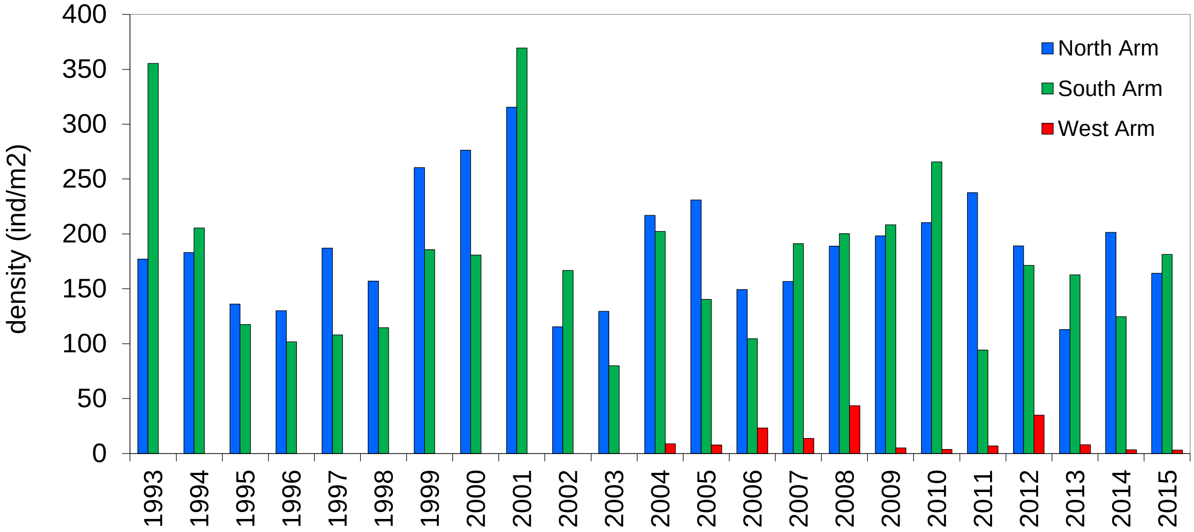
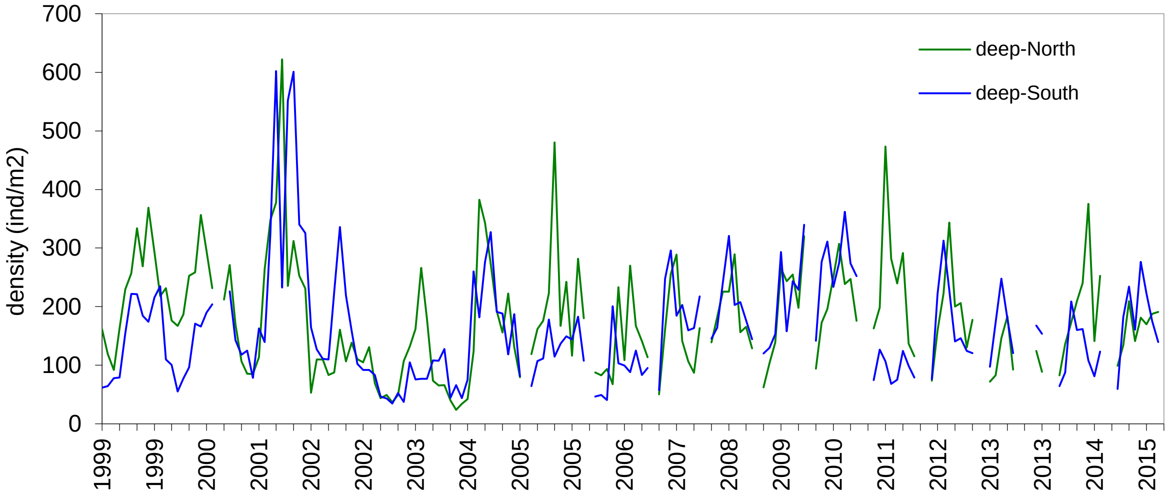


Figure 74. Annual average density of Mysis diluviana in deep sites in the North, South and West Arms of Kootenay Lake, 1993 to 2015. Averages calculated from April to November.



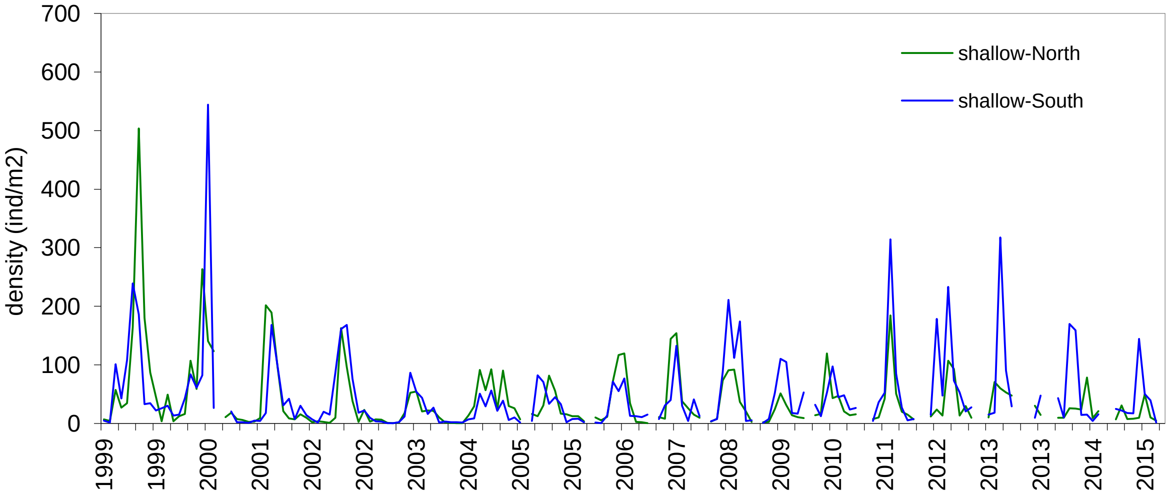


Figure 75. Seasonal average density of Mysis diluviana at pelagic and near-shore stations (1999 to 2015) in Kootenay Lake.

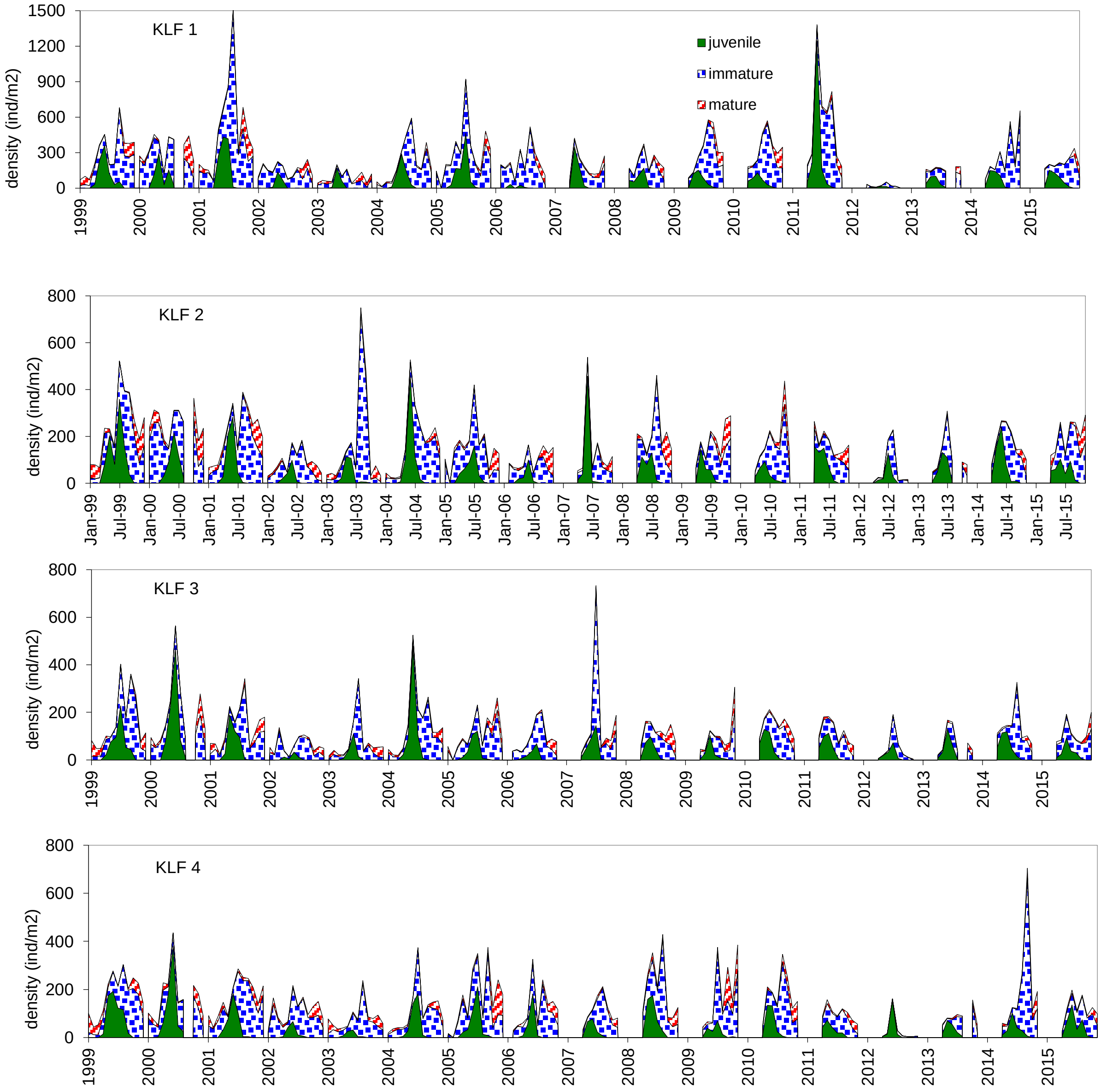


Figure 76. Densities of developmental stages of Mysis diluviana at deep sites, North Arm stations, Kootenay Lake, 1999 to 2015. Note: The graph for station 1 has different scale

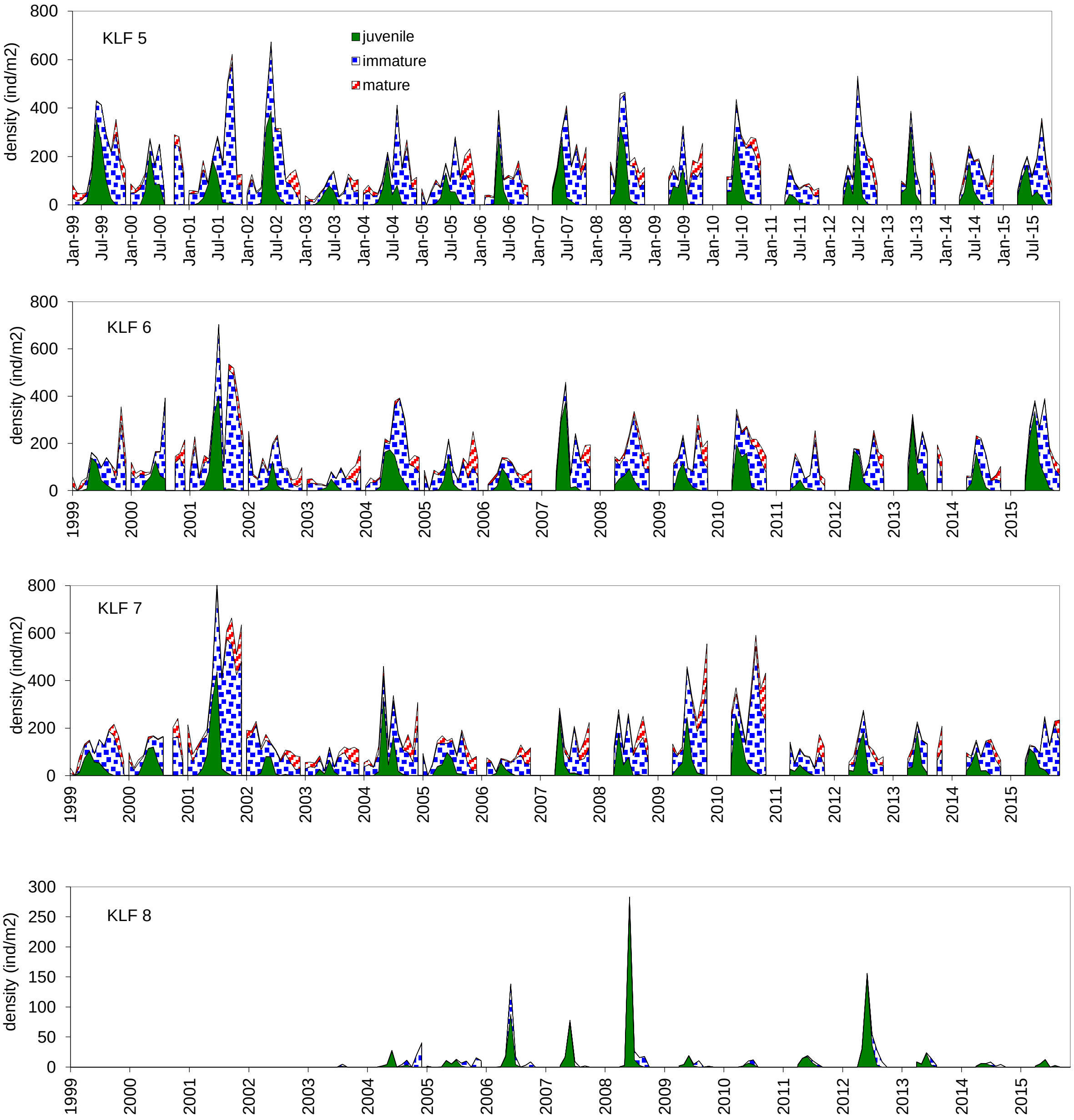


Figure 77. Densities of developmental stages of Mysis diluviana at deep sites, South Arm (KLF 5-7) and West Arm stations (KLF 8), Kootenay Lake, 1999 to 2015. Note: The graph for station 8 has different scale.

Biomass

For both 2014 and 2015, average mysid biomass was greater at deep sites in the North Arm than deep sites in the South Arm (Fig. 78). For both years, biomass at deep sites in the North and West Arm decreased, while biomass increased in the South Arm. Biomass at shallow sites in

2015 decreased in both the North and the South Arm in comparison to 2014 (Fig. 79). 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. 80 and 81). 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). Compared to 2013, biomass in the West Arm decreased by a factor of two in 2014 and again in 2015. The majority of biomass was comprised of the immature developmental life stage. Peak biomass for 2014 occurred in September at KL4 with 5,245.95 mg/m2, and for 2015 in October at station KLF1 with 2,338.75 mg/m2.

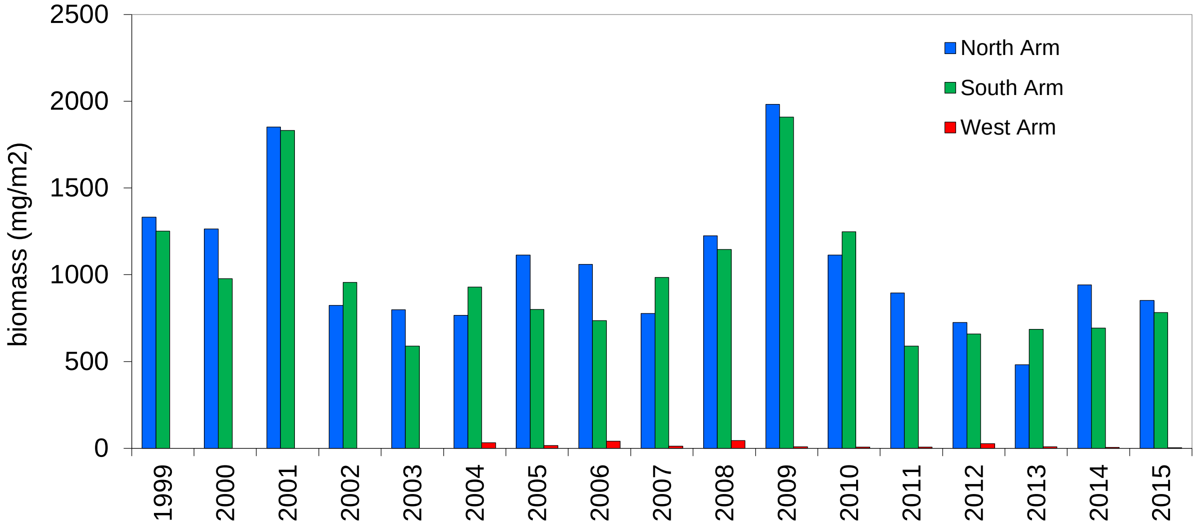


Figure 78. Annual average biomass of Mysis diluviana in deep sites in the North, South and West Arms of Kootenay Lake, 1993 to 2015. Averages calculated from April to November.

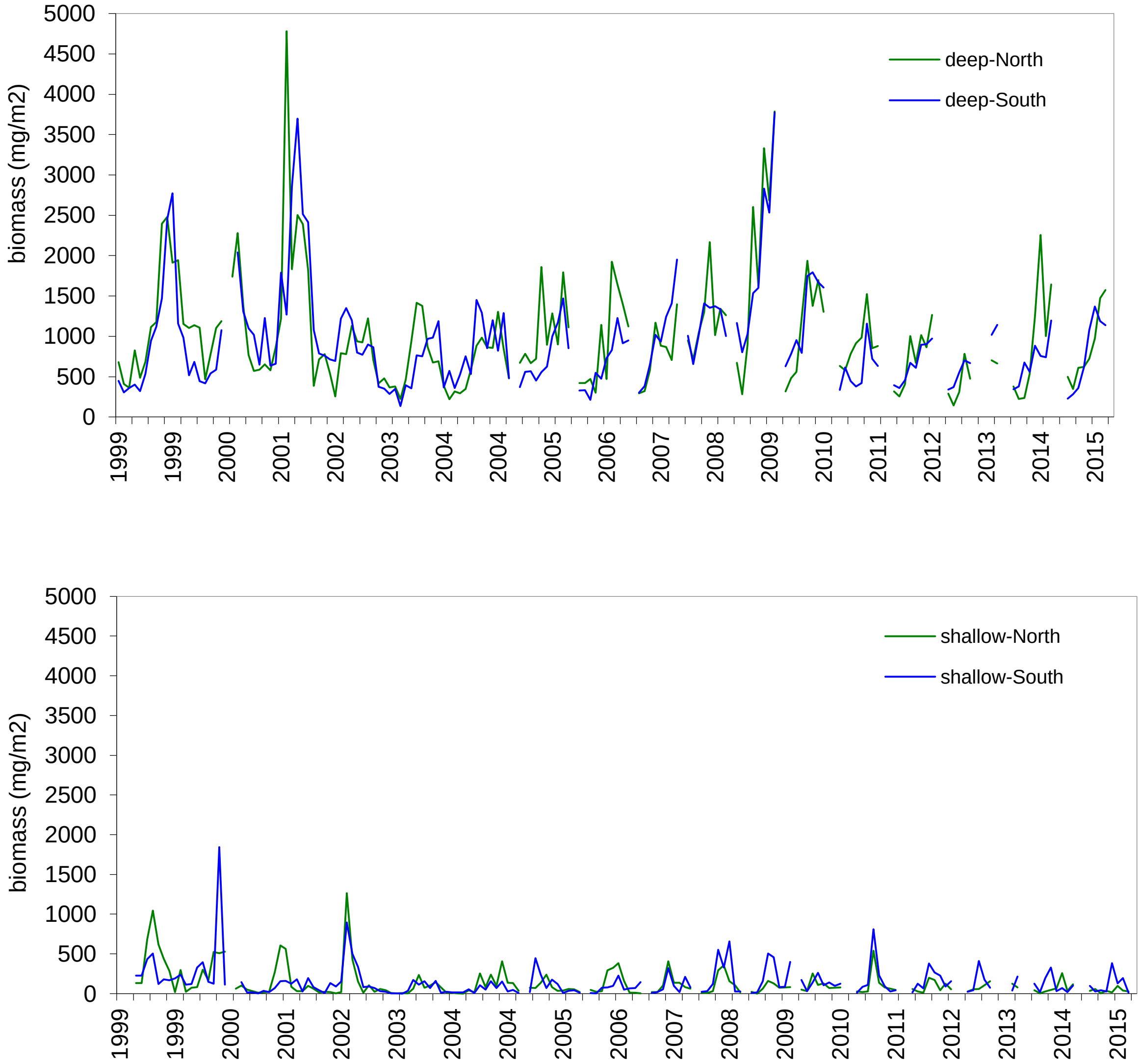


Figure 79. Seasonal average biomass of Mysis diluviana at pelagic and near-shore stations (1999 to 2015) in Kootenay Lake.

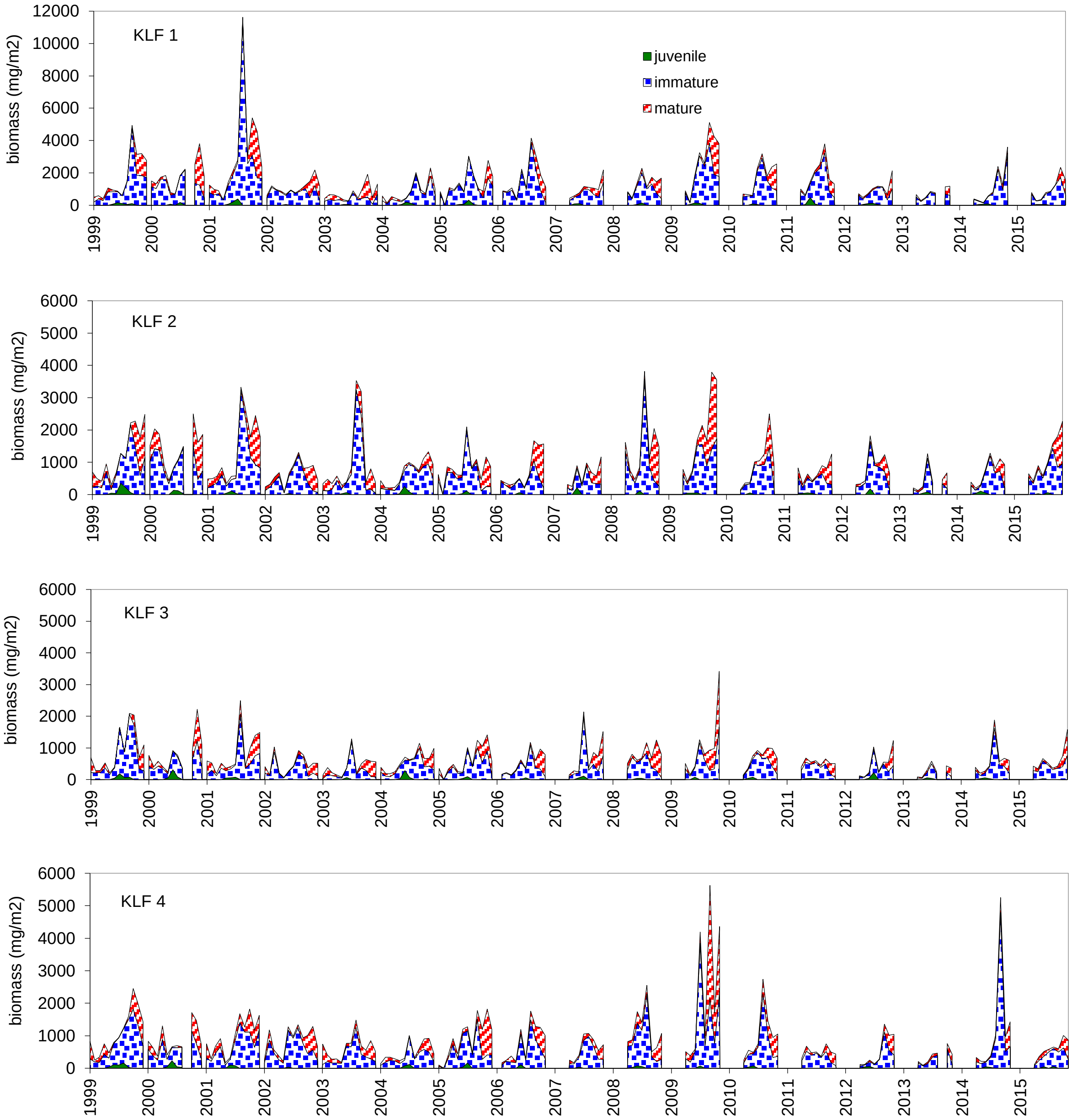


Figure 80. Biomass of developmental stages of Mysis diluviana at deep sites, North Arm stations, 1999 to 2015. Note: The graph for station 1 has different scale

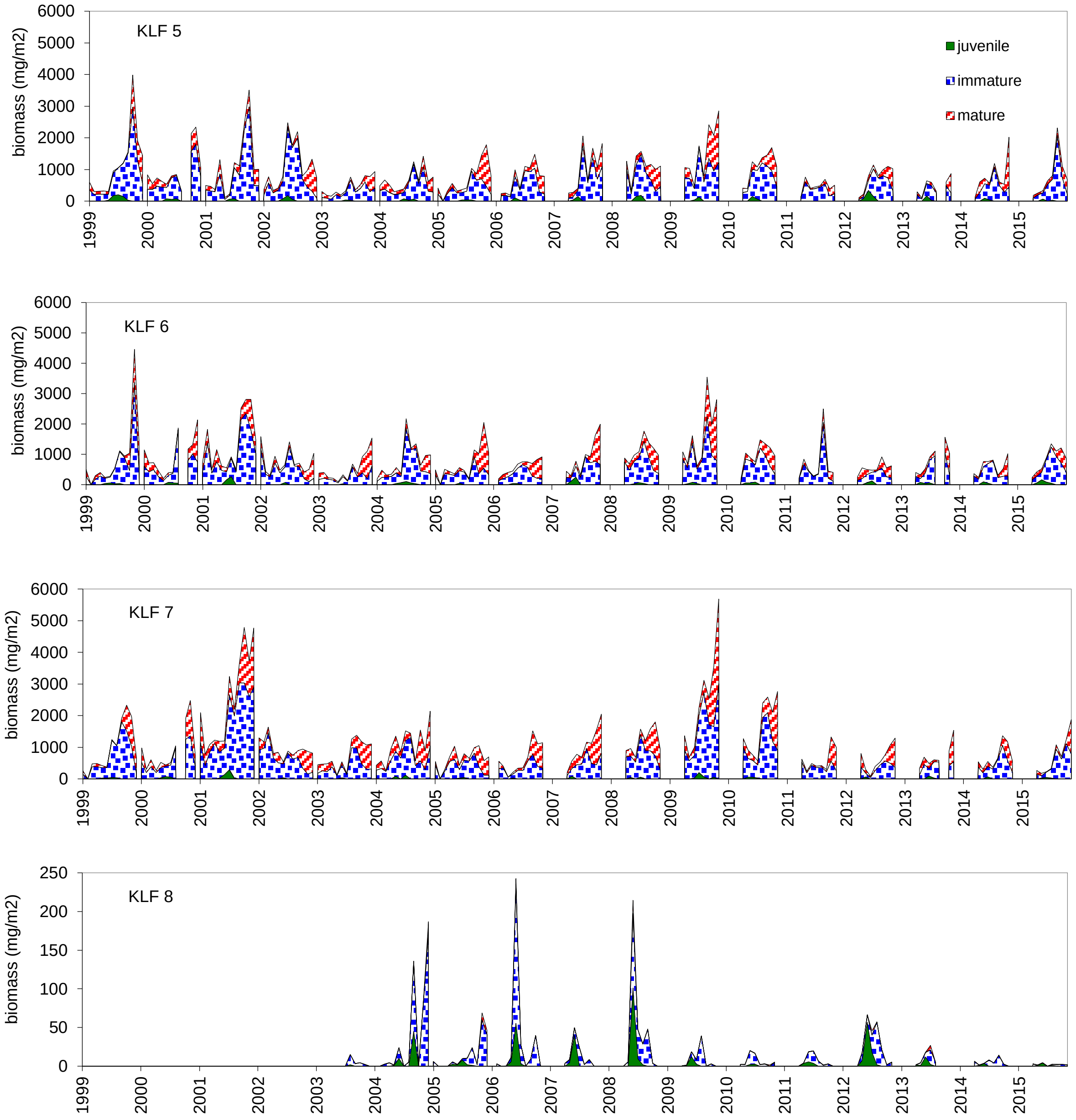


Figure 81. Biomass of developmental stages of Mysis diluviana at deep sites, South Arm (KLF 5-7) and West Arm stations (KLF 8), Kootenay Lake, 1999 to 2015. Note: The graph for station 8 has different scale.

Kokanee

Trends in Kokanee Escapement

Escapement to both Meadow Creek and the Lardeau River decreased in 2014 and again in 2015 compared to 2013. Meadow Creek had the lowest count since the onset of the fertilization program with only 73,500 and 7,653 kokanee returning in 2014 and 2015 respectively (Fig. 82). This was the lowest escapement in the time series starting in 1964. To demonstrate 'normal' conditions we have used 1 SD from the pre and post fertilization averages in figures 82 and 83.

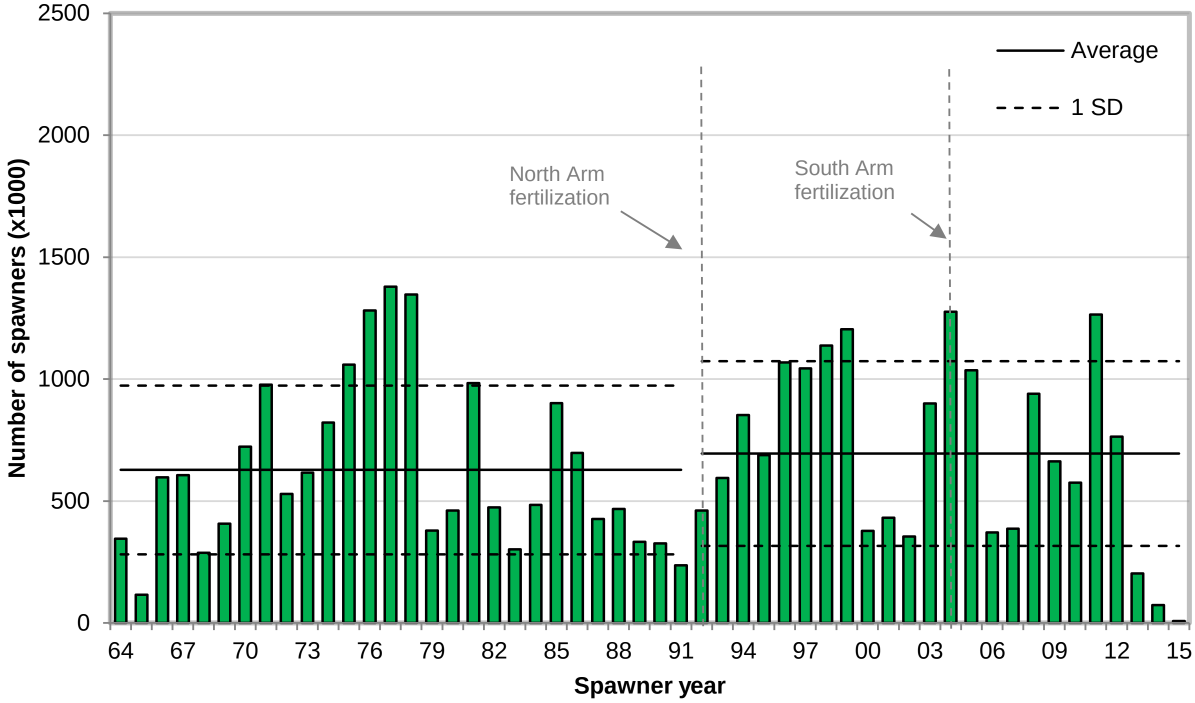


Figure 82. Kokanee escapements to Meadow Creek, North Arm of Kootenay Lake, 1964–2015. (Note: 1964–1991 data from Acara 1970 unpubl. MS).

The Lardeau River escapement was about average in 2013 at 251,000 kokanee and decreased to 73,950 kokanee spawners in 2014 (Fig 83), about 1 standard deviation below the long term average. Escapement in 2015 reached a record low of 10,308 individuals, the lowest number recorded in the time series starting in 1964. Note that a review of the Lardeau escapement time series resulted in minor changes from what has been reported previously; see Appendix 7 for the complete revised dataset and source list.

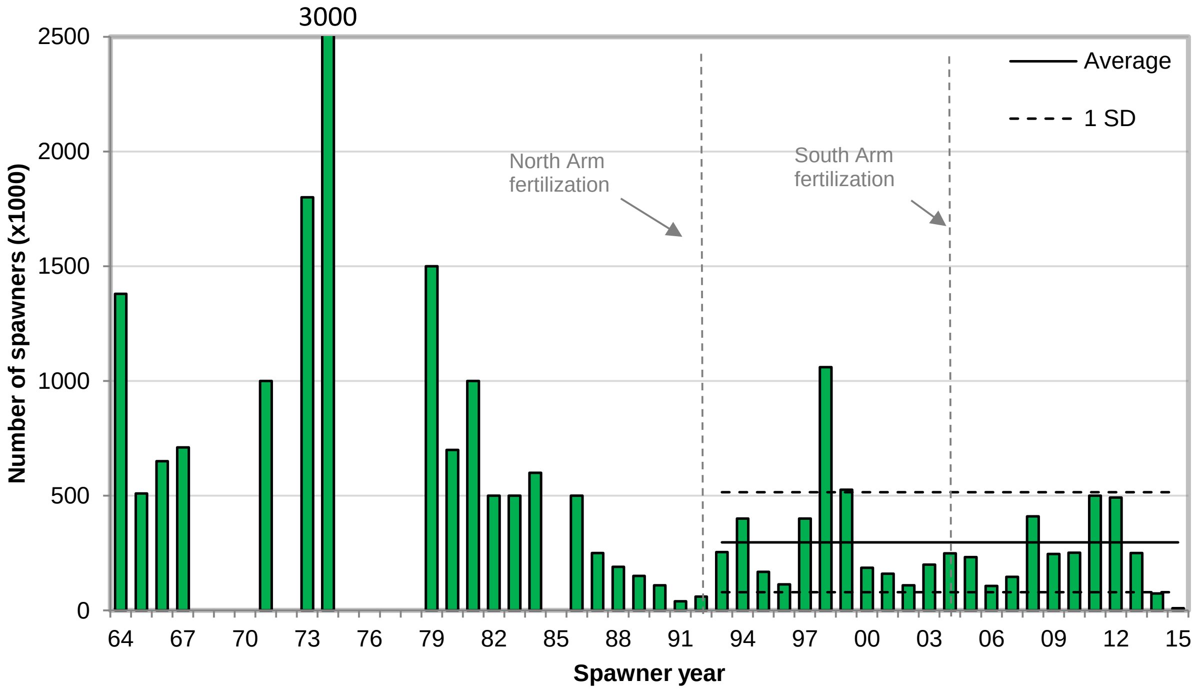


Figure 83. Kokanee escapements to the Lardeau River, North Arm of Kootenay Lake, 1964–2015). No data exist for years without bars; pre-fertilization average omitted due to missing data.

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 (the source of eggs for egg plants), there have been no egg plants in order to mitigate the spread of the disease. In addition, low returns to Meadow Creek spawning channel in 2014 and 2015 precluded egg takes in order to maximize spawning channel production.

Egg plants in BC South Arm tributaries are detailed in Table 9, and index site kokanee spawner counts for BC South Arm tributaries are presented in Table 10. While the tributaries that have not received egg plants (right side, Table 10) continued to have zero or very few spawners counted, the four tributaries which have received egg plants since 2005 (Table 9 & left side, table 10) have had modest numbers of spawners recorded since 2009. Blue shading in Table 10 highlights the returns expected to have resulted from egg plants. In 2014, only the Goat River and Summit Creek index sites had kokanee present. Interestingly, the egg plants in Boulder Creek the fall of 2010 (Table 9) did not produce any spawners returning fall of 2014 (assuming spawner age 3+) (Table 10). While down significantly in 2015, the 235 spawners counted at the Goat River index sites was still well above Crawford and Summit at 36 and 10 respectively. Boulder Creek was counted in 2015, and no fish were observed. While index counts have been highest most years in Goat River, it has also had larger numbers of eggs planted (Table 9).

Table 9. Number of kokanee eyed egg plants in BC South Arm tributaries, 2005–2015.

	British Columbia tributaries				
Year	**Boulder**	**Crawford**	**Goat River**	**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
2012a			1,500,000	700,000	2,200,000
2013*					
2014**					
2015**					

[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)

**No egg take due to low kokanee escapement

Table 10. Kokanee spawner counts from index sites in BC South Arm tributaries, 1992–2014. Data up to 2008 is from Ericksen et al. (2009). NS = not sampled. Blue shading indicates years and streams where we anticipated returns of age 3+ spawners from egg plants four years earlier (see Table 9).

	Egg Plant Tributaries											
Year	**Boulder**	**Crawford**	**Goat River**	**Summit**	**Gray**	**La France**	**Lock-hart**	**Akokli**	**Sanca**	**Midge**	**Cultus**	**Combined**
1992	3	NS	20	30	NS	NS	NS	NS	6	NS	NS	59
1993	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
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	100	3	1	150	7	0	NS	261
1998	0	0	2	0	5	0	0	50	2	5	NS	64
1999	0	0	0	0	20	2	0	20	2	0	NS	44
2000	1	0	0	0	2	0	0	20	0	NS	NS	23
2001	0	0	0	0	8	0	0	6	0	33	NS	47
2002	0	0	0	0	10	0	0	5	0	NS	NS	15
2003	0	5	2	1	35	0	0	151	8	0	NS	202
2004	0	0	0	0	8	0	0	8	0	0	0	16
2005	0	0	0	0	0	0	0	1	0	NS	NS	1
2006	0	0	0	1	9	0	0	2	0	NS	NS	12
2007	0	8	0	0	40	0	3	4	0	NS	100	155
2008	0	0	0	0	6	2	0	0	0	NS	NS	8
2009	0	22	187	114	4	0	0	2	0	NS	NS	329
2010	0	0	0	0	19	2	0	NS	0	NS	NS	21
2011	0	575	274	203	10	0	0	10	0	NS	NS	1,072
2012	3	57	568/1441*	315	1	0	0	0	0	0	0	1,817
2013	0	2	100	1	0	0	0	0	0	NS	NS	103
2014	0	0	34	3	0	0	0	0	0	NS	NS	37
2015	0	36	235	10	0	0	0	13	0	NS	NS	294

*A complete aerial count was conducted in addition to the index site count for the Goat River in 2012.

Egg plants in Idaho South Arm tributaries are detailed in Table 11 and index site kokanee spawner counts for Idaho South Arm tributaries are presented in Table 12. An egg plant of 300,000 eggs was directed exclusively to Boundary Creek in 2009 (instead of distributed more evenly amongst other tributaries) but no spawners were observed during the single survey that occurred in 2013. Boundary Creek received 700,000 eggs planted in 2010 with only 40 spawners counted four years later in 2014, and the 1,000,000 eggs planted in 2011 led to a count of 50 in 2015.

Trout Creek received 300,000 eggs in 2010 and 133 fish were counted at the index site four years later in 2014. In 2011, 500,000 eggs were planted in Trout Creek followed by an index count of 40 spawners four years later in 2015.

Long Canyon index site yielded counts of 7 and 50 spawners in 2014 and 2015. These spawners, assuming they are not strays, would be progeny of natural production as no eggs were planted in that tributary after 2008.

If the index counts are reflective of abundance, recent low index counts could suggest poor survival from egg plants, in particular for Boundary Creek which received the majority of eggs planted since 2008. However, complete spawner surveys would be required in order to evaluate egg to spawner survival among systems.

No eggs were planted in 2014 or 2015 due to a lack of supply at Meadow Creek. Eggs planted in 2012 in Boundary and Trout Creeks should lead to spawner returns in 2016, after which any spawners will be progeny of natural production for the next several years at minimum. Data from 2017 and beyond will inform whether the egg plants up to 2012 will lead to self-sustaining spawner populations in these tributaries.

Kokanee eggs from Hill Creek Spawning Channel 2014 fall spawners were raised to fry in the hatchery and released in the spring of 2015. At Crawford Creek, 92,500 fry were released and at Hendryx Creek, 5000 fry were released.

Table 11. Number of kokanee eyed egg plants in Idaho tributaries 1997–2015. Data 1997-2008 from Ericksen et al. (2009). Data from 2009-2015 received from Kootenai Tribe of Idaho.

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*									
2014**									
2015**									

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

**No egg take due to low kokanee escapement

Table 12. Kokanee spawner index site counts in Northern Idaho streams. Data provided by Kootenai Tribe of Idaho. NS = not sampled. Blue shading indicates years and streams where returns of age 3+ adults were anticipated from egg plants four years earlier (see Table 11).

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
2014	40	7	NS	133	0	NS	NS	180
2015	50	50	NS	20		NS	NS	140

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 from 195–365 mm with the time series mean length of females (228 mm) slightly smaller than that of males (231 mm). Length peaked in 2015 at 341 mm for females and 365 mm for males. Annual average size increased from the second smallest on record in 2012 to the largest on record in 2015 (Fig. 84).

Fecundity increased with spawner size in 2014 and 2015 reaching an average of 517 and 584 eggs per female respectively (Fig. 85). Both years set new records and were well above the time series average (1967-2015) of 274 eggs per female. Notably, in 2013 the average female spawner size was 270 mm, yet the measured fecundity was only 285; well below the value of 385 predicted for a spawner of that size by the fork length fecundity relationship illustrated in Figure 85. In Arrow Lakes Reservoir, lower than predicted fecundity was also noted in 2013, as well as in 2006 and 1998, all of which were years of rapid growth immediately following a period of slow growth and declining spawner sizes (Bassett et. al. 2015). Similarly, 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. In 2014 and 2015 the relative fecundity returned to near the predicted value.

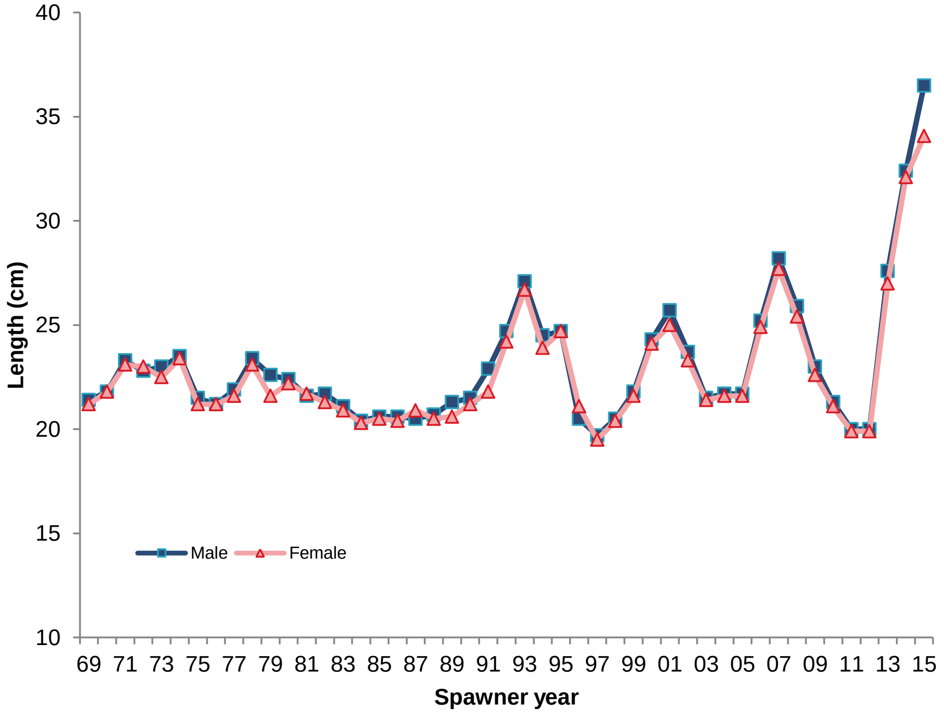


Figure 84. Mean length (cm) of Meadow Creek female and male kokanee, 1969–2015.

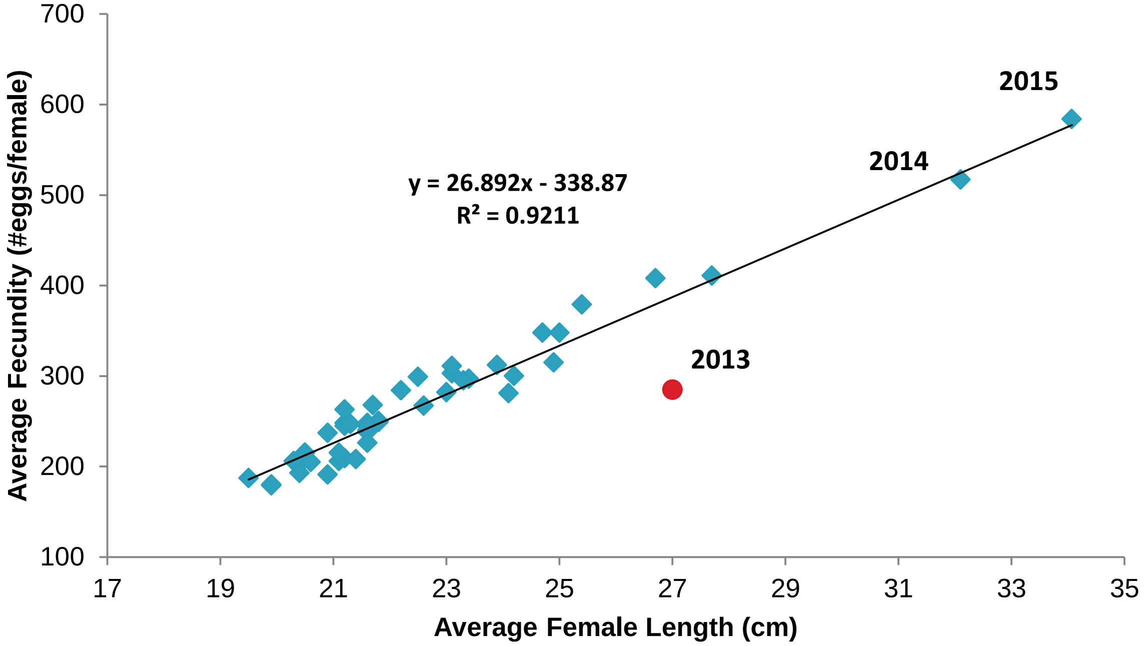


Figure 85. The relationship between annual average female length (cm) of kokanee spawners and average fecundity (# of eggs/female) for years 1969-2015. 2013 is considered an outlier and not included in the regression.

Meadow Creek kokanee fry production

Meadow Creek spawning channel has been the largest contributor of kokanee fry to Kootenay Lake most years, and the management of this channel has had a significant influence on the kokanee population. Since the nutrient restoration program began the number of spawners in the channel has ranged from a maximum of 519,557 in 2012 to a minimum of 5,679 in 2015 (Appendix 11, Fig 82). Fry production from Meadow Creek channel in the spring of 2014 was estimated at 8.59 million, then declined to 7.38 million in 2015; the lowest since 1992 and far below the post fertilization average of 16.65 million (1992-2015). Channel egg to fry survival in 2014 was similar to most years at 42.5%; however in 2015 it increased to the highest on record at 71.5%. Figure 87 illustrates the relationship between channel egg deposition and spring fry estimates for all years on record. The increase in the egg to fry survival may be attributed to improved scarification methods at the spawning (since IHN detection in 2013), or to larger sized fish able to dig deeper redds, or to low densities of fish minimizing redd overlap and disruption. Similar high egg to fry survival rates have been observed at Hill Creek spawning channel since 2012 under relatively low kokanee densities (pers communication, Steve Arndt, FLNRO).

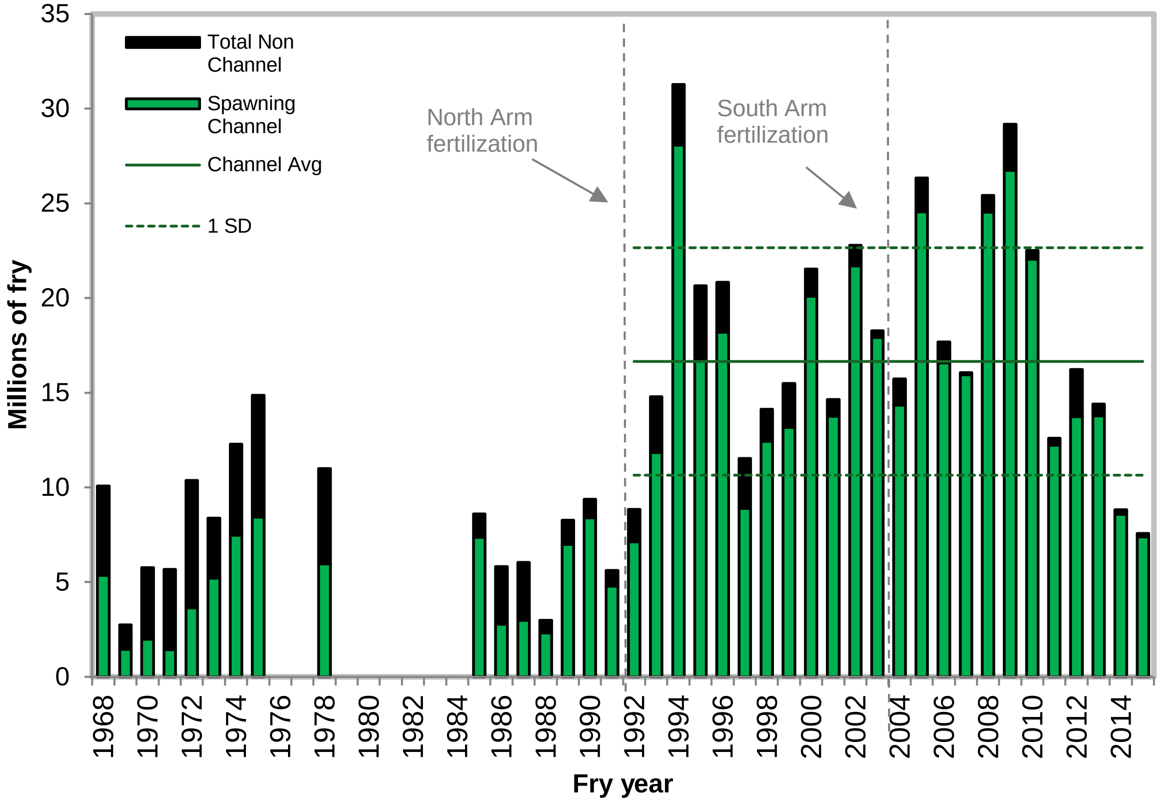


Figure 86. Meadow Creek kokanee fry production from the spawning channel and areas upstream and downstream of the channel, fry year 1968–2015. No data for years without bars.

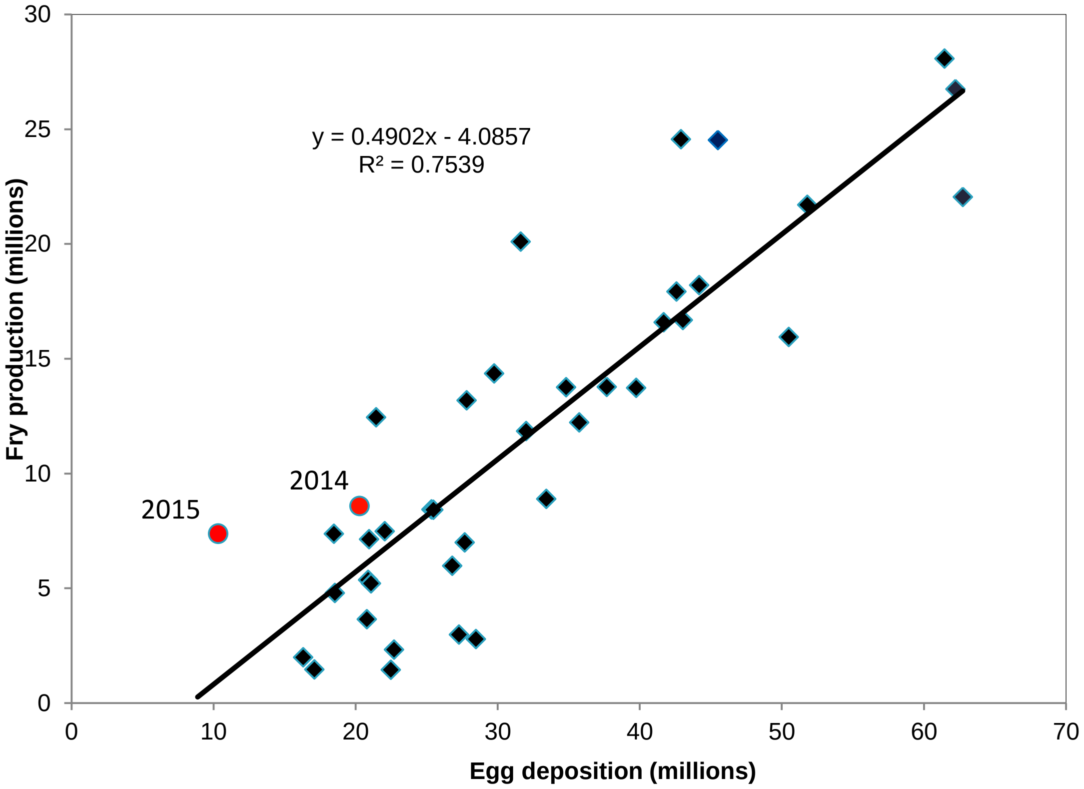


Figure 87. Meadow Creek spawning channel egg deposition versus fry production for years with available data, 1968–2015. Note: The red circles represent the 2014 and 2015 spring fry production.

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 has been initiated annually in late spring. These surveys occur while North and South Arm fry populations are still segregated, and are intended to record fish distribution, abundance, and size information early in the growing season to be used as an index for both North and South Arms. No trawling occurred in the spring surveys in 2014 or 2015 due to wide dispersal and low abundance of fry throughout the water column in the South Arm, making trawling ineffective.

Fall trawl survey sampling in 2014 included eight trawls in the North Arm and nine trawls in the South Arm catching a total of 604 kokanee. The South Arm catch included 114 fry and 9 age 1+ kokanee. The North Arm catch included 476 fry and 5 age 1+ kokanee (Table 13).

The fall 2015 trawl survey sampling consisted of 9 trawls in each of the North and South Arms. The catch in the North Arm included 885 kokanee fry, 23 age 1+, and 1 age 2+, while the catch in the South Arm included 229 fry and 8 age 1+ kokanee (Table 13). The significantly higher catch at the Woodbury Station in 2015 was due to a modification to the standard equipment and methods; the standard trawl boat experienced mechanical issues so a similar vessel was used to trawl only the Woodbury station using a 7x3m opening net as opposed to the standard 5x5m opening net. The methods were modified so that the vast majority of the fish layer was still sampled (a stepped oblique trawl method was still employed), however fewer depth strata were sampled overall with more time fished per strata. Ultimately the result was significantly increased effort fishing directly within the fish layer (as opposed to the margins above and below), which resulted in a much higher catch rate than the standard sampling conducted historically and at all other stations in 2015. The modifications were made in part due to the different net opening size as well as the desire to increase the sample size for biological statistics during a year were very few fish were captured. As such, the increased catch numbers do not reflect an equivalent increase in abundance at the Woodbury station, but are instead reflective of increased sampling effort targeting the fish layer. See the methods section for further details.

Table 13. Kokanee catch statistics from fall trawl surveys in 2014 and in 2015.

Survey time	Section	Station	Hauls	age 0	age 1	age 2	age 3	Total
Spring 2014	*No Trawling Conducted*							
Fall	North Arm	1 Johnson	2	231	1	0	0	232
Fall	North Arm	2 Shutty Bench	3	121	3	0	0	124
Fall	North Arm	4 Woodbury Cr	3	124	1	0	0	125
Fall	South Arm	5 Wilson Creek	3	69	3	0	0	72
Fall	South Arm	6 Rhino Point	3	34	3	0	0	37
Fall	South Arm	7 Redman Pt	3	11	3	0	0	14
Fall	North Arm	total	8	476	5	0	0	481
Fall	South Arm	total	9	114	9	0	0	123
Fall 2014	***Total lake***	***Total survey***	***17***	***590***	***14***	***0***	***0***	***604***
				98%	*2%*	*0%*	*0%*	*100%*

Survey time	Section	Station	Hauls	age 0	age 1	age 2	age 3	Total
Spring 2015	*No Trawling Conducted*							
Fall	North Arm	1 Johnson	3	75	1	0	0	76
Fall	North Arm	2 Shutty Bench	3	69	1	0	0	70
Fall	North Arm	4 Woodbury Cr*	3	741	21	1	0	763
Fall	South Arm	5 Wilson Creek	3	61	0	0	0	61
Fall	South Arm	6 Rhino Point	3	83	2	0	0	85
Fall	South Arm	7 Redman Pt	3	85	6	0	0	91
Fall	North Arm	total	9	885	23	1	0	909
Fall	South Arm	total	9	229	8	0	0	237
Fall 2015	***Total lake***	***Total survey***	***17***	***1114***	***31***	***0***	***0***	***1146***
				97%	*3%*	*>0%*	*0%*	*100%*

*higher level of effort, see methods section

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. 88). The trawl sample in 2014 included only fry and 1+ kokanee while the sample in 2015 include fry, 1+, and a solitary age 2+ kokanee. Typically, there are separately observable modes which correspond to age classes, as was the case in 2011 (Schindler et al 2014b), which can assist to verify the ageing of spawners and trawl captured fish. In 2013, similar to 2012 (Bassett et al 2016), there was considerable overlap between the age 2+ and 3+ (and 4+ in 2012) in-lake kokanee and spawners. This may be due to variable growth and age at maturity in preceding years (persistence of non-maturing 3+ and 4+ kokanee). It should be noted however that the sample size for the older age class fish has been low since 2012/13, limiting the statistical rigour of length at age estimates.

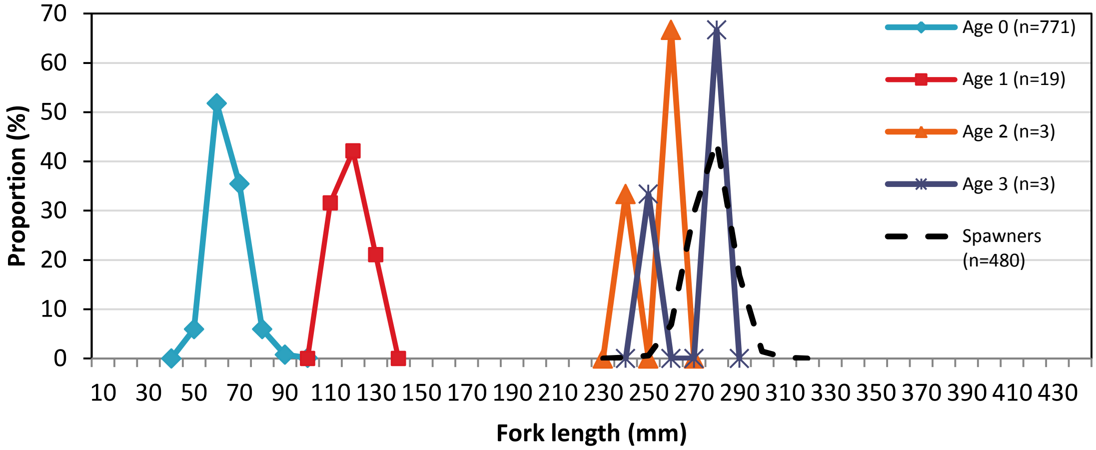
The age 1+ distribution was unimodal in 2015 and 2013, whereas typically they are bimodal as in 2014. In 2014, the fall trawl sampling produced mean length-at-age estimates of 58 mm and 114 mm for ages 0+ and 1+ kokanee respectively (Table 14, Fig. 88 and Fig. 89). In 2015 the mean length-at-age estimates were 62mm for 0+, 120 mm for 1+, and 274 mm for the single 2+ caught. The mean length of spawners measured at Meadow Creek spawning channel was 324 mm in 2014 and 355 mm in 2015. The long term time-series for size at age from trawl caught kokanee and spawners is illustrated in Figure 89. Age 1+ mean size was the smallest on record in 2013 and remained similarly small in 2014. In 2015 mean size of age 1+ increased marginally, and was statistically larger than 2013 though not 2014. We advise caution against using age 1+ mean size at age as a metric of in-lake conditions as historically there are often two size modes of 1+ fish and over-representation of either mode can skew the results. No age 2+ kokanee were captured in 2014 for the first time on record, and the single age 2+ kokanee in 2015 was very large in comparison with the mean size of age 2+ captured in all previous years. The dramatic increase in spawner size which began in 2013 has continued with the largest mean size of spawners on record recorded in 2015. Note that confidence intervals for spawners were not available at time of writing, however sample sizes were large for all years (e.g. >100/yr).

Table 14. Size statistics from trawl-captured kokanee during September survey in 2014 and 2015 (No trawling occurred in early season 2014 or 2015).

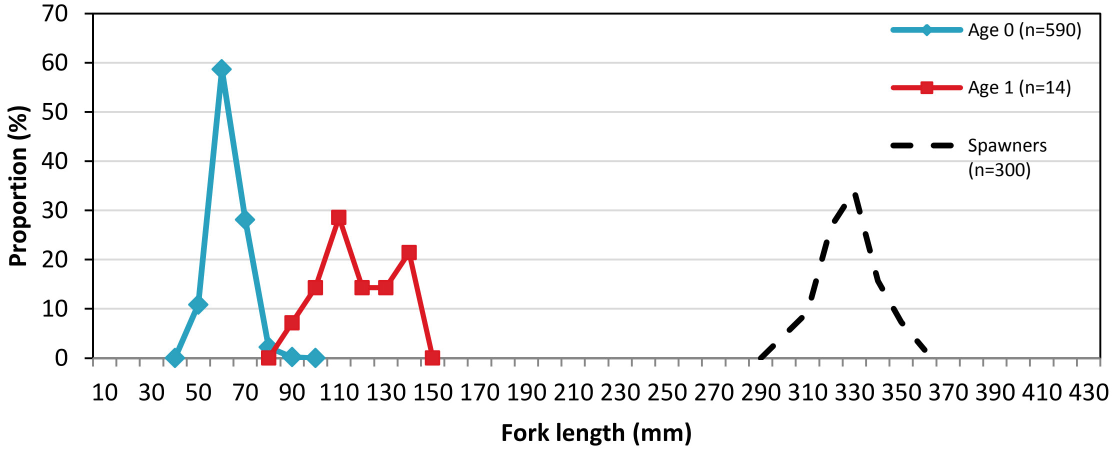
Survey time	Basin	Station	age 0	age 1	age 2	age 3
Sept	North Arm	Avg. length (mm)	57	116	-	-
2014		Length range (mm)	42-77	96-133	-	-
		Standard deviation	5.7	16.1	-	-
		Sample size (n)	476	5	-	-
	South Arm	Avg. length (mm)	61	113	-	-
		Length range (mm)	44-83	89-138	-	-
		Standard deviation	6.8	16.4	-	-
		Sample size (n)	114	9	0	0
	Both Arms - total avg. length (mm)		*58*	*114*	-	-

Survey time	Basin	Station	age 0	age 1	age 2	age 3
Sept	North Arm	Avg. length (mm)	62	120	274	-
2015		Length range (mm)	46-78	104-139	-	-
		Standard deviation	5.5	9.5	-	-
		Sample size (n)	479	23	1	0
	South Arm	Avg. length (mm)	62	119	-	-
		Length range (mm)	47-78	111-134	-	-
		Standard deviation	5.3	8.0	-	-
		Sample size (n)	229	8	0	0
	Both Arms - total avg. length (mm)		*62*	*120*	*274*	-

a) 2013 trawl and spawners



b) 2014 trawl and spawners



c) 2015 trawl and spawners

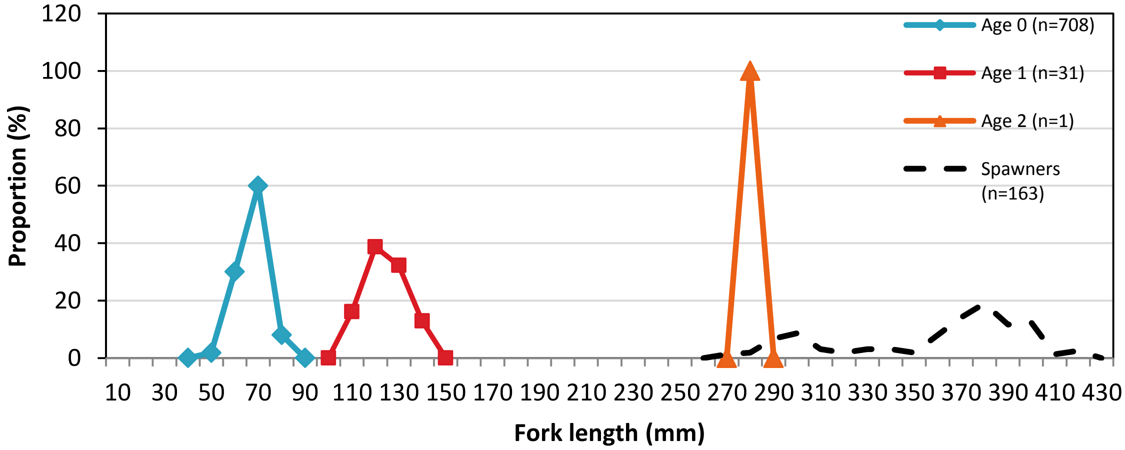


Figure 88. Kokanee length-frequency distribution by age from fall trawling in a) 2013 b) 2014, and c) 2015 and including spawner data from Meadow Creek.

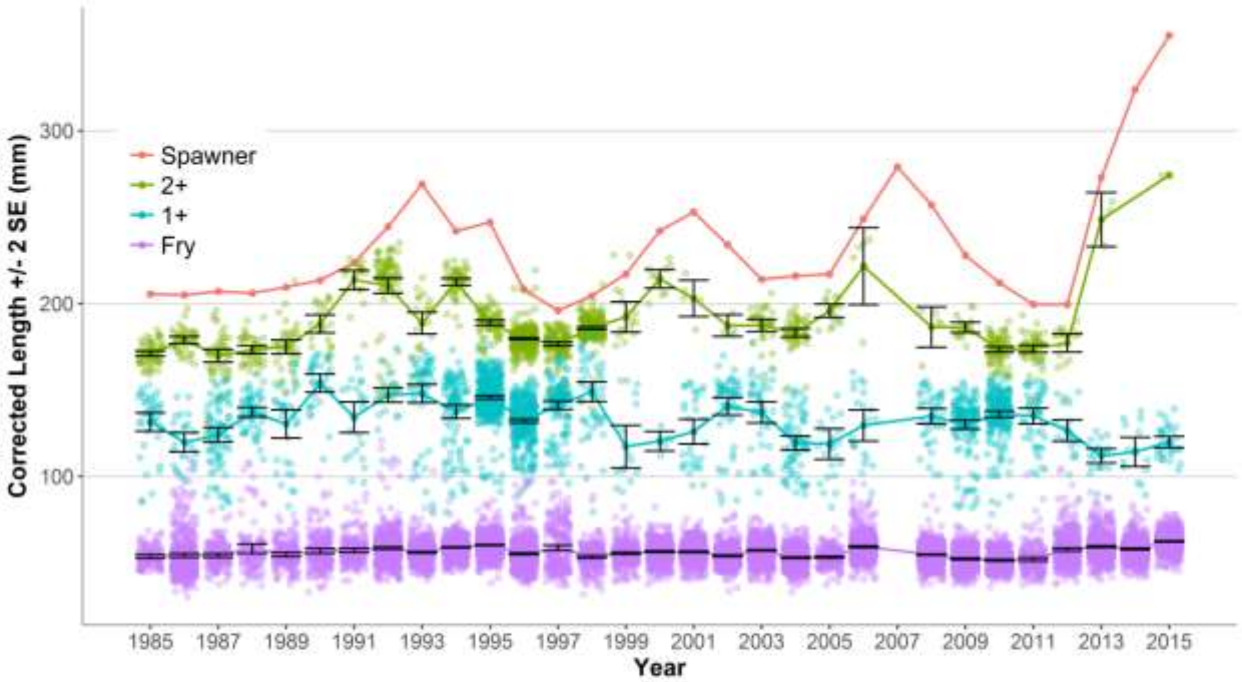


Figure 89. Trends in mean length-at-age for trawl-captured kokanee in Kootenay Lake, 1985–2015. Age 0, 1, and 2 kokanee lengths are corrected to Oct 1st growth date. Length data for spawners were obtained from Meadow Creek kokanee. No trawling occurred in 2007.

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.* (2014b). 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. 90). This is consistent with the hypothesis that reductions in growth rates in successive cohorts induce a shift to older age at maturity (Grover 2005, Leifasbjorn et al. 2004). Patterson *et al.* (2008) suggest sexual 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. And although many of the 2010 cohort spawned as 3+ in 2013, their small average size resulted in some delayed maturation as there was a component of 4+ spawners in 2014. This same scenario occurred in Arrow Lakes, 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).

In 2014 the age at maturity shifted back to predominately age 3+ although a component of age 4+ was still present (80% and 20% respectively). Age at maturity was variable in 2015 with components of age 2+, 3+ and 4+ present (25%, 46%, and 29% respectively).

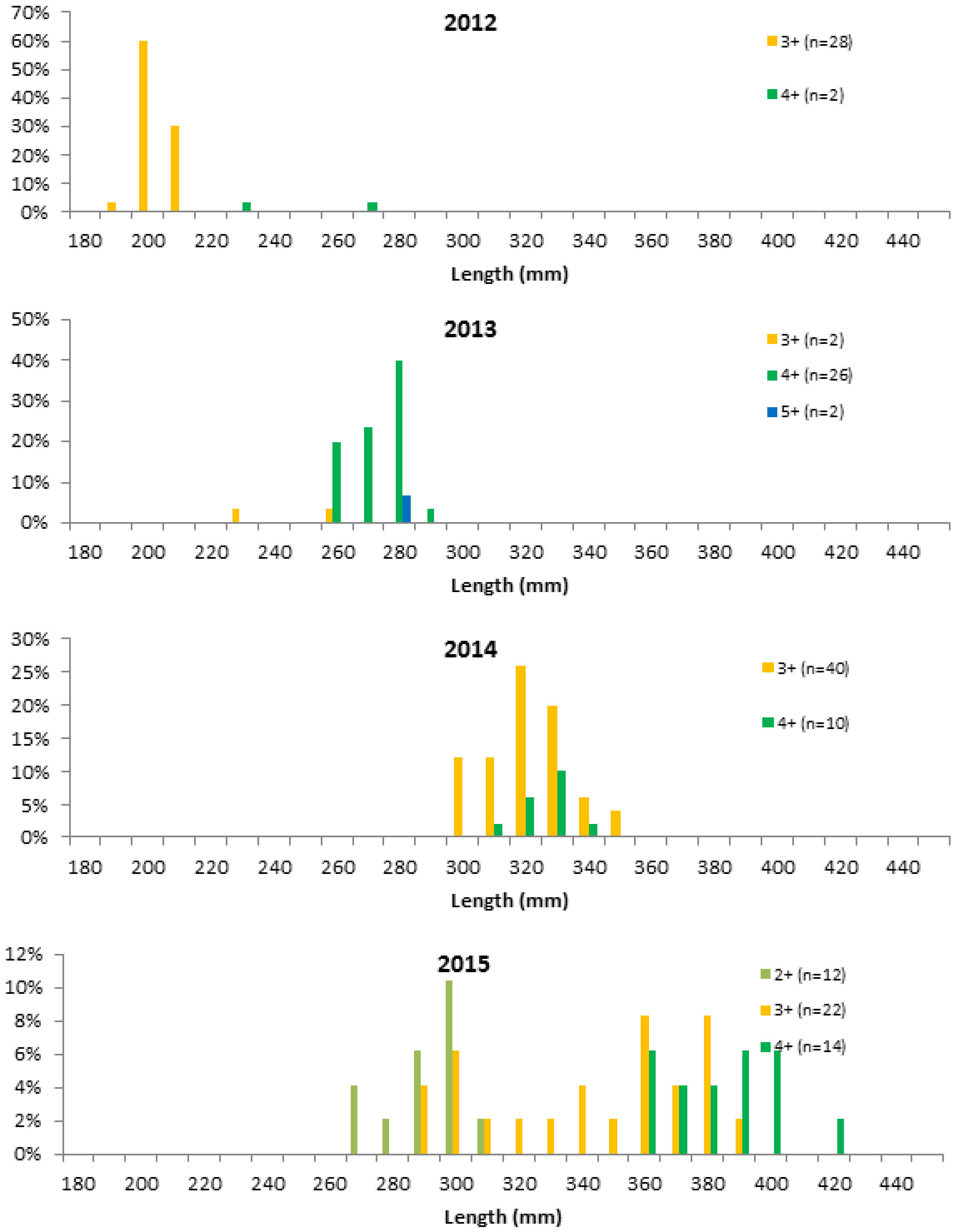


Figure 90. Percent length frequency of kokanee spawners by age returning to Meadow Creek from 2012–2015. Note: y-axis is different for each year.

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. 91). By 1994, two years after the start of lake fertilization, the population reached 35 million kokanee. This increase was mainly due to the rapid growth response to more favourable in-lake conditions at the onset of fertilization, which resulted in a peak of both fecundity and total egg deposition at Meadow Creek in 1993 (Appendix 11). 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 after 2010 then stabilized and have been statistically unchanged since 2012, ranging between ~15-18 million. Total kokanee abundance estimates for 2014 and 2015 were 16.8 (15.0-18.6) million and 15.2 (13.4-17.0) million respectively.

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. 92). 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+. From 2011-2013 the age 1-3+ population decreased from 7.6 million to 1.1 million, the latter being the lowest age 1-3+ population on record. 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. The age 1-3+ estimates for 2014 and 2015 remained stable at 1.1 and 1.2 million respectively. Complete fall kokanee density and abundance statistics for 2014 and 2015 are provided in Appendices 8, 9, and 10.

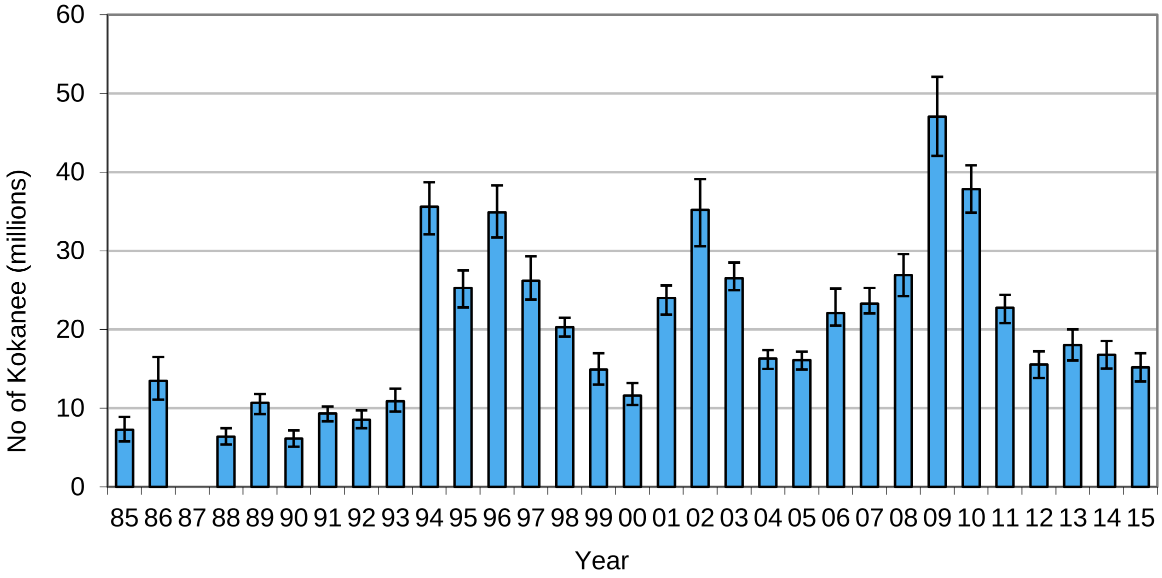


Figure 91. Kootenay Lake kokanee abundance (all ages) based on fall hydroacoustic surveys.

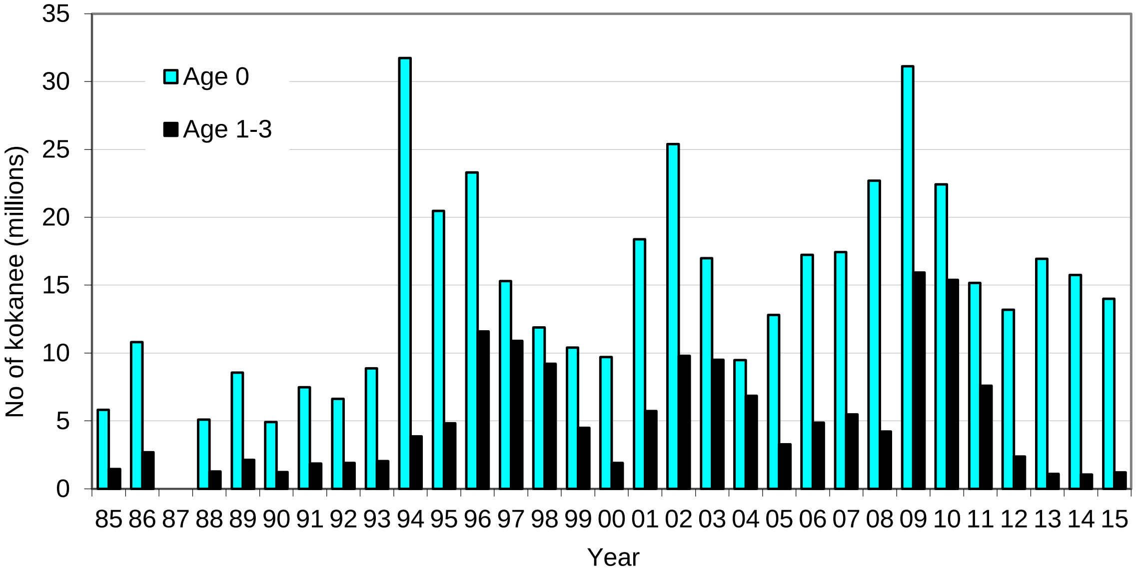


Figure 92. Kootenay Lake age 0+ and ages 1-3+ kokanee abundances based on fall hydroacoustic surveys.

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 1.3 million in 2014 to 6.5 million in 2011 (Table 15) with 2009–2011 being far higher than previous years, similar to the trend of increased lake wide abundance during those years. 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 15. Early summer fry estimates for the South Arm of Kootenay Lake during the South Arm nutrient addition period, 2004-2015.

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	2.58 (1.99 – 3.19)
2014	June 24-26	1.26 (1.00 – 1.52)
2015	June 18-22	3.87 (2.58 – 5.18)

[1] MLE = maximum likelihood estimate

Early season kokanee abundance estimates in the South Arm are higher than would be expected, or possible, based on production solely from the egg plants. Assuming the index counts reflect abundance to some degree for South Arm tributary counts, the acoustic estimates are not biased high, and the North Arm fry have not yet dispersed into the South Arm, there must be another significant source of fry production in the South Arm. As there is currently no evidence of shoal spawners in the main body of Kootenay Lake, one potentially large source of fry in the South Arm is entrained fry through Libby Dam. Investigations by Skaar *et al.* (1996) into entrainment rates at Libby Dam in the early 1990's found 97.5% of entrained fish were kokanee, with age 0 being the large majority of these. The estimate of entrained fish from January 1992 to January 1993 was ~4.5 million fish. Spring season estimates were also produced for the May-June periods in 1993 and 1994, which are perhaps more relevant to understanding the early season fry population in the South Arm of Kootenay Lake. These spring entrainment estimates were ~1.1 million and ~0.5 million respectively in 1993 and 1994.

Although the numbers that were entrained and survived to rear in Kootenay Lake each year since 2004 are unknown, it is apparent that entrained fish from Libby Dam could be a significant component of the South Arm population.

In-lake distribution

Comparisons of the two hydroacoustic surveys conducted each year illustrate the seasonal longitudinal distribution of kokanee fry. 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 and 2014 longitudinal fry distribution followed a similar pattern of southward movement over the summer, although densities remained higher overall in the North Arm in comparison to the South Arm (Fig. 93). In 2015 the same pattern occurred, although by fall the densities were very similar between both arms.

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 the lake to spawn. In July of 2015 there were relatively high densities of adult kokanee at transects 3, 4, and 18. Longitudinal distribution changed throughout the year but with no discernable pattern throughout the time series.

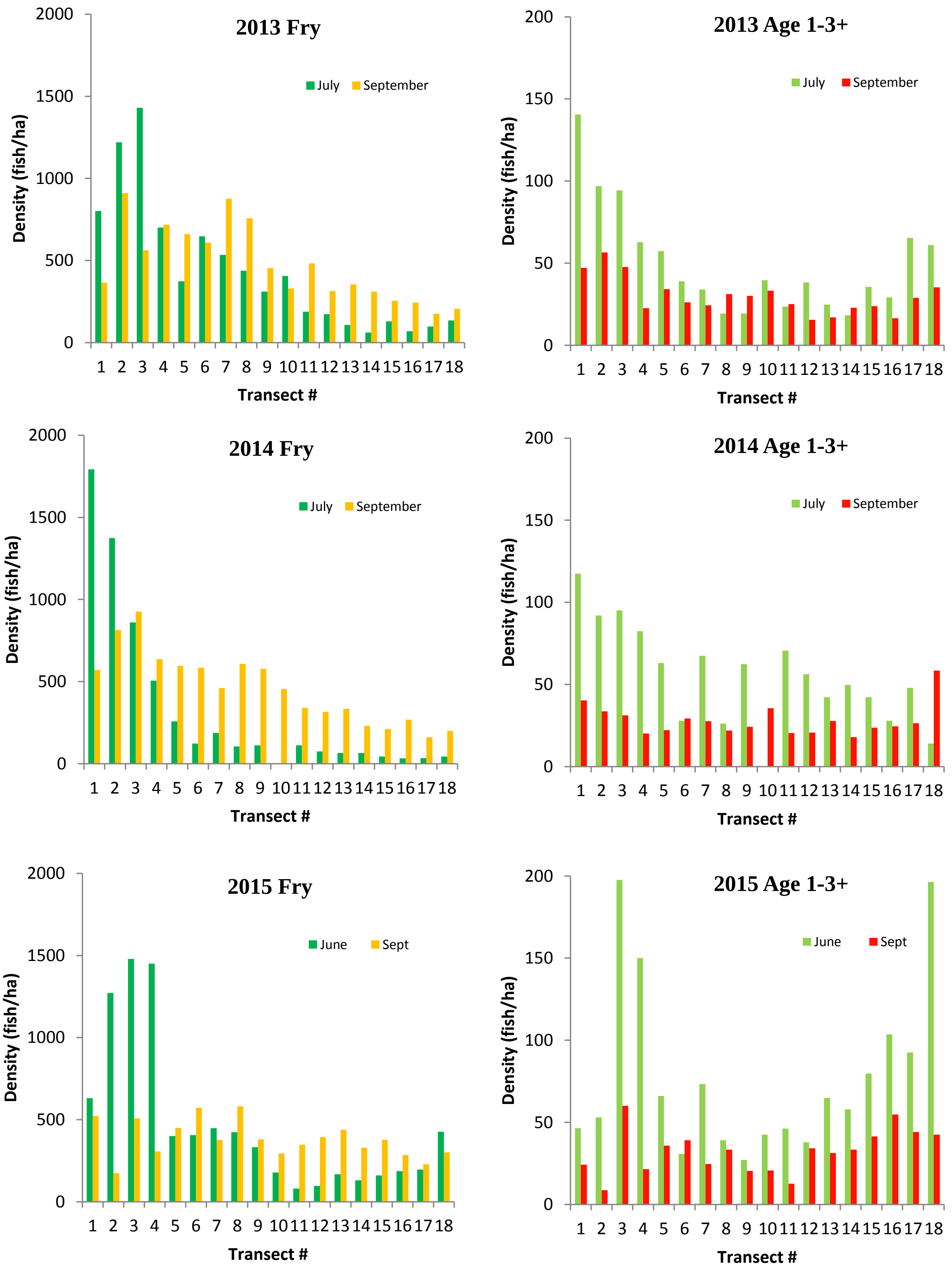


Figure 93. Longitudinal density distributions for age 0+ and ages 1-3+ kokanee in Kootenay Lake during early season and late season 2013-2015. Note: Transects are in order from North to South with #1–10 representing the North Arm and #11–18 representing the South Arm.

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 10a and 10b 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 (1992–2015), the biomass of in-lake kokanee has more than doubled to an average of 7.7 kg/ha (Fig. 94; Appendix 10b). In 2010, the in-lake biomass was estimated at 14.1 kg/ha but declined to the lowest level recorded in 2014 and 2015 at 1.1 kg/ha and 1.4 kg/ha, respectively.

At very low densities of age 1-3+ kokanee (e.g. 2013-2015), biomass estimates become more uncertain and prone to underestimation. The largest age 2+ kokanee, at the lowest densities and of large body sizes, are expected to be less vulnerable to the trawl gear and as a result are under-represented in the catch. For example, zero age 2+ kokanee were captured in the fall of 2014, although age 3+ kokanee still returned to spawn in 2015 proving their existence as age 2+ in 2014. As the largest kokanee impact biomass estimates dramatically, the occurrence of capturing a single age 2+ (as in 2015) versus missing this age class in the trawl (as in 2014) results in a relatively significant impact on the biomass estimate. A desktop exercise of adding a single age 2+ to the catch for 2014 and applying the weight of the age 2+ captured in 2015 increases the biomass estimate by ~40% for 2014. While significant, the 2014 estimate would still be very low from a time series perspective, and we believe the age structure and biomass estimates derived from the trawl catch under recent low densities are still broadly reflective of the actual trend. Methodology aimed at determining biomass estimates from acoustic data alone, where size data from the trawl is incorporated but not age structure, should provide refined estimates and is under development.

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. In 2013 biomass of spawning kokanee was 2.9 kg/ha, up slightly from 2012 but below the post fertilization average of 3.5 kg/ha. This occurred despite a significant increase in the size of spawners and was attributed to decreasing abundance. Size continued to increase in 2014 and 2015 while abundance decreased and the resulting biomass of spawners was 1.6 kg/ha and 0.3 kg/ha (Appendix 10c).

As fall acoustic surveys occur once spawners have left the lake, the in-lake and spawner biomass were summed to estimate the total kokanee biomass in Kootenay Lake. The total biomass was 5.3 kg/ha in 2013, less than half the post fertilization average of 11.7 kg/ha, then decreased further to historical lows of 2.7 kg/ha and 1.8 kg/ha in 2014 and 2015 respectively. While in-lake biomass actually increased slightly between 2014 and 2015, the decrease in total biomass in 2015 is entirely due to lower spawner biomass.

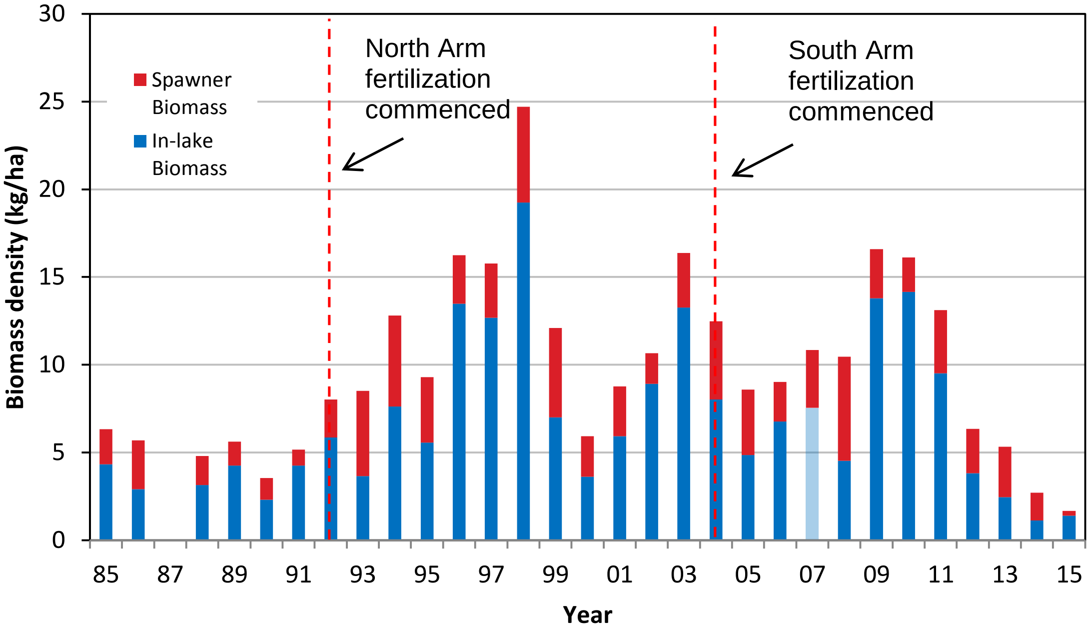


Figure 94. Trends in biomass (kg/ha) for Kootenay Lake based on acoustic and trawl surveys, 1985–2015. The dotted lines indicate the start of nutrient additions to the North Arm in 1992 and South Arm in 2004. Note: No trawling occurred in 2007 and in-lake biomass is estimated based on 2006 weights and age structure.

Meadow Creek Spring Fry to Adult Survival

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 95.

However, given the shift to primarily 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 returning spawners from age 2-5+ for each fry year, and is presented as ‘corrected to age at return’ in Figure 95. The post fertilization average was the same for both methods of calculating survival at ~4.1% and the survival rate trends of both calculation methods are similar (Fig. 95). This suggests that the previously standard method, which assumes age 3+ at maturity, was adequate although the estimate of 2010 fry to adult survival using this method was not reliable given the shift to primarily age 4+ spawners in 2013.

Fry to adult survival for 2010 cohort was 0.13% and for 2011 cohort was 0.51%, well below the post fertilization average of 4.4% and the lowest on record. The 2012 cohort survival, although incomplete if any are to return as 4+ in 2016, is 0.05%. It is not expected that any sizeable portion of the 2012 cohort remains in the lake to spawn as 4+ or older since predominant age at maturity in 2015 returned to 3+ and size at age has been increasing.

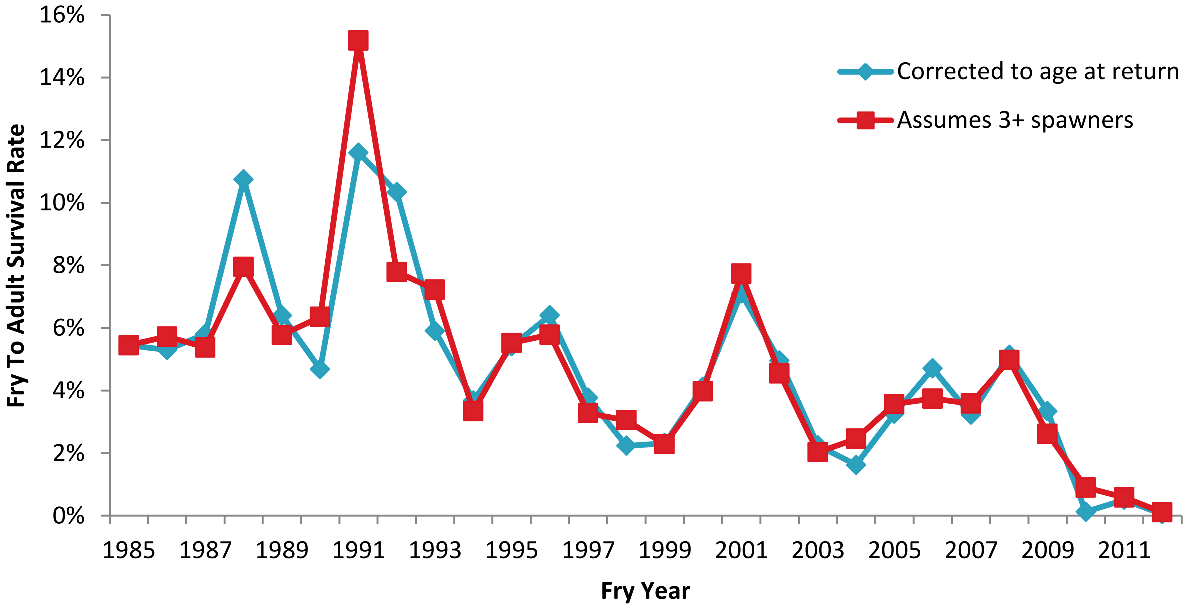


Figure 95. Meadow Creek Kokanee fry to adult survival rate (fry year on x-axis) comparing two different methods. Note: 2012 data point does not include 4+ spawners that may return in 2016.

North Arm Egg to Fall Fry Survival

The Meadow Creek spawning channel (MCSC) provides spring fry estimates which allow for survival estimates to be determined for egg-to-spring fry, discussed above under the meadow creek fry production section. Previously, Bassett *et al.* (2016) also reported on the relationship between MCSC fry production and acoustic fall fry estimates. This relationship demonstrated the importance of the MCSC for total fry production in Kootenay Lake, and provided insight into survival to fall fry. However, in recent years the decline in kokanee abundance has placed increased importance on Lardeau to overall kokanee production. Lardeau spawner numbers (reflected by the peak count trend, not expanded by residence time) surpassed Meadow Creek escapement annually beginning in 2013 (Figs. 82 & 83), which had not occurred since the early 1980's. As such, evaluating survival to fall fry is not possible without including Lardeau River, which appears to have been as, or more important to overall kokanee production than Meadow Creek. Unfortunately, the Lardeau data are typically single peak count estimates, and were not historically intended to be estimates of abundance but rather an index of relative abundance. Nonetheless, these data have been collected in a relatively consistent manner since the mid-1960's, and as an index of abundance still allow for further insight into survival trends. As spring to fall fry estimates are no longer viable owing to a lack of egg to spring fry survival data for the

Lardeau system, in order to evaluate survival to fall fry the better metric is now total North Arm egg deposition to fall fry.

Figure 96 illustrates relative egg to fall fry survival for the both Lardeau and Meadow Creek combined, and demonstrates a dramatic increase in survival to fall fry from the egg stage in 2014 and further in 2015, when the survival value was ~2.7X the post fertilization average (1992-2013). Clearly 2014 and in particular 2015 are exceptionally high, illustrating that the dramatic decline in kokanee abundance in recent years does not appear to be related to poor survival to the fall fry stage. Notably, it is also apparent that egg to spring fry survival must have been exceptional in the Lardeau River, at or near that of the Meadow Creek spawning channel, unless there was dramatically differential survival between the two stocks after emigration to the lake.

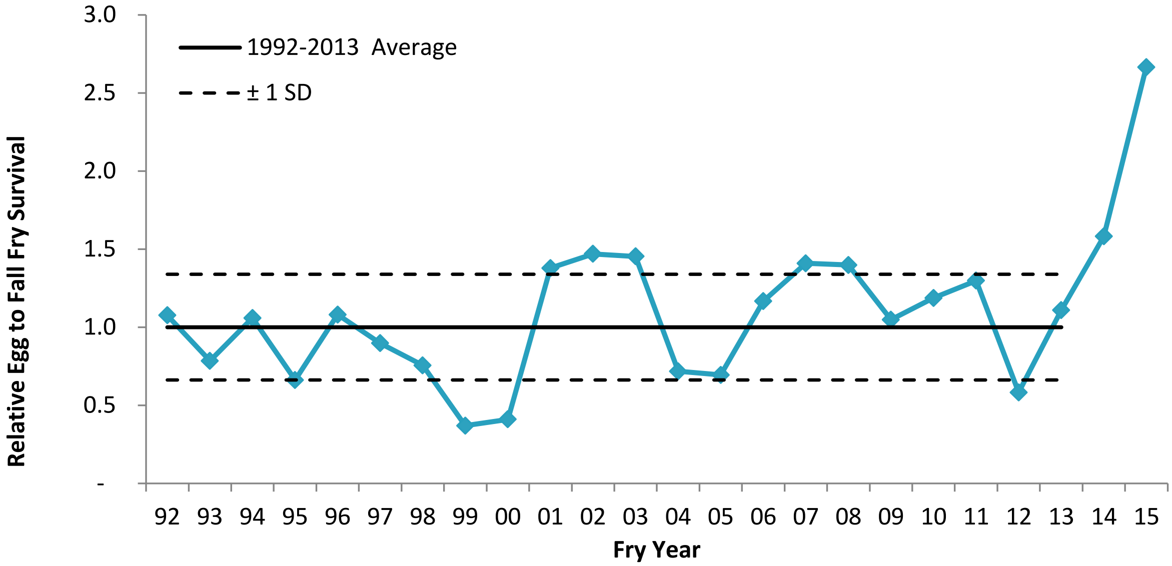


Figure 96. Trends in egg-to-fall fry survival rate relative to the 1992-2013 mean for Kootenay Lake during the post-fertilization era.

Fall Fry to age 1 survival

Figure 97 illustrates that survival from fall age 0+ to the following fall at age 1+ has been highly variable. In contrast to egg to fall fry survival, age 0-1 survival has declined dramatically in recent years, reaching a low of ~6-7 % since 2013, compared to the post fertilization average to 2013 of 25%. This sharp decline follows a record high survival rate in 2010 of 63%. While survival to fall fry has been as low as 6% previously in 2000, four consecutive years of very low survival clearly indicates a significant bottleneck occurring at this life stage.

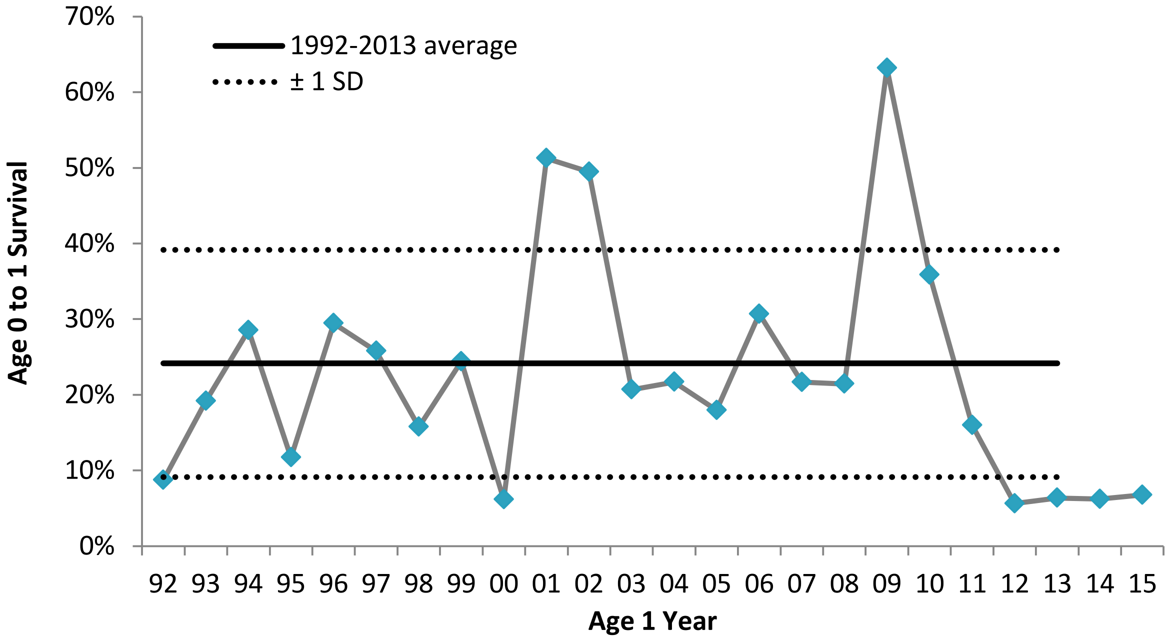


Figure 97. Trends in fall fry to following fall age 1+ relative survival rates for Kootenay Lake during the post-fertilization era.

Gerrard Rainbow Trout

The Gerrard spawner AUC abundance time series, an index of predator abundance, was relatively stable from the 1960's until 2008, ranging between ~300 and 800 spawners (Fig. 98). Beginning in 2009, Gerrard spawners increased dramatically to a peak of 1,532 in 2012. Spawner numbers then plunged steeply declining to 932 spawners in 2014 and to 301 spawners in 2015, the lowest on record since 1971.

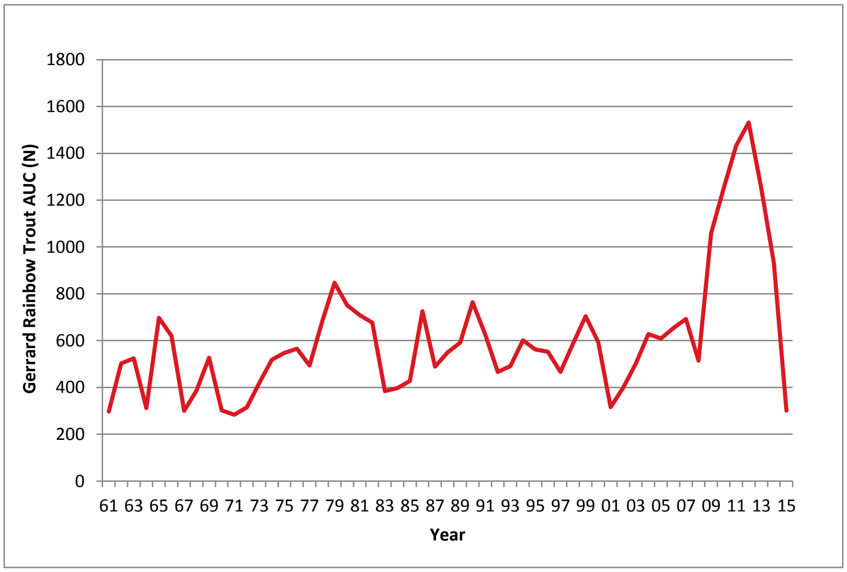


Figure 98. Trends in Gerrard rainbow trout peak spawner estimate during 1961–2015. Data courtesy of MFLNRO Nelson.

SUMMARY

In the North Arm, the total weight of fertilizer applied in 2014 was 26.3 tonnes of phosphorus and 205 tonnes of nitrogen. In the South Arm, 247 tonnes of nitrogen were added. In 2015, 32.1 tonnes of phosphorus, and 213 tonnes of nitrogen were added to the North Arm, and 267 tonnes of nitrogen were added to the South Arm. 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 in the epilimnion ranged from below the reportable detection limit (2 µg/L) to 9.6 µg/L in 2014, and in 2015, ranged from the reportable detection limit (2 µg/L) to 9.4 µg/L. Total phosphorus in the epilimnion ranged from below the reportable detection limit (2 µg/L) to 7.7 µg/L in 2014, and in 2015, ranged from the reportable detection limit (2 µg/L) to 12.8 µg/L. Dissolved inorganic nitrogen collected from epilimnetic integrated samples ranged from 53 to 209 µg/L in 2014, and 53 to 218 µg/L in 2015; both years reached nadir in the summer, this seasonal trend corresponds with phytoplankton uptake and use during summer stratification.

Abundance and biomass of phytoplankton in integrated epilimnetic samples was dominated by bacillariophytes and chryso-cryptophytes and bacillariophytes in 2014 and 2015, respectively. In 2014, bacillariophytes were highest in the summer, and chryso-cryptophytes were highest in the spring. In 2015, bacillariophytes were highest in the summer, whereas chryso-cryptophytes were highest in the spring and fall. The trend of decreased chryso-cryptophytes into the summer coincided with increased zooplankton, suggesting grazing on phytoplankton.

Zooplankton biomass in 2014 and 2015 was significantly higher than the pre and post nutrient addition long-term averages. Copepods were the main contributor to the overall zooplankton population abundance in the spring. Biomass of *Daphnia* sp. was particularly high in both 2014 and 2015. Zooplankton biomass was highest in 2015 since 1992 for all arms. This trend in zooplankton is attributed to the lack of top down pressure on the population.

Mysis diluviana (mysid) 2014 and 2015 densities were below the long-term 1993-2015 average. In 2014 mysid densities in the North Arm were slightly above the long term average (1993-2015), but were below the South Arm average. In 2015, mysid densities in the North Arm were marginally below the average, and in the South Arm, marginally above the long term mean. In both 2014 and 2015, the West Arm densities were marginally below the long term West Arm average.

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 kokanee survival was excellent to older age classes. This led 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). Through this period, 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, is unprecedented in the time series, and is a sign that capacity may have been reached or exceeded at some point in the life cycle of the 2009 cohort.

Following the peak in survival and abundance in 2009/2010, 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 spring seasons in 2011 and 2012 (Fig. 7). In 2011, seasonal spring air temperature was the lowest since the onset of fertilization in 1992. The cold spring may have contributed to the poor zooplankton biomass suggested by the low 2011 *Daphnia* biomass, however low *Daphnia* biomass also occurred in 2004 and 2005 (Fig. 66). The extent to which *Daphnia* abundance and biomass was impacted by top down pressure as opposed to bottom up influences during this time is unknown. High spawner biomass in 2008 was followed by high total (in-lake + spawner) kokanee biomass from 2009-11, which assumedly had a significant impact on the standing crop *Daphnia* trend during that period. However, in-lake kokanee biomass declined to approximately 50% of average in 2012, while *Daphnia* indices remained average. In 2000, kokanee biomass was similar to 2012 results, however average *Daphnia* biomass in 2000 was 50% of the biomass results in 2012. The timing of *Daphnia* differed between the two years – biomass was higher in August in 2000 than compared to August 2012 results, however, biomass was higher in September, October, and November when compared to 2000 results. These results suggest the possibility that temperature could potentially limit zooplankton timing that may affect kokanee survival.

In 2012, spring air temperatures were again well below average and among the coldest since fertilization (Fig. 7). The spring of 2012 was also exceptionally wet (Fig. 8), June precipitation was the highest over the 1992-2015 time period (data not shown). Zooplankton biomass as well as kokanee productivity and survival declined severely in nearby Arrow Lakes 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 different from each other and from Kootenay Lake in many ways (e.g. predator community, mysids presence, hydrology, etc.), which suggests that perhaps regional climatic driver(s) were unfavourable to kokanee production/survival in 2011 and 2012.

From 2013 to 2015 the kokanee fry abundance remained near average while the resulting age 1-3+ population was very low indicating a serious bottleneck in survival beyond the fall fry stage. Spawner numbers declined to lowest levels on record and the size of age 2+ and older kokanee, including spawners, increased substantially but not enough to offset the decreasing abundance and therefore biomass also continued to decline. The increased fecundity of the larger spawners did not offset the decline in abundance of spawners and therefore egg deposition also decreased to historically low numbers. The failure of kokanee survival to improve beyond the fall fry stage regardless of low densities and adequate (or excellent) zooplankton resources is unprecedented.

Measured by spawner returns, in recent years the Lardeau River has become as or more important to overall kokanee production as Meadow Creek after approximately three decades of significantly higher escapements to the Meadow Creek system. Assuming the Lardeau index of abundance is precise enough to allow for this type of trend comparison, this transition suggests that differential survival at one or more life stages must have occurred in order for Lardeau spawner abundance to consistently surpass Meadow Creek escapement in recent years. Given that the spawning channel habitat is enhanced to maximize survival from egg to emergent fry, it is assumed that the un-enhanced wild habitat in Lardeau River would result in significantly lower survival at this key survival stage. Remarkably, this assumption may be incorrect in this case, or alternatively the Lardeau kokanee are experiencing significantly higher survival after the emergent fry stage than the Meadow Creek kokanee. This notable development should be further investigated going forward, as these data may provide significant insight into the implications of long term spawning channel production.

Top down pressure is expected to be a key driver of the continued suppression of kokanee numbers, given the dramatic spike in abundance evident in the Gerrard spawner data. 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. While Gerrard spawner numbers have recently declined to below average, Kootenay Lake recreational fishery data (MFLNRO data on file) indicate high catch rates of small Rainbow and Bull Trout continue in the fishery. Assuming catch rate is proportional to abundance, the high numbers of younger age classes of predators would continue to exert significant pressure on the kokanee population, resulting in the extremely poor survival evident between fall fry and older age classes.

The Ministry of Forests, lands and Natural Resource Operations formed an advisory team of biologists from within the Provincial Government as well as First Nations and other stakeholders in 2014 in order to better understand the cause(s) of the current kokanee collapse. The intent of this team is ultimately to make recommendations on management actions over the next 5 years that will contribute to recovery of the Kokanee population, and ensure predator populations remain viable. Kokanee recovery is also dependent nutrient addition which supports food web function (i.e zooplankton biomass). The Kootenay Lake Action Plan (Redfish Consulting Ltd., 2016), provides further information and summarizes the recommendations of the advisory team.

REFERENCES

Acara, A.H. 1970. The Meadow Creek Spawning Channel. Unpublished MS. Department of Recreation and Conservation, Fish and Wildlife Br., Victoria, BC.

Andrusak, H., and C. Brown. 1987. Kootenay Lake Fisheries Management Plan 1987-89. B.C. Ministry of Environment, 56 pp.

Andrusak, H. and L. Fleck. 2007. Status of Kokanee in the South Arm of Kootenay Lake Prior to Experimental Fertilization. Pages 251 – 272 in Schindler et al. Kootenay Lake Fertilization Experiment, Year 13 (north Arm) and Year 1 (South Arm) (2004) Report, Fisheries Project Report No. RD 117, Ministry of Environment, Province of British Columbia.

Ashley, K.I., L.C. Thompson, D. Lombard, J.R. Yang, F.R. Pick, P.B. Hamilton, G. Larkin, D.C. Lasenby, K.E. Smokorowski, D. Sebastian, and G. Scholten. 1999a. Kootenay Lake Fertilization Experiment–Year 6 (1997/98) Report. Fisheries Project Report No. RD 65. Ministry of Fisheries, Province of British Columbia.

Ashley, K.I, L.C. Thompson, D. Sebastian, D.C. Lasenby, K.E. Smokorowski, and H. Andrusak. 1999b. Restoration of Kokanee Salmon in Kootenay Lake, a Large Intermontane Lake, by Controlled Seasonal Application of Limiting Nutrients in Murphy, T.P. and M. Munawar 1999b. Aquatic Restoration in Canada Backhuys Publishers, Leiden, 1999.

Ashley, Ken, L.C. Thompson, D. C. Lasenby, L. McEachern, K. E. Smokorowski and D. Sebastian. 1997. Restoration of an Interior Lake Ecosystem: the Kootenay Lake Fertilization Experiment. Water Qual. Res. J. Canada 32:295-323.

Audzijonyte, A. and R. Vainola. 2005. Diversity and distributions of circumpolar fresh- and brackish Mysis (Crustacea:Mysida): descriptions of M. relicta Loven, 1862, M. salemaai n. sp., M. segerstralei n. Sp. and M. diluviana n. sp. based on molecular and morphological characters. Hydrobiologia 544:89 – 141.

Baldwin, C. and Polacek, M. 2002. Evaluation of Limiting Factors for Stocked Kokanee and Rainbow Trout in Lake Roosevelt, Washington, 1999. Washington Department of Fish and Wildlife Fish program, Inland Fish Investigations.

Bassett, M.C., Schindler, E.U., T. Weir, D. Sebastian and K. I. Ashley. 2015. Arrow Lakes Reservoir Nutrient Restoration Program Year 15 (2013) Report. Fisheries Project Report No. 148, Ministry of Forests, Lands and Natural Resource Operations, Province of British Columbia

Bassett, M.C., Schindler, E.U., D. Johner, T. Weir, D. Sebastian, L. Vidmanic, and K.I. Ashley. 2016. Kootenay Lake Nutrient Restoration Program, Years 22 (North Arm) and Years 10 (South Arm) (2013) Report.

Beauchamp, D.A., Lariviere, M.G., Thomas, G.L. 1995. Evaluation of Competition and Predation as Limits to Juvenile Kokanee and Sockeye Salmon Production in lake Ozette, Washington. *North American Journal of Fisheries Management*. Vol. 15, Issue 1. Pp.193-207.

Beauchamp, D.A., C.J. Sergeant, M.M. Mazur, J.M. Scheuerell, D.E. Schindler, M.D. Scheuerell, K.L. Fresh, D.E. Seiler, and T.P. Quinn. 2004. Temporal-spatial dynamics of early feeding demand and food supply of sockeye salmon fry in Lake Washington. *Transactions of the American Fisheries Society*. 133:1014-1032.

Binsted, G.A., and K.I. Ashley. 2006. Phosphorus Loading to Kootenay Lake from the Kootenay and Duncan rivers and Experimental Fertilization Program. Prepared for the British Columbia Conservation Foundation.

Brooks, J.L. 1959. Cladocera. Pp. 586-656 In Edmondson, W.T. (Ed.), Fresh-Water Biology, 2nd Ed. John Wiley and Sons, New York.

Canter-Lund, H. and J.W.G. Lund. 1995. Freshwater Algae – Their Microscopic World Explored. BioPress Ltd., Bristol, UK, 360pp.

Casselman, J.M.. 1990. Growth and relative size of calcified structures of fish. Transactions of the American Fisheries Society 119:673-688.

Crozier, R.J., and W.F.A. Duncan. 1984. Kootenay Lake: 1984. British Columbia Ministry of Environment. 187 pp.

Daley, R.J., E.C. Carmack, C.B.J. Gray, C.H. Pharo, S. Jasper, and R.C. Wiegand. 1981. The effects of upstream impoundments on Kootenay Lake, B.C. Canada Inland Waters Directorate, Research Institute, Scientific Series, West Vancouver, British Columbia.

Danielsdottir, M. G., M. T. Brett and G.B. Arhonditsis. 2007. Phytoplankton food quality control of planktonic food web processes. Hydrobiologia 589: 29-41.

Ericksen, R., P. Anders, C. Lewandowski and J. Siple. 2009. Status of Kokanee Populations in the Kootenai River in Idaho and Montana and South Arm Kootenay Lake, British Columbia. Contract report prepared for the Kootenai Tribe of Idaho 30p.

FWCP. 2012. Fish and Wildlife Compensation Program Columbia Basin Large Lakes Action Plan Draft. Fish and Wildlife Compensation Program (FWCP). 33 p. + appendices. **http://fwcp.ca/app/uploads/2015/07/columbia_LargeLakes_ActionPlan_2012_jun.pdf**

Grover, M.C. 2005. Changes in size and age at maturity in a population of kokanee *Oncorhynchus nerka* during a period of declining growth conditions. Journal of Fish Biology 66: 122-134.

Horne, A.J. and C.R. Goldman. 1994. Limnology 2nd edition. McGraw-Hill Inc.

Hoyle G.M., Holderman, C., Anders, P.A., Shafii, B. and K.I. Ashley. 2014. Water quality, chlorophyll, and periphyton responses to nutrient addition in the Kootenai River, Idaho. *Freshwater Science*. 33(4). 1024-1029.

Koerselman, W and A.F.M. Meuleman. 1996. The Vegetation N:P Ratio: a New Tool to Detect the Nature of Nutrient Limitation. Journal of Applied Ecology. 33(6). 1441-1450.

Kongsberg Maritime AS. 2008. Simrad ER60 scientific echosounder reference manual for software version 2.2.0. Kongsberg Maritime, Horten, Norway. 221p. Lakes Fisheries Commission Tech. Rep. 25

Larkin, G.A. 1998. Kootenay Lake phosphorus loading from the Kootenay and Duncan Rivers. Report prepared for the Columbia Basin Fish and Wildlife Compensation Program, 26 p.

Lasenby, D.C. 1977. The ecology of *Mysis relicta* in Kootenay Lake, British Columbia: final report 1976-1977. Manuscript.

Leifasbjorn, V., Peterson, J., and Quinn, TP. 2004. Effects of Freshwater and Marine Growth Rates on Early Maturity in Male Coho and Chinook Salmon. *Transactions of the American Fisheries Society* 133:495-503

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

Martin, A.D., and T.G. Northcote. 1991. Kootenay Lake: An inappropriate model for Mysis relicta introduction in north temperate lakes. American Fisheries Society Symposium 9:23-29.

Mazumder, A., and J.A. Edmundson. 2002. Impact of fertilization and stocking on trophic interactions and growth of juvenile sockeye salmon (Oncorhynchus nerka). Can. J. Fish. Aquat. Sci 59:1361-1373.

McCauley, E. 1984. The estimation of the abundance and biomass of zooplankton in samples. Pp. 228-265 *In* Downing, J.A. and F.H. Rigler (Eds.), A Manual on Methods for the Assessment of Secondary Productivity in Fresh Waters. Blackwell Scientific Publications, Boston.

Minshall, W., Shafii, B., Price, W.J., Holderman, C., Anders, P.A., Lester, G. and P. Barrett. 2014. Effects of nutrient replacement on benthic macroinvertebrates in an ultraoligotrophic reach of the Kootenai River, 2003–2010. *Freshwater Science.* 33(4). 1009-1023.

Ney, J.J. 1996. Oligotrophication and its discontents: effects of reduced nutrient loading on reservoir fisheries. Pages 285-295 in L.E. Miranda and D.R. DeVries, editors. Multidimensional approaches to reservoir fisheries management. American Fisheries Society, Symposium 16, Bethesda, Maryland.

Northcote, T.G. 1973. Some Impacts of Man on Kootenay Lake and Its Salmonids. Great

Northcote, T.G., D.B. Fillion, S.P. Salter, and G.L. Ennis. 1999. Interactions of Nutrients and Turbidity in the Control of Phytoplankton in Kootenay Lake British Columbia, Canada, 1964 to 1966. Misc. Fisheries Project Report No. 1, Province of British Columbia.

Patterson,et al 2008. Sexual Maturation in Kokanee Oncorhynchus nerka. Northwest Science Vol. 82, No. 1. p 30-47.

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

Perrin, C.J., M. L. Rosenau, T. B. Stables, and K. I. Ashley. 2006. Restoration of a Montane Reservoir Fishery via Biomanipulation and Nutrient Addition. North Am. J. Fish. Manag. 26:391-407.

Pieters, R., S. Harris, L.C. Thompson, L. Vidmanic, M. Roushorne, G. Lawrence, J.G. Stockner, H. Andrusak, K.I. Ashley, B. Lindsay, K. Hall and D. Lombard. 2003. Restoration of kokanee salmon in the Arrow Lakes Reservoir, British Columbia: Preliminary results of a fertilization experiment. Pages 177-196 *in* J.G. Stockner, editor. Nutrients in salmonid ecosystems: sustaining production and biodiversity. American Fisheries Society, Symposium 34, Bethesda, Maryland.

Prescott, GW. 1978. Freshwater Algae, 3rd Edition, W.C. Brown Co., Dubuque, Iowa.

Redfish Consulting Ltd. 1999. Performance Evaluation of Six Kokanee Spawning Channels in British Columbia. Ministry of Fisheries, Province of British Columbia, Victoria, BC.

Redfish Consulting Ltd. 2002. West Arm of Kootenay Lake Kokanee Sport Fishery and Kokanee Food Habits 2002. Contract report for the Nelson Fisheries Branch of the BC Ministry of Water, Land and Air Protection, Nelson, BC.

Redfish Consulting Ltd. 2016. Kootenay Lake Action Plan. Contract report for BC Ministry of Ministry of Forests, Lands and Natural Resource Operations (MFLNRO), Nelson, BC. http://www.env.gov.bc.ca/kootenay/fsh/main/pdf/KLAP%20Kootenay%20Lake%20Action%20PLan%20final%209_May_2016.pdf

Reynolds, J.B. and G.M. DeGraeve. 1972. Seasonal population characteristics of the opossum shrimp, *Mysis relicta,* in southeastern Lake Michigan, 1970-71. Proc. 15th Conf. Great Lakes Res. 1972: 117-131.

Rieman, B.E. and D.L. Myers. 1992. Influence of Fish Density and Relative Productivity on Growth of Kokanee in Ten Oligotrophic Lakes and Reservoirs in Idaho. Trans. Am. Fish. Soc. 121:178–191.

Rydin, E., T. Vrede, J. Persson, S. Holmgren, M. Jansson, L. Tranvik and G. Milbrink. 2008. Compensatory nutrient enrichment in an oligotrophicated mountain reservoir – effects and fate of added nutrients. Aquat. Sci. 70:323-336.Sandercock, G.A. and Scudder, G.G.E. 1996. Key to the Species of Freshwater Calanoid Copepods of British Columbia. Department of Zoology, UBC Vancouver, BC.

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

Schindler, E.U., K.I. Ashley, R. Rae, L. Vidmanic, H. Andrusak, D. Sebastian, G. Scholten, P. Woodruff, F. Pick, L.M. Ley and P.B. Hamilton. 2006. Kootenay Lake Fertilization Experiment, Years 11 and 12 (2002 and 2003). Fisheries Report No. 114, Ministry of Environment, Province of British Columbia.

Schindler, E.U., R. Rae, K.I. Ashley, L. Vidmanic, D. Sebastian, H. Andrusak, G. Scholten, P. Woodruff, J. Stockner, F. Pick, L.M. Ley, P.B. Hamilton, G.F. Andrusak and L. Fleck. 2007a. Kootenay Lake Fertilization Experiment, Year 13 (North Arm) and Year 1 (South Arm) (2004)

Report. Fisheries Project Report No. RD 117, Ministry of Environment, Province of British Columbia.

Schindler, E.U., H. Andrusak, K.I. Ashley, G.F. Andrusak, L. Vidmanic, D. Sebastian, G. Scholten, P. Woodruff, J. Stockner, F. Pick, L.M. Ley and P.B. Hamilton. 2007b. Kootenay Lake Fertilization Experiment, Year 14 (North Arm) and Year 2 (South Arm) (2005) Report. Fisheries Project Report No. RD 122, Ministry of Environment, Province of British Columbia.

Schindler, E.U., D. Sebastian, G.F. Andrusak, H. Andrusak, L. Vidmanic, J. Stockner, F. Pick, L.M. Ley, P.B. Hamilton, M. Bassett and K.I. Ashley. 2009. Kootenay Lake Fertilization Experiment, Year 15 (North Arm) and Year 3 (South Arm) (2006) Report. Fisheries Project Report No. RD 126, Ministry of Environment, Province of British Columbia.

Schindler, E.U., D. Sebastian, H. Andrusak L. Vidmanic, S. Harris, G.F. Andrusak, F. Pick, L.M. Ley, P.B. Hamilton, D. Johner, P. Woodruff, M. Bassett and K.I. Ashley. 2010. Kootenay Lake Nutrient Restoration Program, Year 16 (North Arm) and Year 4 (South Arm) (2007) Report. Fisheries Project Report No. RD 127, Ministry of Environment, Province of British Columbia.

Schindler, E.U., D. Sebastian, H. Andrusak, L. Vidmanic, G. F. Andrusak, M. Bassett, T. Weir and K. I. Ashley. 2011. Kootenay Lake Nutrient Restoration Program, Year 17 (North Arm) and Year 5 (South Arm) (2008) Report. Fisheries Project Report No. RD 131. Ministry of Forests, Lands and Natural Resource Operations, Province of British Columbia.

Schindler, E.U., D. Sebastian , T. Weir, H. Andrusak, G.F. Andrusak, M. Bassett, L. Vidmanic, and K.I. Ashley. 2013. Kootenay Lake Nutrient Restoration Program, Years 18 and 19 (North Arm) and Years 6 and 7 (South Arm) (2009 and 2010) Report. Fisheries Project Report No. RD 136, Ministry of Forests, Lands, and Natural Resource Operations, Province of British Columbia.

Schindler, E.U., D. Johner, T. Weir, D. Sebastian , M. Bassett, L. Vidmanic, and K.I. Ashley. 2014. Kootenay Lake Nutrient Restoration Program, Years 20 and 21 (North Arm) and Years 8 and 9 (South Arm) (2011 and 2012) Report. Fisheries Project Report No. RD 147, Ministry of Forests, Lands, and Natural Resource Operations, Province of British Columbia

Sebastian, D., H. Andrusak, G. F. Andrusak, and P. Woodruff. 2010. South Arm of Kootenay Lake Response to Nutrient Additions 2004 – 2007. Pages 231 – 268 *in* Schindler, E.U.et al. 2010. Kootenay Lake Nutrient Restoration Program, Year 16 (North Arm) and Year 4 (South Arm) (2007) Report. Fisheries Project Report No. RD 127, Ministry of Environment, Province of British Columbia.

Sebastian, D. and T. Weir. 2013. Kinbasket and Revelstoke Reservoirs Kokanee Population Monitoring - Year 5 (2012). Prepared for BC Hydro under the Columbia River Water Use Plan, Water Licence Requirements Study No. CLBMON-2. 42p

Simmonds, J., and D. MacLennan. 2005. Fisheries acoustics: Theory and practice. Blackwell, Oxford, UK.

Skaar, D., J. DeShazer, L. Garrow, T. Ostrowski, and B. Thornburg. 1996. Investigations of fish entrainment through Libby Dam, 1990-1994. Montana Dept. of Fish, Wildlife, and Parks, Prepared for Bonneville Power Administration, Project Number 83-467, Portland, Oregon.

Smokorowski, K.E. 1998. The response of the freshwater shrimp, Mysis relicta, to the partial fertilization of Kootenay Lake, British Columbia. Ph.D. thesis, Trent University, Peterboriugh, Ontario, Canada, 227 p.

Stockner, J.G. 1987. Lake fertilization: The enrichment cycle and lake sockeye salmon (Onchorhynchus nerka) production. Pages 198-215 in H.D. Smith, L. Margolis and C.C. Woods, editors. Sockeye salmon (Onchorhynchus nerka) populations biology and future management. Canadian Special Publication of Fisheries and Aquatic Sciences 96.

Stockner, J. G., and E.A. MacIsaac. 1996. British Columbia lake enrichment program: two decades of habitat enhancement for sockeye salmon. Regul. Rivers Res. Manag. 12:547-561.

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

Vernon, E. H. 1957. Morphometric Comparison of Three Races of Kokanee (Oncorhynchus nerka) Within a Large British Columbia Lake. Journal of the Fisheries Research Board of Canada 27:1239–1250.

Vidmanic, L. 2011. Zooplankton and Mysis diluviana response to nutrient addition in Kootenay Lake – 2008. Pages 90-143 in Schindler et al. 2011. Kootenay Lake Nutrient Restoration Program, Year 17 (North Arm) and Year 5 (South Arm) (2008) Report. Fisheries Project Report No. RD 131. Ministry of Forests, Lands and Natural Resource Operations, Province of British Columbia.

Wetzel, R.G. 2001. Limnology. 3rd Ed, Academic Press, San Diego.

Wilson, M.S. 1959. Free-living copepoda: Calanoida. Pp. 738-794 In Edmondson, W.T. (ed.) Fresh-Water Biology, 2nd Ed., John Wiley and Sons, New York.

Wright, M.E., K.I. Ashley, H. Andrusak, H. Manson, R. Lindsay, R.J. Hammond, F.R. Pick, L.M. Ley, P.B. Hamilton, S.L. Harris, L.C. Thompson, , L. Vidmanic, D. Sebastian, G. Scholten, M. Young, and D. Miller. 2002. Kootenay Lake Fertilization Year 9 (2000/2001) Report. Fisheries Project Report No. RD 105. Ministry of Water, Land and Air Protection, Province of British Columbia.

APPENDICES

Appendix 1a. Kootenay Lake participants, activities, and affiliation for 2014 studies.

Contribution	**Personnel**	**Affiliation**
Project co-ordination, management and scientific liaison	Marley Bassett Eva Schindler	Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson
Report compilation	Marley Bassett	Resource Management, MoFLNRO, Nelson
Report editing	Marley Bassett Eva Schindler Ken Ashley	Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson BC Institute of Technology Rivers Institute
Fertilizer supplier	Gerry Kroon Wilf Doering Lenora Doering	Agrium, Calgary Agrium, Kamloops Agrium, Kamloops
Fertilizer schedule, loading	Marley Bassett Ken Ashley Wilf Doering	Resource Management, MoFLNRO, Nelson BC Institute of Technology Rivers Institute Agrium, Kamloops
Fertilizer application	Western Pacific Marine Marley Bassett Rob Fox	Western Pacific Marine, Balfour Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson
Physical limnology, water chemistry, phytoplankton, zooplankton, mysid sampling	Don Miller and staff Marley Bassett Eva Schindler Rob Fox Les Fleck Tom Roos	Kootenay Wildlife Services Ltd. Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson Crystal Springs Consulting BC Parks, MoE
Water chemistry analysis	Maxxam Analytics Inc. staff	Maxxam Analytics Inc., Burnaby
Physical limnology, water sampling data analysis and reporting	Marley Bassett	Resource Management, MoFLNRO, Nelson
Primary production sampling	Shannon Harris Allison Hebert Petra Wypkiss Marley Bassett 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	Shannon Harris Allison Hebert Petra Wykpiss	MoE, Vancouver 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, Wildlife and Habitat Management, MoFLNRO, Victoria Fish, Wildlife and Habitat Management, MoFLNRO, Victoria

	Dale Sebastian	British Columbia Conservation Foundation
Kokanee trawling	Don Miller and staff	Kootenay Wildlife Services Ltd.
Kokanee analysis and reporting	Tyler Weir David Johner Dale Sebastian	Fish, Wildlife and Habitat Management, MoFLNRO, Victoria Fish, Wildlife and Habitat Management, MoFLNRO, Victoria British Columbia Conservation Foundation
South Arm tributary adult kokanee enumeration	Les Fleck Marley Bassett Rob Fox Gary Munro	Crystal Springs Contracting Resource Management, MoFLNRO, Nelson R Resource Management, MoFLNRO, Nelson esource Management, MoFLNRO, Nelson
Regional support	Jeff Burrows Matt Neufeld	Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson
FWCP Technical Committee	Jeff Burrows Tyler Weir Guy Martel Karen Bray	Resource Management, MoFLNRO, Nelson Fish, Wildlife and Habitat Management, MoFLNRO, Victoria BC Hydro, Vancouver BC Hydro, Revelstoke
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 Sue Ireland Charlie Holderman Barb Waters Anne Reichert Julie Lawrence Elaine Perepolkin Disa Westerhaug	FWCP FWCP Kootenai Tribe of Idaho Kootenai Tribe of Idaho British Columbia Conservation Foundation Regional Program and Administrative Support, MoE, Nelson Corporate Services Branch, MoFLNRO, Nelson Corporate Services Branch, MoFLNRO, Nelson Corporate Services Branch, MoFLNRO, Nelson

MoFLNRO - Ministry of Forests, Lands and Natural Resource Operations
MoE - Ministry of Environment
FWCP - Fish and Wildlife Compensation Program

Appendix 1b. Kootenay Lake participants, activities, and affiliation for 2015 studies.

Contribution	Personnel	Affiliation
Project co-ordination, management and scientific liaison	Marley Bassett Eva Schindler	Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson
Report compilation	Marley Bassett	Resource Management, MoFLNRO, Nelson
Report editing	Marley Bassett Eva Schindler Ken Ashley	Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson BC Institute of Technology Rivers Institute

Fertilizer schedule, loading	Marley Bassett Ken Ashley Wilf Doering	Resource Management, MoFLNRO, Nelson BC Institute of Technology Rivers Institute Agrium, Kamloops
Fertilizer application	Western Pacific Marine Marley Bassett Rob Fox	Western Pacific Marine, Balfour Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson
Physical limnology, water chemistry, phytoplankton, zooplankton, mysid sampling	Don Miller and staff Marley Bassett Eva Schindler Rob Fox Les Fleck Tom Roos Robbie McClary	Kootenay Wildlife Services Ltd. Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson Crystal Springs Consulting BC Parks, MoE BC Parks, MoE
Water chemistry analysis	Maxxam Analytics Inc. staff (-March 31,2015) ALS Global staff (Jun 1st, 2015-	Maxxam Analytics Inc., Burnaby ALS Global, Burnaby BC
Physical limnology, water sampling data analysis and reporting	Marley Bassett	Resource Management, MoFLNRO, Nelson
Primary production sampling	Shannon Harris Allison Hebert Morgan Davies Marley Bassett 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	Shannon Harris Allison Hebert Petra Wykpiss	MoE, Vancouver 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 Andrew Schellenberg	Fish, Wildlife and Habitat Management, MoFLNRO, Victoria Fish, Wildlife and Habitat Management, MoFLNRO, Victoria MoE, Vancouver
Kokanee trawling	Don Miller and staff	Kootenay Wildlife Services Ltd.
Kokanee analysis and reporting	Tyler Weir David Johner	Fish, Wildlife and Habitat Management, MoFLNRO, Victoria Fish, Wildlife and Habitat Management, MoFLNRO, Victoria
South Arm tributary adult kokanee enumeration	Les Fleck Marley Bassett Rob Fox Katherine McGlynn	Crystal Springs Contracting Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson
Regional support	Jeff Burrows Matt Neufeld	Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson
FWCP Technical Committee	Jeff Burrows Tyler Weir Guy Martel Karen Bray	Resource Management, MoFLNRO, Nelson Fish, Wildlife and Habitat Management, MoFLNRO, Victoria BC Hydro, Vancouver BC Hydro, Revelstoke

FWCP Board	Paul Rasmussen David Tesch Patrice Rother Doug Johnson Rick Morley Grant Trower Dave White Joe Nicholas Adam Neil Howie Wright	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 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 Sue Ireland Charlie Holderman Barb Waters Anne Reichert Julie Lawrence Elaine Perepolkin Disa Westerhaug	FWCP FWCP Kootenai Tribe of Idaho Kootenai Tribe of Idaho British Columbia Conservation Foundation Regional Program and Administrative Support, MoE, Nelson Corporate Services Branch, MoFLNRO, Nelson Corporate Services Branch, MoFLNRO, Nelson Corporate Services Branch, MoFLNRO, Nelson

MoFLNRO - Ministry of Forests, Lands and Natural Resource Operations
MoE - Ministry of Environment
FWCP - Fish and Wildlife Compensation Program

Appendix 2. Sampling activities – Kootenay Lake, 2014 and 2015.

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 mid June) Twice monthly, July and August	KLF 1-8 KLF 2 & KLF 6	Secchi disk (without viewing chamber)
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	Mid June	KLF 1-8	
TP, TN, NO_3, NO_2, TDP, OP	Twice monthly, July and August	KLF 2 & KLF 6	
Total metals	June and September (or October)	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	Monthly, June to September	KLF 2 & KLF 6	Discrete samples at 2 m, 5 m, 10 m, 15 m and 20 m

TP, NO_3, NO_2, TDP, OP			
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
	Mid June	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
	Mid June	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	July and 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	Meadow Creek, the Lardeau River, and selected South Arm tributaries to Kootenay Lake	Standard MoFLNRO, Region 4 procedures

Appendix 3. Summary of missing water temperature data. In reference to Figure 6.

Year	Month	Arm	comments
1993	Sep	North	No data
1993	Nov	South	No data
1997	Nov	North & South	No data
1998	Nov	North & South	No data
1999	Jun	South	No data
1999	Nov	North & South	No data
2000	Nov	North & South	No data
2001	Nov	North & South	No data
2002	Oct	North & South	No data
2002	Nov	North & South	No data
2003	Oct	North & South	No data
2006	May	North & South	No data
2013	Sep	North & South	No data - No Seabird taken this month, issues with the boat.
2014	July-Sep	North & South	No data – Seabird pump malfunction

Appendix 4. The spot check sites and reaches for South Arm Kootenay Lake annual index site enumeration.

Creek	Details	Easting	Northing	Survey type	Source
Crawford Creek	Upper end of survey, Bailey bridge survey point	514143	5505042	Point	GPS
Crawford Creek	Mid-survey, golf course bridge survey point	513447	5504219	Point	GPS
Crawford Creek	Lower end bottom survey, outlet to Crawford Bay	513473	5501419	Start	GPS
Crawford Creek	Upper end of bottom survey	513389	5501830	End	GPS
Gray Creek	Lower end of survey	515243	5496751	Start	GPS
Gray Creek	Upper end of survey	515509	5496734	End	GPS
LaFrance Creek	Highway bridge survey point	515712	5485937	Point	GPS
Lockhart Creek	Highway bridge survey point	515515	5484145	Point	GPS
Akokli Creek	Highway bridge survey point	517901	5474707	Point	GPS
Akokli Creek	Lower pool survey point	517858	5474769	Point	Google Earth
Sanca Creek	Highway bridge survey point	519850	5469336	Point	GPS
Sanca Creek	Lower pool survey point	519614	5469189	Point	Google Earth
Boulder Creek	Highway bridge survey point	525195	5458978	Start	GPS

Boulder Creek	Outlet to the East Branch of Kootenay River	524797	5458905	End	GPS
Goat River	Highway bridge survey point	534893	5436696	Start	GPS
Goat River	Lower end of survey	534538	5436812	End	GPS
Goat River	Upper end of survey below Canyon Lister Rd. bridge	539958	5438171	Point	GPS
Summit Creek	Upper end of survey at Bailey bridge	526397	5443254	Start	GPS
Summit Creek	Lower end of survey	526622	5443295	End	GPS

APPENDIX 5. Kokanee length correction factors for Kootenay Lake. Correction factors for >180-mm fish and for 100–180-mm fish are from Rieman and Myers (1992). Correction factors for <100-mm fish were derived from Okanagan Lake trawl samples collected during 1988–93.

Date	>180 mm	100–180 mm	<100 mm	Date	>180 mm	100–180 mm	<100 mm
1-Sep	1.025	1.064	1.090	7-Oct	1.000	1.000	0.982
2-Sep	1.023	1.061	1.087	8-Oct	1.000	1.000	0.979
3-Sep	1.021	1.058	1.084	9-Oct	1.000	1.000	0.976
4-Sep	1.020	1.056	1.081	10-Oct	1.000	1.000	0.973
5-Sep	1.018	1.053	1.078	11-Oct	1.000	1.000	0.970
6-Sep	1.016	1.050	1.075	12-Oct	1.000	1.000	0.967
7-Sep	1.014	1.047	1.072	13-Oct	1.000	1.000	0.964
8-Sep	1.012	1.044	1.069	14-Oct	1.000	1.000	0.961
9-Sep	1.011	1.042	1.066	15-Oct	1.000	1.000	0.958
10-Sep	1.009	1.039	1.063	16-Oct	1.000	1.000	0.955
11-Sep	1.007	1.036	1.060	17-Oct	1.000	1.000	0.952
12-Sep	1.005	1.033	1.057	18-Oct	1.000	1.000	0.949
13-Sep	1.003	1.030	1.054	19-Oct	1.000	1.000	0.946
14-Sep	1.002	1.028	1.051	20-Oct	1.000	1.000	0.943
15-Sep	1.000	1.025	1.048	21-Oct	1.000	1.000	0.940
16-Sep	1.000	1.023	1.045	22-Oct	1.000	1.000	0.936
17-Sep	1.000	1.022	1.042	23-Oct	1.000	1.000	0.933
18-Sep	1.000	1.020	1.039	24-Oct	1.000	1.000	0.930
19-Sep	1.000	1.018	1.036	25-Oct	1.000	1.000	0.927
20-Sep	1.000	1.017	1.033	26-Oct	1.000	1.000	0.924
21-Sep	1.000	1.015	1.030	27-Oct	1.000	1.000	0.921
22-Sep	1.000	1.013	1.027	28-Oct	1.000	1.000	0.918
23-Sep	1.000	1.011	1.024	29-Oct	1.000	1.000	0.915
24-Sep	1.000	1.010	1.021	30-Oct	1.000	1.000	0.912
25-Sep	1.000	1.008	1.018	31-Oct	1.000	1.000	0.909
26-Sep	1.000	1.006	1.015	1-Nov	1.000	1.000	0.906
27-Sep	1.000	1.005	1.012	2-Nov	1.000	1.000	0.903

28-Sep	1.000	1.003	1.009	3-Nov	1.000	1.000	0.900
29-Sep	1.000	1.001	1.006	4-Nov	1.000	1.000	0.897
30-Sep	1.000	1.000	1.003	5-Nov	1.000	1.000	0.894
1-Oct	1.000	1.000	1.000	6-Nov	1.000	1.000	0.891
2-Oct	1.000	1.000	0.997	7-Nov	1.000	1.000	0.888
3-Oct	1.000	1.000	0.994	8-Nov	1.000	1.000	0.885
4-Oct	1.000	1.000	0.991	9-Nov	1.000	1.000	0.882
5-Oct	1.000	1.000	0.988	10-Nov	1.000	1.000	0.879
6-Oct	1.000	1.000	0.985	11-Nov	1.000	1.000	0.876

Appendix 6. 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 (2014 field calibration)
		-26.88 dB (2015 field calibration)
Single target filter	analysis threshold[1]	-70 to -24 dB (47 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 -62 to -58dB depending on interference from mysids.

[2] Note: echo counting was the main method used for determining fish densities in 2014 and 2015.

Appendix 7. Lardeau Kokanee Spawner Returns.

Year	**Spawner Counts (No.)**	**Year**	**Spawner Counts (No.)**
1964	1,380,000	1997	400,000
1965	510,000	1998	1,060,000
1966	650,000	1999	526,000
1967	710,000	2000	186,240
1968	-	2001	160,000
1969	-	2002	110,000
1970	-	2003	199,969
1971	1,000,000	2004	249,400
1972	-	2005	232,390
1973	1,800,000	2006	107,113
1974	3,000,000	2007	146,821
1975	-	2008	409,731
1976	-	2009	245,555
1977	-	2010	250,958
1978	-	2011	499,572
1979	1,500,000	2012	491,560
1980	700,000	2013	250,844
1981	1,000,000	2014	73,950
1982	500,000	2015	10,308
1983	500,000		
1984	600,000		
1985	-		
1986	500,000		
1987	250,000		
1988	190,000		
1989	150,000		
1990	110,000		
1991	40,000		
1992	60,000		
1993	254,000		
1994	400,000		
1995	167,650		
1996	113,718		

Appendix 8. Transect fish densities (number.ha-1) in Kootenay Lake in a) 2014 and b) 2015.

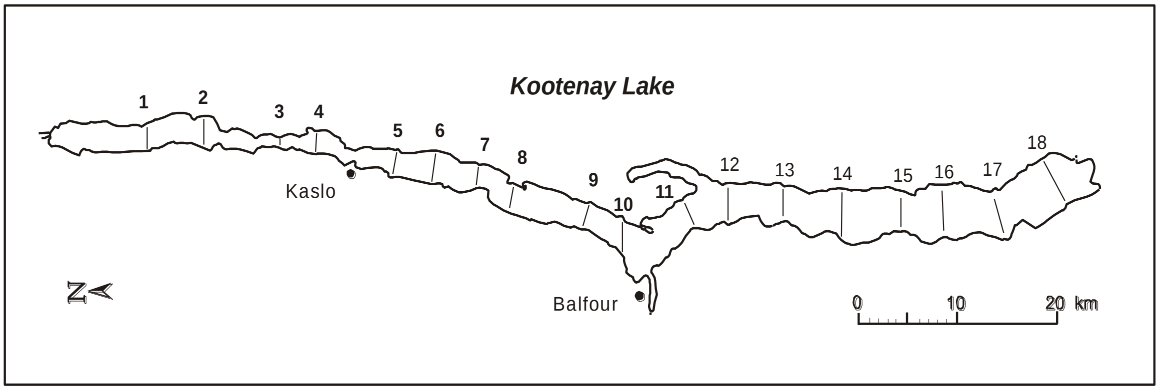
a) 2014 Transect Fish Densities.

Transect Number	June 2014			Sept. 2014		
	All Ages	**Age 0+**	**Age 1-3+**	**All Ages**	**Age 0+**	**Age 1-3+**
1	1911	1813	98	612	578	34
2	1466	1389	77	848	824	24
3	955	875	81	958	939	19
4	588	521	67	657	641	16
5	320	268	52	617	601	17
6	150	125	25	615	592	23
7	254	195	59	489	467	21
8	132	115	16	630	613	17
9	175	118	57	602	585	16
10	ns	ns	ns	491	463	29
11	183	120	63	361	344	17
12	131	79	52	337	322	15
13	108	71	37	361	341	20
14	115	66	48	249	234	15
15	86	45	42	235	218	17
16	60	33	27	293	273	20
17	83	35	47	188	166	22
18	58	47	11	258	208	50

b) 2015 Transect Fish Densities.

Transect Number	June 2015			Sept. 2015		
	All Ages	**Age 0+**	**Age 1-3+**	**All Ages**	**Age 0+**	**Age 1-3+**
1	678	631	47	546	522	24
2	1325	1272	53	183	174	9
3	1677	1479	198	569	509	60
4	1601	1450	150	328	306	21
5	468	401	66	486	451	36
6	437	406	31	611	572	39
7	522	449	73	401	376	25
8	464	424	39	615	581	33
9	360	333	27	401	381	20

10	221	179	43	315	295	21
11	126	80	46	360	347	13
12	135	97	38	428	393	34
13	233	168	65	470	439	31
14	189	131	58	364	330	33
15	241	161	80	419	377	41
16	290	186	104	339	285	55
17	288	196	93	273	229	44
18	624	427	196	344	302	43



Appendix 9a. Maximum likelihood population estimates and bounds for (a) all ages of kokanee and (b) ages 1-3 kokanee in Kootenay Lake in June 2014.

a) Statistics for kokanee of all ages (>–63 dB) two zones (Zone 1=TR 1-03; Zone 2=TR 04-9, 11-18)

Zone	Depth	N	Density	Std. Error	Area	Stratum Pop.	Statistic[1]	Abundance
1	3-5	3	150.6	75.6	5320	801,217		
1	5-10	3	620.6	129.3	5320	3,301,434		
1	10-15	3	292.5	64.3	5320	1,556,001		
1	15-20	3	310.2	27.2	5320	1,650,230		
1	20-25	3	46.3	19.7	5267	244,039		
1	25-30	3	5.1	2.5	5211	26,835	LB=	11,230,102
1	30-35	3	3.6	2.7	5138	18,514	MLE=	13,378,290
1	35-40	3	2.3	0.1	5052	11,555	UB=	15,541,574
1	40-45	3	1.8	0.2	4965	8,960		
1	45-50	3	2.4	0.1	4878	11,668		
1	50-55	3	2.1	0.6	4792	9,984		
1	55-60	3	1	0.4	4721	4,628		
1	60-65	3	2	0.9	4650	9,071		
1	65-70	3	3.6	0.4	4582	16,659		
2	3-5	14	4.6	2.9	32880	152,768		
2	5-10	14	24.1	5.1	32880	790,874		
2	10-15	14	35.4	5.4	32880	1,164,643		
2	15-20	14	51.7	12.4	32880	1,700,046		
2	20-25	14	38.7	13.9	32649	1,263,088		
2	25-30	14	10.1	2.4	32431	326,532		
2	30-35	14	3.5	0.6	32132	111,258		
2	35-40	14	1.6	0.4	31852	52,410		
2	40-45	14	1.8	1	31632	55,575		
2	45-50	14	0.8	0.2	31406	24,176		
2	50-55	14	0.6	0.3	31176	19,287		
2	55-60	14	0.6	0.2	30952	18,914		
2	60-65	14	0.5	0.2	30641	16,426		

b) Statistics for age 1-3+ kokanee (>–50 dB); one zone (Zone 1=TR 1-9, 11-18.)

Zone	Depth	N	Density	Std. Error	Area	Stratum Pop.	Statistic[1]	Abundance
1	3-5	17	0.9	0.9	38200	33,364		
1	5-10	17	3.9	0.9	38200	149,605		
1	10-15	17	10.1	1.7	38200	385,328		
1	15-20	17	23.2	4.4	38200	885,523		
1	20-25	17	12.5	2.7	37916	472,674		
1	25-30	17	3.5	0.7	37642	132,147		
1	30-35	17	1.4	0.2	37271	52,265		
1	35-40	17	0.5	0.1	36903	20,243		
1	40-45	17	0.7	0.3	36596	24,218	LB=	1,780,789
1	45-50	17	0.3	0.1	36284	9,502	MLE=	2,200,694
1	50-55	17	0.3	0.1	35968	10,226	UB=	2,618,815
1	55-60	17	0.1	0.0	35673	2,298		

1	60-65	17	0.2	0.1	35291	8,576
1	65-70	17	0.5	0.1	34953	15,945

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

Appendix 9a cont. Maximum likelihood population estimates and bounds for (c) all ages of kokanee and (d) ages 1-3 kokanee in Kootenay Lake in Sept 2014.

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	5-10	10	8.9	2.7	16740	149,199		
1	10-15	10	17.5	3.9	16740	293,499		
1	15-20	10	50.5	9.4	16740	845,399		
1	20-25	10	210.7	21.4	16575	3,493,082		
1	25-30	10	270.6	38.8	16421	4,443,466		
1	30-35	10	59.9	14.6	16225	972,312	LB=	15,054,583
1	35-40	10	19.5	6.9	16015	312,905	MLE=	16,807,827
1	40-45	10	9.7	3.2	15824	153,028	UB=	18,560,170
1	45-50	10	4.5	2.3	15629	69,879		
2	5-10	8	5	1.4	21460	108,059		
2	10-15	8	8	1.7	21460	170,937		
2	15-20	8	48	4.8	21460	1,029,656		
2	20-25	8	107.7	15.5	21342	2,297,987		
2	25-30	8	69.6	8.4	21221	1,477,276		
2	30-35	8	23.2	3.2	21046	487,334		
2	35-40	8	11	2.7	20888	230,762		
2	40-45	8	8.9	1.8	20773	185,211		
2	45-50	8	3.9	0.9	20655	81,149		

d) Statistics for age 1-3+ kokanee (>–46 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	5-10	10	0.3	0.3	16740	4,523		
1	10-15	10	0.5	0.3	16740	8,850		
1	15-20	10	0.5	0.3	16740	8,799	LB=	905,412
1	20-25	10	2.9	0.7	16575	47,922	MLE=	1,051,135
1	25-30	10	13.1	1.5	16421	214,965	UB=	1,197,457
1	30-35	10	8.2	1.3	16225	133,188		
1	35-40	10	1.5	0.4	16015	23,782		
1	40-45	10	1.2	0.4	15824	19,460		
1	45-50	10	0.4	0.2	15629	6,050		
2	10-15	8	0.2	0.2	21460	5,346		
2	15-20	8	2.4	1.4	21460	52,180		
2	20-25	8	7.5	2	21342	159,440		
2	25-30	8	11.8	1.9	21221	249,601		
2	30-35	8	2.6	0.3	21046	55,477		
2	35-40	8	1	0.2	20888	19,915		
2	40-45	8	1	0.2	20773	21,471		

2	45-50	8	1	0.2	20655	19,894

Appendix 9b. Maximum likelihood population estimates and bounds for (a) all ages of kokanee and (b) ages 1-3 kokanee in Kootenay Lake in June 2015.

a) Statistics for kokanee of all ages (>–62 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	10	124.8	27.7	16740	2,089,530		
1	5-10	10	290.3	65.3	16740	4,859,597		
1	10-15	10	168	38.4	16740	2,812,916		
1	15-20	10	109.1	33.1	16740	1,826,513		
1	20-25	10	47.5	16.6	16575	786,871		
1	25-30	10	14.8	7.1	16421	243,759	LB=	15,222,951
1	30-35	10	9.4	3.1	16225	151,883	MLE=	18,635,434
1	35-40	10	4.8	1.3	16015	76,531	UB=	22,055,158
1	40-45	10	2.5	1.1	15824	39,962		
1	45-50	10	3.9	1.6	15629	61,100		
2	3-5	8	5.2	2.5	21460	112,646		
2	5-10	8	18.7	4	21460	400,956		
2	10-15	8	37.9	6.9	21460	813,474		
2	15-20	8	121.6	38.9	21460	2,608,898		
2	20-25	8	56.8	16.3	21342	1,211,948		
2	25-30	8	15	3.3	21221	317,401		
2	30-35	8	5.9	1.2	21046	123,784		
2	35-40	8	2.8	0.7	20888	58,010		
2	40-45	8	0.9	0.2	20773	19,622		
2	45-50	8	1	0.2	20655	20,007		

b) Statistics for age 1-3+ kokanee (>–50 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	5-10	10	4.9	1.5	16740	81,244		
1	10-15	10	18.1	3.8	16740	303,165		
1	15-20	10	22.8	6.8	16740	381,433		
1	20-25	10	13.6	5.7	16575	225,160		
1	25-30	10	4.8	2	16421	78,055		
1	30-35	10	3.6	1	16225	57,716		
1	35-40	10	2.1	0.6	16015	34,426		
1	40-45	10	1.4	0.6	15824	21,449		
1	45-50	10	1.5	0.8	15629	23,066	LB=	2,378,694
2	5-10	8	4.7	2.2	21460	100,841	MLE=	3,016,718
2	10-15	8	11.1	1.7	21460	237,796	UB=	3,659,543
2	15-20	8	37.1	10.6	21460	796,193		
2	20-25	8	22.1	7	21342	471,617		
2	25-30	8	5.2	1.2	21221	109,730		
2	30-35	8	2.6	0.6	21046	54,501		
2	35-40	8	1.4	0.4	20888	29,132		
2	40-45	8	0.5	0.2	20773	10,477		

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

Appendix 9b cont. Maximum likelihood population estimates and bounds for (c) all ages of kokanee and (d) ages 1-3 kokanee in Kootenay Lake in Sept 2015.

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	10	6.6	4.3	16740	109,861		
1	5-10	10	8.7	2.4	16740	145,064		
1	10-15	10	10.4	3.4	16740	173,639		
1	15-20	10	17.8	4.7	16740	298,052		
1	20-25	10	104.6	14.6	16575	1,732,962		
1	25-30	10	195.8	34.7	16421	3,214,583	LB=	13,432,941
1	30-35	10	48	7.9	16225	779,191	MLE=	15,240,464
1	35-40	10	26.1	7.7	16015	417,947	UB=	17,025,203
1	40-45	10	20.5	8.5	15824	324,387		
1	45-50	10	7.2	2.1	15629	112,209		
2	5-10	8	2.2	1.4	21460	46,158		
2	10-15	8	5	1.6	21460	106,230		
2	15-20	8	7.4	2.2	21460	157,803		
2	20-25	8	85.1	20.8	21342	1,816,731		
2	25-30	8	189.7	18.3	21221	4,025,339		
2	30-35	8	48.6	8.3	21046	1,022,651		
2	35-40	8	21.1	3.8	20888	440,084		
2	40-45	8	10.7	2.7	20773	221,880		
2	45-50	8	5	1.7	20655	102,543		

d) Statistics for age 1-3+ kokanee (>–48 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	10	0	0	16740	-		
1	5-10	10	0.6	0.6	16740	9,446		
1	10-15	10	0.2	0.2	16740	3,959	LB=	1,076,409
1	15-20	10	1.7	0.6	16740	28,558	MLE=	1,244,170
1	20-25	10	2.1	0.3	16575	34,099	UB=	1,410,732
1	25-30	10	8	1.6	16421	131,036		
1	30-35	10	7.1	1.5	16225	114,547		
1	35-40	10	3.6	1.1	16015	57,436		
1	40-45	10	4.4	2.5	15824	70,032		
1	45-50	10	1.2	0.5	15629	19,334		
2	3-5	8	0	0	21460	-		
2	5-10	8	0.5	0.5	21460	9,775		
2	10-15	8	0.6	0.3	21460	12,208		
2	15-20	8	1.6	0.6	21460	34,229		
2	20-25	8	2.1	0.4	21342	44,225		
2	25-30	8	14.8	1.6	21221	313,523		
2	30-35	8	10.4	2.1	21046	218,509		
2	35-40	8	3.3	0.8	20888	68,052		
2	40-45	8	2.3	0.4	20773	47,450		
2	45-50	8	1.4	0.4	20655	29,093		

Appendix 10. 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	54	66
1986	11,603,512	648,799	1,023,105	224,584	1.9	17.9	60	69
1988	3,400,660	1,685,283	1,294,057	-	2.2	26.6	52	
1989	7,423,643	1,368,605	1,700,388	207,364	1.6	25.5	60	68
1990	4,808,922	732,788	480,892	137,398	2.2	39.9	75	89
1991	7,479,751	930,124	775,104	155,021	2.1	29.7	128	131
1992	6,330,000	652,414	1,517,241	30,345	2.1	36.3	121	181
1993	8,800,000	1,212,676	458,451	428,873	1.5	36.5	76	109
1994	31,780,000	2,510,286	1,287,886	21,829	2.0	31.0	114	134
1995	21,000,000	3,721,029	572,466	6,505	2.0	34.2	74	138
1996	22,600,000	6,181,282	5,956,053	162,665	1.4	21.4	57	63
1997	14,270,000	5,824,121	5,824,121	261,758	1.7	25.0	51	77
1998	8,400,000	2,248,680	8,012,903	538,416	1.4	36.8	73	97
1999	10,360,000	2,050,323	2,489,677	-	1.5	25.4	80	
2000	9,690,000	636,667	1,273,333	-	1.4		98	
2001	18,380,000	4,967,368	752,632	-	1.7	25.6	90	
2002	25,450,000	9,091,528	542,778	135,694	1.3	28.9	60	89
2003	17,019,000	5,263,848	4,187,152	-	2.2	31.0	73	
2004	9,490,000	3,692,578	2,782,813	374,609	1.3	17.4	72	80
2005	12,806,000	1,705,208	1,023,125	545,667	1.1	16.5	81	110
2006	17,234,000	3,930,231	935,769	-	2.0	25.5	132	
2007[1]	*17,856,000*	*4,434,231*	*1,055,769*	-	*2.0*	*25.5*	*132*	
2008	22,647,000	3,827,896	445,104	-	1.6	27.1	74	
2009	31,130,000	14,307,590	1,632,410	-	1.4	25.3	74	
2010	22,440,000	11,160,298	4,076,821	152,881	1.0	25.9	53.3	76.5
2011	15,159,000	3,585,377	4,015,623	-	1.3	27.5	61.1	
2012[2]	13,196,000	851,057	806,264	716,679	1.9	21.9	62.6	72.2
2013	16,936,000	839,040	132,480	132,480	2.0	13.0	186.5	188.8
2014	15,759,000	1,051,000	-	-	1.8	12.9		
2015	13,000,000	1,065,625	34,375	-	2.1	15.0	283.4	

[1] *no trawling in 2007; applied approximate proportion by age from the previous year 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.*

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

b) Calculation of in-lake biomass (metric tons) and biomass density (kg·ha^{-1}) of kokanee in Kootenay Lake in September of 2014.

	Biomass (metric tons)					Biomass Density (kg·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	0.20	1.17	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	0.77	0.95	0.32	2.3
1991	16	28	99	20	163	0.41	0.72	2.60	0.53	4.3
1992	13	24	183	5	225	0.35	0.62	4.79	0.14	5.9
1993	13	44	35	47	139	0.35	1.16	0.92	1.22	3.6
1994	64	78	147	3	291	1.66	2.04	3.85	0.08	7.6
1995	42	127	43	1	213	1.10	3.33	1.11	0.02	5.6
1996	32	132	341	10	515	0.83	3.46	8.92	0.27	13.5
1997	24	146	294	20	484	0.64	3.81	7.70	0.53	12.7
1998	12	83	588	52	735	0.31	2.17	15.40	1.37	19.2
1999	16	52	200	-	268	0.41	1.36	5.23	-	7.0
2000	14	-	125	-	138	0.36	-	3.27	-	3.6
2001	31	127	68	-	226	0.82	3.33	1.78	-	5.9
2002	33	263	33	12	341	0.87	6.88	0.86	0.31	8.9
2003	37	163	306	-	506	0.98	4.27	8.00	-	13.3
2004	12	64	200	30	306	0.32	1.68	5.22	0.79	8.0
2005	14	28	83	60	186	0.37	0.74	2.18	1.58	4.9
2006	34	100	124	-	258	0.90	2.62	3.24	-	6.8
2007[1]	*36*	*113*	*140*	-	*288*	*0.94*	*2.96*	*3.66*	-	*7.6*
2008	36	104	33	-	173	0.95	2.72	0.86	-	4.5
2009	44	362	121	-	527	1.14	9.48	3.17	-	13.8
2010	22	289	217	12	540	0.59	7.57	5.69	0.31	14.1
2011	20	99	245	-	364	0.52	2.58	6.42	-	9.5
2012[2]	25	19	50	52	146	0.66	0.49	1.32	1.35	3.8
2013	34	11	25	25	94	0.89	0.29	0.65	0.65	2.5
2014	28	14	-	-	42	0.74	0.35	-	-	1.1
2015	27	16	10	-	53	0.71	0.42	0.26	-	1.4
Pre	12	30	79	13	135	0.3	0.8	2.1	0.4	3.5
Fert	28	102	152	13	295	0.7	2.7	4.0	0.4	7.7

[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 (1992-2015).

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	5.9	8.1
1993	848,959	218	185.2	4.8	3.6	8.5
1994	1,253,000	158	198.2	5.2	7.6	12.8
1995	855,745	167	142.6	3.7	5.6	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	7.0	12.1
2000	563,956	156	88.1	2.3	3.6	5.9
2001	591,308	184	108.8	2.8	5.9	8.8
2002	464,000	144	66.6	1.7	8.9	10.7
2003	1,100,501	108	119.1	3.1	13.3	16.4
2004	1,526,125	112	170.4	4.5	8.0	12.5
2005	1,269,028	112	142.1	3.7	4.9	8.6
2006	478,307	180	86.1	2.3	6.8	9.0
2007[2]	534,073	236	125.8	3.3	*7.6*	11.6
2008	1,349,325	168	226.7	5.9	4.5	10.5
2009	907,839	118	107	2.8	13.8	16.6
2010	826,788	91	75.5	2.0	14.1	16.1
2011	1,764,100	78	137.4	3.6	9.5	13.1
2012	1,255,843	77	96.6	2.5	3.8	6.3
2013	453,592	241	109.5	2.9	2.5	5.3
2014	147,418	410	60.5	1.6	1.1	2.7
2015	17,966	576	10.3	0.3	1.4	1.8
Pre	658,883	102	63.3	1.7	3.5	5.2
Fert	970,143	170	123.6	3.2	7.7	11.0

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[1] 1985 Lardeau spawners not counted, based on prior years was estimated at 500,000

[2] *In-lake biomass assumptions for 2007 outlined in tables above.*

Appendix 11. Summary of production statistics for Meadow Creek spawning channel, 1985-2015.

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
2014	53,468	517	5	38	10.32	8.59	42.4
2015	5,679	584	12	41	1.32	7.38	71.5

[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. Note that percent survival is based on fry from the previous year.