Arrow Lakes Reservoir Nutrient Restoration Program
Year 17 (2015) Report

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Fisheries Project Report No. RD 156
Jan 2018

Ministry of Forests, Lands and Natural Resource Operations
Province of British Columbia

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ACKNOWLEDGEMENTS

Funding for the seventeenth year (2015) of the Arrow Lakes Reservoir Nutrient Restoration Project was provided by the Fish and Wildlife Compensation Program and Arrow Lakes Power Corporation

This Project is funded by the Fish and Wildlife Compensation Program on behalf of its program partners BC Hydro, the Province of B.C., 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.

Arrow Lakes Power Corporation (ALPC) is jointly owned, on a 50/50 basis, by Columbia Power Corporation and CBT Arrow Lakes Power Development Corporation (an indirect subsidiary of Columbia Basin Trust)

EXECUTIVE SUMMARY

This report is a summary of results collected as part of the monitoring of the nutrient restoration program. The 17th year's results are presented in long term datasets. Raw data for 2015 is on file at FLNRO in Nelson BC.

Upper and Lower Arrow Lakes Reservoir (referred to as Upper Arrow and Lower Arrow in the report) is a warm, monomictic lake with isothermal temperatures from late fall to early spring and stratification during the summer months. In 2015, 34 MT of Phosphorus and 185 MT of nitrogen were added to Arrow Lakes Reservoir off the Columbia Ferry.

In 2015, flows were highest since the onset of the program. Flows were remarkably high from June through end of August.

In 2015, Secchi disc measurements in the main body of the reservoir were typical of previous years' results. The seasonal pattern showed decreasing spring-to-summer transparency associated with increasing phytoplankton biomass and increasing turbidity due to spring runoff, followed by increasing transparency in the late summer and fall months.

Epilimnetic phosphorous results in 2015 were within the range of previous years. Total phosphorus concentrations averaged 2.56 µg/L and total dissolved phosphorous concentrations averaged 2.03 µg/L. These results are indicative of oligotrophic conditions. Epilimnetic dissolved inorganic nitrogen results averaged 110 µg/L, above the nitrogen limitation threshold and within range of previous years.

The edible phytoplankton community (edible to zooplankton) was below average while the inedible community increased from the long-term average. Copepods were the main contributor to the overall zooplankton population during the entire sampling season with *Daphnia* appearing in May, peaking in July-August and maintaining a population through November. Copepod abundance was the main contributor throughout the sampling season while the trend in biomass was dominated by *Daphnia* from July-August through October. Overall in 2015, the annual average of zooplankton was low compared to previous years. Mysids biomass decreased from the previous year, and was higher in Lower Arrow versus the Beaton Arm and Upper Arrow.

Kokanee fry recruitment in 2015 exceeded expectations; the fall fry abundance estimate of 6 million was well above average in Upper Arrow, and the estimate of 5.5 million was the highest on record for Lower Arrow. The age 1-3+ population was low at 35% of average for Upper Arrow (37% in 2014) and increased from 61% in 2014 to 69% of

average in Lower Arrow. Spawner numbers declined slightly to 50% of average for Upper Arrow and remained similar to 2014 in Lower Arrow at 59% of average. Age at maturity remained predominantly age 3 in 2015, similar to 2014, although mean size declined by 18% to 251 mm. The growth response realized from low densities in 2013 and 2014 was not evident in 2015, presumably due to poor rearing conditions linked to high flows and flushing rates and colder water temperatures throughout the growing season.

Hill Creek Spawning Channel egg to fry survival was estimated at 81%, the highest on record; however, egg to spawner survival has been low for the last four cohorts, and equivalent over time between Hill Creek and other major tributaries. Lower than average survival rates between age groups beyond fall fry remains problematic for kokanee recovery in Arrow, as are declining growth rates while densities of larger kokanee remain low. As a result, spawner numbers were low and both size and fecundity returned to near average. Consequently, the system wide index stream egg deposition declined from 40 million eggs in 2014 to 27 million in 2015 while the long-term average was 42 million eggs per year.

INTRODUCTION

History of restoration

Nutrient additions have been widely used in lakes and reservoirs throughout British Columbia and Alaska as a technique for improving sockeye and kokanee stocks (Stockner and MacIsaac 1996; Ashley *et al.* 1999; Mazumder and Edmundson 2002; Hyatt *et al.* 2004a; Hyatt *et al.* 2004b; Perrin *et al.* 2006). Nutrient additions have also been used in Scandinavia as a technique for improving Arctic char and brown trout populations (Milbrink *et al.* 2008; Rydin *et al.* 2008). Prior to nutrient additions, systems such as Arrow Lakes Reservoir, Kootenay Lake, Packers Lake, and Wahleach Reservoir were ultra-oligotrophic (Ashley *et al*. 1999; Pieters *et al*. 1999; Mazumder and Edmundson 2002; Perrin *et al.* 2006). An ultra-oligotrophic reservoir or lake has extremely low levels of nutrients, which results in low productivity and biomass at all subsequent trophic levels in the aquatic food web.

To address the ultra-oligotrophic status of these systems, a bottom-up approach has been taken with the addition of nutrients (nitrogen and phosphorus in the form of liquid fertilizer) to increase the production of *Daphnia*, a main food source for kokanee. Lake fertilization has been a successful technique used for both the enhancement and conservation of sockeye salmon populations (Hyatt *et al.* 2004a; Hyatt *et al.* 2004b).

Fertilization has also been successful in restoring kokanee populations in lakes and reservoirs altered by hydroelectric construction (Ashley *et al.* 1999; Perrin *et al.* 2006).

Significant restoration of Upper Columbia basin aquatic systems impacted by hydro developments began several decades ago with construction of two major kokanee spawning channels on Kootenay Lake and Arrow Lakes Reservoir (Redfish Consulting Ltd 1999). A second major restoration initiative began in 1992 on Kootenay Lake which was designed to restore the declining kokanee (*Onchorynchus nerka*) population that top predators Gerrard rainbow trout (*Onchorynchus mykiss*) and bull trout (*Salvelinus confluentus*) depend on (Ashley *et al.* 1999). Nutrient additions to Arrow Lakes Reservoir began in 1999 and were modelled after the successful Kootenay Lake experiment aimed at increasing the kokanee population and their salmonid predators.

The Arrow Lakes Reservoir situation

Arrow Lakes Reservoir (ALR) was formed in 1967 when the Hugh Keenleyside Dam was constructed on the outlet of the former Lower Arrow Lake. Since then two upstream reservoirs, Mica and Revelstoke, have lowered productivity in ALR through retention of nutrients that formerly contributed to ALR productivity (Schindler *et al.* 2009a, b; Utzig and Schmidt 2011). In addition to nutrient losses, wide seasonal variations in reservoir levels have contributed to oligotrophication of ALR. Matzinger *et al.* (2007) modeled hydraulic alterations caused by annual hydro plant water regulation and predicted that further hydraulic modifications, such as deep water withdrawal or increased reservoir levels within the growing season, could also reduce lake productivity by up to 40%. A further confounding factor to ALR fish production has been the introduction of the freshwater shrimp *Mysis relicta*, now *Mysis diluviana* (Audzijonyte and Vainola 2005) in 1968 (Sebastian *et al.* 2000) due to the perceived success of their 1949 introduction in Kootenay Lake (Thompson, 1999). *M. diluviana* are known to be a competitor with kokanee for macrozooplanktors.

In response to these numerous perturbations, the ALR kokanee (*Oncorhynchus nerka*) population verged on collapse in the late 1990s and the provincial government decided to proceed with experimental fertilization of the Upper Arrow basin (Pieters *et al.* 2000). Pieters *et al.* (1999) described the background physical, chemical, and biological data of ALR and the events leading to initial fertilization of the upper basin in 1999, while Schindler *et al.* (2009a) provided a summary of initial trophic level responses to the nutrient additions.

Responses to nutrient additions

Ecological impacts and fish losses due to upstream dams on the ALR system have been described by Pieters *et al.* (1999), Sebastian *et al.* (2000), Stockner and Ashley (2003), Moody *et al.* (2007), Arndt (2009), Utzig and Schmidt (2011), and others. The declining kokanee population observed in ALR in the late 1990s initially responded to lake nutrient additions in a similar manner to Kootenay Lake kokanee, where abundance and biomass increased about three-fold (Schindler *et al.* 2009a, b). Because kokanee are most often the keystone species in many southern British Columbia large lakes, their abundance usually determines the health of predatory species that rely on them as a primary food source. These predators include piscivorous rainbow trout, bull trout, burbot (*Lota lota*), and sturgeon (*Acipencer transmontanaus*) (Andrusak and Parkinson 1984; Sebastian *et al.* 2003; Arndt 2004a; Arndt and Schwarz 2011). Kokanee also provide valued fishing opportunities during the summer months (Sebastian *et al.* 2000; Arndt and Schwarz 2011).

Arndt (2004b) summarized ALR sport fish statistics and demonstrated improved growth and condition of 2003 rainbow trout and bull trout attributable to increased kokanee abundance (Arndt 2004a). Schindler *et al.* (2009a) compared trophic level data from a number of years pre-nutrient additions with data from the first eight years of nutrient additions and concluded that nutrient addition was highly beneficial to production at all trophic levels up to and including kokanee. More recently, Arndt and Schwarz (2011) analyzed sport fishery statistics and rainbow and bull trout biological parameters and confirmed a strong response to nutrient additions, although there has been a decline in more recent years. Unfortunately, the ALR system is hydrologically and operationally complex, which has considerable influence on annual productivity. Thus, close monitoring of trophic level responses to nutrient additions is essential.

In terms of evaluating the higher trophic level responses to ALR nutrient additions, there is a good data set on kokanee that dates to the early 1970s. The early time series data provide the current ALR nutrient addition and monitoring program with context that shows trends over four decades, primarily based on kokanee spawner abundance from several index streams and the Hill Creek spawning channel. Escapements approaching one million were suggested for the 1960s and early 1970s based on run reconstruction assuming that Upper Columbia stocks approached 0.5 million (Sebastian *et al.* 2000). In the early 1980s, the Hill Creek spawning channel was constructed in an effort to replace kokanee that were estimated to be lost due to the Revelstoke Dam blocking access to key spawning areas in the Upper Columbia River. Hill Creek initially experienced large escapements during the late 1980s, possibly due to displaced Upper Columbia kokanee.

Hill Creek spawning channel data includes annual estimates of kokanee fry production and numbers of returning spawners as well as biological characteristics (e.g., length, weight, fecundity, sex ratio, and egg retention).

The nutrient restoration program and reporting

Several partners are involved in the ALR nutrient restoration program led by the Ministry of Forests, Lands and Natural Resource Operations (MoFLNRO). Most of the ALR work is funded by a compensation program jointly established by the provincial government and BC Hydro. The Fish and Wildlife Compensation Program (FWCP) – Columbia Basin has administered the nutrient restoration project and most monitoring of the trophic levels with much of the technical support provided by the Province. Since 1999, the Arrow Lakes Power Corporation, which owns the Arrow Lakes Generating Station adjacent to the Hugh Keenleyside Dam, has also provided funding for the nutrient restoration program.

The following reports have been published with results from the multi-year (1999–2013) nutrient restoration program on ALR:

- Pre-fertilization monitoring in 1997 and 1998: Pieters *et al.* (1998, 1999).
- First three years of fertilization, 1999, 2000 and 2001: Pieters *et al.* (2000, 2003a, 2003b).
- The 4th and 5th years, 2002 and 2003: Schindler *et al.* (2006a).
- A summary report for 1999–2004: Schindler *et al.* (2006b).
- The 6th and 7th years, 2004 and 2005: Schindler *et al.* (2007).
- The 8th, 9th, and 10th years, 2006, 2007 and 2008: Schindler *et al.* (2009a, 2010, 2011).
- The 11th and 12th years, 2009 and 2010: Schindler *et al.* (2013a).
- The 13th and 14th years, 2011 and 2012: Schindler *et al*. (2014)
- The 15th Year, 2013, Bassett *et al.* (2015)
- The 16th Year, 2014, Bassett *et al.* (2016)

This report describes the 17th year (2015) of the program and includes the results and analysis of monitoring for physical limnology, water chemistry, phytoplankton, zooplankton, mysid shrimp, and kokanee in ALR.

A list of personnel contributing to the project is in Appendix 1. A list of the program work is in Appendix 2.

METHODS

Nutrient additions

Since the beginning of the program at ALR, nutrients have been added to the Upper Arrow basin using liquid agricultural grade fertilizer. From 1999–2003, the seasonally adjusted blend of fertilizer was modeled on the Kootenay Lake loading strategy (Ashley *et al.* 1999; Schindler *et al.* 2013b). However, the results in 2003 indicated that we should more closely examine monthly phytoplankton biomass, species composition and water chemistry parameters to adapt the weekly loading schedule for future years of the program. From 2004 onward, the nutrient load has been adaptively managed to ensure an appropriate nitrogen to phosphorus (N:P) ratio for optimal phytoplankton growth. This approach continued in 2015.

In 2015, Upper Arrow received an agricultural grade liquid fertilizer blend of ammonium polyphosphate (10-34-0 $N\text{-}P_2O_5\text{-}K_2O$), % by weight) and urea ammonium nitrate (28-0-0, $N\text{-}P_2O_5\text{-}K_2O$, % by weight). The total weight of fertilizer applied in 2015 was 33.9 tonnes of phosphorus and 185.3 tonnes of nitrogen (Table 1). Applications commenced the week of April 20th and continued until the week of September 7th. The nitrogen to phosphorus (N:P) ratio (weight:weight) of the fertilizer varied throughout the season, with a range of 0.67:1 in the spring to 9.87:1 in the late summer (Appendix 4). Phosphorus loading ranged from 0.0 to 20.3 mg/m^2 and nitrogen loading ranged from 0 to 95.8 mg/m^2 in 2015 (Fig. 1). The seasonal loading of fertilizer was intended to approximate pre impoundment spring freshet conditions for phosphorus (P) loading, and to compensate for biological uptake of dissolved inorganic nitrogen (DIN) as the season progressed. This adaptive management strategy was implemented to ensure that there was not a continued increase in the diatom portion of the phytoplankton biomass. Weekly nitrogen began with low rates in the spring and increased through the summer in an attempt to inhibit the growth of cyanobacteria (blue-green algae) which can be associated with low N:P ratios (Smith, 1983; Pick and Lean, 1987). Phosphorus additions peaked in early-June, decreased through to July and ceased for 4 weeks; the week of July 27th and the weeks of Aug17-Aug24th (Fig. 1). Nitrogen increased as the season progressed, although phytoplankton results and low water clarity drove the decision to cease nutrient additions from Aug 10-Aug27. In 2015 the fertilizer addition season was extended by one week, as September environmental conditions were still suitable for nutrient uptake.

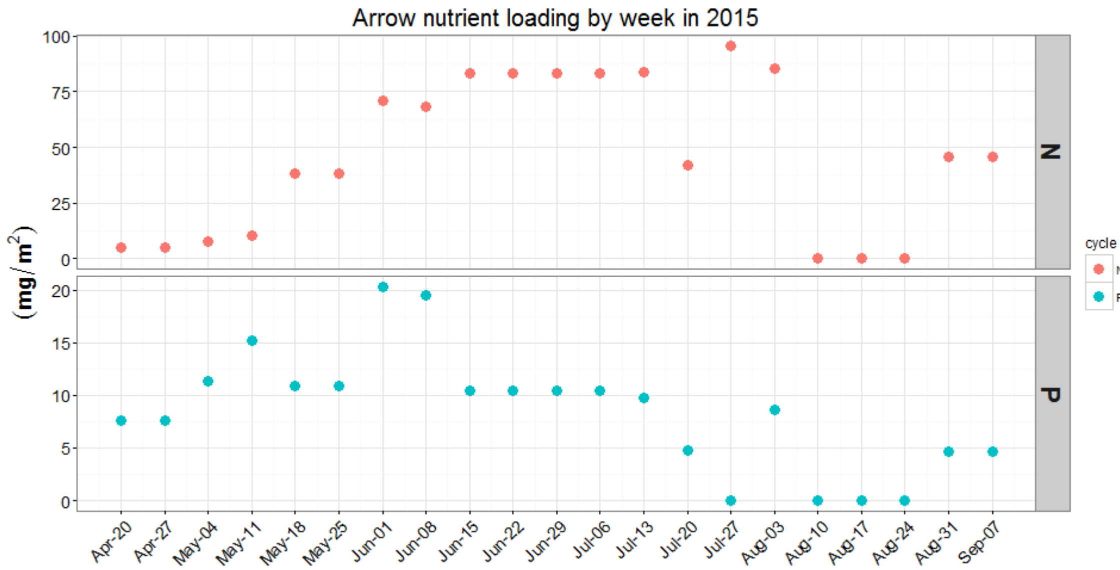


Figure 1. Phosphorus and nitrogen loading to Upper Arrow (mg/m^2/week) from fertilizer, April - September, 2015.

Table 1. Total tonnes of nitrogen and phosphorus dispensed from fertilizer to Upper Arrow between April and September, 1999-2015.

Year	Phosphorus - tonnes	Nitrogen - tonnes
1999	52.8	232.3
2000	52.8	232.3
2001	52.8	232.3
2002	52.8	232.3
2003	52.8	267.8
2004	39.1	276.9
2005	45.0	278.8
2006	41.6	244.9
2007	46.8	267.5
2008	49.5	255.4
2009	47.0	239.0
2010	43.6	235.1
2011	37.5	177.3
2012	14.5	265.9
2013	33.5	244.3
2014	32.9	224.1
2015	33.9	185.3

Fertilizer application

In 2015 fertilizer was dispensed from the Columbia ferry. A truck hauling a 7,570 litre (2000 USG) tank was driven onto the ferry and the fertilizer dispensed during the passenger run. The number of dispensing trips varied depending on the weekly loading schedule (Appendix 4). At most 7 trips were required in a week. Often, 2-3 trips were done in a day, and were timed to go every 2-3 days. The fertilizer was stored at a tank farm located at the Hill Creek Spawning Channel where the contractor filled the tank with the appropriate amount and blend of fertilizer.

A diffuser pipe, was installed on the downstream side of the ferry so the dispensed fertilizer could mix directly into the ferry's propeller wash. The diffuser units were 3.6 m in length and 7.5 cm in diameter, and had 0.6-cm holes spaced at 30-cm intervals along the length of the pipe (Pieters *et al.* 2003a). The ferry crossing time was approximately 25 minutes, and the distance travelled approximately 6 km. The pump was generally activated 5 minutes after leaving the ferry terminal to prevent fertilizer application in the shallower areas.

Sampling stations

In 2015 there were nine sampling stations on ALR. Stations AR 1–3 are located in Upper Arrow, stations AR 4 and AR 5 are in the former river channel that connected the original Upper and Lower Arrow lakes pre-dam impoundment (termed the Narrows), and stations AR 6–8 are located in Lower Arrow (Table 2, Appendix 3). Station HL 1 is in the Beaton Arm. The Beaton Arm is fed by the Incomappleux River, which is a glacial river with high turbidity. Physical data and phytoplankton samples were collected at all nine stations, while chemical, zooplankton, and mysid samples were collected at stations HL 1, AR 1–3 and AR 6–8. Monitoring details are described in Appendix

Table 2. Limnological sampling stations for the Arrow Lakes Reservoir Nutrient Restoration Program.

Site ID	EMS Site No.	Site name	Depth (m)	UTM NAD 83 Zone 11	
				N	E
HL 1	E305210	Arrow Lake, Beaton Arm	175	5619750	443488
AR 1	E225768	Arrow Lake @ Albert Point	220	5605351	434792
AR 2	E225769	Arrow Lake @ Ann Point	285	5589259	433968
AR 3	E225770	Arrow Lake @ Turner Creek	155	5573774	437519
AR 4	E225771	Arrow Lake @ Slewiskin Creek	75	5561516	441756
AR 5	E225779	Arrow Lake, downstream Mosquito Creek	50	5551246	437835
AR 6	E225781	Arrow Lake @ Johnson Creek	145	5502555	417681
AR 7	E225782	Arrow Lake @ Bowman Creek	155	5487806	417923

AR 8	E225783	Arrow Lake @ Cayuse Creek	85	5471663	427481

Physical Limnology

Temperature and oxygen profiles were obtained using a SeaBird SBE 19-plus profiler. At all stations, the profiler logged information every 10 cm from the surface to 5 m off the lake bottom. For graphing purposes, temperature profiles for AR 2 represent the Upper Arrow basin and AR 7 represents the Lower Arrow basin. Water transparency was measured at each station using a standard 20-cm Secchi disc (without a viewing chamber).

Selected parameters, such as Secchi depth and conductivity (data from Seabird), were measured at stations AR 4 and AR 5.

Water Chemistry

Water chemistry sampling in the epilimnion occurred monthly from April through November in 2015. Water samples were collected from stations HL 1, AR 1–3 and AR 6–8 using a 2.54-cm (inside diameter) tube sampler to collect an integrated water sample from 0–20 m. The integrated depth sampling was modified from 30 m in previous years to 20 m, as 20 m is more representative of the lower portion of the epilimnetic layer in ALR. The 30-m depth used (up to and including 2003) occasionally penetrated the thermocline during the summer months and therefore was not fully representative of the epilimnetic layer.

Additional epilimnetic water samples were taken at stations AR 2 and AR 7 at discrete depths from June to September, using a Van Dorn sampler. These samples were obtained from depths of 2, 5, 10, 15, and 20 m.

Hypolimnetic water samples (5 m off the bottom) were collected from May to October at stations AR 1–3 and AR 6–8 using a Niskin (Van Dorn) sampler (Table 2).

Water samples were placed on icepacks in coolers and shipped within 24 h of collection to Maxxam Analytics, Inc. in Burnaby, BC. The integrated epilimnetic and hypolimnetic samples were analyzed for turbidity, pH, total phosphorus (TP), total dissolved phosphorus (TDP), orthophosphate (OP), total nitrogen (TN), nitrate plus nitrite, silica, alkalinity, and total organic carbon (TOC). The discrete-depth epilimnetic samples from AR 2 and 7 were analyzed for TP, TDP, OP, and DIN.

Chlorophyll *a* (Chl *a*) samples were collected from stations AR 1–8 from April to November using the integrated tube sampler (described above) at 0–20 m. Chl *a* samples were also obtained from the discrete-depth epilimnetic draws from 2, 5, 10, 15, and 20 m during June to September. Chl *a* was analyzed by the Ministry of Environment office at the University of British Columbia, Vancouver. Prior to shipping to the lab, Chl *a* samples were prepared by filtering a portion of the integrated water sample through a mixed cellulose ester filter with 0.45-µm pore size. Samples were analyzed using a fluorometric method (Strickland and Parsons 1972). At the time of this report, chlorophyll a data analysis had not been completed.

The results from integrated samples were compared using the statistics software R (ver. 3.1.3). In 2015, the following comparisons were made; differences in means among stations, between basins (the mean of AR 1–3 representing Upper Arrow and AR 6–8 representing Lower Arrow), and between seasons (spring=April–June, summer=July–September, and fall=October–November). In addition, the 2015 annual mean was compared to a pooled 1997–2014 mean. For consistency across years stations AR 4, AR 5, and HL 1 were omitted from this dataset.

The figures in this report illustrate monthly (or bimonthly for select parameters) variations of parameters measured in 2015, as well as annual variations (1997–2015). Detailed analyses of the 1997–2014 data are available in previous annual reports (Pieters *et al.* 1998, 1999, 2000, 2003a, 2003b; Schindler *et al.* 2006a, 2007, 2009a, 2010, 2011, 2013a, 2014; Bassett *et al.* 2015, Bassett *et al.* 2016). All data are on file at the BC Ministry of Forests, Lands and Natural Resource Operations office in Nelson, B.C or on EcoCat, the Ecological Reports Catalogue (https://a100.gov.bc.ca/pub/acat/public/welcome.do).

Phytoplankton

Phytoplankton samples were collected from stations HL 1 and AR 1–8 from April through November using the integrated tube sampler described above. Samples were preserved in Lugol's iodine solution immediately after collection and couriered to West Vancouver for processing by Eco-Logic Ltd. Prior to quantitative enumeration, samples were shaken for 60 seconds, carefully poured into 25 mL settling chambers, and allowed to settle for a minimum of 6–8 hours.

Counts were done on a Carl Zeiss inverted phase-contrast plankton microscope (Utermohl 1958). Counting followed a two-step process: 1. micro-phytoplankton (20–

200 μm) within 5 to 10 random fields were enumerated at 250X magnification, and; 2. pico-phytoplankton (0.2–2.0 μm) and nano-phytoplankton (2–20 μm) within or touching a 10- to 15-mm transect line were counted at 1560X magnification.

The micro-phytoplankton includes diatoms, dinoflagellates, and filamentous blue-greens. The pico-phytoplankton includes minute (< 2.0 μm) autotrophic cells in Class Cyanophyceae, and the nano-phytoplankton includes auto-, mixo-, and heterotrophic flagellates in Classes Chrysophyceae and Cryptophyceae. In total, 250 to 300 cells were consistently enumerated in each sample to ensure statistical accuracy (Lund *et al.* 1958). The compendia of Prescott (1978) and Canter-Lund and Lund (1995) were used as taxonomic references (Stockner 2010). The phytoplankton species list and estimates of each species' biomass (cell biovolume) used for the computation of population and class biomass estimates for ALR in 2015 are given in Appendix 3.1 in Stockner 2010. This list also identifies the genus and species of phytoplankton that are edible and inedible to zooplankton (edibility is discussed later in the report).

Zooplankton

Zooplankton samples have been collected monthly at six stations (AR 1-3, AR 6-8) from May to October in 1997, April to October in 1998 through 2001. In 2002 the sampling season was further lengthened from April to November. In 2015, samples were collected from April 13th to November 5th using a Clarke-Bumpus sampler. In 2013, 2014 and 2015 samples were collected from an additional station HL1 which is located in the Beaton Arm.

At each of the stations, three replicate oblique tows were made. The net had 153-um mesh and was raised from a depth of 40 m to 0 m at a boat speed of 1 m/s. Tow duration was 3 min, with approximately 2,500 L of water filtered per tow. The exact volume sampled was estimated from the revolutions counted by the Clarke-Bumpus flow meter. The net and flow meter were calibrated 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 Arrow Lakes Reservoir were collected at six stations (AR 1-3, AR 6-8) monthly from May to December in 1997, January to December in 1998 through 2004, February to December in 2005, February to November in 2006 and April to November in 2007-2015. In 2013, 2014 and 2015 additional mysid samples were collected at station HL1. 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, two vertical hauls were done at each station using a 1-m2 square-mouthed net with 1,000 µm primary mesh, 210µm terminal mesh, and 100-µm bucket mesh. Two hauls were made in deep water (0.5 nautical miles from both west and east of lake centre). 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% denatured 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

Methods and survey design were identical to previous kokanee monitoring for this project as reported by Schindler *et al*. (2013a and 2014) and Bassett *et al.* (2015 and

2016). Spawner numbers were estimated each fall through a combination of aerial counts and visual ground counts as outlined in Sebastian *et al.* (2000). Peak counts were determined based on aerial (or ground) surveys per spawning season conducted around the time of known peak spawning based on daily counts at Hill Creek Spawning Channel (HCSC). Index stream estimates are indices of abundance that were generated by expanding the peak count by 1.5, while total counts were conducted for the spawning channel using a fish fence. Tributaries used as index streams for monitoring trends in abundance are listed in Table 3 and spawner enumeration results for all systems including a number of smaller streams are presented in Appendix 5.

Table 3. Upper and Lower ALR tributaries used as index sites for kokanee spawner enumeration.

Upper Arrow	Type of Count	Dates of counts (peak bolded)	Lower Arrow	Type of Count	Dates of counts (peak bolded)
Drimmie	Ground	Sep 24, 2015	Mosquito	Aerial	Sep 10 & Sep 17
Hill Creek and spawning channel	Fence and [illegible]	Sep 19 (ground)	Caribou	Aerial	Sep 10 & Sep 17
Halfway	Aerial	Sep 10 & Sep 17	Burton/Snow	Aerial	Sep 10 & Sep 17
Kuskanax	Aerial	Sep 10 & Sep 17	Deer	Ground	Sep 9 & Sep 17

For Upper Arrow, biological data including length, weight, sex, fecundity and egg retention were obtained from Hill Creek spawners. Annual egg deposition was estimated based on the total number of females (from sex ratio of sampled fish) using mean fecundity minus egg retention, determined from samples taken at the entrance to the channel over the spawning period. Fry out-migration was determined each spring by sub-sampling at night as described by Redfish Consulting Ltd. (1999). Theoretical fry production for all other tributaries was calculated assuming fecundity was the same as Hill Creek, sex ratio was 1:1, total spawner numbers were approximately 1.5 times the peak count and an average egg-to-fry survival of 10% for natural spawning habitat. Spawners were collected opportunistically as fresh carcasses and by dip net from Deer Creek on September 15th and Taite Creek on September 18th for length and age data to represent Lower Arrow. The age at maturity was determined from spawner samples using otolith interpretation methods described by Casselman (1990) using only good quality otolith samples (i.e. CSA confidence rating of 6-9) as shown in Appendix 6.

Estimates of fry to adult survival for Upper Arrow were determined by comparing spawning channel fry production and total adult returns to Hill Creek from each fry cohort.

No attempts were made to estimate fry to adult survival by different ages at maturity within the same cohort. The combined percent return of all ages from each fry year has been reported. The data used for fry survival estimates are shown in Appendix 7 with highlights indicating the data used to calculate a specific year.

Hydroacoustic sampling was conducted October 7-9, 2015; one week prior to trawl sampling. Acoustic sampling consisted of 18 standard transects, 10 in the Upper Basin and 8 in the Lower Basin as shown by the map in Appendix 3. An additional four transects were completed in 2015; two in the Narrows (T19 and T20) and two at the upper end of Beaton Arm (T0.5 and T1.5). The Narrows transects have never been included in the ALR kokanee population estimates as they contain a mix of species and represent a very small percentage of total pelagic habitat. The two additional transects in Beaton Arm, also not included in fall population estimates, were done opportunistically to assess kokanee numbers. Baseline information was collected in 2015 in the Beaton Arm while changes to the nutrient addition zone were being considered. Acoustic surveys were conducted at night using a Simrad EK60 120kHz echosounder and ER60 software. Acoustic data were analyzed using SONAR 5 version 6.0.3 software following the specifications in Appendix 8. Appendix 9 shows survey dates, reservoir levels and corresponding habitat areas used for extrapolating fish populations. Fish densities were estimated by the echo counting method; considered suitable based on low fish densities (Appendices 10 and 11), high single echo detection probability, and a low amount of false SED detections (Balk and Lindem, 2011). Fish target strength distributions were evaluated to determine a visible cut-off for separating fry and age 1-3+ kokanee (Appendix 12). As in previous years, contour plots showing fish density by depth and transect (Appendix 13) were used to stratify the basins into zones used for Maximum Likelihood Populations estimates (MLEs) shown in Appendix 14.

Mid-water trawl sampling was conducted at six stations, three in Upper Arrow and three in Lower Arrow during October 12-17, 2015 following standard stepped oblique methods described in Schindler *et al.* (2013a). The net was towed for 16 minutes over consecutive 5 m depth layers from beneath the observed fish layer to a few meters above the layer. The standard beam trawl was 15 meters long with a 5x5 m square opening and was towed at 0.8 $m \cdot s^{-1}$. The net consisted of graduated mesh panels from 10 cm (stretched mesh) at the head bar to 0.6 cm at the cod end. Net depths were estimated from the cable angle and the length of cable deployed.

In 2015 additional trawling was conducted near Halcyon (transect 5) just north of the standard trawl station at Halfway River. The additional trawling was conducted to ensure a larger sample size of age 1-3+ fish for length and weight information during a year with lower kokanee densities. This location was chosen based on evaluation of the acoustic data, which indicated relatively higher kokanee densities. This additional sampling was conducted from the acoustic survey boat equipped with a dual drum beam trawl supporting a 3m wide by 7m deep net with variable mesh sizes comparable to the 5x5 m standard net. Two trawls were conducted, each consisting of three consecutive 7 meter depth layers, each depth layer was twenty minutes in duration for a total of 60 minutes per haul. Each haul spanned ~14-35 meters, which encompassed the entire age 1-3+ fish layer depth observed in the acoustic data. Tow speed was the same as standard trawling at 0.8 $m.s^{-1}$.

Fish samples were kept on ice until processed the following morning. Species, fork length, weight, and stage of maturity were recorded. Age interpretations for trawl caught kokanee were done using length frequency, then verified by scale interpretation conducted at the Ministry of Environment Lab in Abbotsford. Scales were taken from fish >100 mm for aging. Fish lengths from fall sampling were adjusted to an October 1 standard using empirical growth data from Rieman and Myers (1992).

Kokanee biomass in pelagic habitat was estimated by applying the mean weight at age from the trawl catch to the total abundance by age estimated from combined acoustic and trawls surveys (Appendix 15). The abundance of age 0+ fish was determined by applying an acoustic size cut-off at -43dB (~113mm FL) to Upper Arrow and -44dB (~102mm FL) to Lower Arrow in order to separate fry from age 1-3+ fish (Appendix 12). The fry cut-off point was determined as the visible inflection point using cumulative acoustic target strength frequency distributions for each basin. The abundance of age 1-3+ fish was apportioned according to trawl catch by age group. We acknowledge that trawl bias can affect final estimates of abundance by age; however, assuming trawl bias remains consistent over time, the biomass estimates should provide a consistent index of in-lake biomass and biomass density.

RESULTS AND DISCUSSION

The following results and discussion pertain to all aspects of Arrow Lakes Reservoir (ALR) monitoring except the kokanee salmon data. Kokanee results, discussion, and recommendations are presented separately in subsequent sections of the report.

Physical Limnology

Profile data

Temperature

Arrow Lakes Reservoir is a warm monomictic water body, with isothermal temperatures from late fall to early spring and stratification during the summer months. The reservoir began to stratify in June, and perhaps as early as May at AR7, then displayed warming surface temperatures through July and August (Fig. 2). As in previous years, summer stratification occurred with the epilimnion becoming more clearly defined in late summer and early fall, however this was not as pronounced at HL1. Stratification was maintained until as late as November. In 2015, hypolimnetic temperatures ranged from 3.5–4°C throughout the year (Fig. 2), this is comparable to previous years.

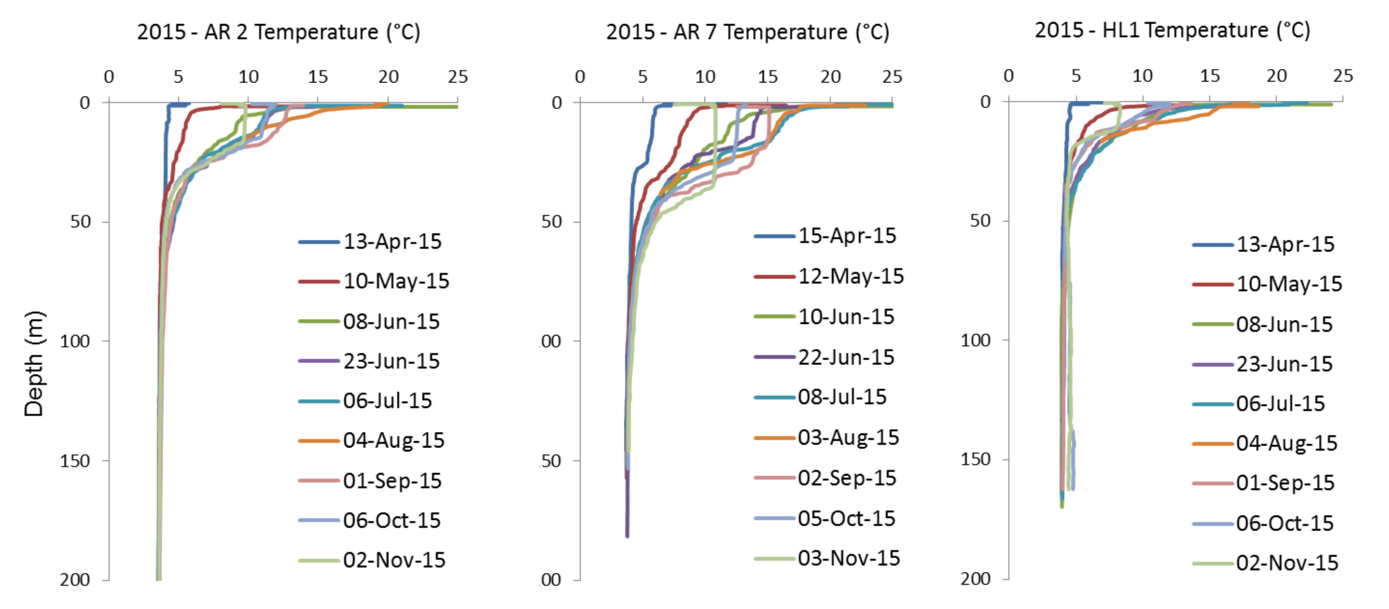


Figure 2. Temperature profiles in Upper and Lower Arrow basins, and the Beaton Arm (AR 2 and AR 7, HL1) in 2015. Data for Aug 04, 2015 is incomplete due to equipment malfunction.

Dissolved oxygen

Results of oxygen profiles were similar to previous years. Arrow Lakes Reservoir 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 2015, oxygen was consistent through the water column and typical of an orthograde profile (Fig. 3). Nutrient enrichment has had no detectable effect on hypolimnetic oxygen concentrations.

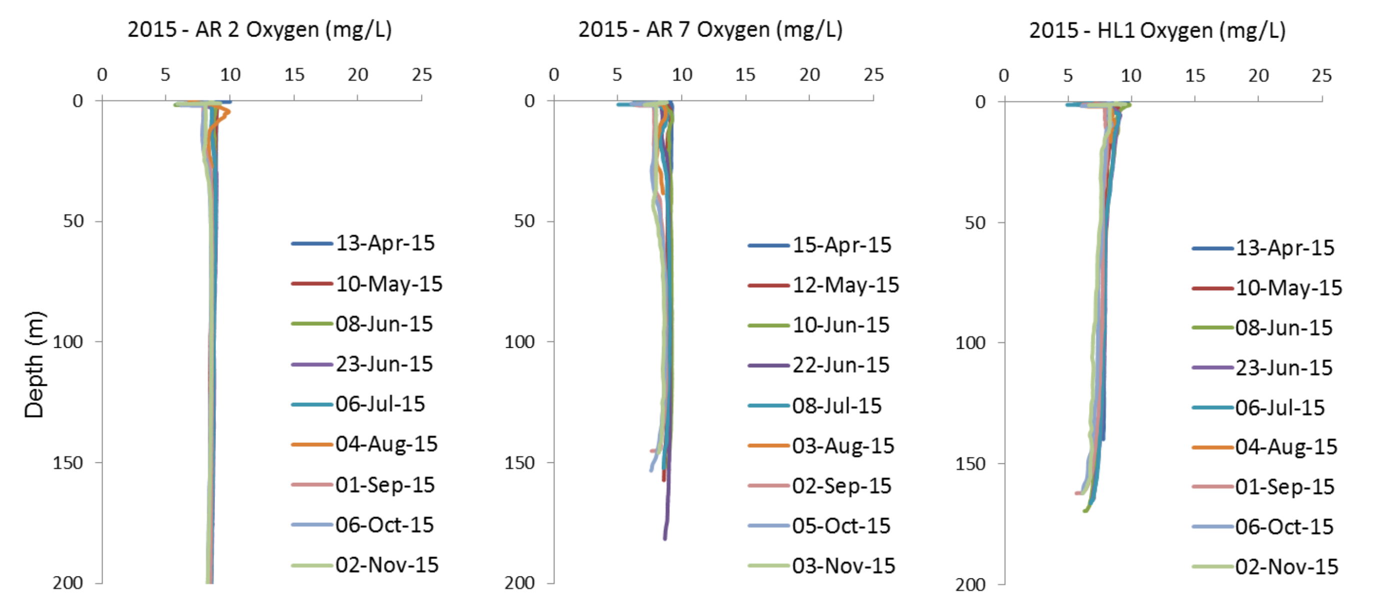


Figure 3. Oxygen profiles in Upper and Lower Arrow basins, and the Beaton Arm (AR 2 and AR 7, HL1) in 2015. Data for Aug 04, 2015 is incomplete due to equipment malfunction.

Specific Conductivity

Conductivity or specific conductance is a measure of resistance of a solution to electrical flow (Wetzel, 2001). In an aqueous solution, the resistance to electrical current declines with increasing ion content (Wetzel, 2001). Seasonally, conductivity was highest in the spring for both Upper Arrow and the Beaton Arm, while in Lower Arrow conductivity was highest in both spring and fall (Fig. 4). Conductivity was lowest in July and August for all stations. Seasonally, epilimnion conductivity varied more in the Beaton Arm than Upper and Lower Arrow stations.

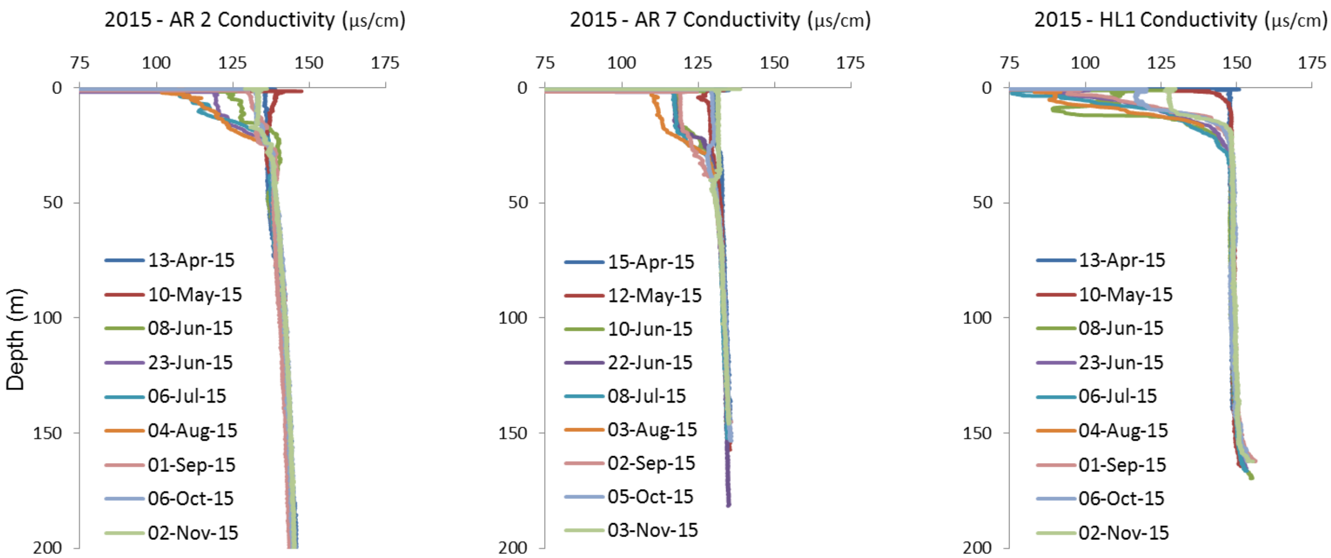


Figure 4. Specific conductivity profiles in Upper and Lower Arrow basins, and the Beaton Arm (AR 2 and AR 7, HL1) in 2015. Data for Aug 04, 2015 is incomplete due to equipment malfunction.

Flow

The mean April-October outflow in Arrow Lakes Reservoir was above the long term 1997-2015 mean by more than ½ standard deviation of the mean (Fig 5). The outflow in 2015 was a record high since the start of the NRP on Arrow, second to 2012. In 2015, high outflows began in early June, declined slightly late in July, and resumed through mid-August (Fig 6).

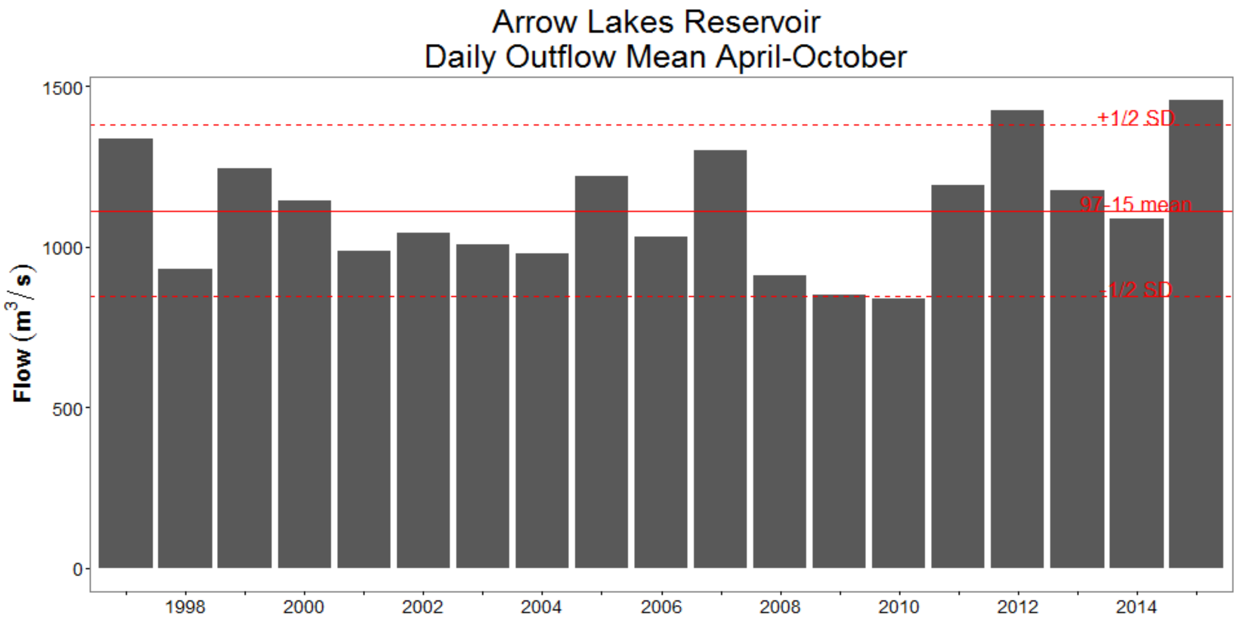


Figure 5. Arrow Lakes Reservoir April-October average outflow 1997-2015 with long term average ± 1/2 S.D.

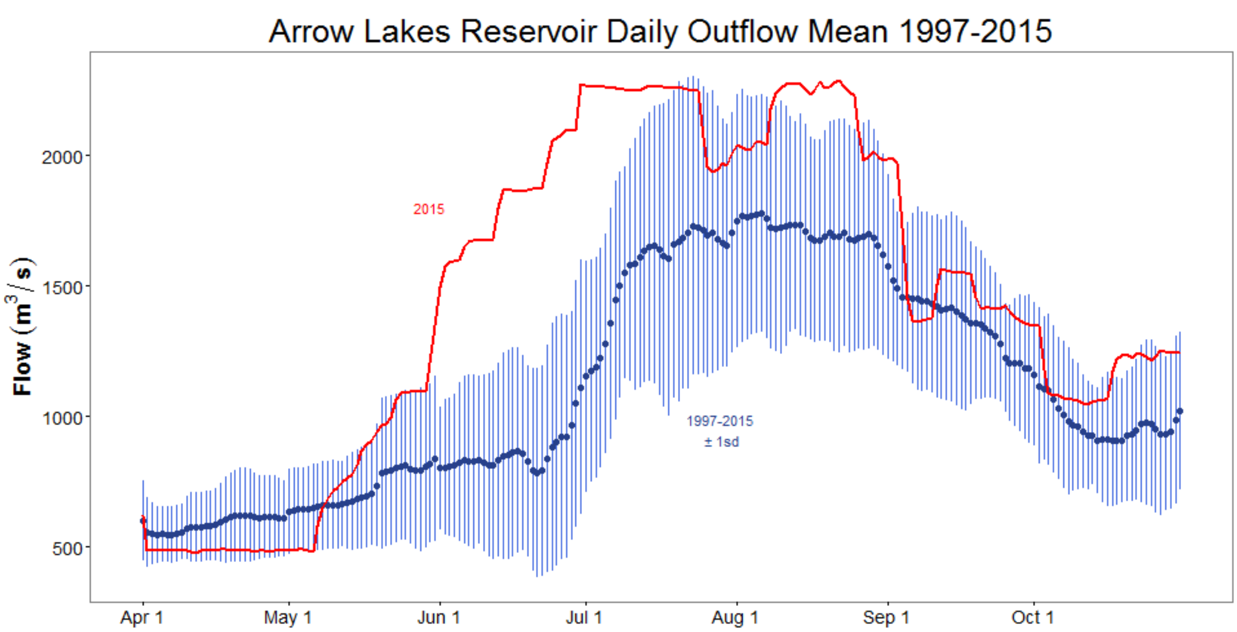


Figure 6. Arrow Lakes Reservoir April-October daily outflow 1997-2015. Blue circles are 1997-2015 daily average, blue vertical lines ± 1 S.D and red line is 2015 daily outflow.

Secchi

Secchi depth measurements evaluate the transparency of water to light and can serve as a general indicator of productivity (Wetzel, 2001). The depth at which the disc can be seen represents the transparency of the water, where increasing Secchi depths indicate increasing transparency.

Secchi disc measurements in Arrow in 2015 suggest a typical seasonal pattern of decreasing transparency associated with the spring phytoplankton bloom and freshet, followed by an increase in transparency as the bloom and freshet gradually abates by the late summer (Fig. 7). In 2015, Secchi disc measurements were taken at the Beaton Arm, the Upper basin, the Narrows, the Lower basin and at Syringa (refer to map in Appendix 3). Beaton Arm is upstream of the Upper basin on the east side of the Reservoir. The Narrows are located between the Upper and Lower basins. Syringa is located down stream of station AR 8.

In 2015, the Beaton Arm had a lower Secchi depth annual mean than the rest of the Reservoir (Fig. 7 and Table 4). The typical seasonal pattern of decreasing transparency in the spring, followed by an increase in transparency in the late summer and fall was observed throughout the reservoir, with the exception of the Beaton Arm where transparency was low throughout the sampling season, due mainly to it being fed by the turbid glacial Incomappleux River. The low Secchi disc measurements in Upper Arrow in late August were atypical for that time of year. Area annual Secchi depth measurements increased from 2014, aside from at Syringa (Fig. 8). Transparency in 2015 was higher than the long term averages for all areas.

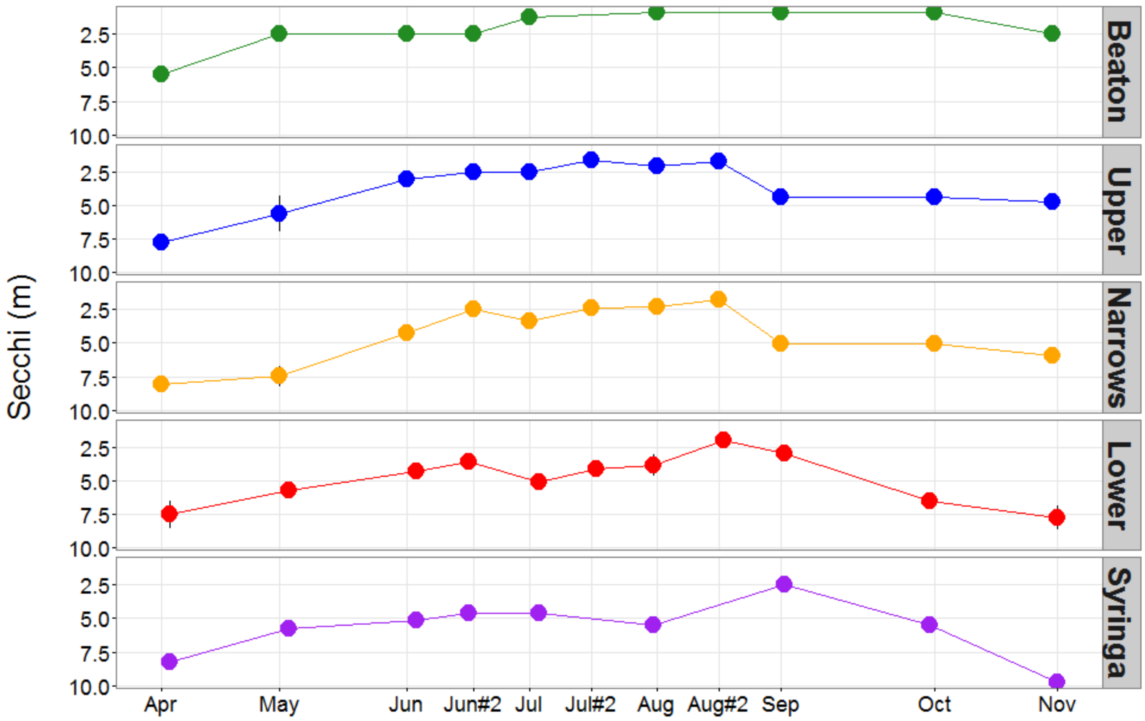


Figure 7. Arrow Secchi disk measurements in 2015, Beaton Arm (green), Upper Arrow (blue), Narrows (orange), Lower Arrow (red) and Syringa (purple). Upper, Lower and Narrows are means ±SE, Beaton and Syringa are monthly values only. July#2 and Aug#2 are AR 3, AR 4, AR 8 and Syringa only. Axes in reverse.

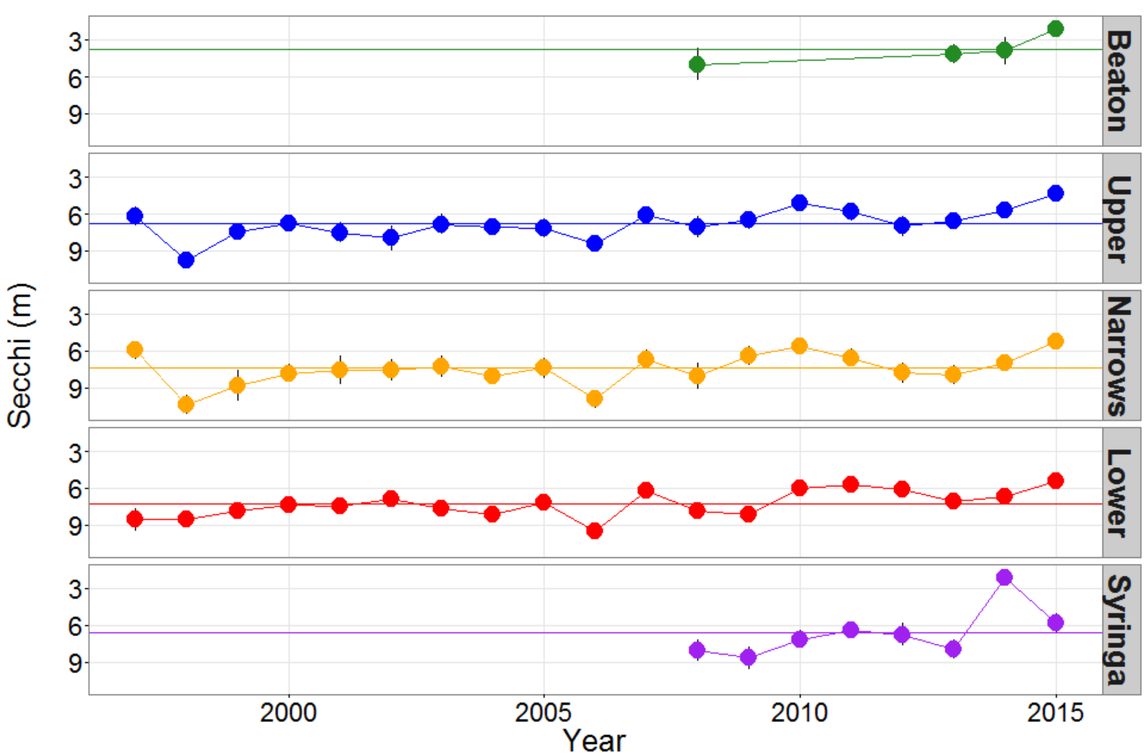


Figure 8. Secchi depth annual mean by basin (Beaton, Upper, Narrows, Lower and Syringa) 1997-2015. Means ±SE. Solid lines indicate long term means by basin. Axes in reverse.

Water Chemistry

Integrated Epilimnion

Table 4. Comparison of Basin means (Beaton=HL1, Upper=AR1-3, Narrows=AR4-5, Lower=AR6-8 and Syringa=HL4) and Season means (Spring=Apr-Jun, Summer=Jul-Sep and Fall=Oct-Nov), Jun_2, Jul_2 and Aug_2 were omitted from analysis. Differing superscript letters withins Basin or Season denote a significant difference of means at 0.05, * indicates parameter was logged prior to analysis.

	Basin					Season		
Parameter	Beaton	Upper	Narrows	Lower	Syringa	Spring	Summer	Fall
Secchi m	2.10^{a}	4.31^{b}	5.18^{b}	5.45^{b}	5.87^{b}	5.69^{b}	3.31^{a}	5.53^{b}
Turbidity* NTU	2.41^{b}	0.87^{a}		0.53^{a}		0.72^{a}	1.10^{b}	1.04^{ab}
TP* µg/L	3.40^{b}	2.58^{ab}		2.26^{a}		2.64^{a}	2.55^{a}	2.45^{a}
TDP* µg/L	2.00^{a}	2.05^{a}		2.01^{a}		2.06^{a}	2.00^{a}	2.00^{a}
OP µg/L	1.00^{a}	1.03^{a}		1.09^{a}		1.13^{a}	1.00^{a}	1.00^{a}
TN* µg/L	203.1^{c}	158.8^{b}		136.6^{a}		187.1^{b}	132.1^{a}	143.6^{a}
DIN* µg/L	169.5^{c}	119.7^{b}		80.1^{a}		136.3^{b}	85.7^{a}	106.4^{ab}
Silica mg/L	3.16^{a}	3.15^{a}		2.98^{a}		3.73^{c}	2.46^{a}	3.03^{b}
pH pH units	7.90^{c}	7.97^{a}		7.99^{b}		7.98^{a}	7.96^{a}	7.96^{a}
TOC* mg/L	0.97^{a}	0.99^{a}		1.14^{a}		1.06^{a}	1.12^{a}	0.94^{a}
Alkalinity* mg/L	54.98^{a}	56.45^{a}		54.80^{a}		57.62^{b}	51.89^{a}	57.88^{b}
N:P DIN/TDP	84.75^{c}	58.38^{b}		39.90^{a}		66.34^{b}	42.80^{a}	53.20^{ab}

Phosphorus

Phosphorus is commonly used as an indicator of productivity due to the valuable role it plays in biological metabolism. Phosphorus is monitored throughout the season to both evaluate limitations, and to monitor the 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. For total phosphorus and total dissolved phosphorus, this is 2 µg/L, and for orthophosphate this is 1 µg/L. In 2015, 48% total phosphorus (TP) values, 67% total dissolved phosphorus (TDP) and 93% orthophosphate (OP) values were reported less than the RDL.

In 2015, there was more variability observed for total phosphorous in the Beaton Arm than the Upper and Lower Basins (Fig. 9). The basin mean for the Beaton Arm was significantly higher than the Lower Basin mean, with no significant difference between these two and Upper Basin (Table 4). There was no seasonal difference in total phosphorous (Table 4). Total phosphorus in 2015 was lower than the long term basin means, with the exception of the Beaton Arm (Fig. 10).

Total dissolved phosphorus (TDP) ranged minimally over the course of the 2015 sampling season (Fig. 11). There was no significant difference between basins or by season (Table 4). In 2015, TDP was lower than the 1997-2015 means for all basins (Fig. 12).

Orthophosphate did not change significantly over the course of the sampling season in 2015 (Fig. 13), and there was no difference across the basins or by season (Table 4). In 2015, orthophosphate was lower than the 1997-2015 means for all basins (Fig. 14).

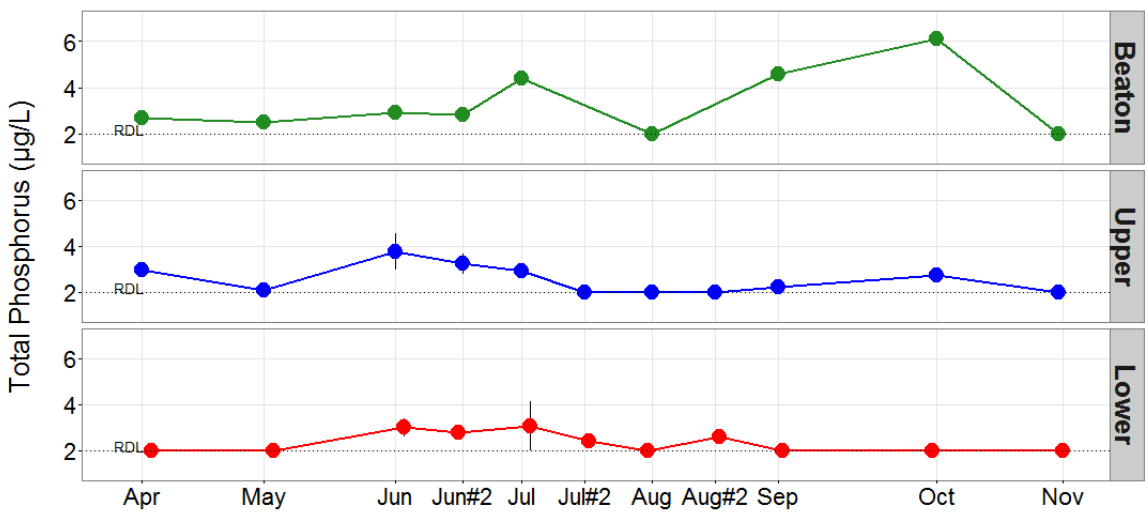


Figure 9. Arrow total phosphorus by basin (Beaton (HL1), Upper (AR1-3) and Lower (AR6-8)) in 2015. Means ±SE. July#2 and Aug#2 are AR 3 and AR 8 only.

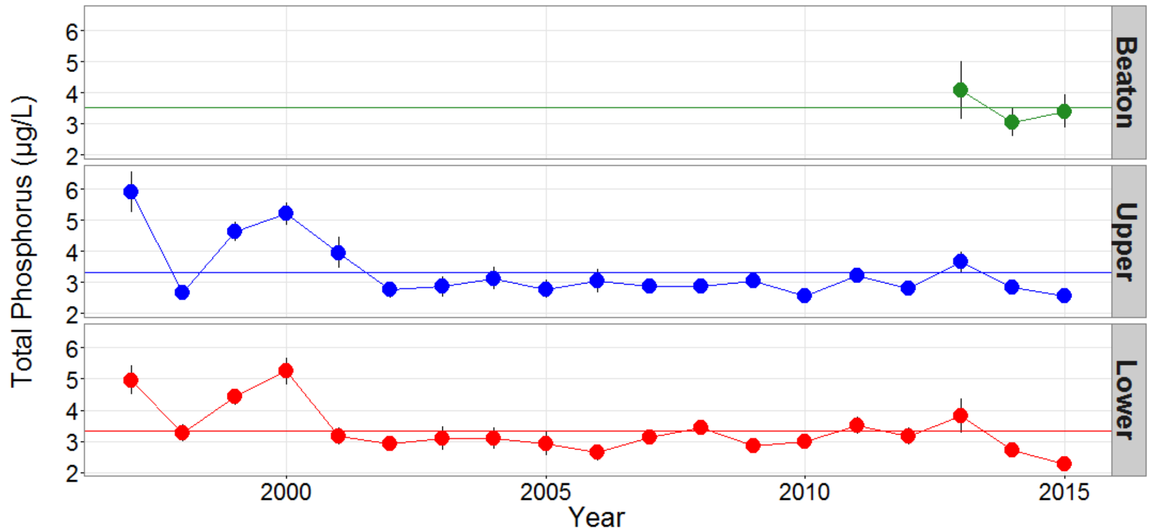


Figure 10. Arrow total phosphorus annual mean by basin (Beaton, Upper and Lower) 1997-2015. Means ±SE. Solid lines indicate long term means by basin.

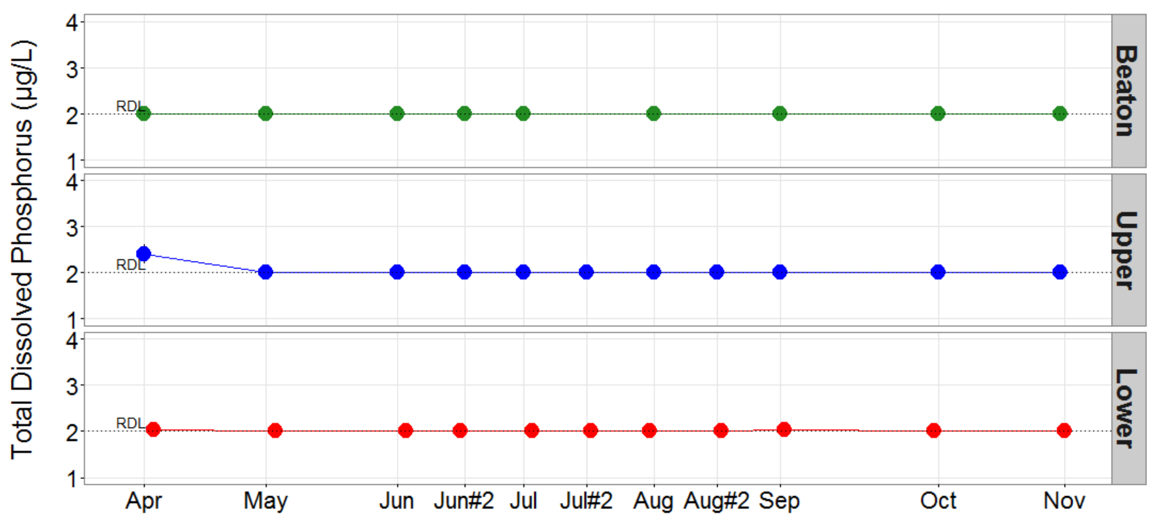


Figure 11. Arrow total dissolved phosphorus by basin (Beaton (HL1), Upper (AR1-3) and Lower (AR6-8)) in 2015. Means ±SE. July#2 and Aug#2 are AR 3 and AR 8 only.

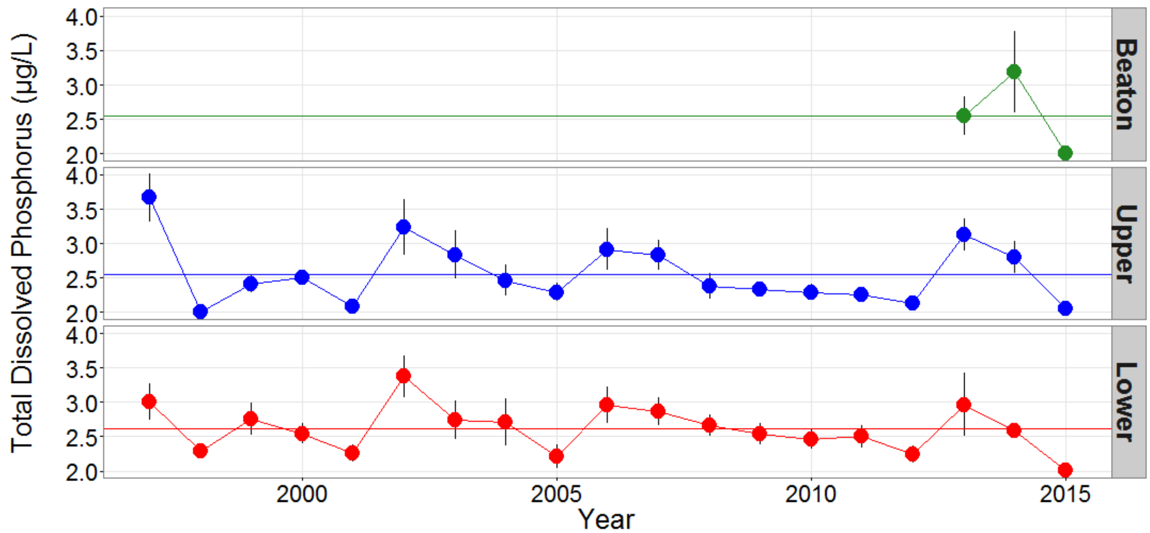


Figure 12. Arrow total dissolved phosphorus annual mean by basin (Beaton, Upper and Lower) 1997-2015. Means ±SE. Solid lines indicate long term means by basin.

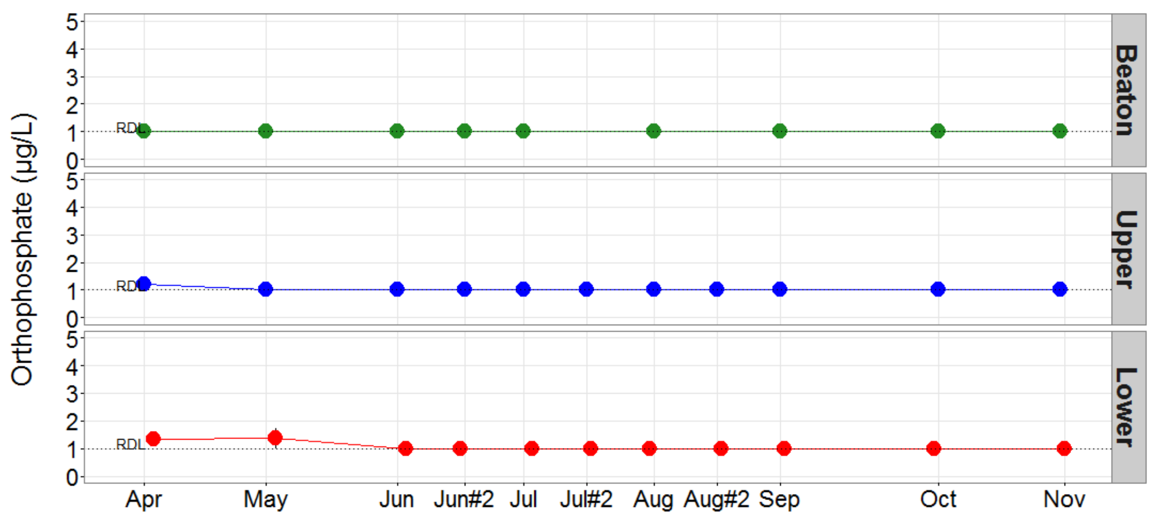


Figure 13. Arrow orthophosphate by basin (Beaton (HL1), Upper (AR1-3) and Lower (AR6-8)) in 2015. Means ±SE. July#2 and Aug#2 are AR 3 and AR 8 only.

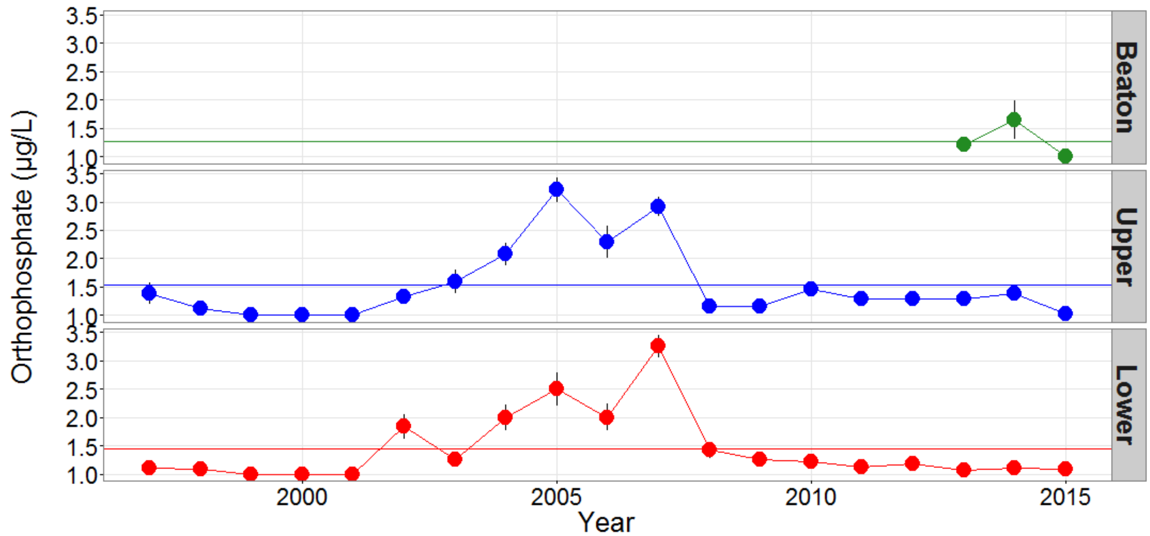


Figure 14. Arrow orthophosphate annual mean by basin (Beaton, Upper and Lower) 1997-2015. Means ±SE. Solid lines indicate long term means by basin.

Nitrogen

In fresh water, complex biochemical processes utilize nitrogen in many forms: 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; 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).

Total nitrogen in 2015 was significantly different across all basins; highest in the Beaton Arm, and lowest in Lower Arrow (Table 4, Fig. 15). Total Nitrogen was highest in in the spring and varied minimally in the summer and fall (Table 4, Fig. 15). Total Nitrogen in 2015 was lower than the 2004 - 2015 mean (Fig. 16).

Dissolved inorganic nitrogen (DIN), consists of nitrite, nitrate and ammonia. Nitrate and ammonia are the forms of nitrogen most readily available to phytoplankton (Wetzel, 2001). For the 2015 integrated samples 67% of the ammonia results were reported under the RDL of 5 µg/L. Additionally, 82% of nitrite values in the integrated samples were reported under RDL of 1 µg/L. As the majority of ammonia and nitrite values are below RDL, DIN results are for the most part the nitrate values.

Dissolved inorganic nitrogen was also significantly different across all basins, being highest in the Beaton Arm and lowest in Lower Arrow (Table 4). Seasonally, DIN was lowest in summer (Fig. 17). The spring mean was significantly higher than the summer mean (Table 4).

In 2015, DIN was above the long term mean for Beaton Arm and Upper Arrow while Lower Arrow's 2015 annual mean was slightly below the long term mean (Fig. 18). The difference between pre and post 2004 seasonal means may be attributed to changes in sampling methodology; from 1997 to 2003 integrated samples were collected from 0–30 m, and from 2004 to 2010 samples were collected from 0–20 m. The 0–30 m samples collected nitrate-enriched water from below the thermocline.

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

Overall the NP ratio was highest in the spring and lowest in the summer (Table 4). The NP ratio peaked in May in the Beaton Arm, and the lowest observations were in Lower

Arrow in the later August sampling period (Fig. 19). The 2015 annual means for the basins were all significantly different, where the mean in the Beaton Arm was highest, and the mean in Lower Arrow was the lowest (Table 4). The NP ratio in 2015 was near the long term mean for Upper and Lower Arrow, whereas the Beaton Arm mean in 2015 was higher than the 2013-2015 mean (Fig. 20).

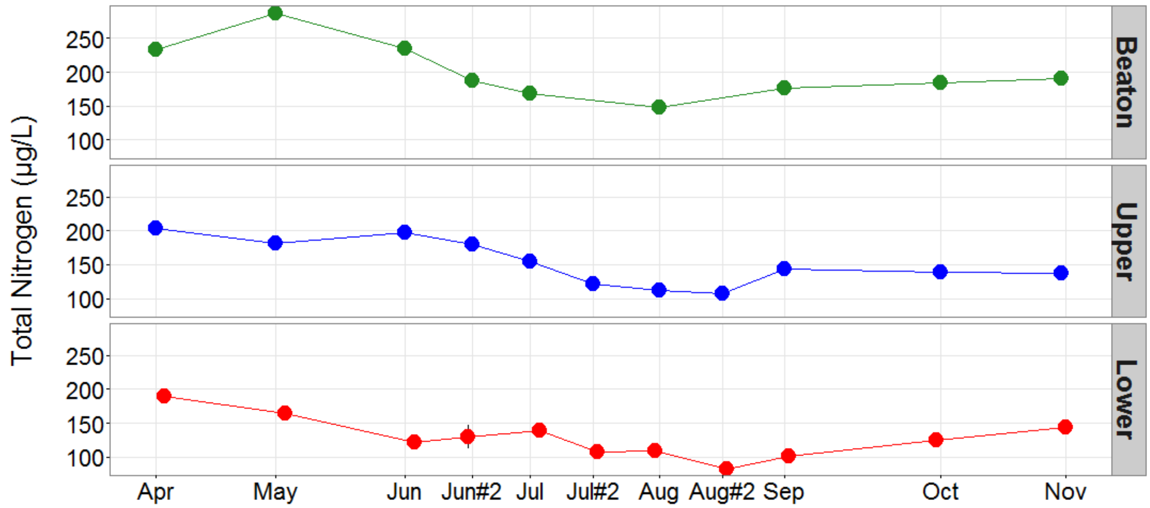


Figure 15. Arrow total nitrogen by basin (Beaton (HL1), Upper (AR1-3) and Lower (AR6-8)) in 2015. Means ±SE. July#2 and Aug#2 are AR 3 and AR 8 only.

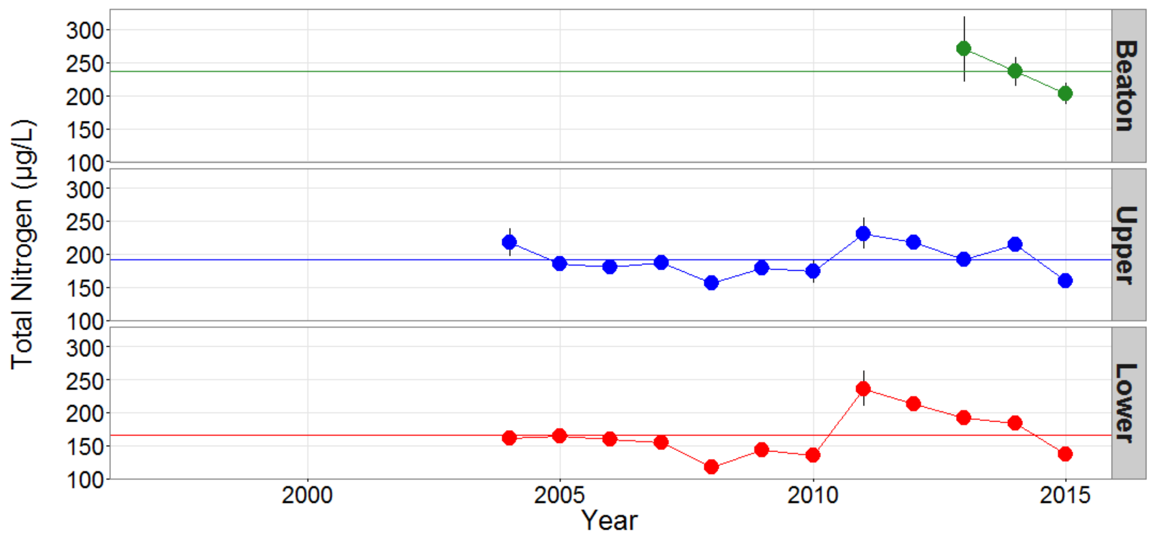


Figure 16. Annual total nitrogen annual mean by basin (Beaton, Upper and Lower) 2004-2015. Means ±SE. Solid lines indicate long term means by basin.

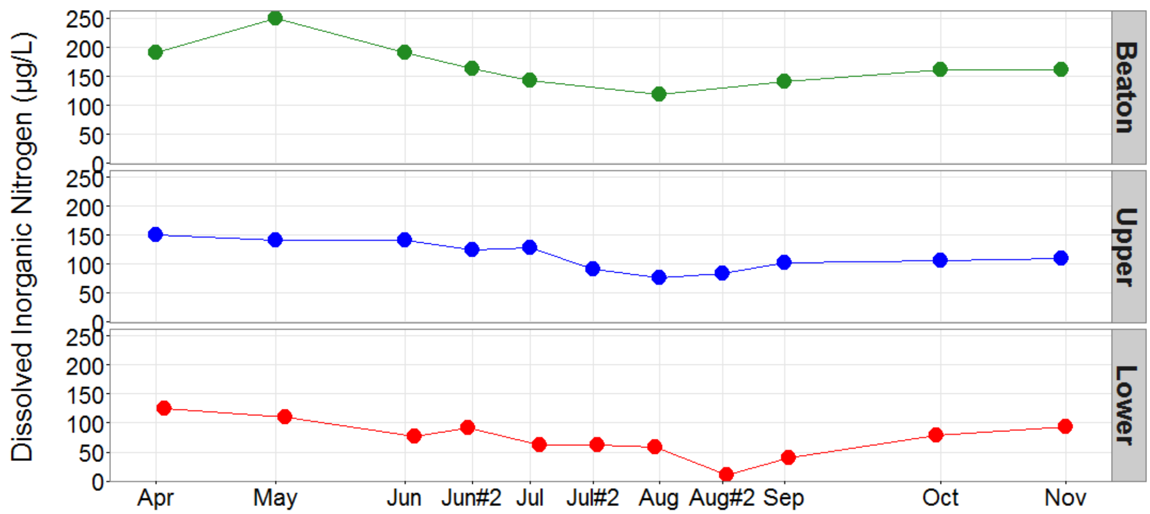


Figure 17. Arrow dissolved inorganic nitrogen by basin (Beaton (HL1), Upper (AR1-3) and Lower (AR6-8)) in 2015. Means ±SE. July#2 and Aug#2 are AR 3 and AR 8 only.

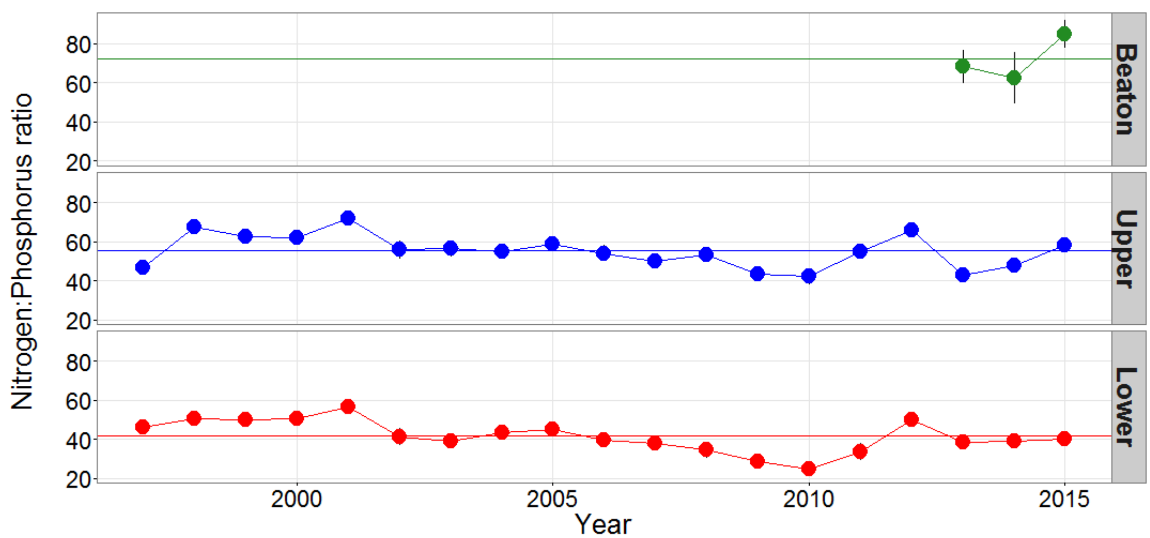


Figure 18. Annual dissolved inorganic nitrogen annual mean by basin (Beaton, Upper and Lower) 1997-2015. Means ±SE. Solid lines indicate long term means by basin.

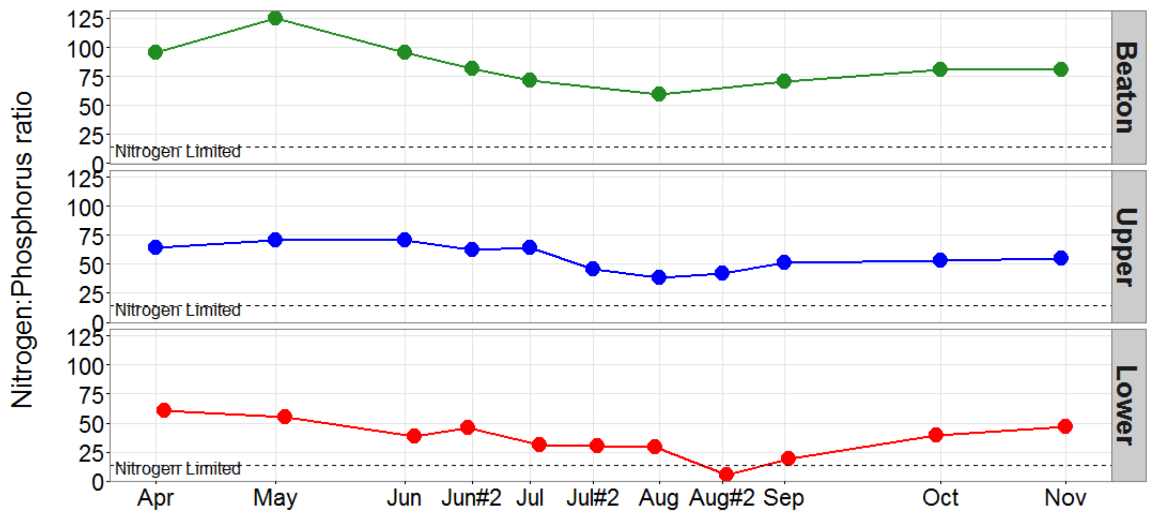


Figure 19. Arrow nitrogen:phosphorus ratio (dissolved, weight:weight) by by basin (Beaton (HL1), Upper (AR1-3) and Lower (AR6-8)) in 2015. Means ±SE. July#2 and Aug#2 are AR 3 and AR 8 only.

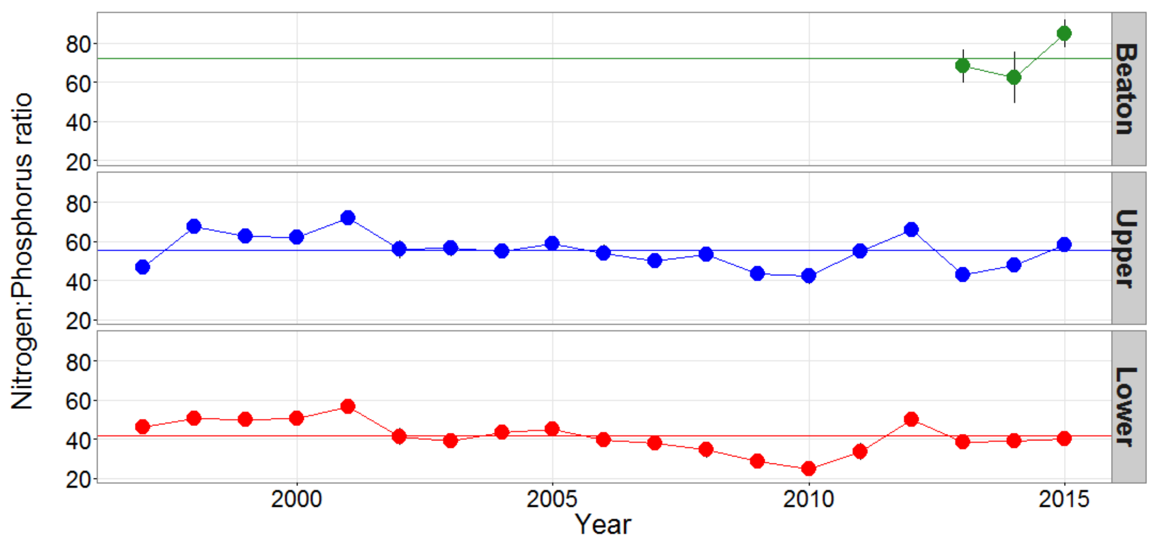


Figure 20. Annual nitrogen:phosphorus ratio (dissolved, weight:weight) by basin (Beaton, Upper and Lower) 1997-2015. Means ±SE. Solid lines indicate long term means by basin.

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 2015, turbidity was significantly higher and more variable in the Beaton Arm than in both the Upper and Lower Basins

(Fig. 21, Table 4). Seasonally, there was a significant difference between the spring and summer means (Table 4). Compared to the 1997-2015 mean, turbidity was high in 2015, particularly in the Beaton Arm and in the Upper Basin where it is the highest on record (Fig. 22).

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 is measured as an indicator of available silica to diatoms. There was not a significant difference between the basins in 2015, however silica was significantly different across seasons where spring was the highest and summer was the lowest (Table 4, Fig. 23). Silica did not reach levels which would be considered limited for diatom production of 0.5 mg/L). Silica was marginally lower than the long-term 1997-2015 mean, particularly in Lower Arrow (Fig. 24).

The pH in the basins differed significantly, where pH in Lower Arrow was the highest and Beaton Arm the Lowest (Table 4, Fig. 25). There was no seasonal expression of pH in 2015 (Table 4). Overall, pH in Arrow Lakes Reservoir indicated slightly alkaline conditions. The levels observed in 2015 were higher than the previous two years and marginally higher than the 1997-2005 mean (Fig. 26). In summary, results vary minimally over the course of the program, with the exception of 2005 (Fig. 26). It was 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 2015, alkalinity decreased from the spring to summer, before increasing into the fall (Fig. 27). The summer mean was significantly different from the spring and fall means (Table 4). Overall, there was not a significant difference between basins (Table 4). Alkalinity was high in 2015, although not outside of results observed in the long term dataset (Fig. 28).

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 2015, total organic carbon did not differ across basins, and there was no a notable seasonal expression (Table 4 Fig. 29). Total organic carbon was marginally lower in 2015 in all basins (Fig. 30).

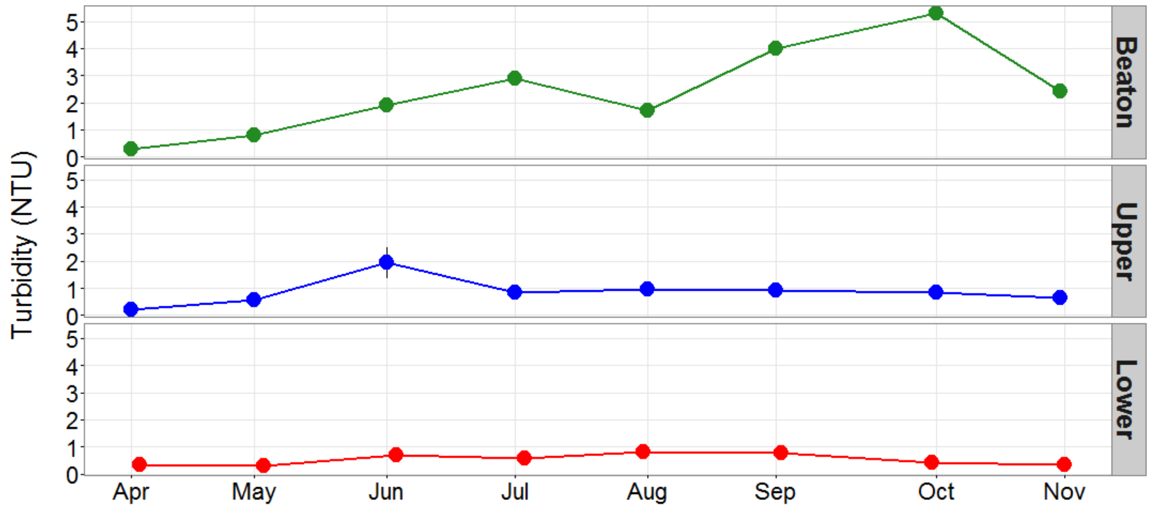


Figure 21. Arrow turbidity (NTU) by by basin (Beaton (HL1), Upper (AR1-3) and Lower (AR6-8)) in 2015. Means ±SE.

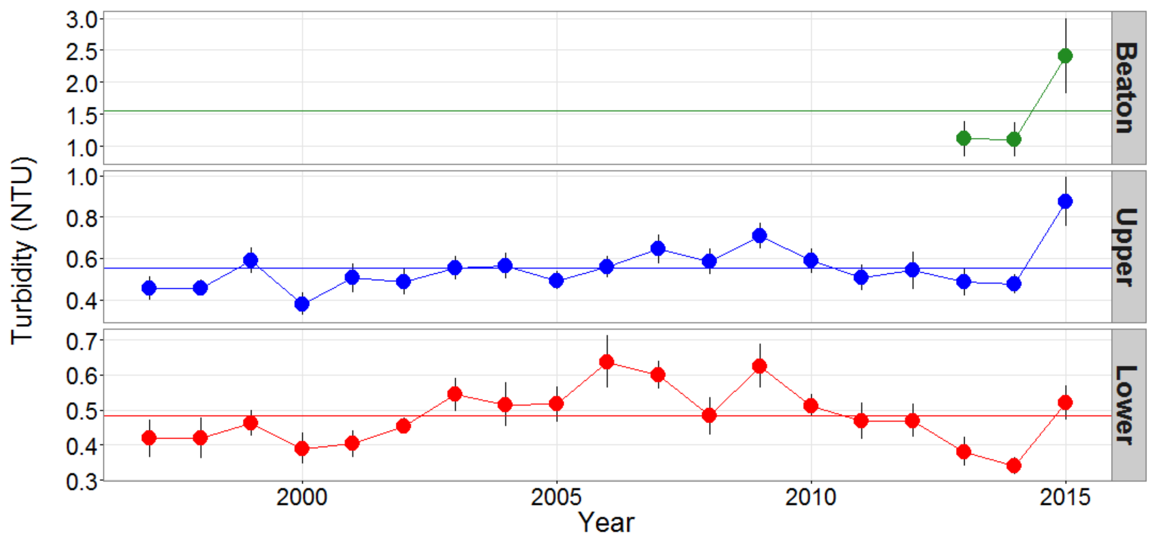


Figure 22. Annual turbidity (NTU) by basin (Beaton, Upper and Lower) 1997-2015. Means ±SE. Solid lines indicate long term means by basin.

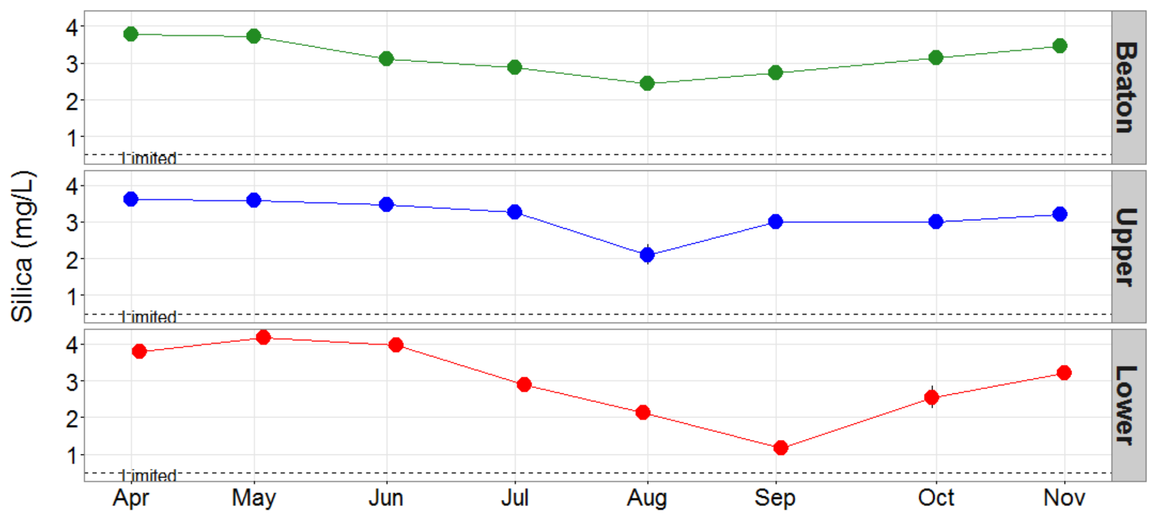


Figure 23. Arrow silica (mg/L) by by basin (Beaton (HL1), Upper (AR1-3) and Lower (AR6-8)) in 2015. Means ±SE. Dotted line denotes silica limitation for diatoms.

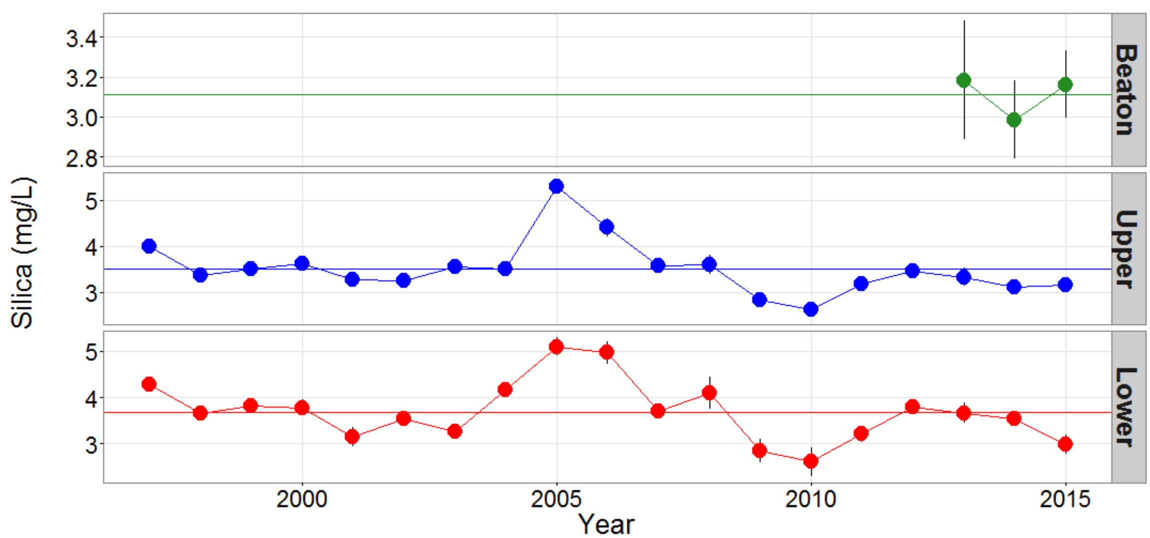


Figure 24. Annual silica (mg/L) by basin (Beaton, Upper and Lower) 1997-2015. Means ±SE. Solid lines indicate long term means by basin.

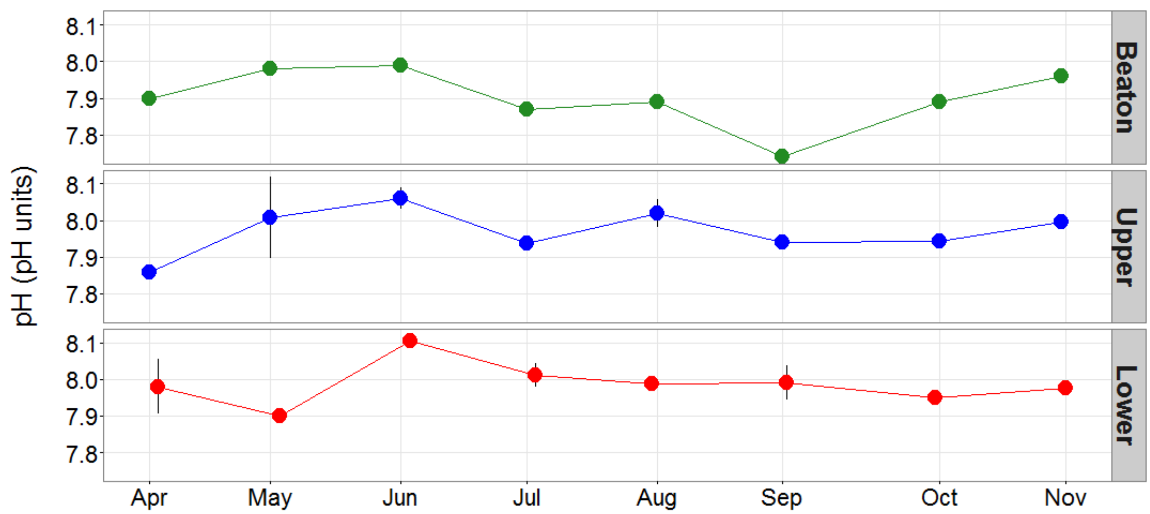


Figure 25. Arrow pH (pH units) by by basin (Beaton (HL1), Upper (AR1-3) and Lower (AR6-8)) in 2015. Means ±SE.

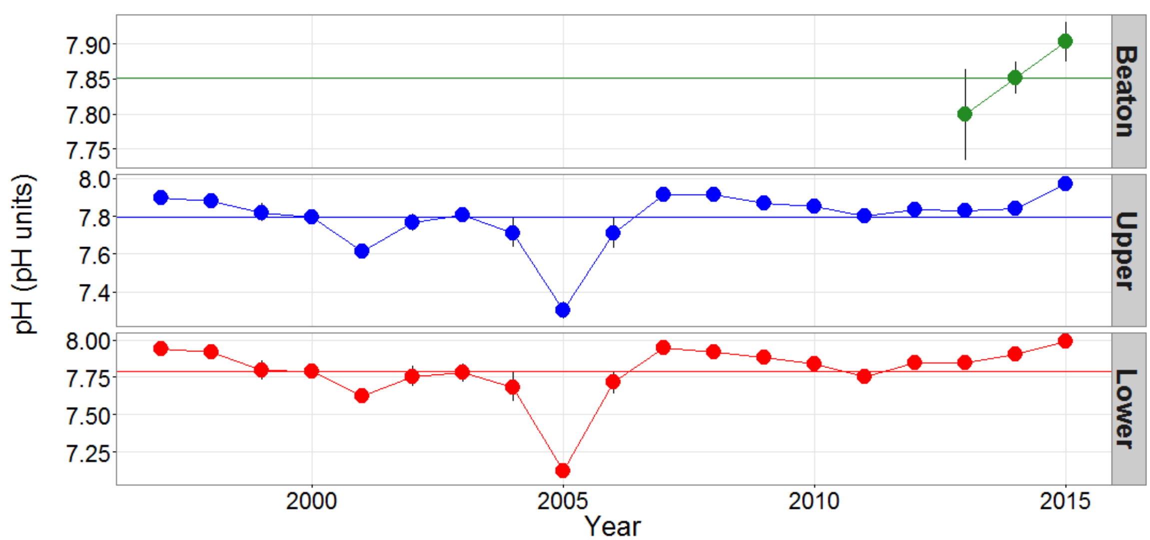


Figure 26. Annual pH (pH units) by basin (Beaton, Upper and Lower) 1997-2015. Means ±SE. Solid lines indicate long term means by basin.

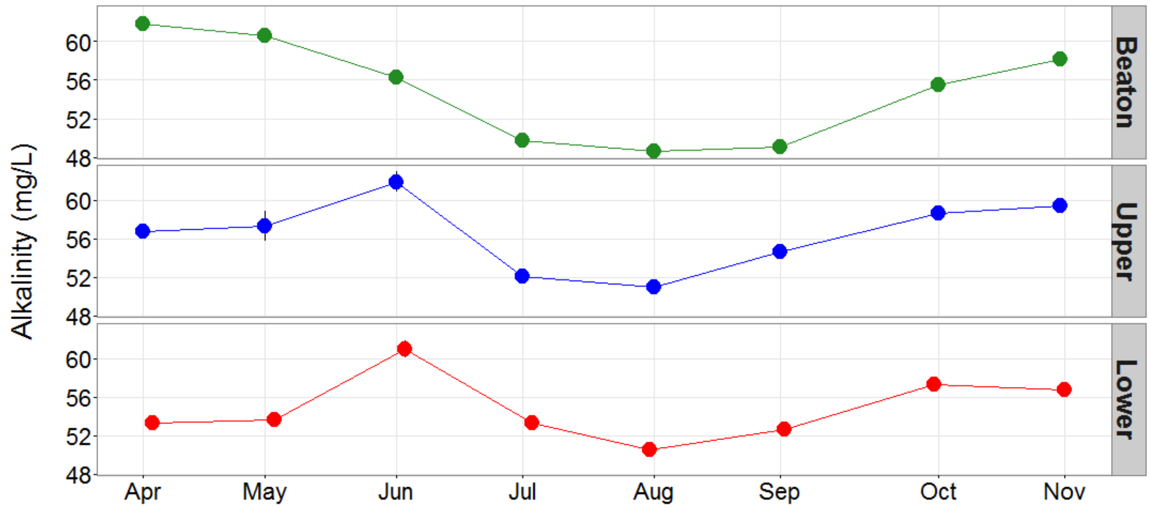


Figure 27. Arrow Alkalinity (mg/L) by by basin (Beaton (HL1), Upper (AR1-3) and Lower (AR6-8)) in 2015. Means ±SE.

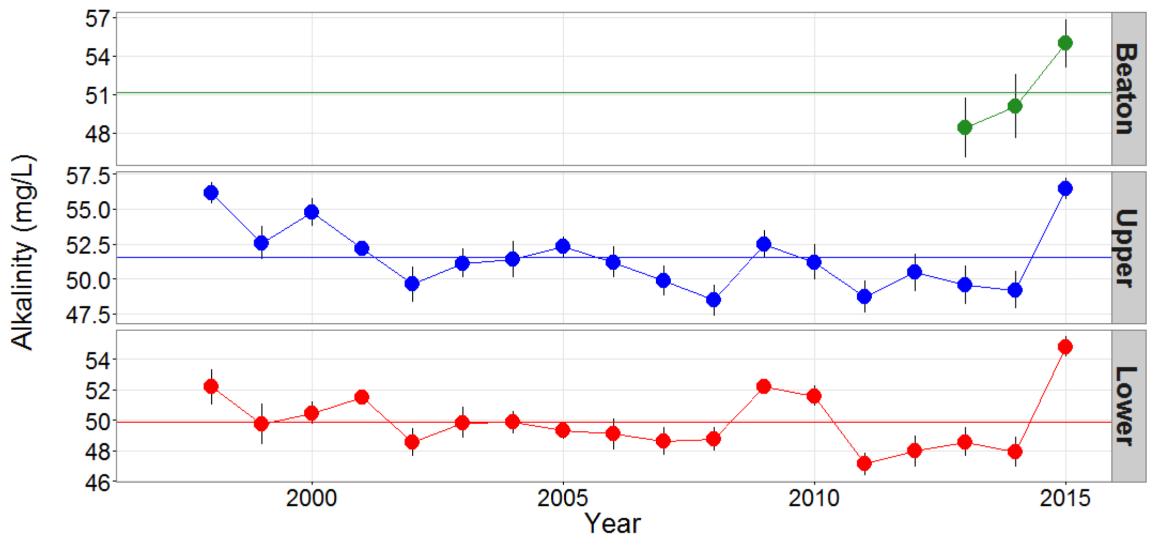


Figure 28. Annual Alkalinity (mg/L) by basin (Beaton, Upper and Lower) 1997-2015. Means ±SE. Solid lines indicate long term means by basin.

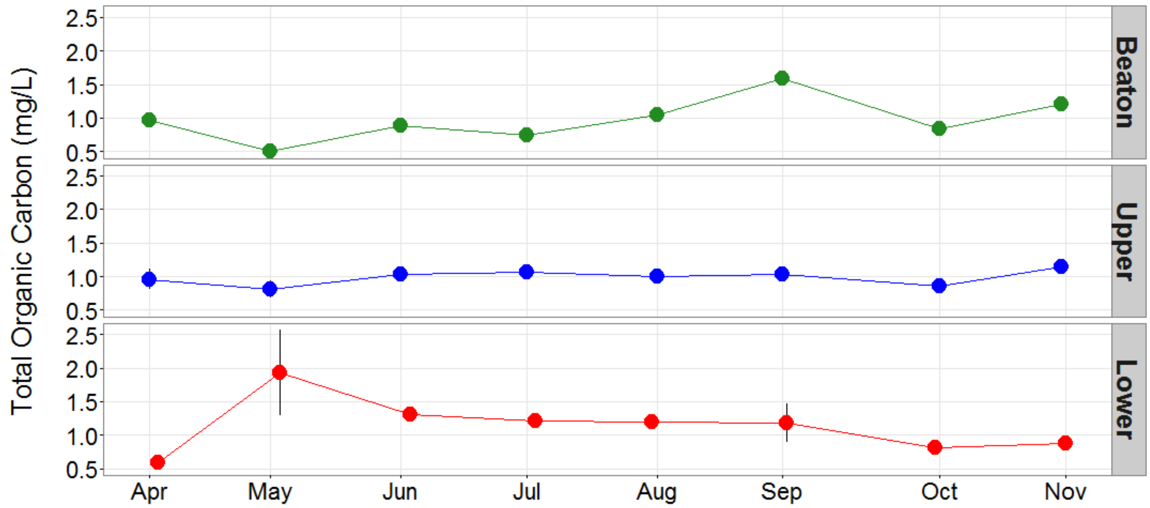


Figure 29. Arrow total organic carbon (mg/L) by by basin (Beaton (HL1), Upper (AR1-3) and Lower (AR6-8)) in 2015. Means ±SE.

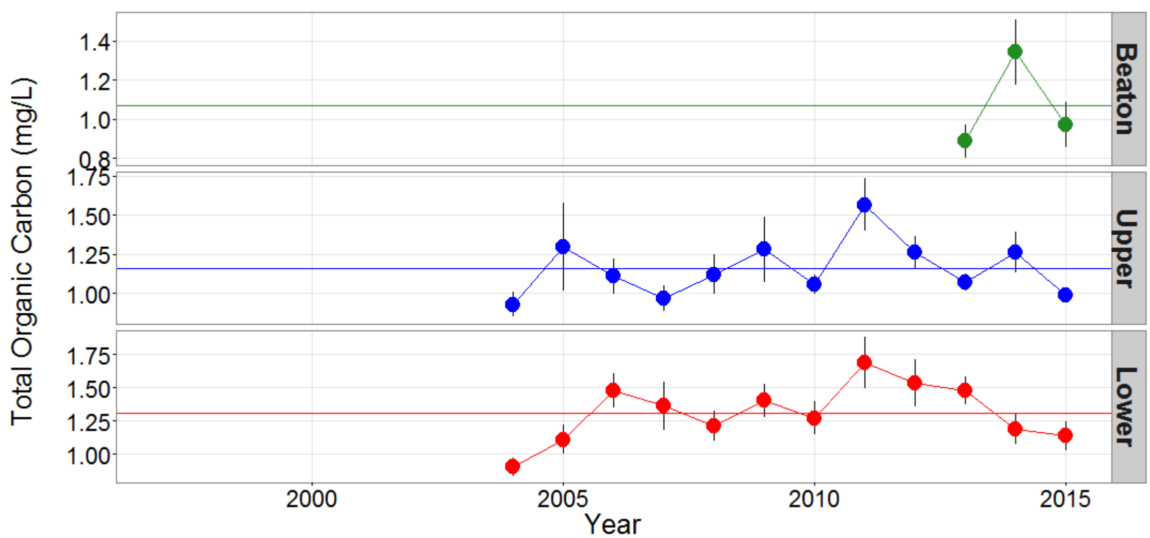


Figure 30. Annual total organic carbon (mg/L) by basin (Beaton, Upper and Lower) 1997-2015. Means ±SE. Solid lines indicate long term means by basin.

Discrete Epilimnion

Total Phosphorus

In 2015, TP in the Upper basin (AR 2) ranged from the RDL (2 µg/L) to 5.4 µg/L (June at 5m; Fig. 31). In the Lower basin (AR 7), TDP ranged from the RDL to 11.4 µg/L (July at 5m; Fig. 31).

Total Dissolved Phosphorus

In 2015, TDP in the Upper basin (AR 2) ranged from the RDL (2 µg/L) to 4 µg/L (June at 5 m; Fig. 31). In the Lower basin (AR 7), TDP ranged from the RDL to 2.7 µg/L (September at 5 and 20m; Fig. 31). Results were higher in Lower Arrow compared to Upper Arrow in September.

Dissolved Inorganic Nitrogen

In 2015, DIN in the Upper Basin ranged from 11 – 164 µg/L, and for all months an increase in DIN occurred with increased depth, particularly in August (Fig. 31). In the Lower Basin, this trend was less pronounced and DIN observations (28-98 µg/L) were not at high or variable than in the Upper Arrow Basin. The results indicate that DIN needs to be closely monitored, especially in Lower Arrow, to ensure nitrogen-fixing algae do not appear at low DIN values (approx. 30 µg/L).

Nitrogen:Phosphorus

In 2015, the N:P ratio (weight:weight, dissolved) generally increased with depth in the epilimnion. Upper Arrow ranged from 5.5 – 82.0 µg/L, and peaked in June at 20 m (Fig. 31). In Lower Arrow, the N:P ratio ranged from 10.9 – 48.9, and peaked in August, also at 20m (Fig. 31). Generally, Arrow Lake Reservoir verged on being limited by phosphorus. However, in August (2m & 5m, Upper Arrow) and September (all depths Lower Arrow) there was more of a nitrogen limitation observed.

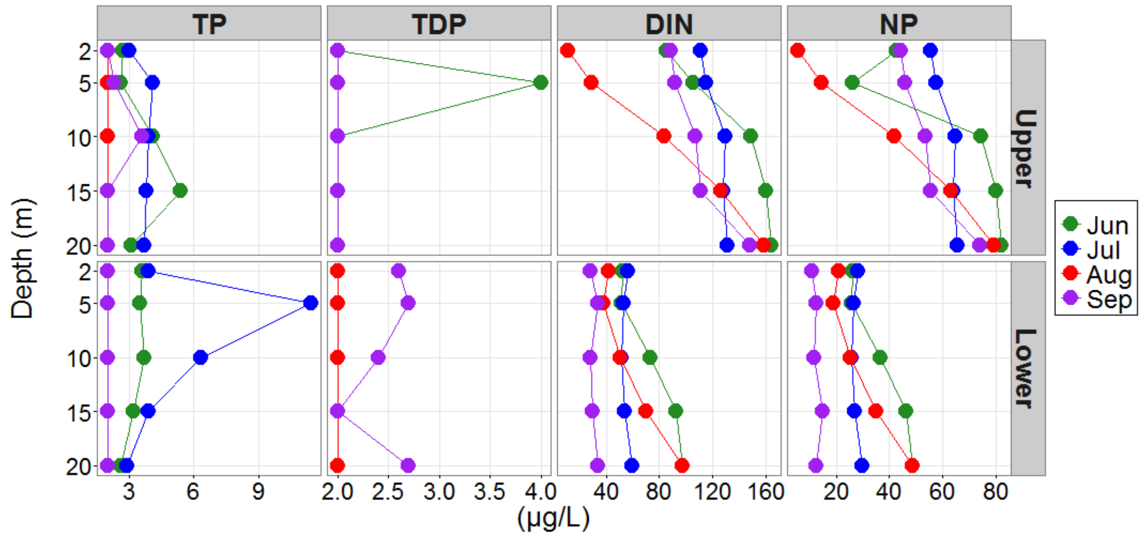


Fig. 31. Discrete depth profiles of Upper Arrow (AR 2) and Lower Arrow (AR 7), June - September 2015. Note x scale changes by parameter.

Hypolimnion

Table 5. Comparison of basin means (Upper=AR1-3 and Lower=AR6-8) Differing superscript letters within Basin denote a significant difference of means at 0.05 , * indicates parameter was logged prior to analysis.

	Basin	
Parameter	Upper	Lower
TP* µg/L	2.16b	2.02a
TDP* µg/L	2.04a	2.01a
OP* µg/L	1.21a	1.02a
TN µg/L	182.94a	182.33a
DIN µg/L	167.11a	163.94a
Turbidity* NTU	0.47b	0.265a
Silica mg/L	3.91a	4.26b
Alkalinity mg/L	62.32b	59.08a
pH pH units	7.89a	7.88a
TOC* mg/L	0.75a	0.91a

Phosphorus

Hypolimnetic Total phosphorus (TP) in 2015 ranged from below the RDL (2 µg/L) to 2.7 µg/L in Upper Arrow, and from below the RDL (2 µg/L) to 2.3 µg/L in Lower Arrow. Higher values in September and October in were observed in Upper Arrow (Fig. 32). In Upper Arrow, Total dissolved phosphorus (TDP) ranged from below the RDL (2 µg/L) to 2.8 µg/L; in Lower Arrow, TDP ranged from below the RDL (2 µg/L) to 2.2 µg/L. Higher values were observed in September in Upper Arrow. Hypolimnetic orthophosphate (OP) ranged from below the RDL (1 µg/L) to 4.4 µg/L (in May at station AR3) in Upper Arrow. In Lower Arrow, OP ranged from below the RDL (1 µg/L) to 1.3 µg/L. While there was a significant difference between Upper and Lower basin means for Total Phosphorous, there was no significant difference between basins for the TDP or OP means (Table 5).

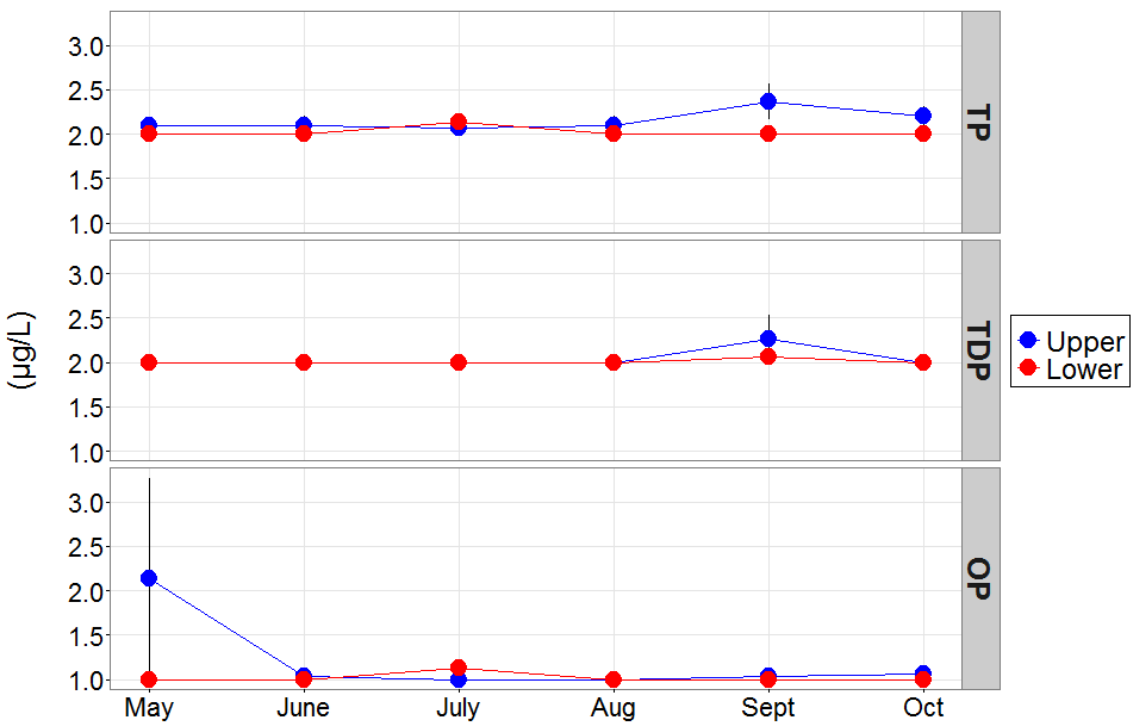


Figure 32. Arrow phosphorus; total phosphorus (TP), total dissolved phosphorus (TDP) and orthophosphate (OP) in discrete hypolimnetic samples in 2015, Upper Arrow (blue) and Lower Arrow (red). Means ±SE.

Nitrogen

Hypolimnetic total nitrogen (TN) in 2015 ranged from 154 to 286 µg/L in Upper Arrow, whereas in Lower Arrow TN ranged from 164 to 211 µg/L. There was no significant difference between Upper and Lower basins (Table 5, Fig. 33). Dissolved inorganic nitrogen (DIN) also did not differ significantly between Upper and Lower Arrow basins (Table 5). In Upper Arrow, DIN ranged from 152 to 192 µg/L, whereas in Lower Arrow, DIN ranged from 147 to 188 µg/L. An increasing trend from spring to fall was observed for DIN in both basins (Fig. 33).

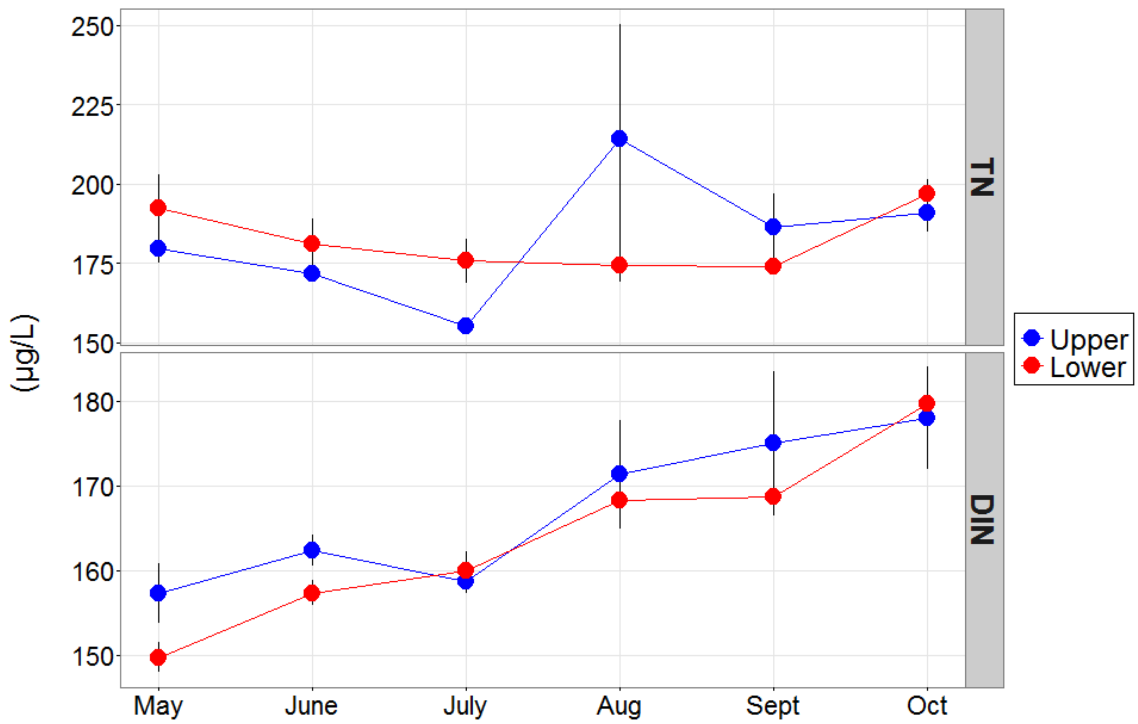


Figure Fig 33. Arrow nitrogen; total nitrogen (TN) and dissolved inorganic nitrogen (DIN in discrete hypolimnetic samples, Upper Arrow (blue) and Lower Arrow (red). Means ±SE. Note y scale changes by parameter.

Turbidity, Silica, Alkalinity, pH and Carbon

Hypolimnetic turbidity results in 2015 ranged from 0.15 to 1.02 NTU in Upper Arrow and from 0.19 to 0.45 NTU in Lower Arrow. There was a significant difference between the basins, where the Upper Arrow turbidity mean was higher than the Lower Arrow mean (Table 5, Fig. 34).

Silica in the hypolimnetic samples ranged from 3.48 to 4.52 mg/L in Upper Arrow and from 3.92 to 4.54 mg/L in Lower Arrow. There was a significant difference between the basins (Table 5), where silica monthly means were consistently higher in Lower Arrow than Upper Arrow (Fig. 34).

Alkalinity in the hypolimnetic samples ranged from 55.3 to 72.1 mg/L in Upper Arrow and from 55.0 to 71.1 mg/L in Lower Arrow. There was a significant difference between the basins (Table 5), where alkalinity monthly means were consistently higher in Upper Arrow, aside from in June (Fig. 34).

Hypolimnetic pH results in 2015 ranged from 7.76 to 8.03 pH units in Upper Arrow and from 7.74 to 8.05 pH units in Lower Arrow. There was no significant difference between the basins (Table 5, Fig. 34).

Total organic carbon in the hypolimnion in 2015 ranged from 0.5 to 0.98 mg/L in Upper Arrow and from 0.5 to 2.39 mg/L in Lower Arrow (Fig. 34). There was no significant difference between the basins (Table 5, Fig. 34).

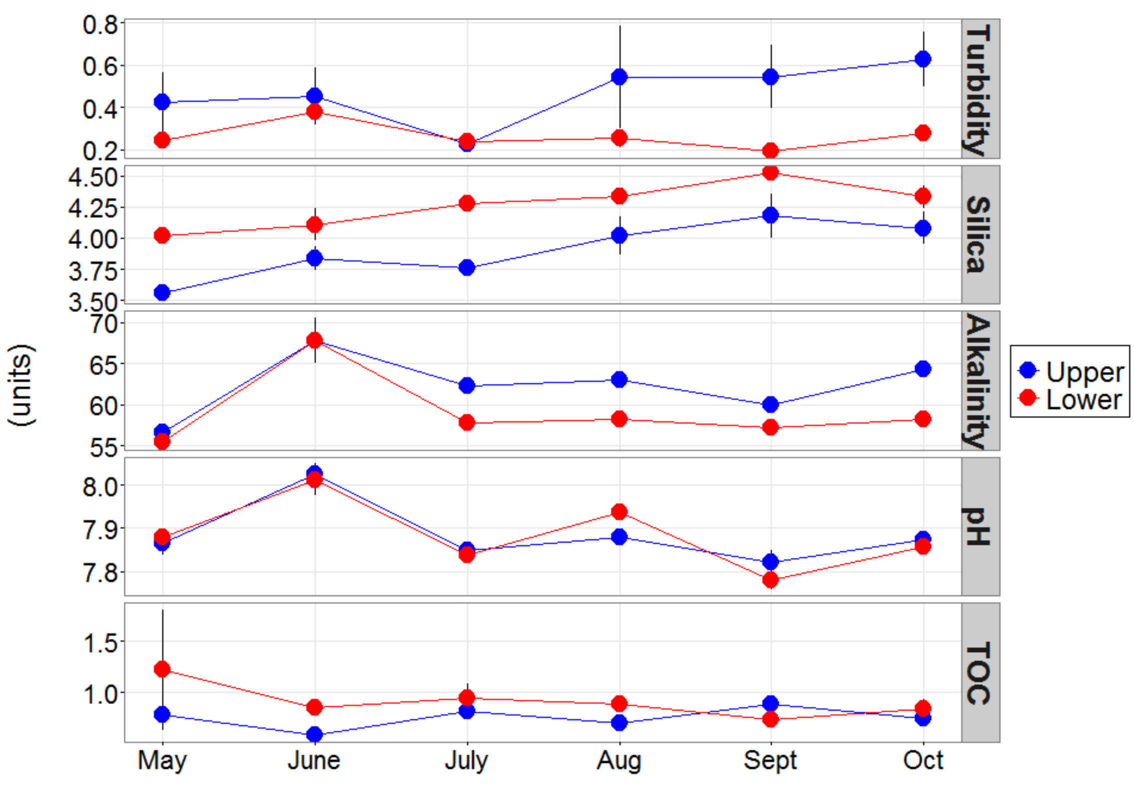


Figure 34. Arrow turbidity (NTU units), silica (mg/L units), alkalinity (mg/L units), ph (pH units) and total organic carbon (TOC; mg/L units) in discrete hypolimnetic

samples, Upper Arrow (blue) and Lower Arrow (red). Means ±SE. Note y scale changes by parameter.

Phytoplankton

Month and Basin Group Abundance and Biovolume trends in 2015

Abundance of phytoplankton groups by basin is shown in Figure 35 and biomass by group in Figure 36. Total abundance and total biomass was highest in August, largely contributed to by high bacillariophyte results.

High abundance and biomass bacillariophyte results were largely made up of the species *Asterionella formosa var1* and *synedra nana*. There was no significant difference between basin means in 2015, however the Jun_2, Jul_2 and Aug_2 results were not included in this analysis. The peak of bacillariophyte results occurred in Lower Arrow in Aug_2, largely due to contributions from the species *synedra nana.*

Chlorophyte abundance and biovolume was highest in Lower Arrow, and lowest in the Beaton Arm (Fig. 35 and Fig. 36). Abundance fluctuated throughout the season, with high observations in June, July and October (Fig. 35). The species that contributed the most to these high abundances were *Chlorella* and *Scourfieldia*. The species with the highest biovolume in 2015 in Arrow were *Phacus, Oocystis sp.,* and *Scourfieldia.*

Chryso-cryptophyte abundance was highest in late July in Upper Arrow, October in the Narrows, and August in Lower Arrow (Fig. 35), largely from high counts of *small microflagellates.* Biomass was highest in Lower Arrow, and peaked in the fall (Fig. 36). High biomass is from the species *Cryptomonas* and *Dinobryon*.

Cyanophyte abundance peaked in May in the Beaton Arm, and in the late July samples from Upper Arrow, the Narrows and Lower Arrow (Fig. 35). The species that contributed most to the late July results were *Synechococcus* and *Microcystis*. Apart from these spring samples abundance fluctuated minimally during the season, however fall abundance was marginally higher driven by species *Synechococcus species (rod)* and *Microcystis sp*. Cyanophyte biomass on the other hand was highest in October, in Lower Arrow, due to higher observations of *Lyngbya* species.

Dinophyte results are predominantly *Gymnodinium* species. Minimal seasonal trends were observed, with abundance and biomass peaking in the summer (Fig. 35 and Fig. 36).

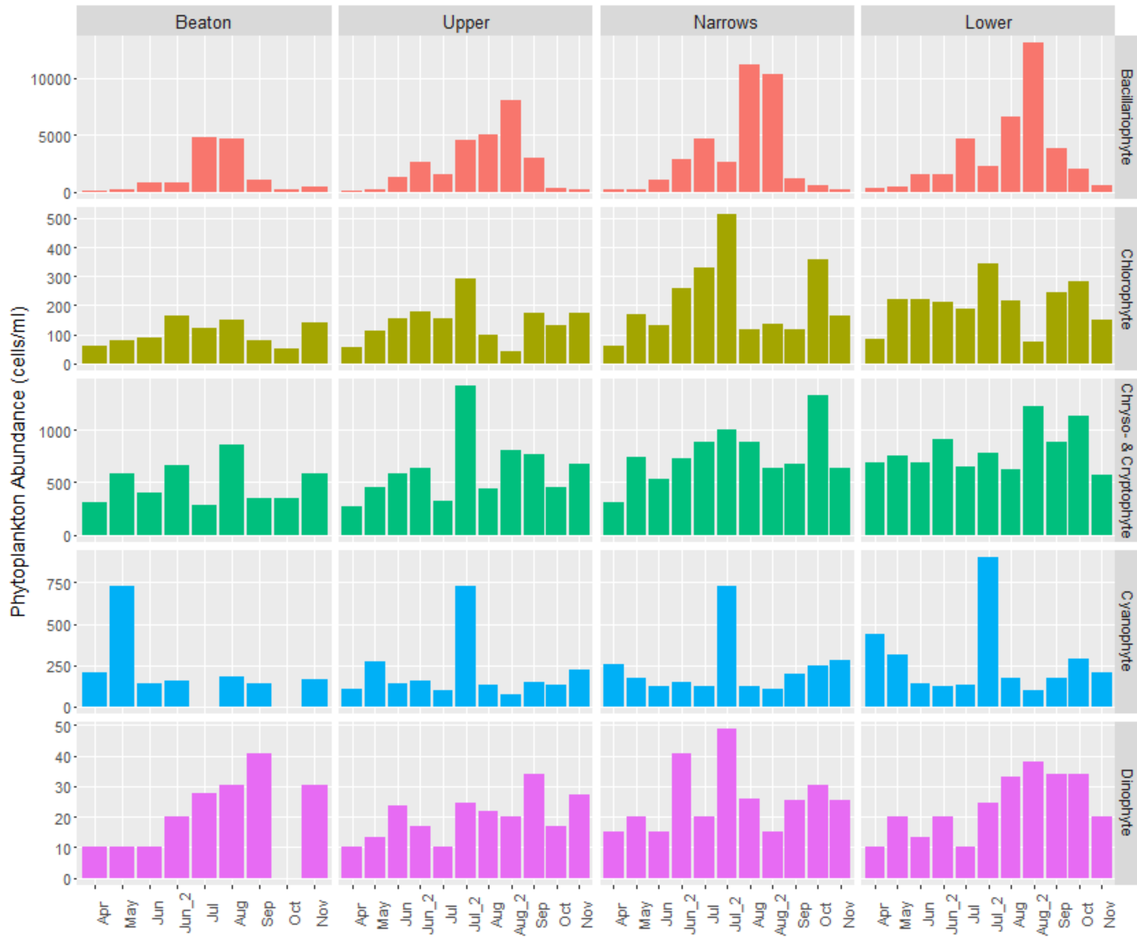


Figure 35. Phytoplankton group abundance (cells/ml) by basin (Beaton, Upper and Lower); Beaton Arm (HL 1), Upper (AR 1-3), the Narrows (AR 4-5) and Lower (AR 6-8) Arrow. April-November, 2015. July#2 and Aug#2 are AR 3, AR4 and AR 8 only. Note y scale changes by phytoplankton group.

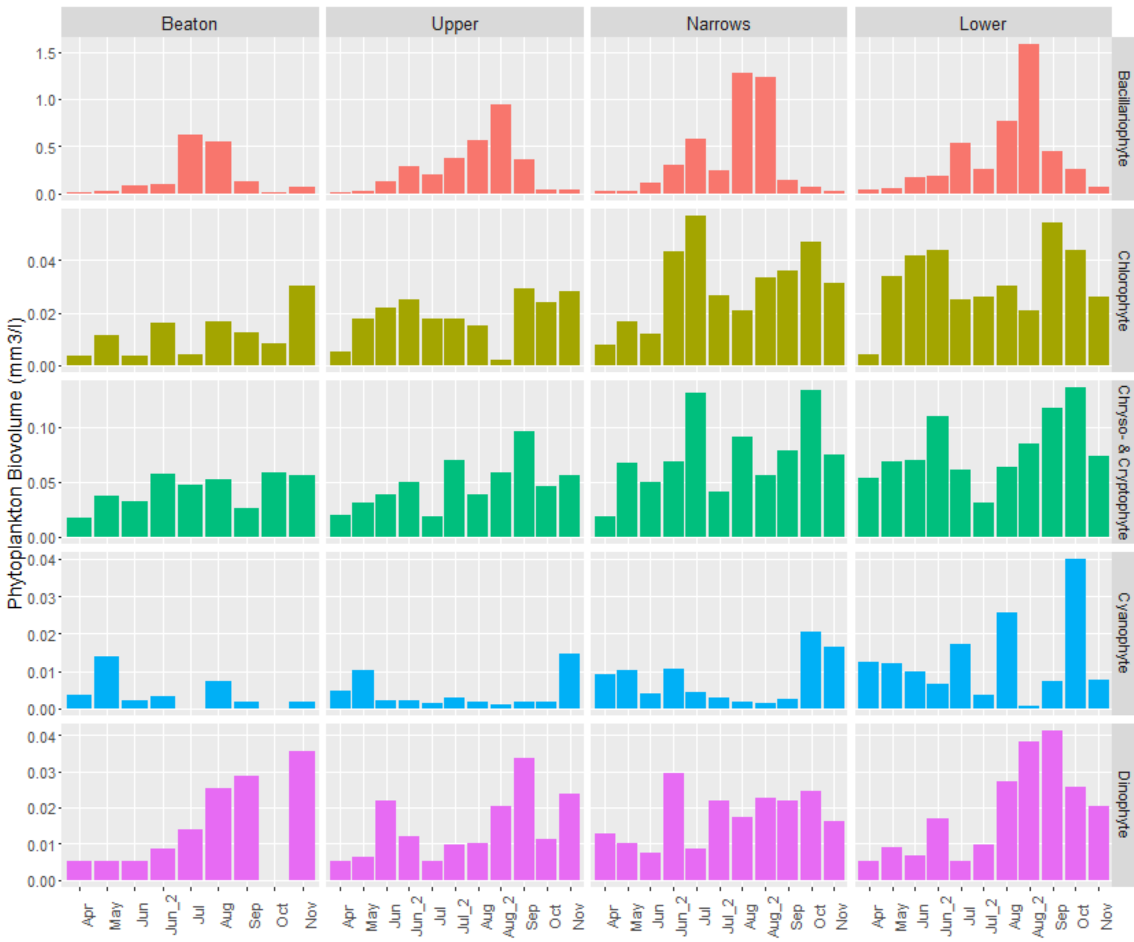


Figure 36. Phytoplankton group biovolume (mm^3/L) by basin (Beaton, Upper and Lower); Beaton Arm (HL 1), Upper (AR 1-3), the Narrows (AR 4-5) and Lower (AR 6-8) Arrow. April-November, 2015. July#2 and Aug#2 are AR 3, AR4 and AR 8 only. Note y scale changes by phytoplankton group.

Edible and Inedible Phytoplankton Abundance and Biovolume

Month and Basin trends in 2015

Abundance of edible versus inedible phytoplankton by basin for the 2015 season is shown in Figure 37, and biovolume by group in Figure 38. Edible phytoplankton abundance was highest in the Jul_2 sample in Upper Arrow, largely from edible chryso-cryptophyte and cyanophyte species. Inedible phytoplankton abundance was highest in the Aug_2 sample in Lower Arrow, largely from high counts of the diatom *Synedra nana.* Edible phytoplankton biovolume was highest in the Narrows in the July samples from high contributions of chryso-cryptophyte species. Inedible phytoplankton biovolume was highest in Lower Arrow in the Aug_2 sample, largely from high counts of the diatom *Synedra nana.*

Stations, Basins and Months were compared for differences; the Jul_2 and Aug_2 results were omitted from this analysis. Edible phytoplankton abundance and biovolume did not differ significantly by stations, however both abundance and biovolume was significantly higher in the Lower Basin compared to the Beaton Arm and Upper Basin. Inedible phytoplankton abundance and biovolume did not differ significantly by stations or by basins. The abundance and biovolume of edible phytoplankton was highest in the summer months. The abundance and biovolume of inedible phytoplankton was significantly higher in August.

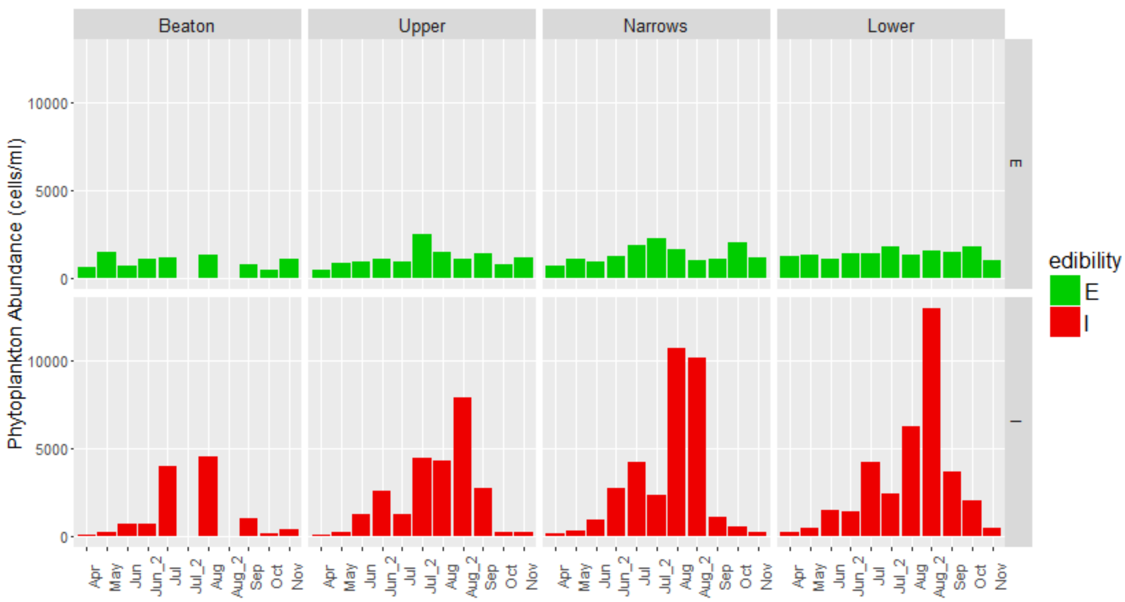


Figure 37. Abundance of edible (green) and inedible (red) phytoplankton by basin (Beaton, Upper and Lower); Beaton Arm (HL 1), Upper (AR 1-3), the Narrows (AR 4-5) and Lower (AR 6-8) Arrow. April-November, 2015. July#2 and Aug#2 are AR 3, AR4 and AR 8 only.

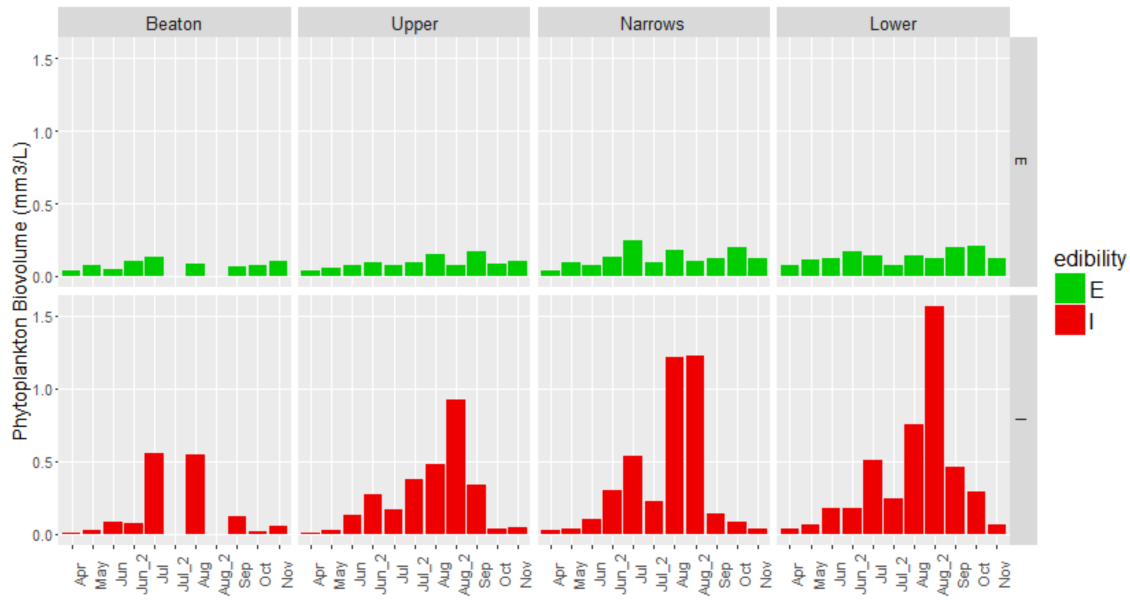


Figure 38. Biovolume of edible (green) and inedible (red) phytoplankton by basin (Beaton, Upper and Lower); Beaton Arm (HL 1), Upper (AR 1-3), the Narrows (AR 4-5) and Lower (AR 6-8) Arrow. April-November, 2015. July#2 and Aug#2 are AR 3, AR4 and AR 8 only.

Comparisons amongst years

Annual average edible and inedible phytoplankton (to zooplankton) abundance and biovolume for the reservoir between 1998 and 2015 is illustrated in Figures 39 and 40.

Edible phytoplankton abundance in 2015 decreased from 2014 (Fig. 39). The 2015 edible mean (1195 cells/ml) was significantly lower than the 1998-2014 pooled mean of 2561 cells/ml. Inedible phytoplankton abundance in 2015 increased from 2014. The 2015 inedible mean (2120 cell/ml) was significantly higher than the 1998-2014 pooled mean of 1469 cells/ml.

Biovolume of edible phytoplankton decreased from 2014 (Fig. 40). Edible phytoplankton biovolume previously showed little variation since 1998, varying minimally around 0.2 mm^3/L, however the edible mean in 2015 (0.12 mm^3/L) was significantly lower than the 1998-2014 mean of 0.2 mm^3/L. The reverse trend was observed with inedible phytoplankton, which increased from the previous year. However, the inedible mean in 2015 (0.26 mm^3/L) was not significantly different than the 1998-2014 mean of 0.22 mm^3/L. The highest phytoplankton biovolumes occurred in 2001, 2005 and 2011, all due to high contributions of inedible diatoms; *Asterionella formosa* and *Fragiliaria sp*. in 2001 and 2005, and *Syndera nana* and *Syndera acus* in 2011 (Fig. 40).

In Upper Arrow, the Narrows and in Lower Arrow, the 2015 abundance and biomass of edible phytoplankton decreased from the previous year (Fig. 41, Fig. 42). In Upper Arrow, the abundance and biomass of inedible phytoplankton decreased from 2014, whereas in Lower Arrow and the Narrows, abundance of inedible phytoplankton increased from the previous year.

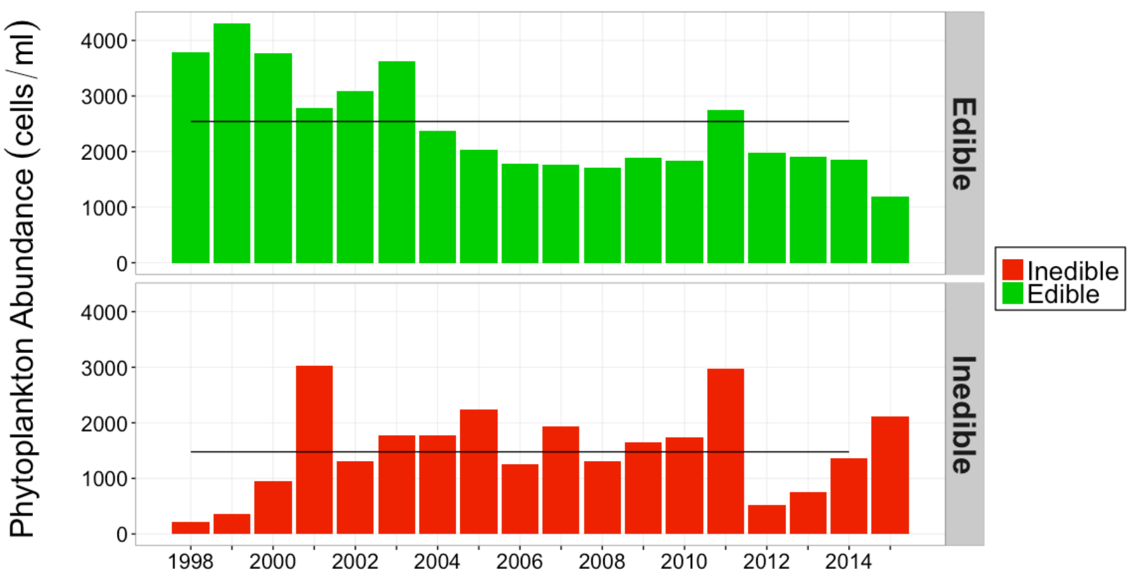


Figure 39. Annual mean abundance (cells/ml) of edible and inedible phytoplankton, stations AR 1-8, 1998-2015. Edible and inedible pooled 1998-2014 means (black lines).

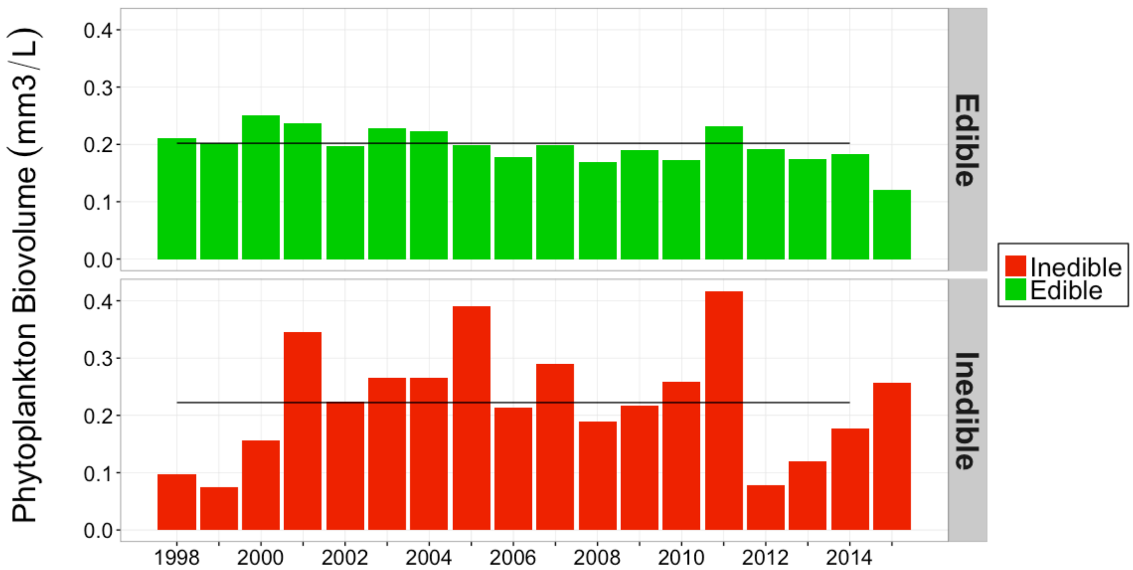


Figure 40. Annual mean biovolume (mm^3/L) of edible and inedible phytoplankton, stations AR 1-8, 1998-2015. Edible and inedible pooled 1998-2014 means (black lines).

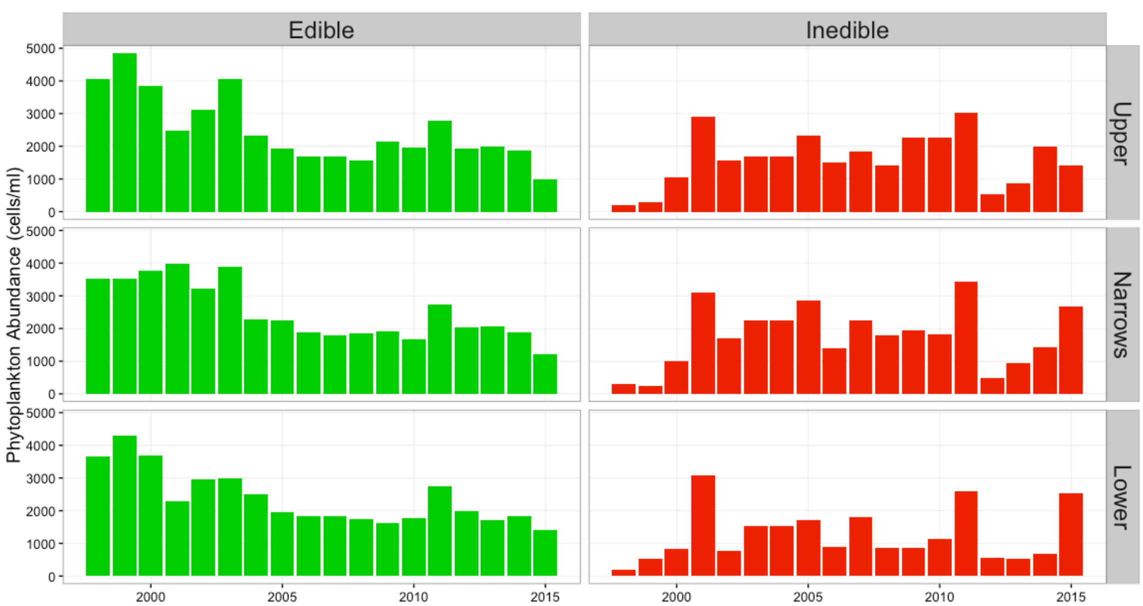


Figure 41. Annual mean edible (green) and inedible (red) phytoplankton abundance (cells/ml) at Upper Arrow (stations AR 1-3), narrows (stations AR 4 and 5) and Lower Arrow (stations AR 6-8), 1998-2054.

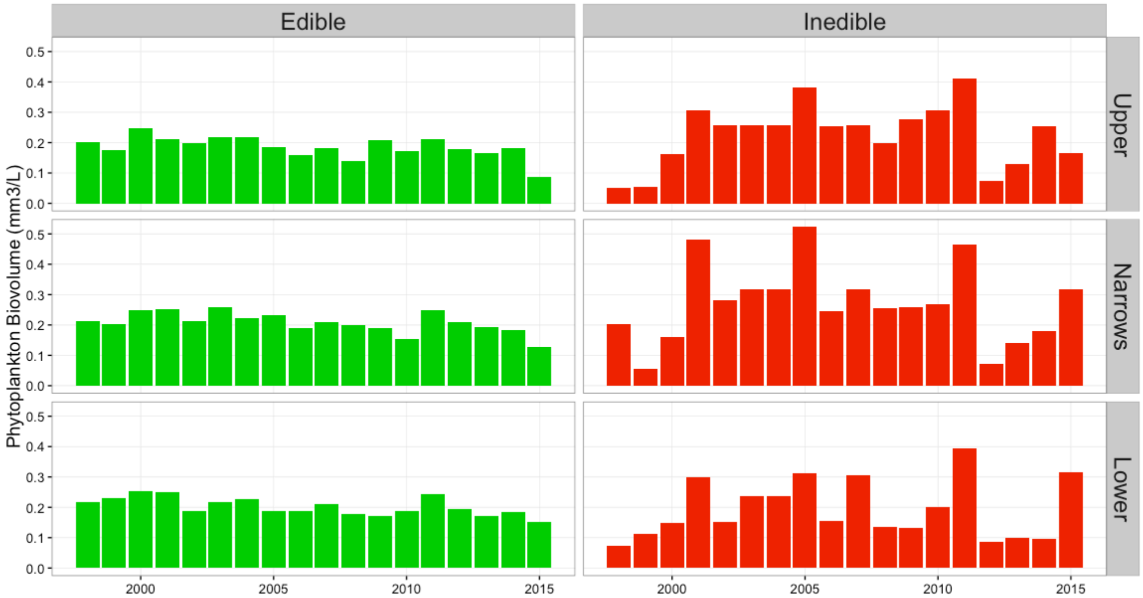


Figure 42. Annual mean edible (green) and inedible (red) phytoplankton biovolume (mm^3/L) at Upper Arrow (stations AR 1-3), narrows (stations AR 4 and 5) and Lower Arrow (stations AR 6-8), 1998-2015.

Zooplankton

Species

Twenty species of macrozooplankton were identified in the samples over the course of the 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. In 2015 three calanoid copepod species, *Epischura nevadensis* (Lillj.), *Leptodiaptomus ashlandi* (Marsh) and *Leptodiaptomus sicilis* (Forbes) were identified in samples from Arrow Lakes. Only one cyclopoid copepod species, *Diacyclops bicuspidatus thomasi* (Forbes), was identified during the same time period.

In 2015 the following Cladocera species were present: *Daphnia galeata mendotae* (Birge), *Daphnia pulex* (Leydig), *Daphnia longispina* (O.F.M.), *Daphnia schoedleri* (Sars), *Bosmina longirostris* (O.F.M.), *Leptodora kindtii* (Focke). Other rare species such as *Diaphanosoma brachyurum* (Lievin) and *Scapholeberis rammneri* (Dumont and Pensaert) were observed sporadically.

Density

The average zooplankton density in the Upper Arrow in 2015 was dominated by copepods which comprised 96% of zooplankton density with 3.62 individuals/L (Fig. 43). Other cladocerans comprised 3% of zooplankton density with 0.21 individuals/L, while *Daphnia* sp. contributed to only 1% with 0.09 individuals/L. In the Lower Arrow, the composition was similar with 92% copepods (16.64 individuals/L), 3 % *Daphnia* sp. (0.62 individuals/L) and 5% cladocerans other than *Daphnia* sp. (0.88 individuals/L). At station HL1 copepods comprised 97% (8.11 individuals/L), *Daphnia* sp. 1% (0.09 individuals/L) and cladocerans other than *Daphnia* sp. 2% (0.20 individuals/L) of the total zooplankton density.

The average zooplankton density in Upper Arrow decreased in 2015 to 6.61 individuals/L from 13.68 individuals/L in 2014, as well as in Lower Arrow to 18.14 individuals/L in 2015 from 21.44 individuals/L in 2014 (Fig. 44).

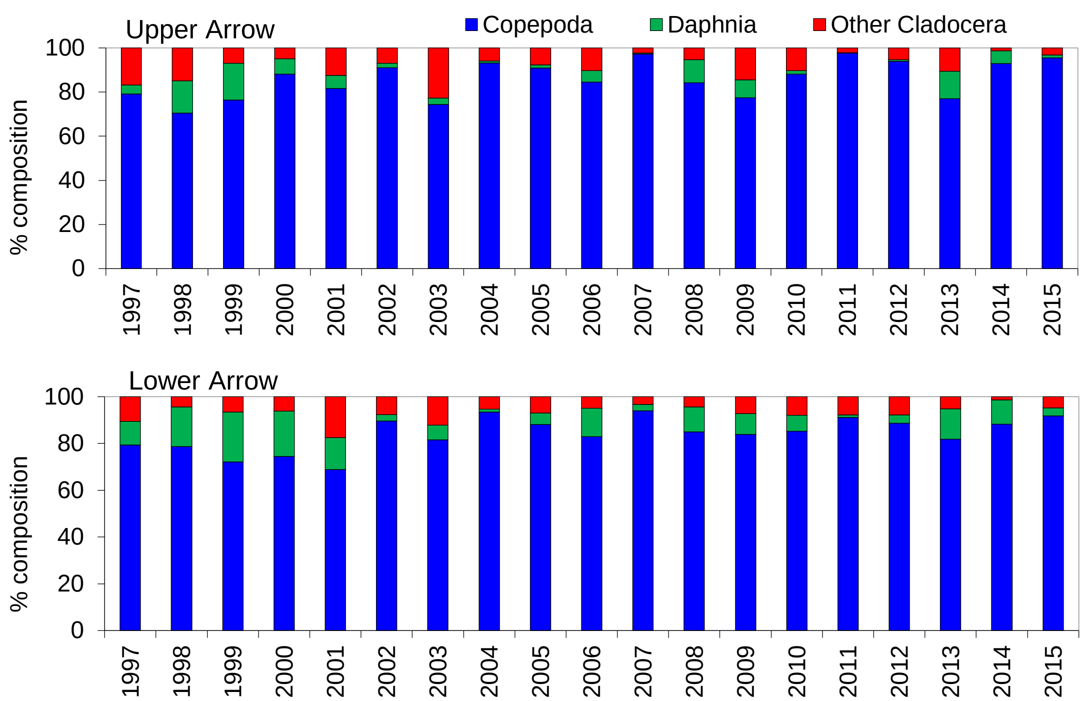


Figure 43. Seasonal composition of zooplankton as a percentage of average density in the Arrow Lakes, 1997 to 2015.

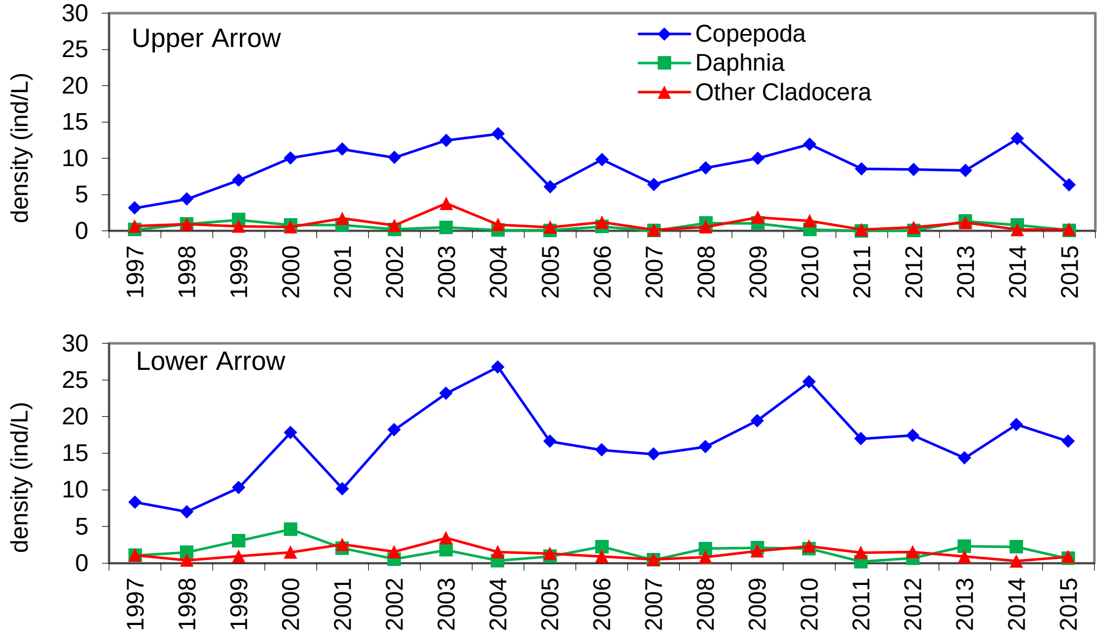


Figure 44. Seasonal average zooplankton density in Arrow Lakes 1997 to 2015.

Biomass

The average zooplankton biomass in Upper Arrow in 2015 was comprised of 83% copepods (9.31 ug/L), 12% *Daphnia* sp. (1.32 ug/L), and 5% cladocerans other than *Daphnia* sp. (0.52 ug/L) (Figs. 45 and 46). Lower Arrow favoured a higher composition of *Daphnia* sp., which comprised 26% of zooplankton biomass (8.99 ug/L), while copepods made up 70% (24.09 ug/L), and cladocerans other than *Daphnia* sp. only 4% (1.54 ug/L). At station HL1, copepods comprised 91% (16.28 ug/L), *Daphnia* sp. 7% (1.19 ug/L) and cladocerans other than *Daphnia* sp. 2% (0.35 ug/L) of the total zooplankton biomass.

The average zooplankton biomass decreased among all stations in 2015 compared to the previous year. In Upper Arrow it decreased threefold from 34.26 ug/L in 2014 to 11.14 ug/L in 2015, in Lower Arrow from 69.03 ug/L to 34.62 ug/L, and at station HL1 from 22.14 ug/L to 17.82ug/L (Fig. 46).

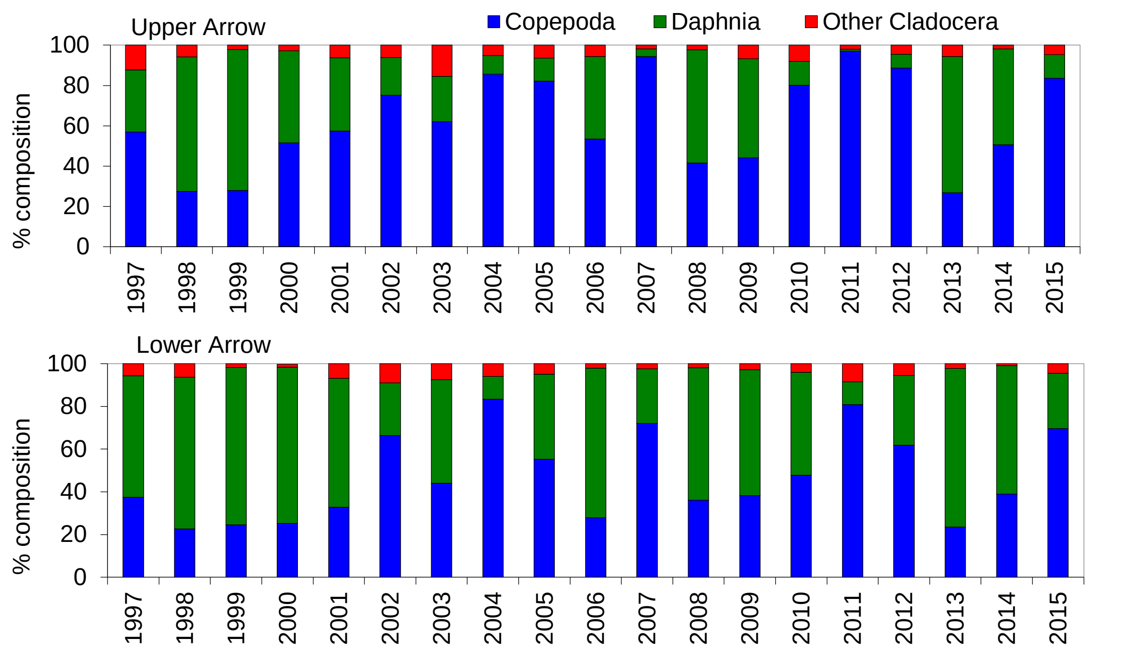


Figure 45. Seasonal composition of zooplankton as a percentage of average biomass in the Arrow Lakes 1997 to 2015.

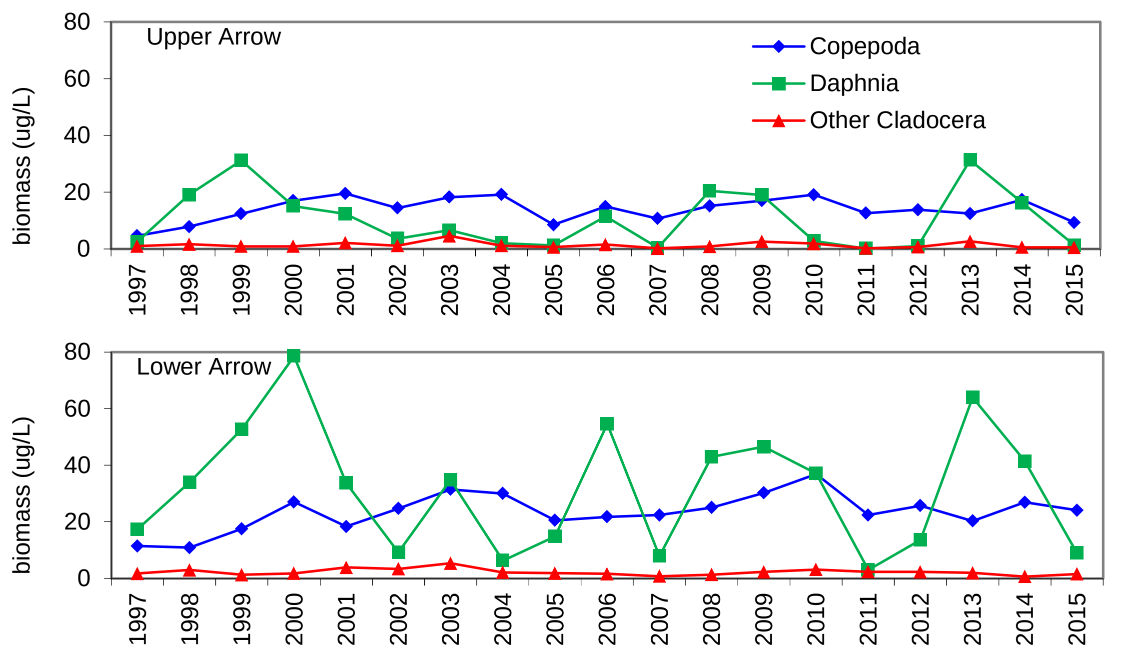
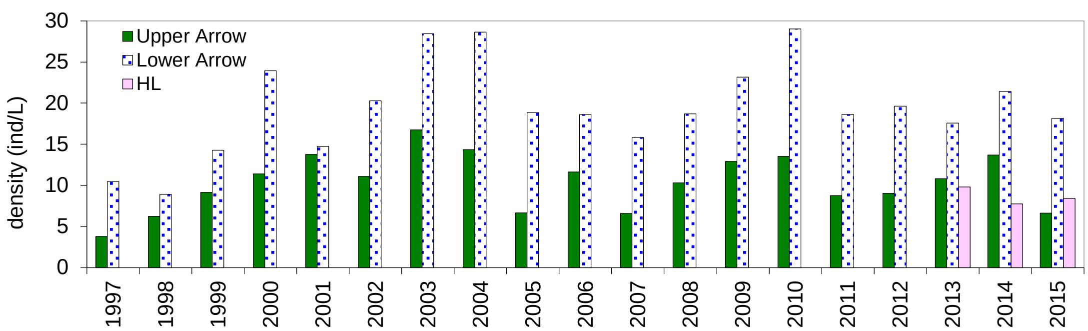


Figure 46. Seasonal average zooplankton biomass in Arrow Lakes 1997 to 2015.

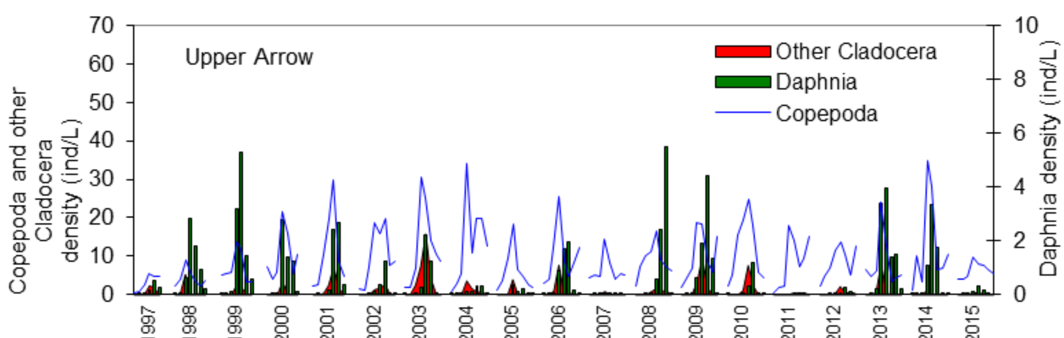
Seasonal and lake patterns

Copepods were the main contributor to the overall zooplankton population during the entire sampling season with *Daphnia* appearing in May, peaking in July-August and maintaining a population through November. This pattern occurred both in Upper and Lower Arrow in 2015 (Fig. 47 for abundance and Fig. 48 for biomass). Copepods dominated abundance and biomass throughout the sampling season in 2015. This is not the typical trend observed in other years, where *Daphnia* dominated total zooplankton biomass from July-August through October.

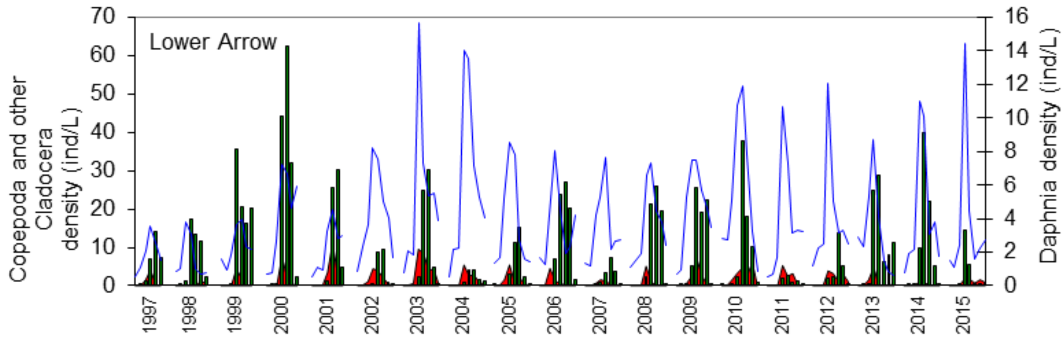
Total zooplankton density was higher in Lower Arrow than Upper Arrow in 2015, a pattern that is repeated in each studied year. The average density in Lower Arrow was more than double than that of station HL1, which in turn had slightly higher zooplankton density than Upper Arrow. Total zooplankton biomass was three times higher in Lower Arrow than in Upper Arrow, while at station HL1 biomass was almost two times lower than the Lower Arrow and slightly higher than biomass in Upper Arrow.



a. Seasonal average density of total zooplankton in Arrow Lakes 1997 to 2015.

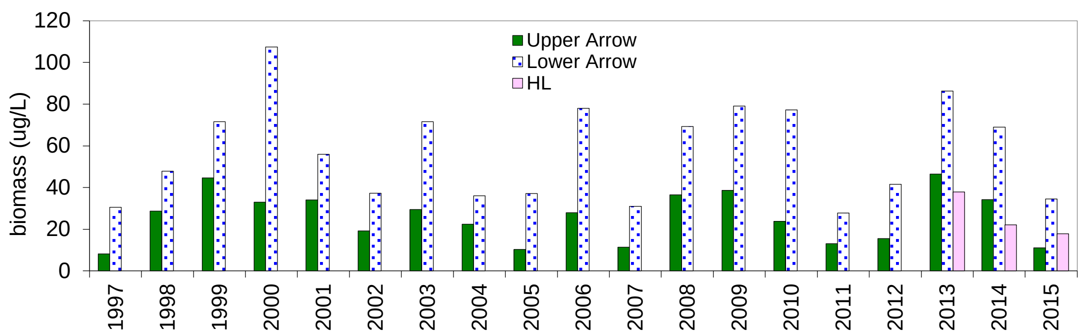


b. Seasonal density of zooplankton in Upper Arrow 1997 to 2015.

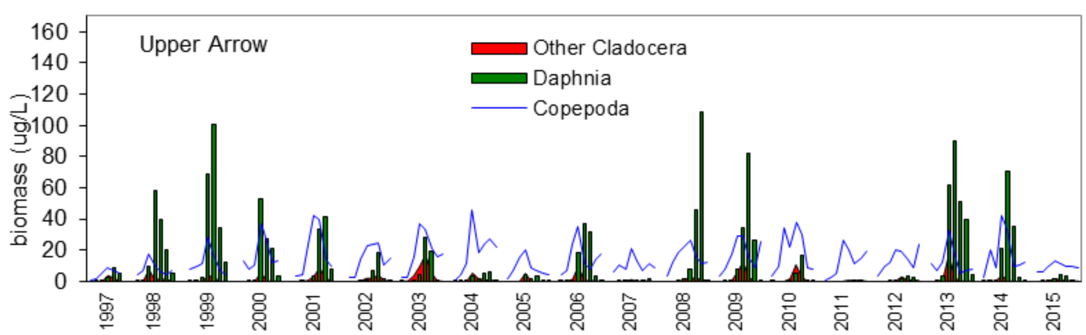


c. Seasonal density of zooplankton in Lower Arrow 1997 to 2015.

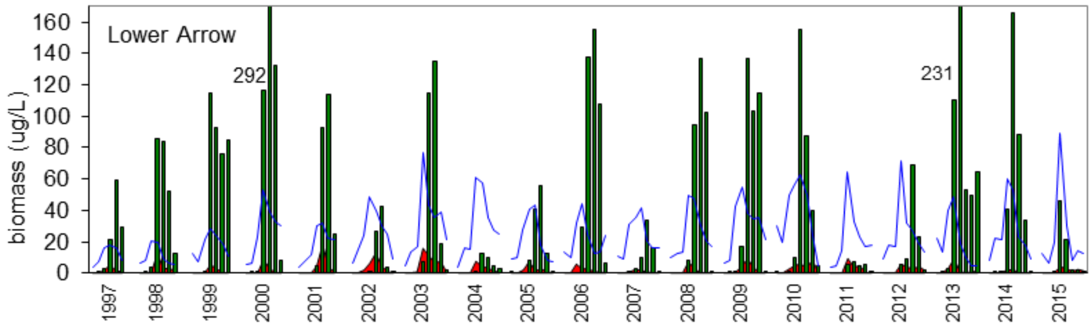
Figure 47. Zooplankton density in Arrow Lakes 1997 to 2015.



a. Seasonal average biomass of zooplankton in Arrow Lakes 1997 to 2015.



b. Seasonal biomass of zooplankton in Upper Arrow 1997 to 2015.



c. Seasonal biomass of zooplankton in Lower Arrow 1997 to 2015.

Figure 48. Zooplankton biomass in Arrow Lake 1997 to 2015.

2015 Monthly Results

When comparing densities by months, results were similar amongst stations in Lower Arrow, while in Upper Arrow density at station AR 3 was higher than other stations from August through October (Fig. 49). Biomass results were similar among stations during all months in Lower Arrow, while in Upper Arrow biomass fluctuated and differed from station to station throughout the sampling season.

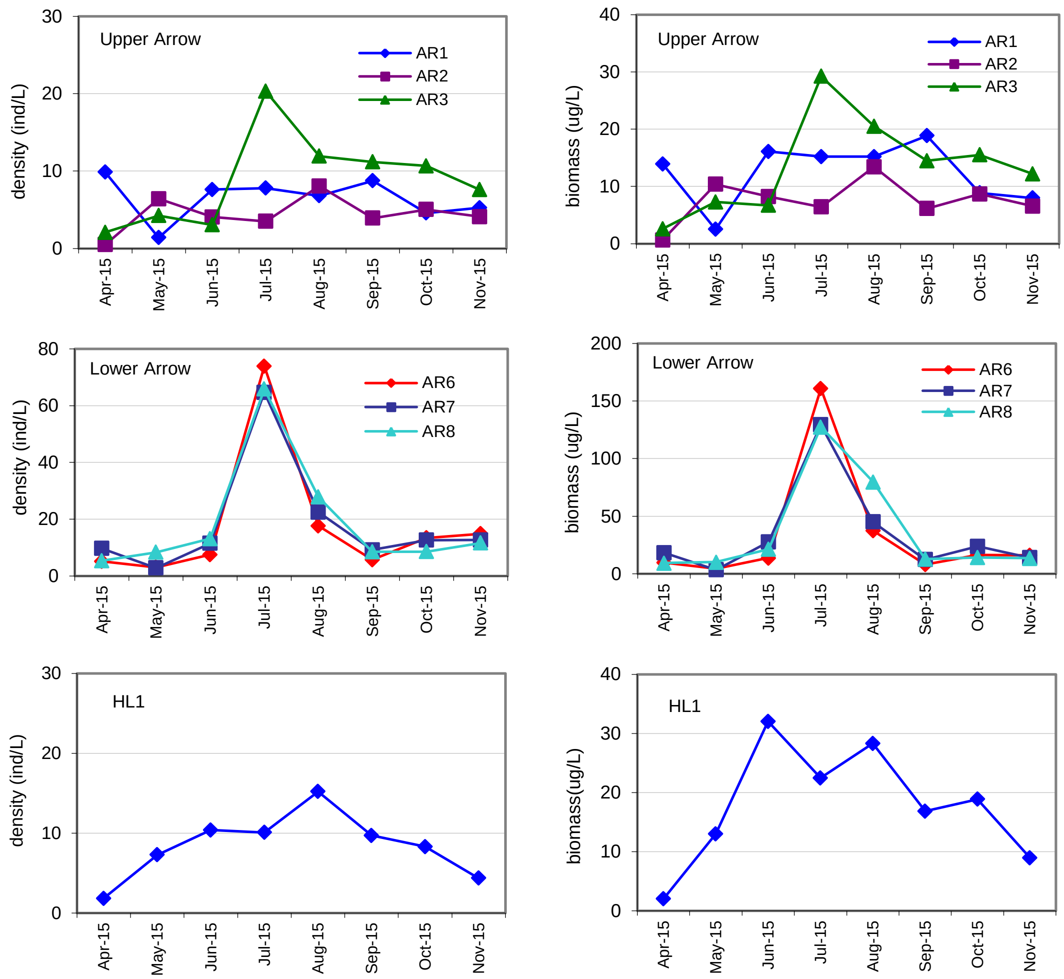


Figure 49. Total zooplankton density and biomass at each station in Arrow Lakes, April to November 2015.

Mysis diluviana

Density

Density of Mysis diluviana fluctuated over the course of the studied years. In 2015, densities of mysids decreased in Upper and Lower Arrow (Fig. 50), and increased at station HL1 in comparison to the 2014 results. Average densities were higher in Lower than the Upper Arrow, a similar trend that was consistent from 1997-2001, 2006-2008 and 2012-2014 (Fig. 51). The peak density in 2015 in Upper Arrow occurred in November at station AR3 with 574 ind/L, mainly due to an increased number of juveniles and mature males and females. In Lower Arrow the peak density occurred in

October at station AR8 with 502 ind/L, mainly due to an increased number of mature males, and immature males and females (Figs. 52 and 53).

In both Arrow Lakes, Upper and Lower, seasonal average mysid densities during the nutrient addition period (1999 through 2015) were higher than results from pre nutrient addition period 1997-1998 (Fig. 51). During the nutrient addition period, the highest density was observed in 2010 in Upper Arrow and 2009 in Lower Arrow. From 1997 to 2004, sampling of mysids began in January and continued until December, in 2005 samples were not collected in January, while in 2006 samples were not collected in January and December. From 2007 to 2015 samples were collected for eight months from April to November. Annual average data for each year represent the eight month period from April to November.

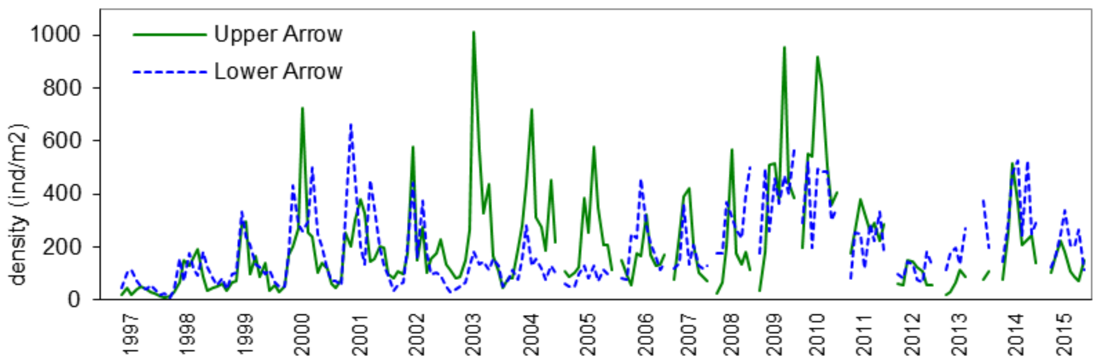


Figure 50. Seasonal average density of Mysis diluviana in Arrow Lakes (1997 to 2015).

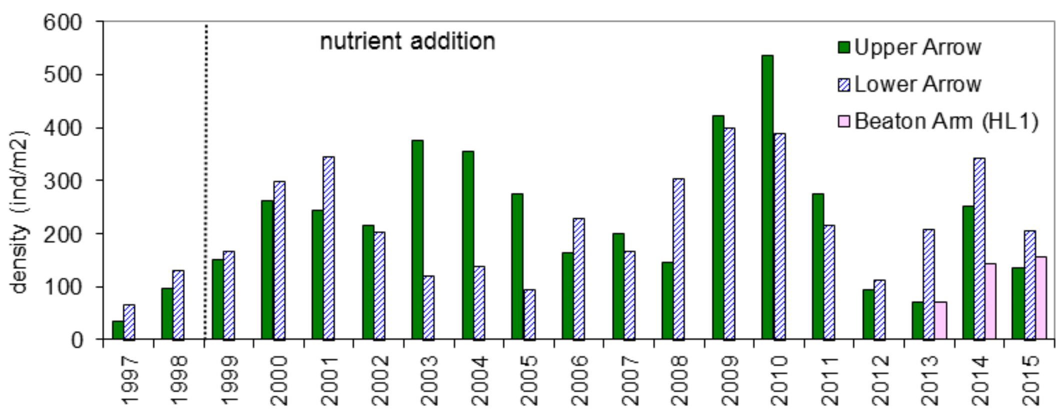


Figure 51. Annual average density of Mysis diluviana in Arrow Lakes 1997 to 2015. Averages calculated from April to November.

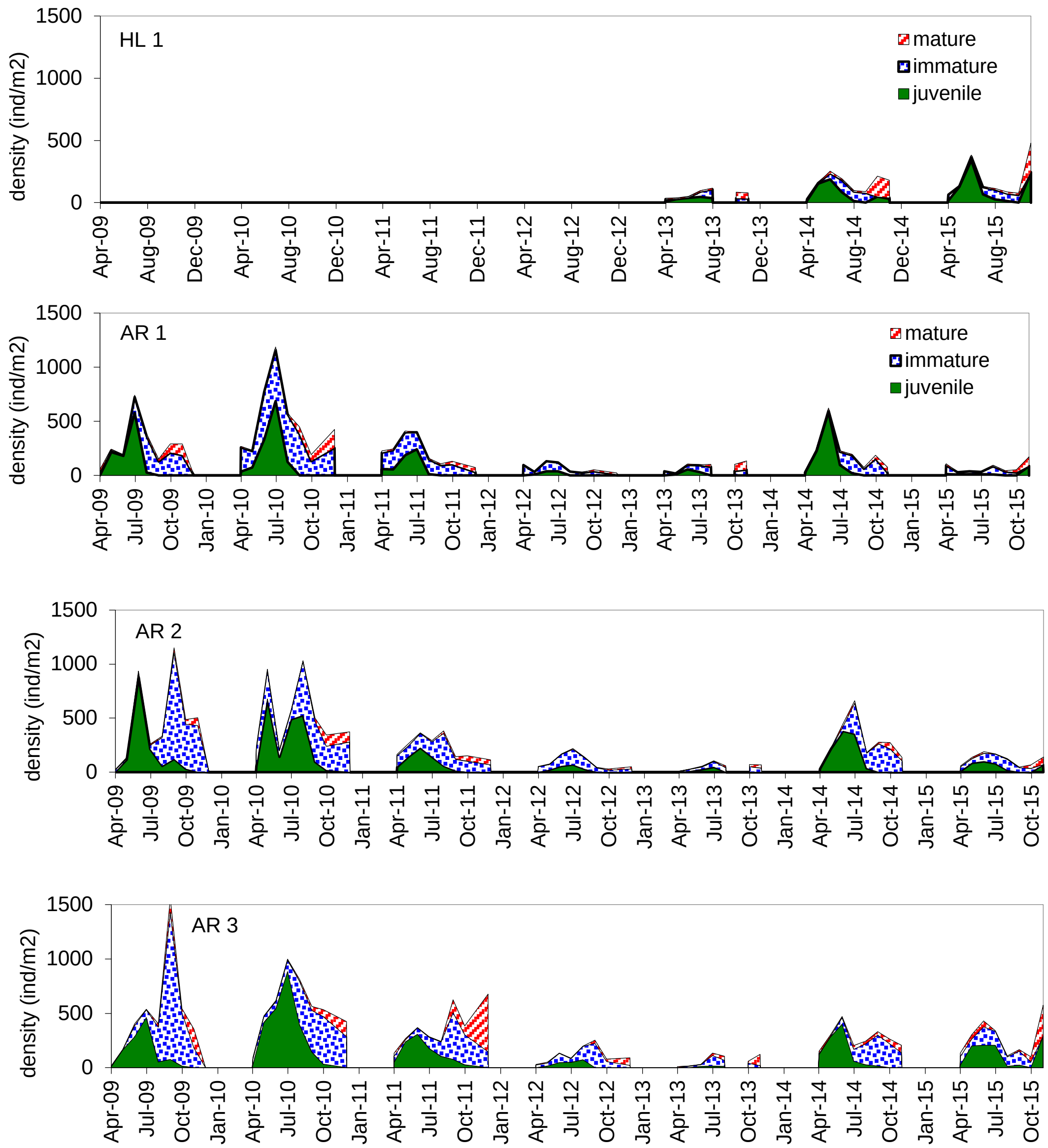


Figure 52. Densities of developmental stages of Mysis diluviana in Upper Arrow 2009 to 2015.

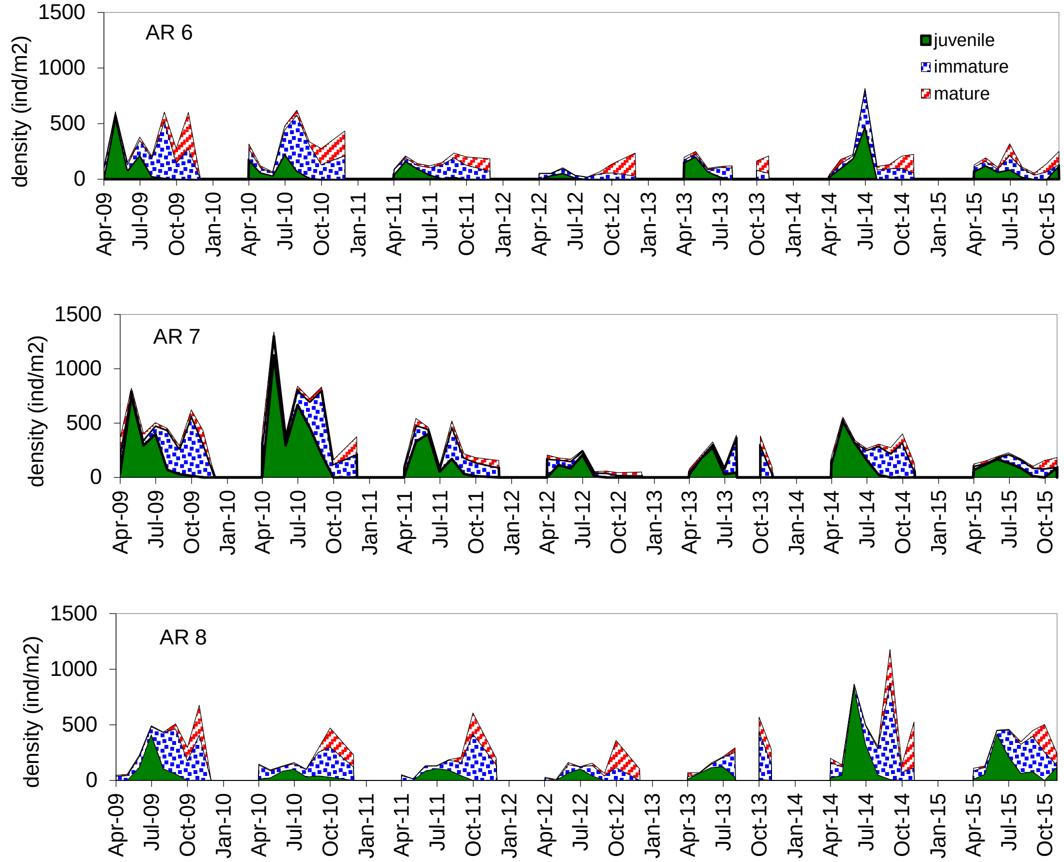


Figure 53. Densities of developmental stages of Mysis diluviana in Lower Arrow 2009 to 2015.

Biomass

Average mysid biomass decreased in 2015 compared to 2014 (Fig. 54). Biomass was higher in Lower Arrow than in Upper Arrow (Fig. 55), and at station HL1 biomass was lower than in both Arrow Lakes. 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 from April through July of each year (Figs. 56 and 57). 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). Peak biomass in 2015 in Upper Arrow occurred in November at sampling station AR3 with 4454.66 mg/m2, and in Lower Arrow in October at station AR8 with 4298.28 mg/m2. Mysid biomass at station HL1 was lower than in the Upper or Lower Arrow. The highest biomass at this station was found in November with 2754.09 mg/m2. The majority of biomass at all stations was comprised of juveniles and the mature males and females.

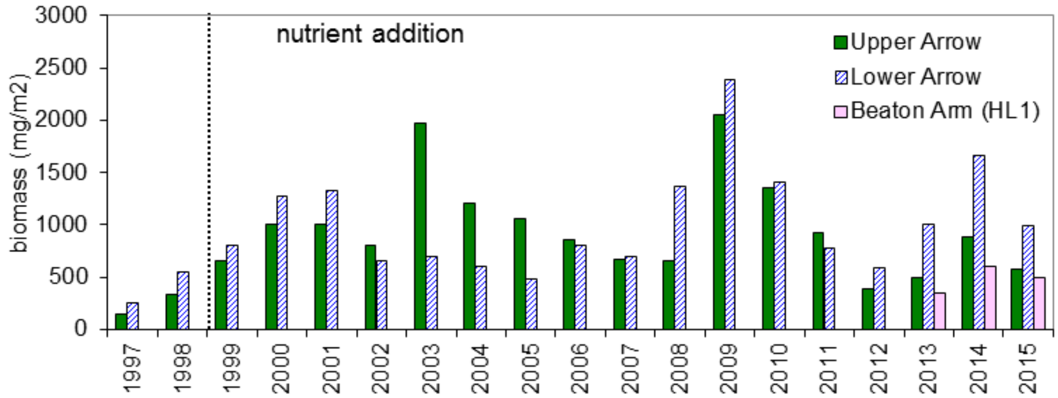


Figure 54. Annual average density of Mysis diluviana in deep sites in Arrow Lakes 1997 to 2015. Averages calculated from April to November.

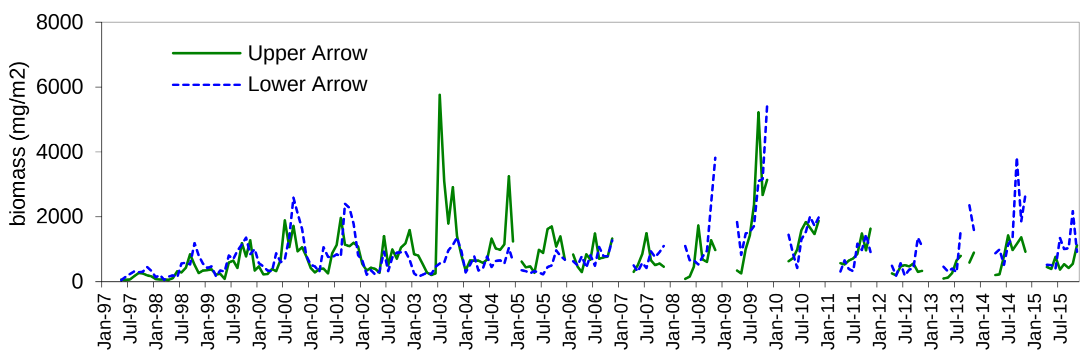


Figure 55. Seasonal average biomass of Mysis diluviana at pelagic stations in Arrow Lakes (1997 to 2015).

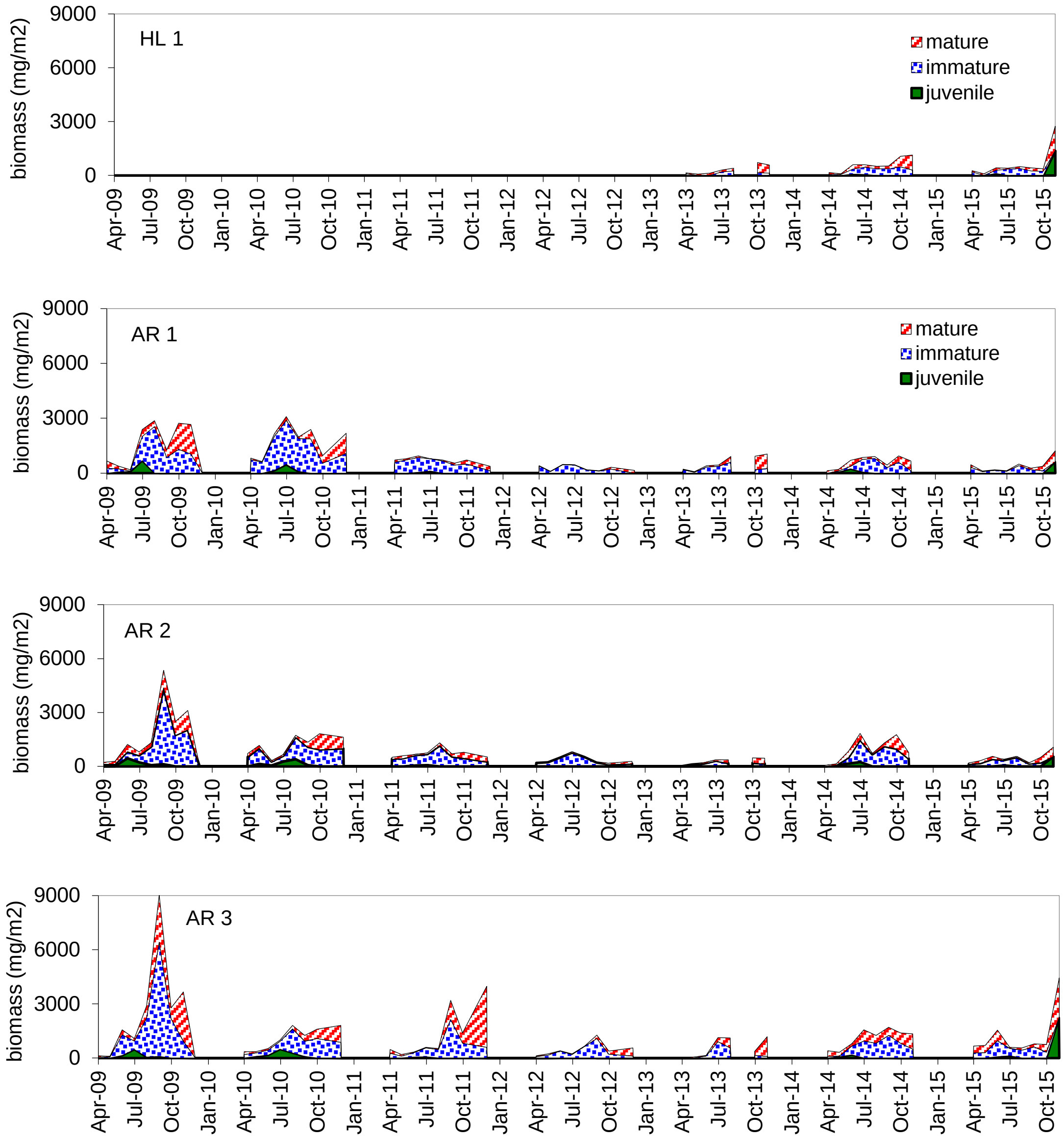


Figure 56. Biomass of developmental stages of Mysis diluviana at deep sites, Upper Arrow, 2009 to 2015.

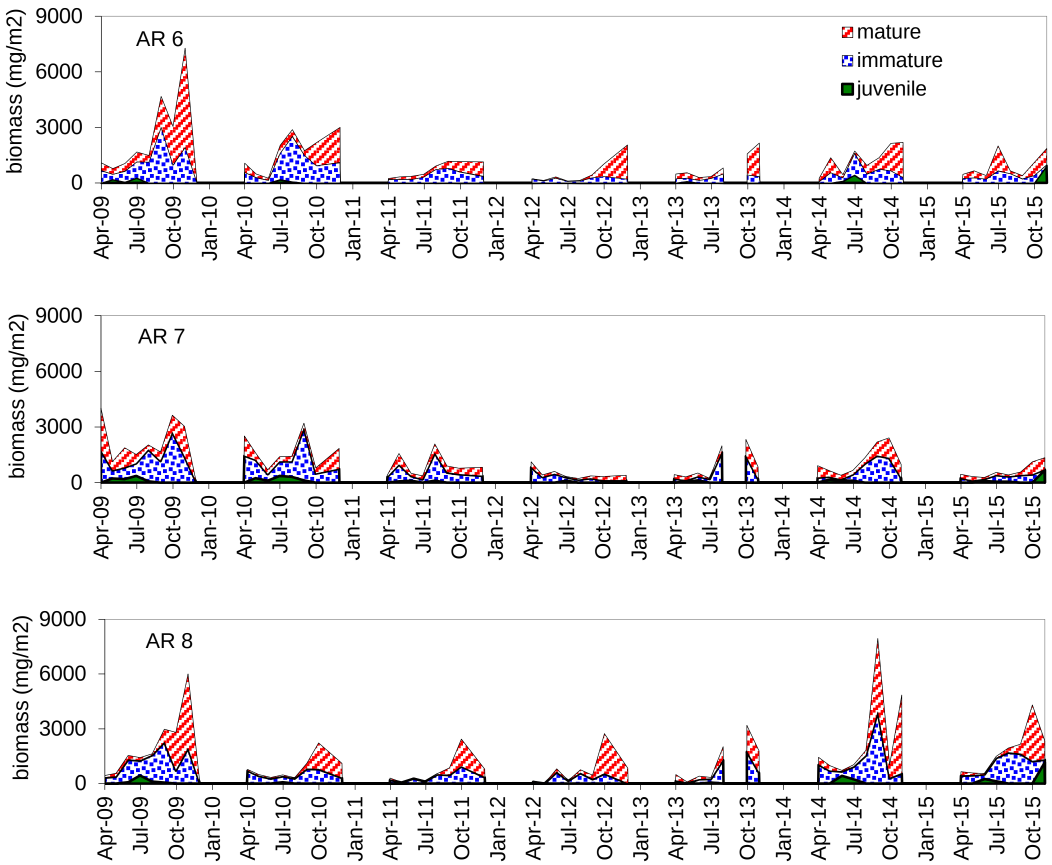


Figure 57. Biomass of developmental stages of Mysis diluviana at deep sites, Lower Arrow, Kootenay Lake, 2009 to 2015.

Kokanee

The following results and discussion pertain to the Kokanee component of the Arrow Lakes Reservoir nutrient restoration program.

Water level and flow

Pool elevation during the October 7-17, 2015 survey period was 428.58 m (11.7 m below full pool). Compared to other years, pool elevation at the time of the 2015 survey was 5.3 m below the average for fall surveys and was the lowest since 2001. The total area of pelagic habitat (i.e. >20m depth) was estimated at 193 km^2 in Upper Arrow and 91 km^2 in Lower Arrow and was approximately 2% lower than the long-term average for fall surveys (Appendix 9). Arrow Lakes Reservoir levels were low because of the high water releases called for by the Columbia River Treaty that were triggered by dry conditions south of the US border (Columbia River Operations Summary – spring 2016). Additional release of water from Kinbasket Reservoir was used to mitigate drawdown in Arrow Reservoir during summer and fall of 2015. As a result, water flow through Arrow Reservoir was higher than average, and more similar to 2012 than to 2013 and 2014 as shown by the April to October outflows records at Hugh Keenleyside Dam (Fig. 5).

Trawl catch

A total of 561 kokanee were captured at the six standard trawl stations in 2015; 223 from Upper Arrow and 338 from Lower Arrow (Table 6). An additional 28 kokanee were captured near Halcyon (Transect 5) with a non-standard (3x7m) trawl net. Non-target species included three pygmy whitefish in Lower Arrow; one at Edgewood and two at Cayuse.

The additional non-standard trawling conducted at Halcyon occurred to verify a localized concentration of age 1-3+ fish observed during the acoustic survey, and to increase total catch sample size for greater confidence in biological statistics for Upper Arrow. The additional trawling more than doubled the total sample size from all three standard stations combined in Upper Arrow, and confirmed that this aggregation was predominantly age 1+ fish. The additional trawling sampled the entire age 1-3+ fish layer using the oblique tow method, and as such is considered comparable to the standard trawling for estimating age structure within the age 1-3+ population component. The additional trawling samples are pooled with the standard trawl catch for determination of age structure and mean length/weight estimates in this report.

In 2015, the Upper Arrow trawl catch (standard trawl sampling only) was 202, 17, and 4 for ages 0+, 1+, and 2+ respectively (Table 6). In Lower Arrow, the standard trawl sampling produced catches of 197, 118, and 23 for ages 0+, 1+, and 2+ respectively. The age 1+ catch in Lower Arrow in 2015 was the highest on record and 5 times higher than the post fertilization average of 24.

Table 6. Kokanee catch statistics from the trawl surveys in October 2015.

Basin	Station	Hauls	age 0	age 1	age 2	age 3	Total
Upper Arrow	T1 Albert Pt.	3	135	10	0	0	145
Oct-15	*T2a Halcyon*	*2*	*6*	*21*	*1*		*28*
	T2 Halfway R.	3	48	2	1	0	51
	T3 Nakusp	3	19	5	3	0	27
	Total of Upper	11	208	38	5	0	251
	Percent (%) by age		*83*	*15*	*2*	*0*	*100*
Lower Arrow	T6 Johnston Cr.	3	107	101	21	2	231
Oct-14	T7 Bowman Cr.	3	43	11	1	0	55
	T8 Cayuse Cr.	3	47	5	0	0	52
	Total of Lower	9	197	117	22	2	338
	Percent (%) by age		*58*	*35*	*6.4*	*0.6*	*100*
Total Arrow	**Both basins**	**20**	**405**	**155**	**27**	**2**	**589**
2015	*Percent (%) by age*		*69*	*26*	*5*	*0.3*	*100*

Note: T2a Halcyon was an additional and non-standard station

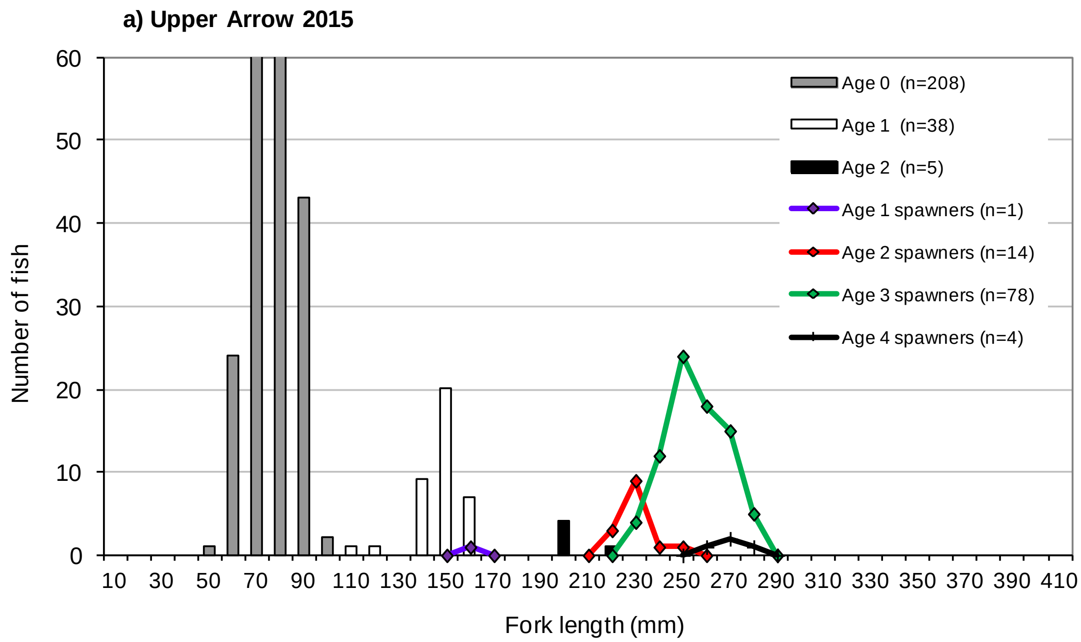
Size and age interpretation

Compared with 2014, the trawl samples in 2015 were much easier to age since fry and age 1+ both showed strong modes. Instead of two modes (130 and 200mm in 2014), age 1+ fish in both Upper and Lower Arrow showed a single strong mode at 150mm (Fig. 58). Age 2+ fish ranged from 180-220mm, (except for one fish at 149mm), with a single mode at 200mm (based on 10mm intervals) in both Upper and Lower Arrow. Compared with 2014, modes of age 1+ and 2+ fish have shifted to the left indicating slower rates of growth for both Upper and Lower Arrow.

Fry in Upper Arrow were significantly larger than in Lower Arrow in 2015, which is exceptional and has only occurred, to a similar degree, two times since 1989 (1993 & 1997). Closer inspection shows a bimodal distribution of fry in Upper Arrow with modes at 65mm and 85mm while Lower Arrow showed a single mode at 70mm (Fig. 59). A comparison of fry size distribution in Upper and Lower Arrow over the last four consecutive survey years illustrates that fry were typically smaller in Upper Arrow. The majority of large fry were captured at Albert Point in 2015, the northernmost trawl station. It is possible that the large fry mode is comprised of entrained fish from Revelstoke Reservoir that entered Upper Arrow from the Revelstoke Flats area (see Discussion section).

Age specific length frequencies for spawning kokanee from Hill Creek in Upper Arrow and from Deer and Taite Creeks in Lower Arrow were consistent with trawl age specific length frequencies for Upper and Lower Arrow respectively (Fig. 58a, 58b). The majority of spawners were age 3+ in both basins and were centered around 250mm or approximately 50mm larger than the average age 2+ fish in the trawl. A component of age 2+ spawners overlapped in size with the smaller age 3+ spawners in both basins. The Upper basin had very few age 4+, which overlapped the upper end of the age 3+

distribution. In contrast, there was a higher proportion of age 4+ spawners in Lower Arrow and the majority were larger than the age 3+ fish. The age 2+ spawners were slightly larger than age 2+ trawled fish suggesting that the larger individuals from this cohort spawned. This continues to support the notion of a minimum size requirement for full maturation. The only exception was one very small (161mm) spawner from Upper Arrow, which appeared to be age 1+. Although it appears to have been aged correctly as it aligned well with trawl caught age 1+ fish, it is highly unusual to find a mature kokanee at such a small size in Arrow Reservoir.



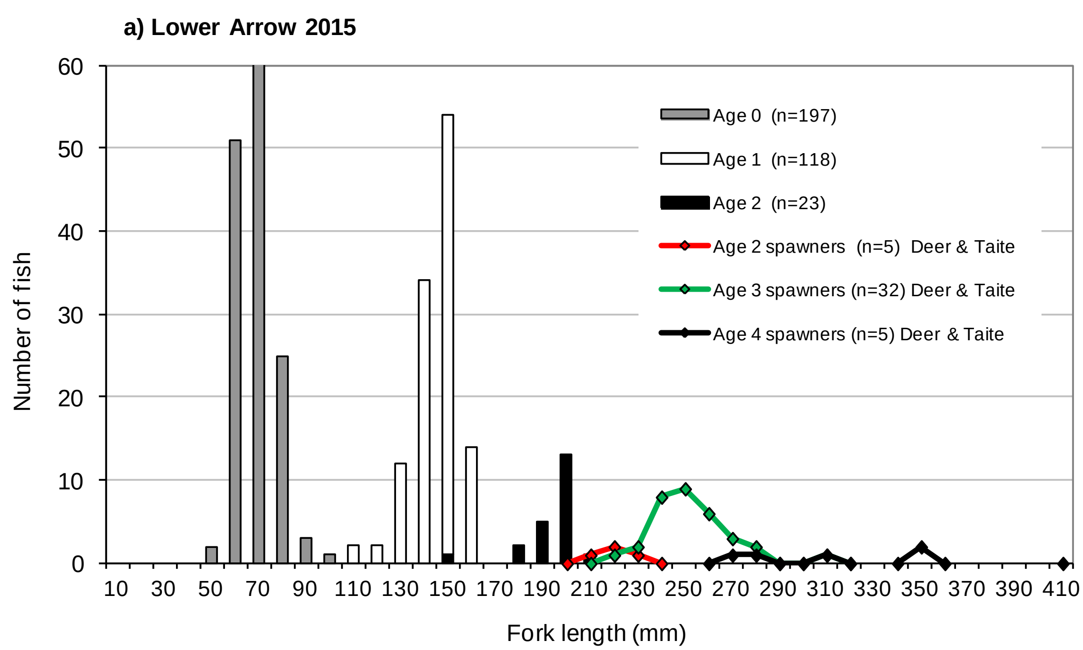


Figure 58. Kokanee length frequency for a) Upper Arrow and b) Lower Arrow basins by age from 2015 trawl sampling with ages verified by scale interpretation. Included are spawner samples collected from Hill Creek (Upper Arrow) and Deer and Taite creeks (Lower Arrow) with ages verified by otolith interpretation.

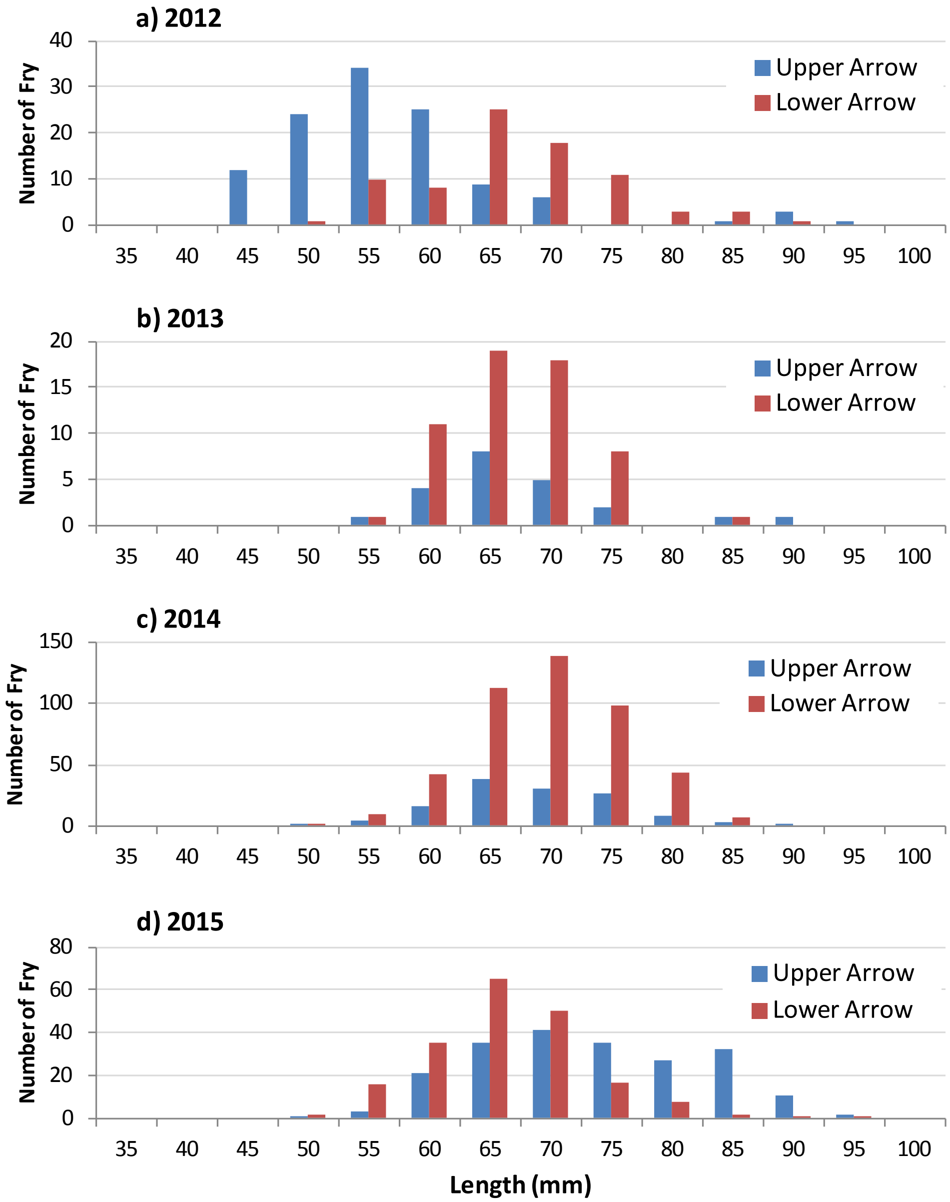


Figure 59. Comparison of fry size in Upper and Lower Arrow based on trawl captures over the last four years (2012-2015).

Kokanee size statistics for trawl caught fish are presented in Table 7. In Upper Arrow the average fork length (± 2SE) adjusted to October 1 was 68 ± 1.2mm for age 0+, 143 ± 2.8mm for age 1+ and 199 ± 6.8mm for age 2+ fish. The size of age 1+ and age 2+ fish were smaller than in 2014, but the difference was not significant largely due to wide bounds on the 2014 estimates. By contrast, the fry in Upper Arrow were significantly larger in 2015 than Lower Arrow. In Lower Arrow the average fork (± 2SE) was 64 ± 0.9mm for age 0+, 140 ± 1.8mm for age 1+, 189 ± 4.8mm for age 2+ and 202 ± 13mm for age 3+ fish. Compared with 2014, age 0+ fish in 2015 were the same size while age 1+ and 2+ fish were significantly smaller.

Table 7. Kokanee size statistics from the October 2015 trawl surveys corrected to Oct. 1

Survey time	Basin	Station	Age 0	Age 1	Age 2	Age 3
October 2015	Upper	Ave. length (mm)	68	143	199	
		Length range (mm)	44-88	110-154	194-213	
		Standard deviation	9	8.7	7.7	
		Sample size (n)	208	38	5	0
October 2015	Lower	Ave. length (mm)	64	140	189	202
		Length range (mm)	47-87	100-155	149-202	196-209
		Standard deviation	6.5	10	11.3	9.1
		Sample size (n)	197	117	22	2

In contrast with 2014, a combination of larger sample sizes and single mode length distributions resulted in improved precision for kokanee mean size at age estimates in 2015 from the trawl sampling as shown by tighter bounds in 2015 (Fig. 60).

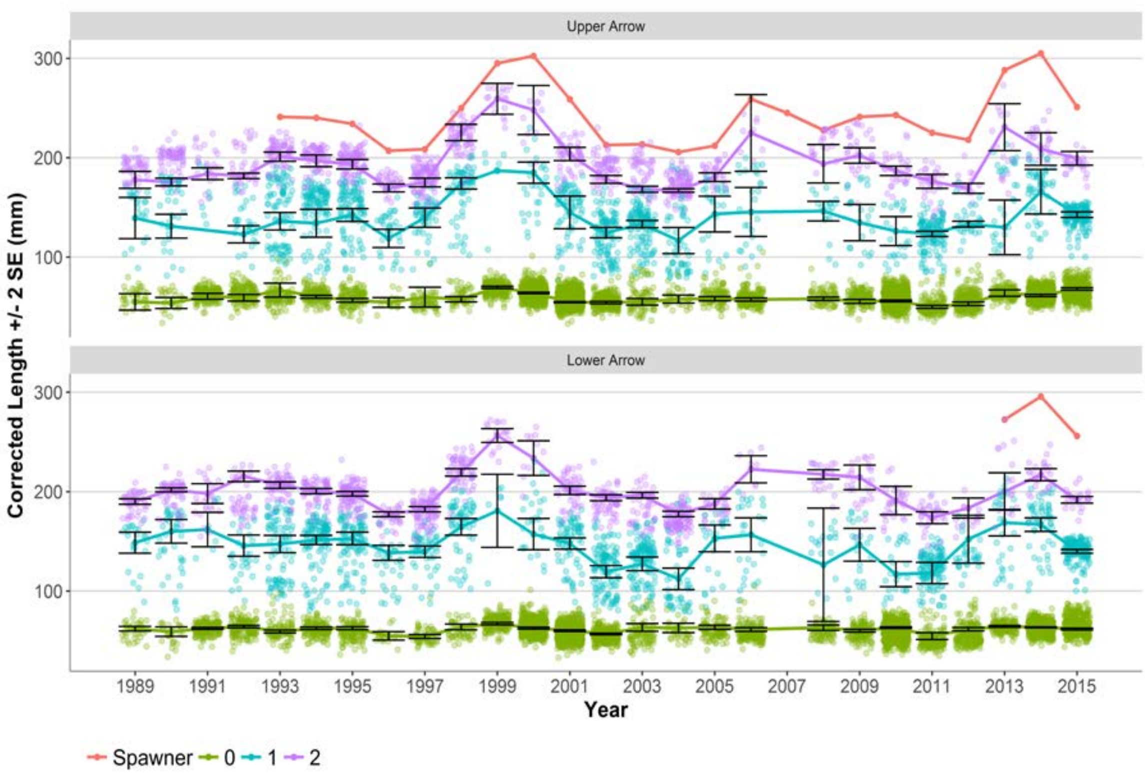


Figure 60. Trends in kokanee length at age adjusted to October 1 for a) Upper Arrow and b) Lower Arrow basins based on trawl survey data (1989-2015). *Error bars denote ±2 S.E. (95% C.I. of mean FL); average spawner size was obtained from Hill Creek to represent Upper Arrow and Deer Creek to represent Lower Arrow. Combined data for Deer and Taite Creeks was used to represent Lower Arrow in 2014-15.*

Figure 60 shows trends in the average size at age from trawl caught kokanee in Upper and Lower Arrow for the past 26 years. The mean size of spawners at Hill Creek has been included for the past 22 years to represent Upper Arrow while only the last three years of estimates were available from Deer and Taite Creeks for Lower Arrow. In 2013 the mean length of age 2+ fish in Upper Arrow reached a third peak since fertilization began, and have since declined for two consecutive years to reach average size by 2015. In Lower Arrow trends in growth were similar with age 1+, age 2+ and spawners all increasing from 2011 to reach a peak in 2014 (a year later than in Upper Arrow) and then returned to near average size in 2015.

Spawner size, age and fecundity

Length frequency distributions show a single mode of spawners returned to Hill Creek for the last five consecutive years suggesting a strong likelihood that the majority of fish have been returning at predominantly the same age (i.e., from the same cohort) (**Fig. 61**). Otolith aging confirmed this for the last five years however it also confirmed that the dominant age of spawning shifted from age 3+ during 2011-12 to age 4+ in 2013 concurrent with a large increase in spawner size. Although spawners in 2014 were even larger than in 2013, the dominant age had shifted back to age 3+. In 2015, there was a significant decline in spawner size in both Upper and Lower Arrow while the dominant age remained at age 3+ (Table 8). Otolith analyses based on the Casselman (1990) method has been applied since 2007 to determine spawner ages and the proportion by age returning each year (Appendix 6) and is the preferred method. Note that spawner ages and proportions in Table 8 are for Hill Creek only. In Hill Creek, spawner size peaked at an average length of 246mm in 2010, declined to 218mm by 2012 and then increased sharply to 288mm in 2013 and further to 305mm in 2014. The average size declined to 251mm in 2015 and was close to the fertilization era average of 247mm.

Lower Arrow spawner sizes were slightly smaller than Upper Arrow in 2013 and 2014, and similar in 2015. There appears to be a greater range in the size of spawners in Lower Arrow streams than in Hill Creek. Even though the average size was the same or slightly smaller, there was a contingent of larger, older individuals in Lower Arrow that were not evident in Hill Creek (Fig. 61). The degree to which the proportion of these larger fish (in comparison to the main mode) was affected by sampling bias (dip net) is unknown.

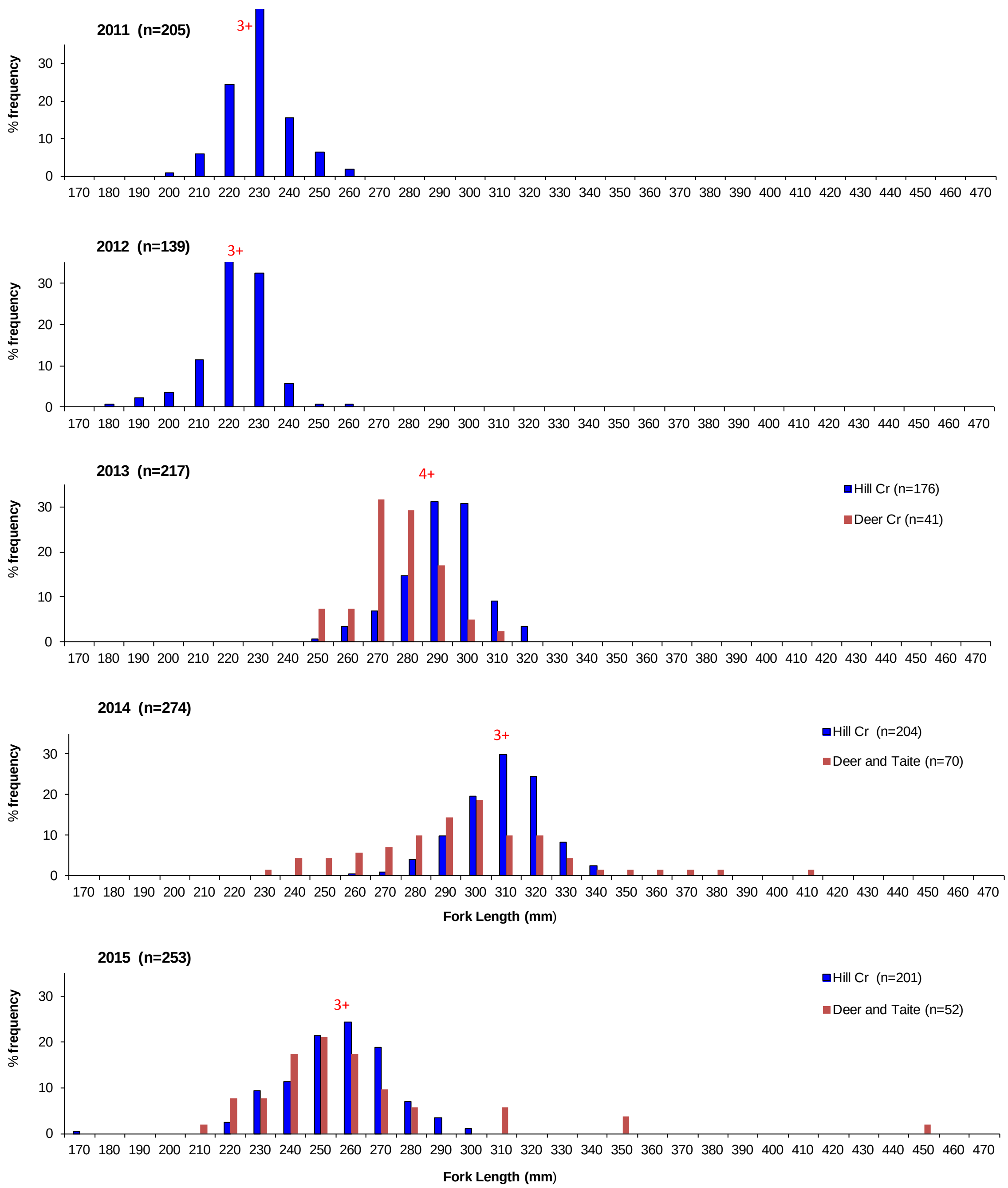


Figure 61. Length frequency distributions and dominant age of modes for Hill Creek kokanee spawners during 2011-2015 representing Upper Arrow tributaries, and for Deer Creek for 2013 and combined Deer and Taite Creeks in 2014-2015 representing Lower Arrow tributaries.

Table 8. Percent age composition for kokanee spawners returning to Hill Creek during the nutrient addition era (1999-2015) based on otolith analyses.

Year	Sample (n)	% by otolith analysis 1+	2+	3+	4+	5+	Comments
1999	182		20	73	7	0	
2000	194		52	46	2	0	
2001	253		49	51	<1	0	
2002	200		50	50	0	0	
2003[1]	159		94	6	0	0	
2004	*99*		5	94	1	0	
2005	99		2	92	5	0	
2006	100		0	48	51	0	
2007[2]	99		30	46	24	0	Began Casselmen (1990) method
2008	97		44	55	1	0	
2009	120		10	86	4	0	
2010	115		15	81	4	0	
2011	100		7	93	0	0	
2012	53		13	75	11	0	
2013	73		0	8	91	1	large mort could be 5+ or older
2014	99		3	93	4	0	
2015	96	1	15	80	4	0	161mm fish appeared to be 1+

1 Otolith ages in 2003 were all shifted by 1 year to coincide with trawl age 2+ size

2 From 2007-2015 otolith analyses followed the Casselmen (1990) method accepting only ratings of 6 or higher.

Spawning Escapement

A return of 89,255 spawners to Hill Creek in 2015 represented 56% of average for the nutrient addition period and was down slightly from 62% of average in 2014 and similar to 2013 returns of 85,800 fish (Fig. 62a). A return of only 4,040 spawners to all other index tributaries in Upper Arrow in 2015 represented only 15% of the fertilization era average.

A spawning return of 117,300 to Lower Arrow tributaries was slightly higher than 2014 and represented a modest recovery to 59% of the nutrient era average from about 22% of average for 2011-12 (Fig. 62b).

The sum of both Upper and Lower Arrow total returns (i.e., index plus other tributaries) of 232,300 spawners in 2015 was 55% of the fertilization era average and remained well below the target range (371,000 to 584,000 returning adults) identified in the Fish and Wildlife Compensation Program Large Lakes Action Plan (FWCP 2012). Even though spawners were slightly larger than average, their total biomass of 39 metric tons remained well below the target spawner biomass of 59-93 metric tons for the Arrow system set by FWCP in 2012.

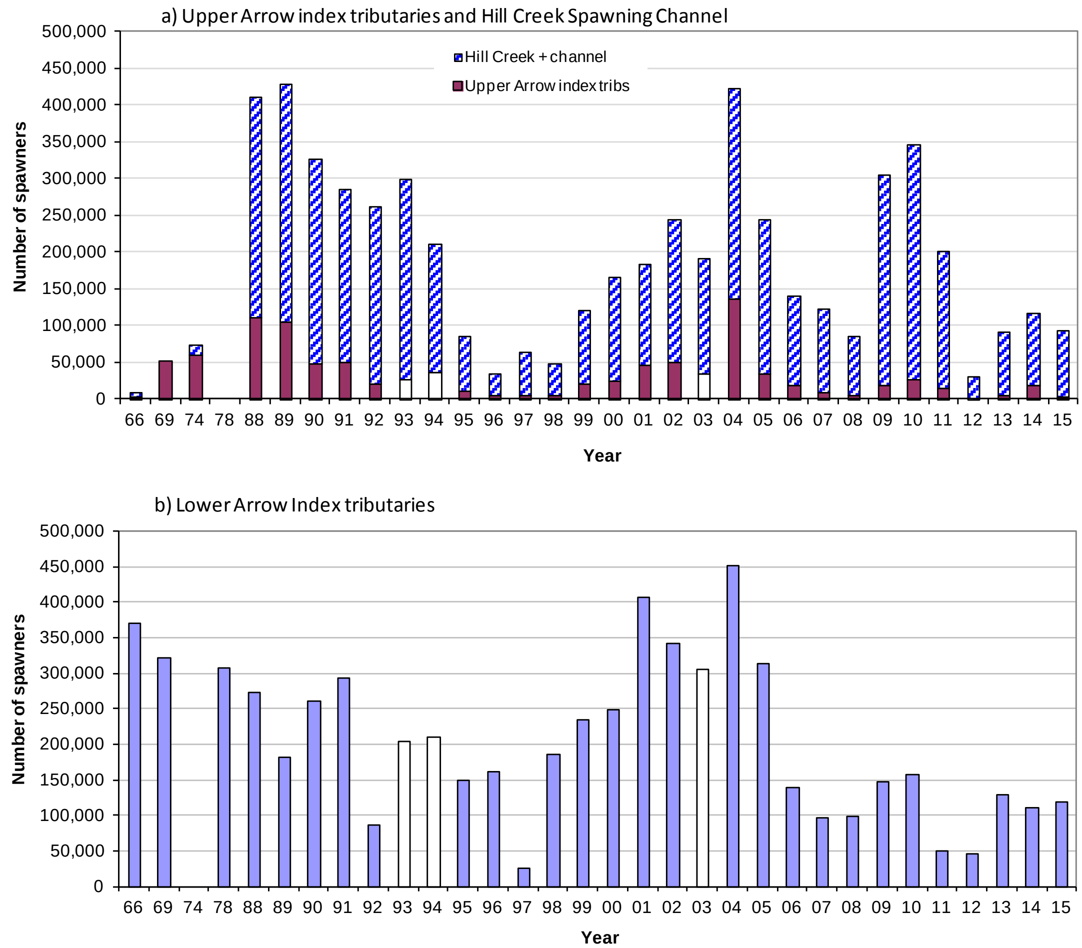


Figure 62. Trends in kokanee spawner returns to a) Hill Creek Spawning Channel and three key index streams (Drimmie, Halfway and Kuskanax) in the Upper Arrow and b) four index streams (Burton/Snow, Caribou, Deer and Mosquito) in Lower Arrow Reservoir during 1966, 1969,1974, 1978 and 1988-2015. All index stream counts have been expanded by 1.5 to approximate total run size. Note: clear bars were estimated by averaging the previous four consecutive years for years where no data exist.

Fish density and distribution

Hydroacoustic surveys provide information about in-lake distribution and abundance of kokanee. Within the standard transects used to generate the abundance estimate (i.e. 1-18; omitting 19 & 20), reservoir fry densities in 2015 ranged from 118-1493 $fish \cdot ha^{-1}$, and averaged 301 $fish \cdot ha^{-1}$ in Upper Arrow and 610 $fish \cdot ha^{-1}$ in Lower Arrow (Appendix 10). Upper Arrow showed a familiar pattern with highest fry densities at the upper end in Beaton Arm and Galena Bay, lowest density mid-basin, and then slightly increasing density toward the lower end of Upper Arrow (Fig. 63b). As in 2014 (63a), fry densities were approximately two times higher in Lower Arrow compared with Upper Arrow. In Lower Arrow fry densities were highest at the upstream end in the vicinity of transects 18 and 12, and lowest downstream of Edgewood at transects 13-15. There was a second concentration of fry toward the lower end of the basin at transects 16 and 17.

In 2015, the average density of age 1-3+ fish for all transects was 56 fish·ha^{-1} and ranged from 14-152 (Appendix 10). Densities remained low throughout Upper Arrow, averaging 30 fish·ha^{-1} with the exception of Halcyon (Transect 5), where the age 1-3+ density reached 66 fish·ha^{-1}. Targeted trawling near Halcyon identified these as primarily age 1+ kokanee. Age 1-3+ kokanee densities were on average nearly 3 times higher in Lower Arrow at 81 fish·ha^{-1} in 2015. Similar to fry, the age 1-3+ distribution showed higher concentrations of fish at transects 18 and 12 at the upper end of the Lower Arrow basin with the lowest density found at transect 15 near Deer Park.

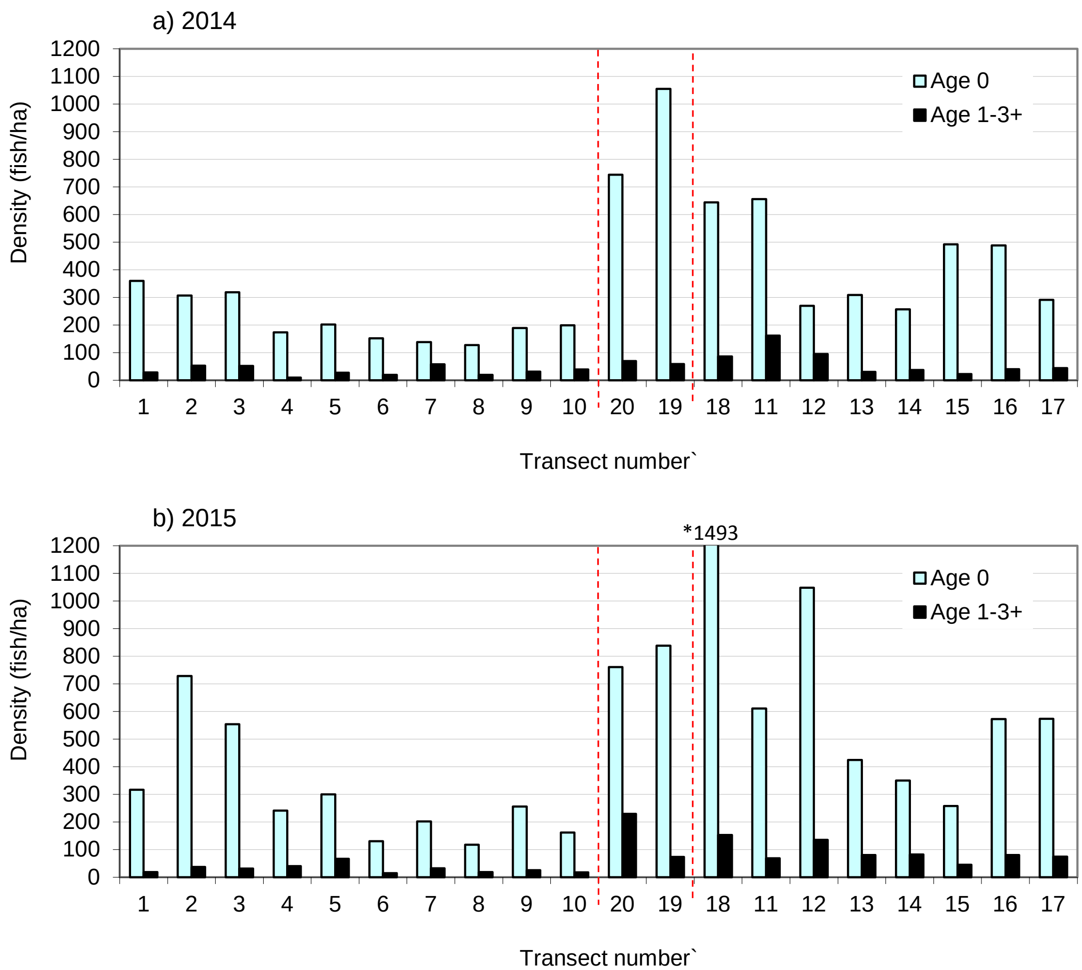


Figure 63. Longitudinal distribution of age 0+ and age 1-3+ kokanee in ALR during October of a) 2014 and b) 2015 based on acoustic surveys. Note: Transects 19 and 20

between red dashed lines are in the Narrows between Upper and Lower Arrow and were not used for estimating total kokanee abundance.

In-lake Abundance

Annual hydroacoustic estimates for kokanee during fall surveys have ranged from 5-20 million and averaged 10 million since the nutrient addition began in 1999 (Table 9). In 2013, an estimate of 5.2 million (4.4-6.0) was the second lowest for the 17 year period of nutrient addition and the lowest since 2005. The total estimate increased to 9.1 million (8.1-10.1) or near average in 2014 and again to slightly above average for 2015 at 12.3 million (10.1-14.6). The 95% confidence limits shown in brackets following individual annual estimates indicate that increases between 2014 and 2015 were not statistically significant in either Upper or Lower Arrow.

Table 9. Comparison of maximum likelihood abundance estimates (and 95% C. L.) for kokanee by basin and year for Arrow Lakes Reservoir during the nutrient addition period, 1999-2015 (all age classes combined).

Year of Treatment	Year	Month	Upper Arrow (millions)	Lower Arrow (millions)	Arrow Reservoir (millions)
1	1999	October	4.0 (3.2-4.9)	2.1 (1.8-2.4)	6.1 (5.3-7.1)
2	2000	October	7.6 (7.1-8.1)	4.1 (3.6-4.6)	11.6 (10.9-12.4)
3	2001	October	13.4 (12.2-14.6)	6.5 (5.5-7.5)	20.0 (18.3-21.4)
4	2002	October	12.5 (11.3-13.6)	7.7 (5.9-9.6)	20.1 (18.1-22.3)
5	2003	September	7.6 (7.0-8.7)	3.8 (3.5-4.3)	11.7 (10.8-12.7)
6	2004	October	4.6 (4.0-5.0)	2.8 (2.5-3.2)	7.3 (6.7-8.0)
7	2005	October	3.3 (3.0-3.5)	1.7 (1.4-1.9)	5.0 (4.5-5.6)
8	2006	October	6.3 (5.9-6.8)	2.4 (2.2-2.7)	8.8 (8.4-9.8)
9	2007	October	3.8 (3.0-4.2)	1.7 (1.6-2.3)	5.5 (5.0-6.0)
10	2008	October	5.9 (4.5-7.3)	2.6 (2.0-3.1)	8.5 (6.8-9.8)
11	2009	October	5.4 (4.0-6.6)	3.6 (3.0-4.1)	9.1 (8.1-10.3)
12	2010	October	8.6 (7.3-10.0)	5.9 (3.8-8.0)	14.5 (12.0-17.1)
13	2011	Sept/Oct	8.9 (7.2-10.7)	2.3 (1.7-2.9)	11.2 (9.4-13.1)
14	2012	October	4.2 (3.3-5.1)	2.6 (2.3-2.9)	6.8 (5.9-7.8)
15	2013	October	2.7 (2.1-3.3)	2.5 (2.1-3.0)	5.2 (4.4-6.0)
16	2014	October	4.9 (4.1-5.6)	4.2 (3.6-4.9)	9.1 (8.1-10.1)
17	2015	October	6.4 (4.5-8.3)	5.9 (4.8-7.1)	12.3 (10.1-14.6)
Nutrient Era mean (± 1 S.D.)			*6.5 (3.4-9.5)*	*3.7 (1.8-5.8)*	*10.1 (5.6-14.7)*

Note: the bracketed values in italicized blue font do not represent 95% C.L. but rather refer to ± one standard deviation of the nutrient era mean (1999-2015). This statistic represents the range of values around the mean that can be considered typical.

Figure 64 shows that the majority of increases in kokanee abundance in both 2014 and 2015 were due to a rebound in the fry populations in both Upper and Lower Arrow. Improvements in the age 1-3+ populations were relatively small in 2014 largely due to very low fry population in 2013. Following improved fry production in both basins in 2014, Upper Arrow showed a slight (11%) decline in the age 1-3+ abundance in 2015 suggesting no recovery at all (Fig. 64a), while Lower Arrow showed only a modest (29%) increase in age 1-3+ abundance in 2015 (Fig. 64b). Upon closer inspection of individual age class abundances (Appendix 15), the numbers of age 1+ fish improved by 31% in Upper Arrow and 54% in Lower Arrow, although the very weak 2+ cohort in 2012 masked these improvements within the combined age 1-3+ estimates.

Spawner populations have remained low following three consecutive years (2012 - 2014) of low age 1-3+ abundance. The current age structure does not suggest a significant increase in spawner numbers is likely until the fall of 2017 depending on dominant age at maturity.

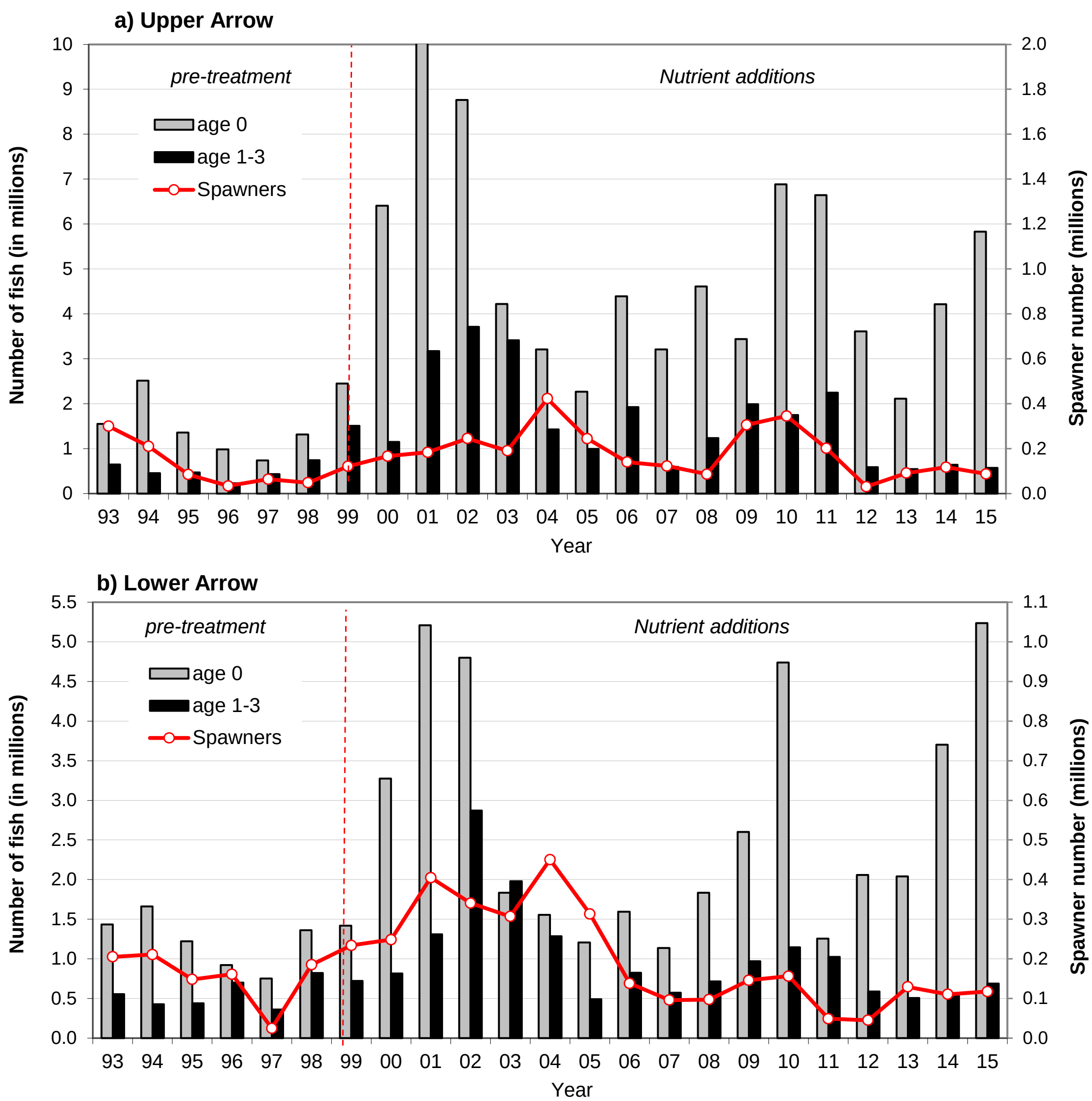


Figure 64. Trends in age 0+, age 1-3+ and kokanee spawner abundance for a) Upper Arrow and b) Lower Arrow Reservoir based on fall hydroacoustic and spawner surveys during 1993-2015. Note: spawners are index tributary count data presented in

Figure 63 above, and the scale used for displaying spawner counts was 1/5th scale for acoustic in-lake estimates and is shown on right-hand Y-axis.

Biomass

Since 2013, the biomass estimates have been reported separately for the two basins, and include only the in-lake biomass density in each reservoir based on fall acoustic and trawl data. Prior to nutrient additions, with only six years of data, biomass density averaged 1.9 $kg \cdot ha^{-1}$ in Upper Arrow and 4.4 $kg \cdot ha^{-1}$ in the more productive Lower Arrow (Fig. 65). The average biomass during the nutrient addition era has increased to 6.6 $kg \cdot ha^{-1}$ (3.6 times pre-nutrient era) in Upper Arrow; and to 10.0 $kg \cdot ha^{-1}$ (2.3 times pre-nutrient era) in Lower Arrow. If the initial boom period during the first 3-4 years (approximately one complete life cycle for kokanee) is excluded, the fertilization era averages 5.27 $kg \cdot ha^{-1}$ (2.8 times pre-nutrient era) for Upper Arrow and 8.43 $kg \cdot ha^{-1}$ for Lower Arrow (1.9 times pre-nutrient era). Defining "average" conditions as ± one standard deviation (S.D.) of the mean, the trend shows above average conditions (for biomass) occurred in Upper Arrow in 2003, 2006, and 2009 while lower than average conditions occurred in 2012 and 2015. Applying these same criteria to Lower Arrow, conditions were above average in 2003 and below average in 2015. It is worth noting that age 2+ kokanee typically comprise the highest proportion of total in-lake biomass (50-60%) of any age group. The lower than average biomass in both Upper and Lower Arrow can be largely attributed to a very weak age 2+ cohort in 2015, the progeny of very low numbers of very small spawners in 2012.

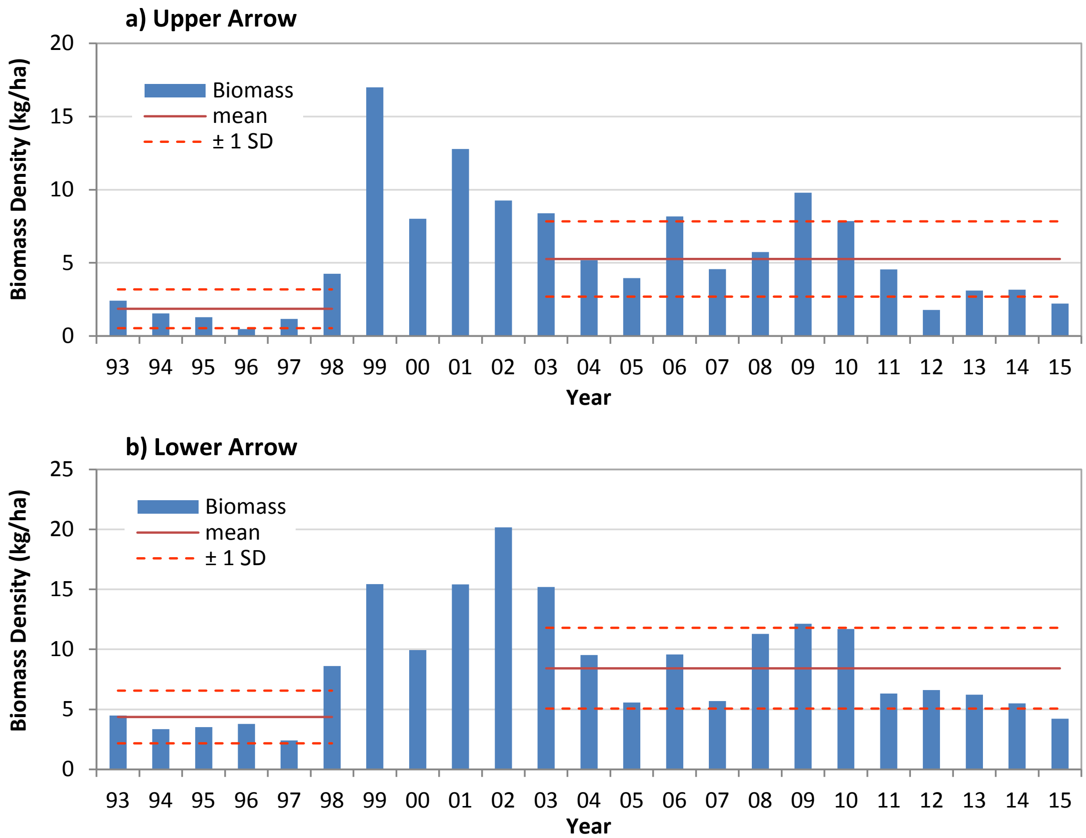


Figure 65. Trends for in-lake biomass density (kg·ha^{-1}) of kokanee in a) Upper Arrow and b) Lower Arrow reservoirs based on fall acoustic and trawl survey data. Note: fertilization era means do not include the first 4 years (one kokanee life cycle) after fertilization until initial boom from additions had stablized.

Hill Creek production

Production statistics for the Hill Creek Spawning Channel are presented in Table 10. A peak in spawner returns, fecundity and egg deposition during 2009-11 resulted in record levels of annual fry production averaging ~16 million during 2010-12 (compared to ~5.7 million annually from 1999-2009). This period was immediately followed by the lowest adult return on record in 2012 and returns have remained below average since. Current operational objectives, in place since 2013 for Hill Creek Spawning Channel, are aimed at maintaining fry production near 3.8 million/yr. This target was based on the post fertilization median fry output from the channel from 1999-2011. As a result, the proportion of fish allowed access into the spawning channel was reduced to ~44% of the run compared to 80%+ previously. Resulting fry production from the spawning channel declined from a fertilization era average of 7.2 million annually (1999-2011) to an average of 3.7 million in 2012-15; a reduction of 50%. In 2015, the egg deposition estimate for the spawning channel was 5.5 million based on 42,568 adults or 17,793 females (41.8%) with a net fecundity of 309 eggs/female (Table 10). The 2015 egg deposition was similar to the previous two years and produced a fry emigration of 4.4 million from the Hill Creek Spawning Channel.

Table 10. Kokanee production statistics for Hill Creek spawning channel 1991-2015.

Spawning year	Spawner counts[1] (no.)	Mean Fecundity (egg no.)	Egg Retention (egg no.)	Females[2] (%)	Egg Deposition[3] (millions)	Fry emigration[4] (millions)	Egg-to-fry survival (%)
1987	73,437				9.92	4.36	44
1988	150,000				13.8	7.92	57
1989	150,000				15.7	5.76	37
1990	180,000				12.4	5.49	44
1991	75,000	219	13	49	7.57	2.87	38
1992	75,000	263	33	50	8.63	3.00	35
1993	75,000	248	31	52	8.54	3.43	40
1994	75,000	302	51	51	9.41	2.22	24
1995	16,328	274	1	51	2.26	0.68	30
1996	25,030	172	8	52	2.15	0.69	32
1997	22,566	182	6	50	1.99	0.93	47
1998	19,087	226	12	44	1.81	0.86	47
1999	78,024	424	36	41	12.37	3.72	30
2000	102,597	469	2	47	22.36	8.46	38
2001	122,400	379	7	41	18.82	8.32	44
2002	151,826	212	5	39	12.26	3.93	32
2003	133,951	233	9	48	14.43	0.11	0.8
2004	199,820	189	4	35	9.53	0.27	2.8
2005	142,755	214	5	48	12.99	4.66	36
2006	92,567	240	8	48	10.21	5.46	52
2007	97,731	236	4	46	10.07	6.96	69
2008	72,068	236	4	38	6.41	3.76	59
2009	241,508	258	7	50	30.07	20.05	67
2010	267,243	272	5	43	30.35	17.46	57
2011	155,405	267	5	44	17.88	11.05	62
2012	24,342	255	4	47	2.85	2.04	71
2013	43,521	252	3	54	5.85	3.63	62
2014	33,812	438	5	41	6.03	4.64	77
2015	42,568	314	5	42	5.50	4.44	81
Pre fert ave[5]	78,037	236	19	50	7.85	3.18	40
Fert era ave[6]	122,473	286	7	44	13.91	6.66	46

1. Refers only to fish in spawning channel
2. Derived by fish sampling at channel
3. Potential egg depostion = no of channel females x (fecundity - retention)
4. Fry emigration from spring time sampling (excludes non-channel fry production)
5. Pre-fertilization average includes years not included on this table
6. Fertilization average excludes 2003-2004 where channel had almost no production

Note: 2013 spawner numbers were back-calculated from fry emigration estimate (Arndt and Barney, 2014)

KOKANEE DISCUSSION

Following the format of the 2011-2014 reports, the kokanee discussion section in this report focuses on the 2015 results by highlighting similarities and differences from the "average" conditions over the nutrient addition period and by comparison to the previous year's results. A more complete description of kokanee response to nutrient additions including a longer-term chronology of events over the entire experimental period has been provided by Schindler *et al.* (2013a, 2014). To reduce the length of annual reports, the current report has remained as a data report with only limited interpretation.

Kokanee status overview to 2015

The recovery of kokanee reported for 2009 and 2010 in Schindler *et al.* (2013a) relapsed into a period of poor growth and low survival resulting in record low returns of small sized spawners starting in the fall of 2012 (Schindler *et al*, 2014). Of particular concern was the combination of low numbers and small size of kokanee spawners returning in 2012, which impacted fry recruitment levels in 2013 and the numbers of age 1+ fish in 2014 (Bassett et al, 2016). A similar trend of low in-lake kokanee abundance and smaller size of spawners reported for Kinbasket Reservoir in 2011 by Sebastian and Weir (2013) led to speculation that region wide environmental conditions may be contributing to recent kokanee declines.

Bassett et al (2016) speculated that record high flows and low water residence time in 2012 possibly led to zooplankton being flushed out of Upper Arrow Reservoir at a high enough rate that their availability as food for kokanee declined. The 2015 data provides further evidence to support the notion that high flushing during the growth season negatively affects zooplankton and kokanee production in the Arrow system, particularly in Upper Arrow. The average April to October outflow from Arrow in 2015 of 1456 $m^3.s^{-1}$ was the highest for the fertilization era and was most comparable to the high flow year of 2012, which had average outflows of 1420 $m^3.s^{-1}$ (Fig. 5). The longitudinal distribution of kokanee in 2015 may also provide some evidence in support of flushing of zooplankton from Upper Arrow and consequent relocation of kokanee from Upper to Lower Arrow. The density of age 1-3+ kokanee was very low in Upper Arrow but a concentration of fry and age 1-3+ fish was evident in the Narrows and at the head end of Lower Arrow (i.e., where the Narrows enters Lower Arrow).

Bassett et al (2015) describe poor growth conditions for kokanee that delayed maturation of the 2009 fry cohort, which then primarily spawned at age 4+ in 2013. The absence of age 3+ spawners in 2012 led to very low spawner returns that year. As mentioned above, the effects of the low 2012 spawner returns can be followed through to the very low numbers of age 2+ fish and record low biomass in 2015, particularly in Upper Arrow. A strong fry production year in 2010 was hardest hit by poor growth and survival conditions and included a large-scale die-off event in 2012 (Schindler *et al.* 2014). The result was the lowest fry to adult survival on record for the 2010 cohort, estimated at 0.08% at Hill Creek compared to the post fertilization average of 7.5 % prior to then. The 2010 fry cohort from Hill Creek was estimated at >20 million yet culminated in only 15,350 spawners returning. Even though spawner size increased in 2013, their fecundity did not increase as much as expected (see discussion on fecundity). However, by 2014 both spawner length and fecundity reached near maximum levels for Arrow Reservoir at 30cm and 438 eggs/female, and the total Index stream egg deposition increased from a very low level of ~9 million in 2012 to ~40 million by 2014, or near average for the period of record (Appendix 16).

Egg to emergent fry survival was excellent in the spring of 2015, estimated at 81% for the Hill Creek Spawning Channel. By the fall of 2015, the average egg deposition of 2014 had translated into an above average fall fry estimate near 11 million. While survival from egg to fall fry was near average in 2015, it is possible that up to 25% (1-1.5 million) of the Upper Arrow fall fry estimate in 2015 were comprised of entrained Revelstoke fry (see 'Evidence of fry immigration' section below). If true, this would artificially inflate survival estimates to fall fry for 2015. Regardless, the fall fry estimates overall are still above average, and whether they form the basis leading to a recovery in spawner numbers depends on conditions in Arrow over the next three years.

The slightly above average fry abundance of 8 million in 2014 led to approximately one million age 1+ fish for both basins combined in 2015 (Appendix 15). This translates to a relative survival rate of ~14% for fry to age 1+ kokanee in 2015, which was below the long-term average of 20%. Nonetheless, the number of age 1+ kokanee increased over the two previous years. Age 2+ kokanee in Arrow reached the lowest abundance on record at ~174,000 fish for the combined basins in 2015, although this cohort was the progeny of the record low spawner returns in 2012. Regardless, the survival index from 2014 age 1+ to age 2+ in 2015 was extremely low in Upper Arrow at only 17%, and while higher in Lower Arrow at 29%, both values are well below the long-term average of 74% for the combined basins. This is contrary to the expectation of increased survival rates at low abundance for a species widely understood to show strong density dependant compensation in survival and growth. Similarly, growth was also less than expected given the low densities, as mean sizes of all age classes except fry decreased in 2015.

The reason(s) for the low survival rates beyond fall fry in Arrow are not well understood, but the habitat/environmental parameter that stands out in 2015 was the high outflow/flushing rate. This points to an increased likelihood of entrainment and/or food limitation; similarly poor outcomes for kokanee occurred in 2012, when extremely high outflow rates also occurred. Other potential factors include disease and predation, discussed further below.

Spawner numbers in 2015 declined slightly from 2014 while spawner size and fecundity returned to near average levels from very high levels in 2014. With lower numbers and smaller spawners, the fry prediction for 2016 is for a return to lower than average fry numbers.

The 2016 monitoring will shed some light on whether the one million age 1+ fish from 2015 will translate to an increase in the age 2+ population. The strong fall fry abundance in 2015 (10 million fry) provides an opportunity for an increased age 1+ population.

The following includes more detailed discussions of kokanee status indicators comparing 2015 to earlier and nutrient era average results.

Kokanee survival

Hill Creek fry to spawner survival

Monitoring at Hill Creek Spawning Channel provides an excellent opportunity to directly assess fry to adult survival in Upper Arrow since the channel produces the majority of fry recruitment to the upper basin. Adult ages determined from otoliths have enabled the partitioning of adults returning each year into age groups that were aligned with the appropriate fry production year from the spawning channel, producing reliable estimates of survival for each fry production year (Appendices 6 and 7). Bassett et al (2016) presented the relationship of fry to adult survival on fry production fit with a power model (R^2=0.62) for the first 12 years of the nutrient addition era (i.e., 1999 to 2010). Addition of the 2011 fry production year to the same plot fit slightly improved the correlation coefficient (R^2=0.66) (Fig. 66a). The 2010 and 2011 years differed from previous years with a policy change aimed at maximizing fry output from the spawning channel. The 2010 cohort had by far the lowest fry to adult survival to date at only 0.08% followed the 2011 cohort, which only showed slight improvements in survival to 0.54%, remaining well below the fertilization era average of 6.6%.

Figure 66b shows a slightly different presentation of the same data by comparing adult returns directly to fry production levels. Prior to the 2010 fry year, post fertilization fall fry production reached a maximum of ~10 million and produced a maximum return of approximately 300,000 spawners. The 2010 data point demonstrates that an extremely strong cohort of ~20 million emergent channel fry culminated in a total return of only 15,300 spawners. The second strongest cohort of 17.7 million fry in 2011 also produced a relatively low return of 96,000 adults having a low survival rate of only 0.54%. These two consecutive high fry output years were the result of a channel operation management decision to maximize spawning channel output and test the capacity of the channel at high spawner densities. The egg to emergent fry survival was above average both years, demonstrating that the spawning channel has the capacity to produce up to 20 million fry without affecting egg to emergent fry survival. However, the extremely poor survival from emergent fry to returning spawner identified in Figure 10 indicates it is possible that in-lake rearing capacity may have been exceeded at those production levels, resulting in significant declines in adult returns. This in itself is not conclusive as it does not consider other factors which may have limited survival of the 2010 and 2011 fry years, such as record high flows in 2012, disease (die-off) also in 2012, or a higher predation rate which also could have contributed significantly to the low returns from these cohorts.

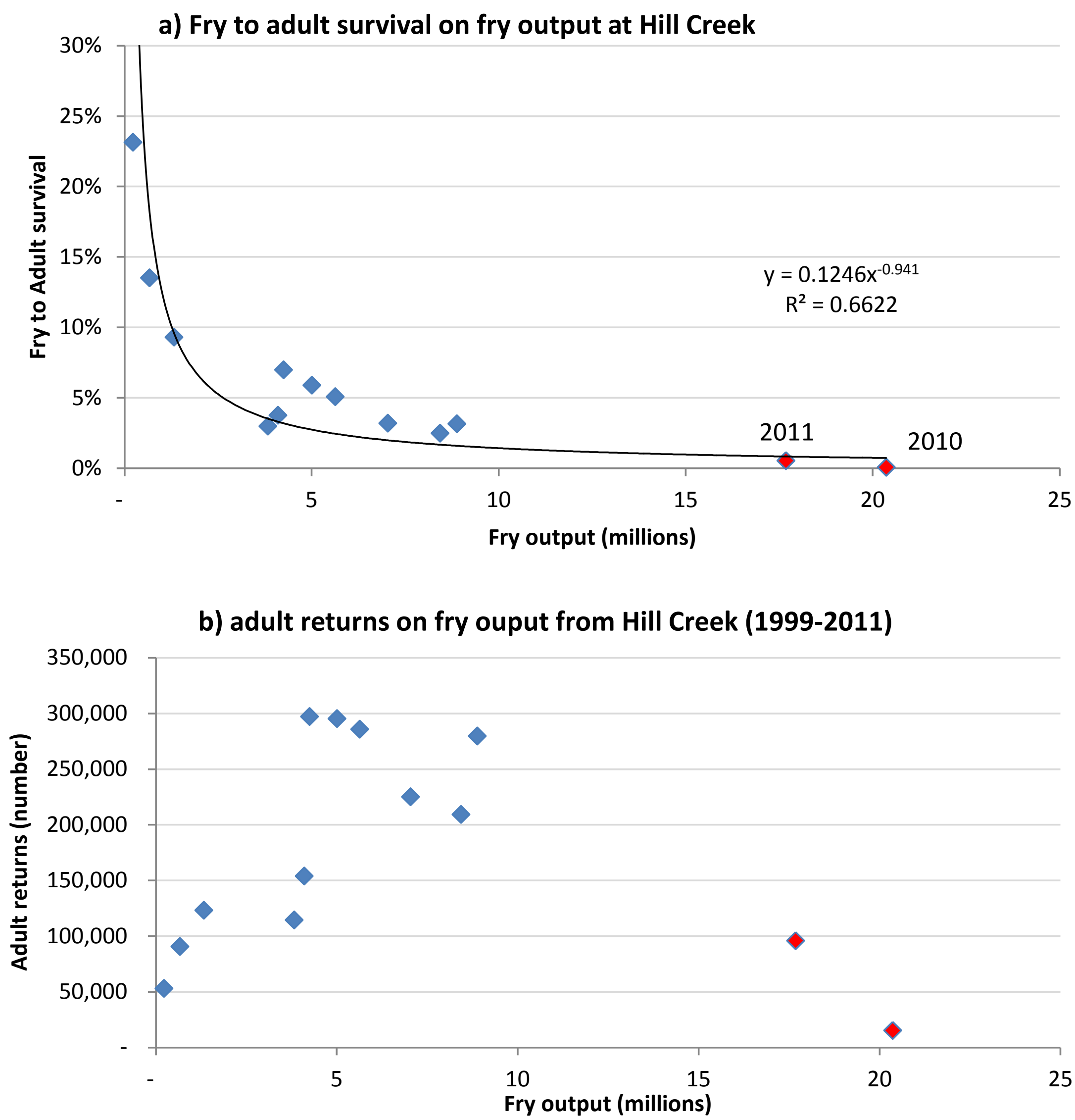


Figure 66. Relation of fry production and fry to adult survival for Hill Creek Spawning Channel for the nutrient addition era. Note the red points represent the 2010 and 2011 (most recent) fry years returning as age 2+, 3+ and 4+ spawners in during 2013 to 2015.

Egg to spawner survival

Although emergent fry estimates are not available for any non-channel spawning habitat, survival from the egg stage to spawner was estimated and compared for both Upper Arrow and Lower Arrow index tributaries (Appendix 16). Egg deposition was calculated by applying the annual spawner attribute data measured at Hill Creek (fecundity and sex ratio) to tributary spawner escapement estimates (peak counts multiplied by 1.5). An index of survival was calculated using the estimates 4 years later, which assumes age 3+ spawners. While age at maturity was not consistently age 3+ (see table 8), most years the majority were, and accordingly we believe the general trends and overall conclusions are valid. This approach to evaluate survival assumes straying is not relevant and would not affect overall trends.

Tributaries were grouped by Upper and Lower Arrow in order to evaluate differences between the two basins, and by Hill Creek vs all other Upper Arrow tributaries combined to evaluate survival trends within Upper Arrow alone. Post nutrient enrichment, Hill Creek spawners have comprised 87% of Upper Arrow spawners on average, and the proportion has been closer to 100% in recent years; as such, the survival index trends for Upper Arrow (Hill Creek Spawning Channel + Hill Creek non-channel + Upper Arrow index tributaries) are very similar and essentially interchangeable (not shown; $R^2 = 0.99$).

Figure 67 illustrates the trends in egg to spawner survival for Upper and Lower Arrow since the period of (mostly) continuous spawner count data began in 1988. Data points are missing as no counts occurred in 1993, 1994, and 2003 in any index tributaries except Hill Creek, affecting survival estimates those three years as well as those for 1989, 1990, and 1999. Survival spiked in both basins for the 1996 to 1998 brood year cohorts that were in-lake at various age classes during the onset of fertilization. Survival index estimates reached 3-10% for Upper Arrow and 19% in Lower Arrow in 1997. The Upper Arrow 1997 brood year index value seems suspiciously high and may reflect an issue with either the spawner estimate in 1997 or the return year count in 2001, although it is also possible that a shift in spawner age at maturity one or both years may have affected that estimate. After the initial increase at the onset of fertilization, survival to spawner declined sharply by 2000 and remained low until another period of increased survival for the 2005-2007 brood years in Upper Arrow. This was a period of lower abundance and biomass following the substantial increase in numbers and biomass immediately following fertilization, and signifies the expected density dependant survival compensation for these low abundance cohorts. Lower Arrow kokanee demonstrated a more muted survival response during this period with only 2006 increasing noticeably compared to the years immediately before and after. Upper Arrow egg to spawner survival declined for the 2008 to 2011 brood years, with very low survival index rates at 0.3-0.5%. Lower Arrow survival improved and surpassed Upper

Arrow beginning for the 2008 brood year, and has remained 2-4 times higher since. Survival for the Lower Arrow 2011 brood year (2015 spawners) increased substantially to near 2%, equivalent to 1996 and 1998 around the onset of the fertilization period.

The transition to consistently better survival for the four most recent cohorts is remarkable given that the Upper Arrow survival index values were driven by Hill Creek production, and Hill Creek production was driven by enhanced spawning channel habitat. The spawning channel provided optimal and controlled habitat conditions intended to improve egg to fry survival, and was expected to exceed the productive capability of wild habitat at a critical life stage where typically the highest mortality was expected to occur. In order for egg to spawner survival in Lower Arrow tributaries to equal or exceed that in Upper Arrow (i.e. Hill Creek), the egg to fry survival would have to have been consistently far better than expected in the natural habitat (a bio-standard of 10% is often applied when lacking empirical data in BC streams). Alternatively, or in addition, in-lake survival after emergence would have to have been far better in Lower Arrow than in Upper Arrow. Lower Arrow is more productive in general than Upper Arrow, and appeared to be less affected by poor rearing conditions related to high flow or other habitat issues. While the trends signal a possible change in relative survival between Upper and Lower Arrow tributaries, these changes were not statistically significant due to wide variability and relatively few data points.

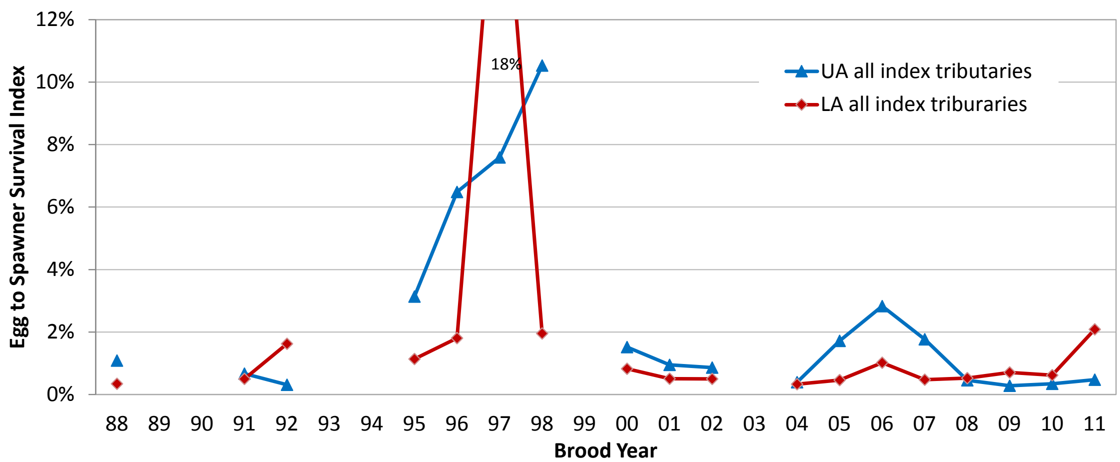


Figure 67. Egg to spawner survival index trends for Upper and Lower Arrow spawning tributaries. Upper Arrow includes Hill Creek in addition to all other Upper Arrow spawner index tributaries. Missing data points are a result of no spawner count data for 1993, 1994, and 2003 in any index tributaries except Hill Creek.

Figure 68 illustrates egg to spawner survival in Upper Arrow by comparing survival index trends for Hill Creek with the remainder of the Upper Arrow index tributaries. The 'Remaining Upper Arrow index tributaries' survival index values were calculated as described above, by applying the annual Hill Creek spawner sex ratio and fecundity data to the annual combined spawner count value for all Upper Arrow index tributaries except Hill Creek to estimate egg deposition, then dividing into the combined spawner count for the same tributaries 4 years later. The survival index values for Hill Creek were calculated using the channel egg deposition and the total spawner return 4 years later. It was assumed that eggs from non-channel spawners were "surplus" and would not contribute significantly to overall fry production from Hill Creek. The spawning channel received the majority of the total Hill Creek egg deposition most years (Appendix 16).

During the period near the onset of fertilization, both Hill Creek as well as the other Upper Arrow index tributary cohorts demonstrated dramatic increases in survival. With the exception of 1997 and 2000, the annual survival index values for kokanee from other Upper Arrow tributaries remained well below Hill Creek from 1988 to 2006, as expected given that enhanced spawning channel habitat dominates the Hill Creek production. However for the past five consecutive brood years, from 2007 onward, the egg to spawner survival index estimates track very closely, with averages of 0.67% for Hill Creek and 0.55% for all other Upper Arrow tributaries. The measured egg to emergent fry survival rates at Hill Creek spawning channel averaged 63% for those 5 cohorts, and the spawning channel received 59% of the eggs in Hill Creek on average over that period. It seems unlikely that the other Upper Arrow tributary eggs would have survived at that high of a rate in non-channel natural habitat. Assuming any biases in spawner count data are consistent for index tributary counts across time, survival after out-migration to the lake must have been significantly better for progeny of spawners in tributaries other than Hill Creek. Similar to the comparison between Upper Arrow and Lower Arrow tributary survival trends discussed above, comparison of average survival between Hill Creek and the remaining Upper Arrow tributaries did not show a significant change had occurred. It is noteworthy that regardless of the era chosen (all years, past 10 years, past 5 years are shown in Appendix 16), Hill Creek did not demonstrate a statistically higher egg to spawner survival rate than other Upper Arrow tributaries, as would be expected.

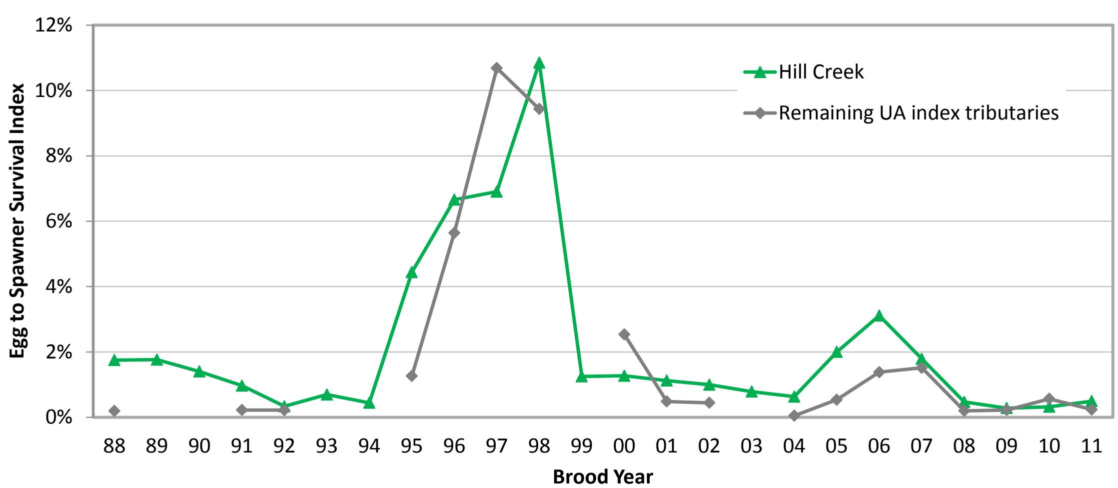


Figure 68. Egg to spawner survival index trends for Hill Creek and all other Upper Arrow spawner index tributaries. Missing data points are a result of no spawner count data for 1993, 1994, and 2003 in any index tributaries except Hill Creek.

Potential explanations for these surprising results are speculative, but it is possible that predators have learned to key in on and intercept either out-migrating fry or returning spawners staging to enter Hill Creek; however, it is not apparent as to why this would disproportionately affect Hill Creek kokanee. Another possible explanation is that IHNV or another undetected disease is affecting survival at some life stage for Hill Creek kokanee disproportionately. The IHNV was not detected in Hill Creek until 2013, which would not explain the statistically equivalent survival for earlier brood years. Another possibility is that long term operation of the spawning channel may have resulted in reduced genetic fitness or altered heritable traits that lead to reduced survival (e.g altered run timing/emergence) relative to their wild spawning contemporaries.

The possibility that survival to spawn was statistically similar between Hill Creek and other tributaries in Upper Arrow and has recently declined for Hill Creek kokanee relative to other tributaries is remarkable, and whether these same patterns continue going forward may provide insight into whether this was an anomalous period (that perhaps defies a clear explanation), or, if it continues, whether a causal mechanism becomes clear. It is notable that a similar analysis with data from nearby Kootenay Lake (MFLRNO unpublished) demonstrates a similar pattern is occurring. Comparison of egg to spawner survival between the Meadow Creek Spawning Channel and the Lardeau River, a nearby major spawning tributary, demonstrates that the survival patterns have reversed there, and natural habitat spawners in the Lardeau River have survived at a better rate than Meadow Creek kokanee for the three most recent brood years (2009-11).

Fry to age 1+ survival

The following analyses are based on the premise that age 1+ kokanee are most likely to comprise the largest proportion of the age 1-3+ population most years. It follows then that fluctuations in the age 1-3+ abundance are most likely caused by changes in age 1+ abundance. The proportion of age 1-3+ to previous year fry abundance was assumed to provide a reasonable relative index of age 0+ to age 1+ survival. In order to quantify and compare the survival rates between basins, proportions were estimated separately for the upper and lower basins (Table 11). We recognized that this approach assumes that movement between the basins is relatively insignificant between fry and age 1+ stages. Vastly different survival between basins the same year could indicate years where significant movements of fish between basins had occurred. A more thorough analysis would indicate whether other productivity indices affecting survival (e.g. flow/entrainment, zooplankton abundance/biomass) appeared similar between basins.

Differences in survival between basins was treated the same as other comparisons, where the long term mean ± 1 standard deviation were considered to represent average conditions. In this case, a difference outside the range of -0.17 to +0.28 may indicate that significant movement between basins occurred. By these analyses, strong positive values (i.e. more than 1 standard deviation greater than the mean) indicated that downstream migrations may have occurred in 1994, 2004 and 2012.

Since movement between basins was not indicated for 2015, the main reason for including Table 11 in this report was to compare 2015 survival estimates (indices) to recent years and to the long-term average. In Upper Arrow, 2012 was the lowest survival estimate on record and was the only estimate less than 1 S.D. below the mean, although 2013 and 2015 were very near the lower S.D. value. By contrast, the two highest survival estimates were in 1998 and 1999 near the start of the fertilization program.

Lower Arrow showed poor survival in 2011, 2013 and again in 2015 (Table 11). Compared to Upper Arrow the recent low survival estimates started a year earlier (2011) in Lower Arrow. A substantial difference in survival between the two basins in 2012 suggested either the possibility of downstream movement of fish to Lower Arrow, or dramatically different rearing conditions between the two basins. Regardless, three of the last four consecutive years (i.e. 2012-15) had the lowest survival estimates on record for the combined basins indicating that rearing conditions were relatively poor overall in Arrow Reservoir.

Interestingly, the highest apparent survival on record occurred in Upper Arrow in 1999, the first year of nutrient addition. Significant differences between the two basins suggest that fish may have moved upstream from Lower Arrow during the first year of nutrient addition. Also of interest is that the second highest survival year was identified as 1998 when very low densities of fry survived very well during a year with below average flows through the summer period (Table 11; Fig. 5). There is growing evidence that kokanee survival can be influenced by flow conditions, particularly in Upper Arrow Reservoir. The results of these analyses were discussed in more detail in Bassett et al, (2016).

Table 11. Proportion of age 1-3+ relative to previous year fry abundance by year for Upper and Lower Arrow kokanee.

Year (age 1-3)	Upper Arrow	Lower Arrow	Total Arrow	Difference[1]	Evidence of movement[2]
94	0.29	0.30	0.30	0.01	
95	0.19	0.26	0.22	0.08	
96	0.17	0.57	0.36	0.41	Downstream migration indicated
97	0.44	0.39	0.42	-0.05	
98	1.01	1.09	1.05	0.08	
99	1.15	0.53	0.83	-0.62	Upstream migration indicated
00	0.47	0.57	0.51	0.11	
01	0.49	0.40	0.46	-0.09	
02	0.36	0.55	0.43	0.19	
03	0.39	0.41	0.40	0.02	
04	0.34	0.70	0.45	0.36	Downstream migration indicated
05	0.31	0.32	0.31	0.01	
06	0.85	0.68	0.79	-0.17	
07	0.14	0.36	0.20	0.22	
08	0.39	0.63	0.45	0.24	
09	0.43	0.53	0.46	0.10	
10	0.51	0.44	0.48	-0.07	
11	0.33	0.22	0.28	-0.11	
12	0.09	0.47	0.15	0.38	Downstream migration indicated
13	0.15	0.25	0.19	0.09	
14	0.30	0.32	0.31	0.02	
15	0.14	0.19	0.16	0.05	
pre-nutrient	0.42	0.52	0.47		
nutrient era	0.40	0.45	0.40		
22 yr average	0.41	0.46	0.42	0.06	
S.D	0.28	0.20	0.23	0.22	
S.D./mean	68%	44%	54%		
Range ± 1 S.D.	0.13 to 0.68	0.26 to 0.67	0.19 to 0.64	-0.16 to 0.27	

Note: proportions > 1 SD below the mean are shown in RED font and above the mean are in GREEN font:
1. Difference in apparent survival = (Lower Arrow survival - Upper Arrow survival)
2. A large enough difference suggests movement between basins.
A strong positive value suggests movement was downstream from Upper to Lower Arrow

Evidence of fry immigration

A bimodal length distribution of fry was evident at the uppermost trawl station in Upper Arrow (i.e. Shelter Bay). A closer examination of trends in fry size between Upper and Lower Arrow suggests that fry size distributions typically have a single mode and that fry tend to be slightly smaller in the Upper Basin. In 2015, a main mode of fry in Upper Arrow was typical with a peak around 70mm while a secondary group of larger fry were found from 75-95mm length with a peak around 85mm. Using various size intervals the large group of fry were partitioned from the main group and their proportion was estimated for the three trawl stations. These proportions were applied to total fry abundance estimates from the acoustic survey for each of the three areas associated with trawl stations to estimate the total numbers of large fry (Appendix 17). The highest proportion of large fry were found at the north end of Upper Arrow and proportions declined to the south. Since no trawl sampling was done in Beaton Arm, one option assumed that no large fry existed in Beaton Arm and a second option assumed that proportions would be similar to Shelter Bay, the nearest trawl station. Although speculative, it appears that the large fry component ranged from 1 to 1.5 million or about 18-27% of total fry in Upper Arrow. These fry may have survived entrainment from Revelstoke Reservoir and the shallow riverine habitat of the Revelstoke flats. It is possible that entrainment at Revelstoke may have been more likely in 2015 as a result of high flushing rates throughout the growing season. The unusually high densities of kokanee immediately above the dam during a July acoustic survey of Revelstoke combined with the very low densities further upstream in Revelstoke Reservoir also supports the notion of higher than average entrainment in 2015 (Sebastian and Weir, 2016). The distribution of these large fry, at a density gradient declining from north to south in Upper Arrow, also lends weight to the likelihood they were entrained from Revelstoke. To improve our understanding of the role of upstream entrainment on Arrow Lakes' kokanee production, it is recommended that consideration be given to conducting some genetic and/or trace metal analyses on kokanee from Revelstoke and Kinbasket Reservoirs. Providing some unique identifiers can be established, these could be used to determine the proportion, if any, of fish from upstream reservoirs that contribute to the kokanee population in Arrow Reservoir.

Fecundity

Bassett *et al.* (2015) reported that the average fecundity of 252 estimated at Hill Creek in fall 2013 did not correspond to the substantial increase in spawner size. A regression of average fecundity on mean female length predicted a fecundity of 425 eggs per female for 2013 females based on an average length of 283mm (Fig. 69). By contrast, an estimated mean fecundity of 438 in 2014 indicated by a green point on Figure 69 was more consistent with the regression estimate of 476 based on an average female length of 301mm. In 2015, a sharp decline in both length and fecundity was observed, although the relation of length to fecundity was very close to the regression average (Fig. 69). The smaller size and lower fecundity resulted in a substantial reduction in the system wide (index tributary) egg deposition from ~40 million in 2014 to 27 million in 2015 or about 64% of the 1988-2015 average of 42 million (Appendix 16). With the spawners returning to average size, the prediction is for below average fry abundance in 2016.

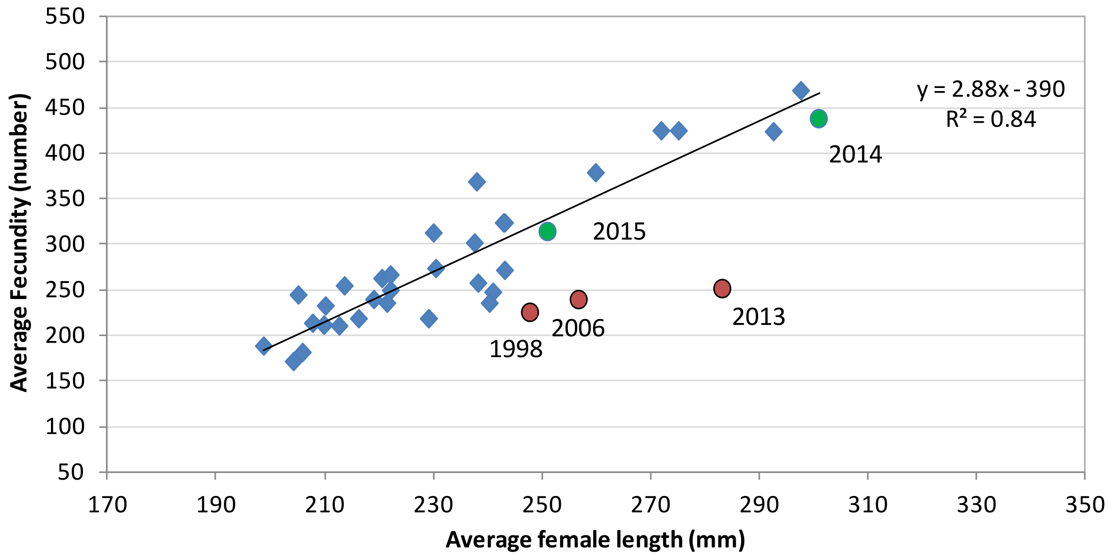


Figure 69. Empirical relation of average fecundity to average spawner length for kokanee returning to Hill Creek during 1977-2015 (n=37 yrs). Note: red points are considered outliers and not included in regression equation.

Growth and age at maturity

Growth trajectories were plotted from mean length at age data in order to help visualize when changes of growth occurred that led to a shift in the average age at maturity from age 3+ to age 4+ and then back to age 3+ (Fig. 70). This plot also demonstrates the extent to which spawners from different cohorts can overlap in size even though ages are different (e.g., age 4+ spawners from the 2008 fry cohort had the same mean length as age 3+ spawners from the 2009 fry year). In Figure 70, each cohort is represented by a separate colored line beginning at the fry stage (i.e. age 0+) though to spawner. There were insufficient spawner data for Lower Arrow to produce separate growth trajectories for the Upper and Lower basins, so trawl results were combined for the two basins and spawner results from Hill Creek were used to represent the entire reservoir.

A key observation is that kokanee growth appears to be approximately linear until age 2+ for nearly all years. The growth slope generally declines (i.e. trajectory flattens out as fish enter a period of maturation at age 2+ to 4+) and energy is redirected from somatic growth to gonad development. This flattening out of the growth curves was observed beyond age 2+ in all fry cohorts from 2004 through 2008. The 2009 fry cohort experienced the typical decline in growth between age 2+ and 3+ (2011 to 2012) but shifted to good growth between age 3+ and 4+ presumably due to extremely low densities following a period of high mortality. Note that the poor growth year for older fish in 2011-12 would include the extremely high flow during spring and summer of 2012 and the spring mortality event that occurred in Upper Arrow in May 2012. By comparison, 2013 and 2014 were very good growth years having low density of age 1-3+

kokanee and also a high relative abundance of preferred food for kokanee (eg. *Daphnia*).

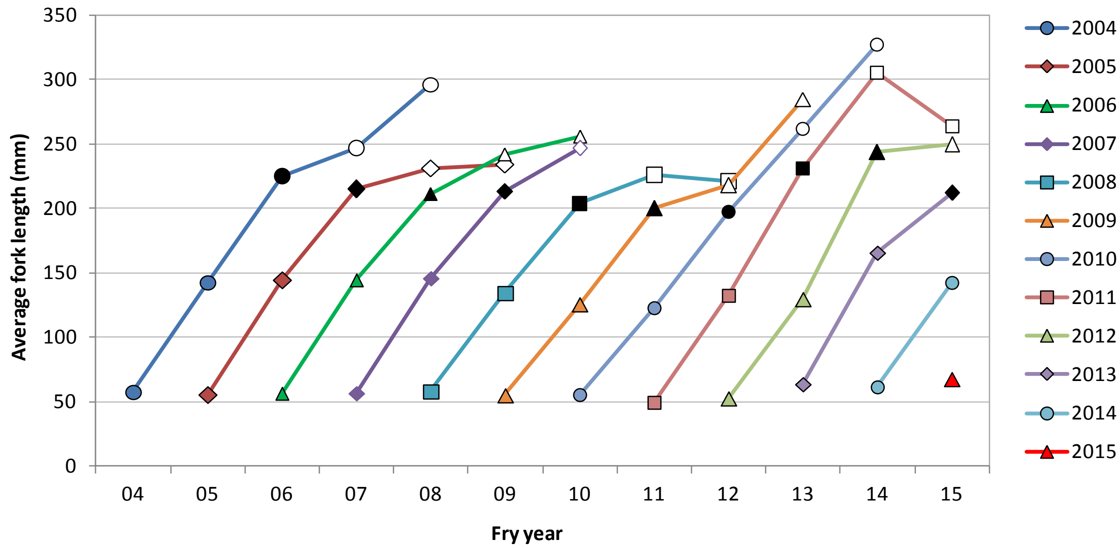


Figure 70. Kokanee mean length at age showing growth trajectories for individual cohorts identified by fry year for 2004 to 2015; each curve represents a cohort followed through from fry to spawners. Markers filled with solid colors represent trawl data, points with solid black fill represent an average between age 2+ fish from the trawl and age 2+ spawners (from the same cohort) and white filled points represent spawner data only.

The 2010 and 2011 (fry) cohorts showed near linear growth for four and three consecutive years respectively to return as larger than average age 3+ and age 4+ spawners indicating that 2013 and 2014 were very good growth years. However, as stated previously, the 2010 cohort started out very strong but experienced high mortality at the fry stage and again during a spring mortality event at age 2+ (in Upper Arrow). All returning fish from the 2010 and 2011 cohorts spawned during years with low abundance of age 1-3+ fish. From this it appears that with good conditions in the reservoir (average to high *Daphnia* numbers) and with relatively low abundance of age 1-3+, kokanee can achieve maturation without compromising somatic growth. By this analysis, 2015 was a relatively poor year for growth compared with the two previous years, with growth curves for all ages flattening out. There was a small number of age 4+ fish from the 2011 fry year that returned at a smaller size than age 3+ fish from the same cohort the previous year. It is likely that high flows and flushing (Figure 5) and colder water temperatures in 2015 (Appendix 18) were largely responsible for reduced growth rates in kokanee.

Disease and predation impacts on kokanee survival

Recent declines in relative survival of the older age groups suggests the possibility of increased predation over the nutrient addition period as predator populations build, although creel information does not appear to support an increase in predator abundance or condition (Arndt, 2016). While quantifying latent impacts of introduced lake trout on kokanee populations in Lake Chelen, Washington, Schoen et al (2012) describe situations they encountered where CPUE from the fishery indicated predators were declining while the predation pressure on kokanee from a few larger older individuals continued to increase. Their results pointed to considerable lag time between management actions, measurable responses and impacts on prey populations, which could be applicable to bull trout/kokanee interactions on Arrow Reservoir. However, the Bull Trout redd count surveys conducted in 2011, 2013, and 2015 do not demonstrate any abnormal fluctuation or increase in Bull Trout numbers in recent years (FLNRO data on file), although heavy rain resulted in an inability to conduct surveys in Upper Arrow tributaries in 2015. Information on piscivorous rainbow abundance in ALR is minimal, however catch rates and sizes have declined to very low levels in recent years in the creel data. The one dataset on Arrow Reservoir where an index of spawner abundance for piscivorous rainbow exists is the redd count conducted at Hill Creek Spawning Channel. The count of large Rainbow Trout redds has declined steadily to among the lowest in the period of record in 2015 (2005-2015) (FLNRORD, unpublished data; Steve Arndt, Pers. Com). While not conclusive, a lack of any indicators suggesting any increases in rainbow or bull trout abundance leads to a weight of evidence suggesting it is unlikely that predation was the key driver of recent poor kokanee survival.

Disease is another potential cause for poor kokanee survival. There have not been any reports of kokanee die-offs since 2012, although infectious hematopoietic necrosis virus (IHNV) was present in the Hill Creek Spawning Channel spawners from 2013-2015 (the emergent fry in spring 2015 tested negative). The IHNV may have played a role in the 2012 die off although samples were not tested from that event. The IHNV has not been widely linked to mortality in older age classes of kokanee in-lake, except for a few documented cases including a die-off of age 2+ Kokanee in Cowichan Lake, BC (Traxler, 1986). In that case, kokanee were found floating at the surface dead or moribund and swimming erratically. Several sampled fish had skin hemorrhaging, and the event occurred in May, with surface water temperatures around 11.5-12°C. Remarkably, the circumstances in Upper Arrow in May 2012 were virtually identical, suggesting that IHNV may have played a role in that large-scale mortality event. However, as there has not been another observation of these circumstances since, we suggest that IHNV is not the primary agent of continued suppressed survival. It is possible that IHNV or another undetected disease could be resulting in higher mortality by other less obvious means, or similar smaller scale or localized die-offs have gone unnoticed.

Summary

Following two consecutive years of average flow and climatic conditions, 2015 represented a return to high flows and flushing rates and colder water temperatures throughout the growing season, similar to 2012. A key difference between 2012 and 2015 is that high flows in 2012 were the result of an extremely wet year, while high flows in 2015 was due to deliberate release of water from Arrow and Kinbasket Reservoirs in order to mitigate the impacts of drought conditions south of the border. The fry recruitment level in 2015 exceeded expectations; the fall fry abundance estimate of 6 million was well above average in Upper Arrow, and the estimate of 5.5 million was the highest on record for Lower Arrow. High fry numbers resulted from large spawner sizes and high fecundity in 2014, but were also possibly related to higher than average incubation survival during the mild winter of 2014-15. Hill Creek Spawning Channel egg to fry survival was estimated at 81%, the highest on record; however, egg to spawner survival has been low on average for the last four cohorts, and equivalent over time between Hill Creek and other major tributaries. The age 1-3+ population was low at 35% of average for Upper Arrow (37% in 2014) and increased from 61% in 2014 to 69% of average in Lower Arrow. With higher flushing and colder water temperatures in 2015, kokanee growth declined to near average even though age 1-3+ fish densities remained well below average. Lower than average survival rates between age groups remains problematic for kokanee recovery in Arrow, as are declining growth rates while densities of larger kokanee remain low. The growth response realized from low densities in 2013 and 2014 was not evident in 2015 presumably due to poor rearing conditions. As a result, spawner numbers were low and both size and fecundity returned to near average. Consequently, the system wide index stream egg deposition declined from 40 million eggs in 2014 to 27 million in 2015 while the long-term average was 42 million eggs per year. Fry production from 2015 spawning is likely to decline from current high levels to below average in 2016. The potential for future recovery will depend on improvements in survival of the older age groups. There is a basis for age 1+ abundance to increase substantially in 2016 from the strong fry year in 2015. Age 2+ fish may also increase in 2016, which will improve biomass from the record low of 2015.

Recommendations

1. Continue current kokanee monitoring program including acoustic, trawl and spawner surveys.
2. Continue to collect time series data at Hill Creek Spawning Channel for adult numbers, length, sex, fecundity and fry production.
3. Continue collecting spawner samples from Lower Arrow tributaries to determine length, sex, age at maturity and proportion by age for LAR tributary spawning populations.
4. Collect samples from kokanee for genetic analysis from spawners and trawl samples as this will assist in determining the amount of mixing of stocks between the Upper and Lower basins.

5. Explore the idea of using trace metals to determine if some portion of the trawl catch can be tied to entrainment, providing some unique markers can be identified in Revelstoke/Kinbasket kokanee than are distinct from Arrow fish.

REFERENCES

Andrusak, H. and E.A. Parkinson. 1984. Food habits of Gerrard stock rainbow trout in Kootenay Lake, British Columbia. B.C. Ministry of Environment, Fish and Wildlife Branch, Fisheries Technical Circular No. 60. 1984.

Arndt, S. 2004a. Post-Fertilization Diet, Condition and Growth of Bull Trout and rainbow Trout in Arrow Lakes Reservoir ALR. Report for the Columbia Basin Fish & Wildlife Program 28 p.

Arndt, S. 2004b. Arrow Lakes Reservoir Creel Survey 2000-2002. Report for the Columbia Basin Fish & Wildlife Program 23 p. + appendices.

Arndt, S. 2009. Footprint Impacts of BC Hydro Dams on Kokanee Populations in the Columbia River Basin, British Columbia. Report for the Fish and Wildlife Compensation Program – Columbia Basin, Nelson, BC. 70 p.

Arndt, S. and C. Schwarz. 2011. Trends in angling and piscivore condition following eleven years of nutrient additions in Arrow Lakes Reservoir (Arrow Lakes Reservoir Creel Survey 2003-2009). Report for the Fish and Wildlife Compensation Program, Nelson BC.

Arndt, S. and J. Burrows. 2012. Kootenay Fisheries Field Report on May 13-14, 2012 activities to assess kokanee die-off on Upper Arrow Lakes Reservoir – on file at FLNRO, Nelson, BC.

Arndt, S. and B. Barney. 2014. Hill Creek and Hill Creek Spawning Channel – Revised Adult Enumeration 2013 – on file at FLNRO, Nelson, BC.

Arndt, S. 2015. Arrow Lakes Reservoir Angler Creel Survey 2014. Report for the Fish and Wildlife Compensation Program – Columbia Basin, Nelson, BC. 30 p.

Arndt, S. 2016. Arrow Lakes Reservoir Angler Creel Survey 2015. BC Ministry of Forests, Lands and Natural Resource Operations, Fish and Wildlife Compensation Program – Section. https://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=50677

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

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.

Balk and Lindem, 2011. Sonar4 and Sonar5-Pro post processing systems, Operator manual version 6.0.1, 464p. Lindem Data Acquisition Humleveien 4b. 0870 Oslo Norway.

Bassett, M., E.U. Schindler, D. Sebastian, T. Weir and L. Vidmanic. 2015. Arrow Lakes Reservoir Nutrient Restoration Program Year 15 (2013) Report. Fisheries Project Report No. RD 148, Ministry of Forests, Lands and Natural Resource Operations, Province of British Columbia. 122p.

Bassett, M., E.U. Schindler, L. Vidmanic, T. Weir and D. Sebastian. 2016. Arrow Lakes Reservoir Nutrient Restoration Program Year 16 (2014) Report. Fisheries Project Report No. RD 151, Ministry of Forests, Lands and Natural Resource Operations, Province of British Columbia. 122p.

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.

Emery, A.R. 1970. Fish and crayfish mortalities due to an internal seiche in Georgian Bay, Lake Huron. Journal of the Fisheries Research Board of Canada, 27:1165–1168.

FWCP. 2012. Columbia Basin Large Lakes Action Plan Draft. Fish and Wildlife Compensation Program report. https://www.bchydro.com/content/dam/hydro/medialib/internet/documents/about/our_commitment/fwcp/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

Hyatt, K. D., D. J. McQueen, K. S. Shortreed, and D. P. Rankin. 2004a. Sockeye salmon (Oncorhynchus nerka) nursery lake fertilization: Review and summary of results. Environ. Rev. 12:133 – 162.

Hyatt, K.D., McQueen, D.J., Rankill, P.O., Hanslit, B., Sutey, S., Carey, E., Nelson, H., and Svanvik, B. 2004b. Lake fertilization and enhanced growth of juvenile sockeye salmon at Woss Lake, British Columbia: a food web analysis. Can. Manuscr. Rep. Fish. Aquat. Sci. 2689: 169 p.

Johner, D. and T. Weir. 2012. Kinbasket and Revelstoke Reservoirs Kokanee Population Monitoring – Year 4 (2011). Prepared for BC Hydro under the Columbia River Water Use Plan, Water Licence Requirements Study No. CLBMON-2. 39pp.

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.

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

Love, R. H. 1977. Target strength of an individual fish at any aspect. J. Acoust. Soc. Am. 62(6): 1397-1403.

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. Hydrobiology 11: 143-170.

Matzinger, A.R., Pieters, K.I., Ashley, G.A., Lawrence, and A. Wuest. 2007. Effects of impoundment on nutrient availability and productivity in lakes. Limnology and Oceanography 52: 2629-2640.

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 Biovolume of zooplankton in samples. In: Downing, J.A. and F.H. Rigler, editors. A Manual on Methods for the Assessment of Secondary Productivity in Fresh Waters. Blackwell Scientific Publications, Boston.

Milbrink, G., E. Petersson and S. Holmgren. 2008. Long-term effects of nutrient enrichment on the condition and size-structure of an alpine brown trout population. Environ. Biol. Fish. 81:157-170.

Moody, A., P. Slaney, and J. Stockner. 2007. Footprint impact of BC Hydro dams on aquatic and wetland productivity in the Columbia Basin. Report prepared by AIM Ecological Consultants Ltd. In association with Eco-Logic Ltd. and P. Slaney Aquatic Science Ltd. for Fish and Wildlife Compensation Program, Nelson, BC

Parkinson, E., and S. Arndt. 2014. Results of a Workshop on Management Policy Options for Arrow Lakes. http://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=42669

Patterson, S.D., D.L. Scarnecchia, J.L. Congleton. 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.

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

Pieters, R., L.C. Thompson, L. Vidmanic, S. Pond, J. Stockner, P. Hamblin, M. Young, K. Ashley, B. Lindsay, G. Lawrence, D. Sebastian, G. Scholten, and D.L. Lombard. 1998. Arrow Reservoir limnology and trophic status report, Year 1 (1997/98). RD 67, Fisheries Branch, Ministry of Environment, Lands and Parks, Province of British Columbia.

Pieters, R., L. C. Thompson, L. Vidmanic, M. Roushorne, J. Stockner, K. Hall, M. Young, S. Pond, K. Ashley, B. Lindsay, G. Lawrence, H. Andrusak, D. Sebastian, G. Scholten. 2000. Arrow Lakes Reservoir Fertilization Year 1 (1999/2000) Report. Fisheries Project Report No. RD 82. Province of BC, Ministry of Environment, Lands and Parks.

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

Pieters, R., L. Vidmanic, S. Harris, J. Stockner, H. Andrusak, M. Young, K. Ashley, B. Lindsay, G. Lawrence, K. Hall, A. Eskooch, D. Sebastian, G. Scholten and P.E. Woodruff. 2003b. Arrow Reservoir Fertilization Experiment - Year 3 (2001/2002) Report. Fisheries Project Report No. RD 103.Ministry of Water, Land and Air Protection, Province of British Columbia.

Pieters, R., L.C. Thompson, L. Vidmanic, M. Roushorne, J. Stockner, K. Hall, M. Young, S. Pond, M. Derham, K. Ashley, B. Lindsay, G. Lawrence, D. Sebastian, G. Scholten, F.

McLaughlin, A. Wüest, A. Matzinger and E. Carmack. 1999. Arrow Lakes Reservoir Limnology and Trophic Status Report, Year 2 (1998/99). RD 72. Fisheries Branch, Ministry of Environment, Lands and Parks, Province of British Columbia.

Prescott, G.W. 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. Unpub. MS. Ministry of Fisheries, Province of British Columbia Victoria BC.

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.

Schindler, E.U., R. Pieters, L. Vidmanic, H. Andrusak, D. Sebastian, G. Scholten, P. Woodruff, J. Stockner, B. Lindsay and K.I. Ashley. 2006a. Arrow Lakes Reservoir Fertilization Experiment, Years 4 and 5 (2002 and 2003). Fisheries Project Report No. RD 113, Ministry of Environment, Province of British Columbia.

Schindler, E.U., D. Sebastian and H. Andrusak. 2006b. Arrow Lakes Reservoir Fertilization Experiment Summary (1999 and 2004). Fisheries Project Report No. RD 116, Ministry of Environment, Province of British Columbia.

Schindler, E.U., L. Vidmanic, D. Sebastian, H. Andrusak, G. Scholten, P. Woodruff, J. Stockner, K.I. Ashley and G.F. Andrusak. 2007. Arrow Lakes Reservoir Fertilization Experiment, Year 6 and 7 (2004 and 2005) Report. Fisheries Project Report No. RD 121, Ministry of Environment, Province of British Columbia.

Schindler, E.U., D. Sebastian, L. Vidmanic, H. Andrusak, J. Stockner, M. Bassett and K.I. Ashley. 2009a. Arrow Lakes Reservoir Fertilization Experiment, Year 8 (2006) Report. Fisheries Project Report No. RD 125, 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. 2009b. 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, L. Vidmanic, H. Andrusak, J. Stockner, M. Bassett and K.I. Ashley. 2010. Arrow Lakes Reservoir Nutrient Restoration Program, Year 9 (2007) Report. Fisheries Project Report No. RD 128, Ministry of Environment, Province of British Columbia.

Schindler, E.U., D. Sebastian, L. Vidmanic, H. Andrusak, M. Bassett and K.I. Ashley. 2011. Arrow Lakes Reservoir Nutrient Restoration Program, Year 10 (2008) Report. Fisheries Project Report No. RD 132, Ministry of Environment, Province of British Columbia.

Schindler, E.U., D. Sebastian, T. Weir, H. Andrusak., G. F. Andrusak, M. Bassett and K.I. Ashley. 2013a. Arrow Lakes Reservoir Nutrient Restoration Program, Years 11 and 12 (2009 and 2010) Report. Fisheries Project Report No. RD 137, 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. 2013b. 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., T. Weir, D. Sebastian, M. Bassett and K. I. Ashley. 2014. Arrow Lakes Reservoir Nutrient Restoration Program Years 13 and 14 (2011 and 2012) Report. Fisheries Project Report No. 146, Ministry of Forests, Lands and Natural Resource Operations, Province of British Columbia. 137p.

Schoen, Erik R., David A. Beauchamp & Nathanael C. Overman (2012) Quantifying Latent Impacts of an Introduced Piscivore: Pulsed Predatory Inertia of Lake Trout and Decline of Kokanee, Trans.of the Amer. Fisheries Society, 141:5, 1191-1206. http://dx.doi.org/10.1080/00028487.2012.681104

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.

Sebastian, D. and T. Weir. 2016. Kinbasket and Revelstoke Reservoirs Kokanee Population Monitoring - Year 8 (2015). Prepared for BC Hydro under the Columbia River Water Use Plan, Water Licence Requirements Study No. CLBMON-2. 63p.

Sebastian, D., H. Andrusak, G. Scholten and L. Brescia. 2000. Arrow Lakes Reservoir Fish Summary. Stock Management Report 2000. Province of BC, Ministry of Fisheries. Victoria BC. 106p.

Sebastian, D., R. Dolighan, H. Andrusak, J. Hume, P. Woodruff and G. Scholten 2003. Summary of Quesnel Lake Kokanee and Rainbow Trout Biology with Reference to Sockeye Salmon. Stock Management Report No. 17. Province of British Columbia 2003.

Smith, V.H. 1983. Low nitrogen to phosphorus ratios favour dominance by blue-green algae in phytoplankton. Science, 221:669 – 671.

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, Peterborough, Ontario, Canada, 227 p.

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.

Stockner, J.G. 2010. Phytoplankton populations in Arrow Lakes Reservoir – 2007. Pages 71 - 106 In Schindler *et al*. Arrow Lakes Reservoir Nutrient Restoration Program, Year 9 (2007) Report. Fisheries Project Report No. RD 128, Ministry of Environment, Province of British Columbia.

Stockner, J.G., and K.I. Ashley 2003. Salmon Nutrients: Closing the Circle. Pages 3-16 in Stockner, J. G., editor. 2003. Nutrients in salmonid ecosystems: sustaining production and biodiversity. American Fisheries Society, Symposium 34, Bethesda, Maryland.

Strickland, J.D.H and T.R. Parsons. 1972. A practical handbook of seawater analysis, Fisheries Research Board of Canada, 167 pp.

Traxler, G.S. 1986. An epizootic of infectious haematopoietic necrosis in 2-year-old kokanee, Oncorhynchus nerka (Walbaum) at Lake Cowichan, British Columbia. Journal of Fish Diseases, 9(6), pp.545-549.

Thompson, L.C. 1999. Abundance and Production of Zooplankton and Kokanee Salmon (*Onchorynchus* nerka) in Kootenay Lake, British Columbia During Artificial Fertilization. Thesis submitted to Department of Zoology. University of British Columbia. Need to add Lisa Thompson's thesis.

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

Utzig, G. and D. Schmidt. 2011. Dam Footprint Impact Summary-BC Hydro Dams in the Columbia Basin. Contract report prepared for the Fish and Wildlife Compensation Program-Columbia Basin, Nelson BC

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

Wetzel, R.G. and G.E. Likens. 2000. Limnological Analyses, 3rd ed. Springer-Verlag New York, Inc.

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

APPENDICES

Appendix 1. List of personnel involved in the 2015 Arrow Lakes Reservoir project.

Project Focus	Personnel	Affiliation
Project management	Marley Bassett	Resource Management MoFLNRO, Nelson
Fertilizer schedule	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 application	Crescent Bay Construction The Columbia Ferry	Crescent Bay Construction, Nakusp Waterbridge ferries, Nakusp
Physical limnology, water chemistry, phytoplankton, zooplankton, mysid sampling	Don Miller and staff Marley Bassett Rob Fox Les Fleck Dave Heagy Chris Price	Kootenay Wildlife Services Ltd. Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson Crystal Springs Consulting BC Parks, MoE BC Parks, MoE
Chemistry analysis	Maxxam Analytics Inc. staff (- March 31,2015) ALS Global staff (Jun 1st, 2015 -)	Maxxam Analytics Inc., Burnaby ALS Global, Burnaby BC
Chlorophyll analysis	Shannon Harris Allison Hebert	MoE, Vancouver
Phytoplankton analysis	Dr. John Stockner	Eco-Logic Ltd.
Phytoplankton report	Marley Bassett	Resource Management MoFLNRO, Nelson
Zooplankton analysis	Dr. Lidija Vidmanic	Limno-Lab Ltd., Vancouver
Mysid analysis	Dr. Lidija Vidmanic	Limno-Lab Ltd., Vancouver
Zooplankton and mysid report	Dr. Lidija Vidmanic	Limno-Lab Ltd., Vancouver
Kokanee acoustic surveys	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., Nelson
Kokanee aerial spawner surveys	Marley Bassett Eva Schindler Matt Neufeld Albert Chirico Robert Andrews	Resource Management MoFLNRO, Nelson Resource Management MoFLNRO, Nelson Resource Management MoFLNRO, Nelson Resource Management MoFLNRO, Nelson Highland Helicopters, Nakusp
Kokanee ground spawner surveys	Steve Arndt Marley Bassett Rob Fox Eva Schindler	Resource Management MoFLNRO, Nelson

	Katherine McGlynn Kristen Murphy Karen Bray Beth Manson	 BC Hydro
Kokanee analysis and Reporting	Tyler Weir David Johner	Fish, Wildlife and Habitat Management, MoFLNRO, Victoria Fish, Wildlife and Habitat Management, MoFLNRO, Victoria
Kokanee scale ageing	Shannon Harris Allison Hebert Andrew Schellenberg Carol Lidstone	Ministry of Environment, Vancouver British Columbia Conservation Foundation Birkenhead Scale Analyses
Creel survey (separate report)	Steve Arndt Val Evans Brian Barney Darlene Riehl Glen Olson Gail Olson Deb Imeson Lorne Imeson Credence New	Resource Management, MoFLNRO, Nelson Kingfisher Silviculture Ltd. G. O. Contracting Ltd Scottie's Marina
Regional support	Jeff Burrows	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/John Krebs Dave Tesch Patrice Rother Doug Johnson Dave White Grant Trower Rick Morley Joe Nicholas James Pepper	Resource Management, MoFLNRO, Nelson/Cranbrook Environmental Sustainability Division, MoE, Victoria BC Hydro, Burnaby BC Hydro, Castlegar Public Representative Public Representative Public Representative First Nations Representative First Nations Representative
Policy Committee	Mark Zacharias Rebecca Reid Edie Thome	MoE, Victoria Fisheries and Oceans, Vancouver BC Hydro, Burnaby
Project co-ordination and scientific liaison	Marley Bassett Eva Schindler	Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson
Annual report preparation	Eva Schindler Marley Bassett Tyler Weir	Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson Fish, Wildlife and Habitat Management, MoFLNRO, Victoria
Editorial comments	Eva Schindler Steve Arndt Krista Watts Dale Sebastian	Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson Columbia Power Corporation British Columbia Conservation Foundation

Contract administration	Crystal Klym Lorraine Ens Eva Schindler	FWCP, BC Hydro, Castlegar FWCP, BC Hydro, Burnaby Resource Management, MoFLNRO, Nelson
Administration	Trevor Ousorren Crystal Klym Lorraine Ens Barb Waters Anne Reichert Elaine Perepolkin Disa Westerhaug	FWCP FWCP FWCP British Columbia Conservation Foundation Resource Management, MoFLNRO 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. Arrow Lakes Reservoir physical, chemical, plankton, and kokanee sampling program for 2015.

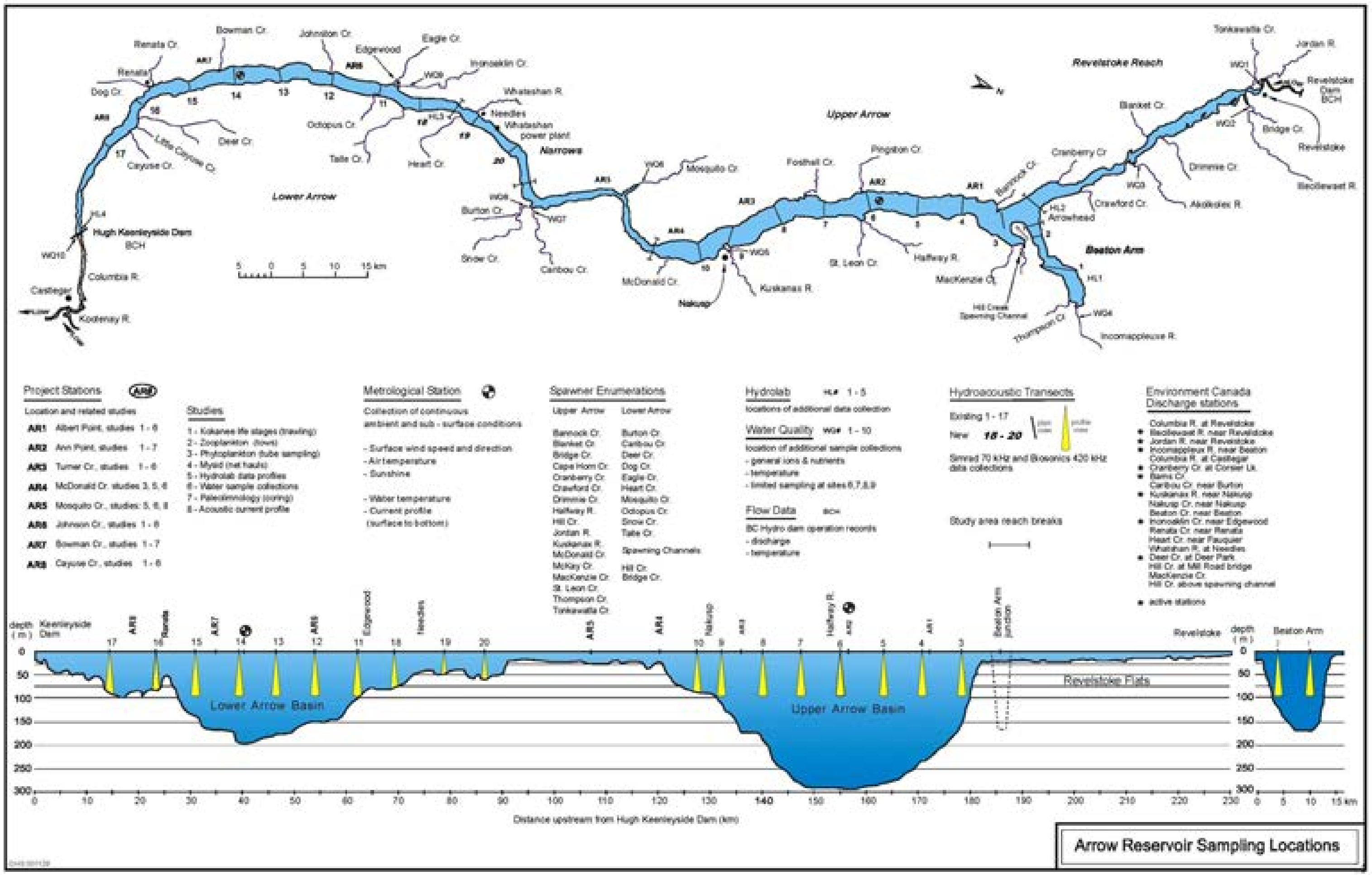
Parameter sampled	Sampling frequency	Sampling technique
Temperature, dissolved oxygen, specific conductance	Apr – Nov[1]	SeaBird profiles at HL 1&4, AR 1-8 from surface to 5 m off the bottom
Transparency	Apr – Nov[2]	Secchi disk (without viewing chamber) at HL 1&4, AR 1-8
Water chemistry: pH, silica, alkalinity, turbidity, TOC, TIC, and nutrients (TP, TDP, OTP, TN, Nitrate and Nitrite) pH, silica, alkalinity, Turbidity, TOC, TIC, and nutrients (TP, TDP, OTP, TN, Nitrate and Nitrite) nutrients (TP, TDP, OTP, TN, Nitrate and Nitrite) turbidity and nutrients (TP, TDP, OTP, TN, Nitrate and Nitrite) Total and dissolved metals	Apr – Nov[1] May - Oct Jun - Sep Late July and Late August Jun and Sept	Integrated sampling tube at 0 - 20 m at stations HL 1, AR 1-3 and AR 6-8. Hypolimnion 5 m off the bottom at stations AR 1-3, 6-8 Discrete depth profiles, 2, 5, 10, 15 and 20 m at stations AR 2 and AR 7. Integrated sampling tube at 0 - 20 m at stations AR 3 and AR 8. Integrated 0-20 m and a discrete sample 5 m off the bottom at stations AR 1-3 and AR 6-8.
Chlorophyll a (not corrected for phaeophytin)	Apr – Nov[2] Jun – Sep	Integrated sampling tube at 0 - 20 m at stations AR 1-8 Discrete samples - 2, 5, 10, 15 and 20 m, stations AR 2 and AR 7
Phytoplankton	Apr – Nov[2]	Integrated sampling tube at 0 - 20 m at stations AR 1-8
Macrozooplankton	Apr - Nov	3 oblique Clarke-Bumpus net hauls (3-minutes each) from 40-0 m at stations AR 1-3 and AR 6-8 (150 µm net)
Mysid net sampling	Apr - Nov	3 replicate hauls with mysid net,

		two deep at stations AR 1-3 and 6-8
Kokanee acoustic sampling	Fall survey	Standard MoE Simrad and Biosonics hydroacoustic procedure at 20 transects in Upper and Lower Arrow
Kokanee trawling	Fall trawl series	Standard trawl series using oblique hauls at AR 1-3 and 6-8 in Upper and Lower Arrow

[1] Monthly (twice in June)

[2] Monthly (twice in June, twice in July and August- AR 3, AR 4 and AR 8)

Appendix 3. Map of Arrow Lakes Reservoir with sampling locations.



Appendix 4. Arrow Lakes Reservoir nutrient loading from fertilizer during 2015– liquid ammonium polyphosphate (phosphorus: 10-34-0; N-P_2O_5-K_2O) and liquid urea-ammonium nitrate (nitrogen: 28-0-0; N-P_2O_5-K_2O).

Week #	Week	P Load (mg/m^2)	P Amount (Kgs)	10-34-0 Amount (MT)	N Load (mg/m^2)	N Amount (Kgs)	28-0-0 Amount (MT)	Total Amount (MT)	N:P ratio wt:wt
1	Apr-20	7.6	1440.2	9.7	5.1	970.0	0.0	9.7	0.67
2	Apr-27	7.6	1440.2	9.7	5.1	970.0	0.0	9.7	0.67
3	May-04	11.4	2167.7	14.6	7.7	1460.0	0.0	14.6	0.67
4	May-11	15.2	2895.2	19.5	10.3	1950.0	0.0	19.5	0.67
5	May-18	10.9	2078.6	14.0	38.3	7280.0	21.0	35.0	3.50
6	May-25	10.9	2078.6	14.0	38.3	7280.0	21.0	35.0	3.50
7	Jun-01	20.3	3860.3	26.0	71.2	13520.0	39.0	65.0	3.50
8	Jun-08	19.5	3711.8	25.0	68.4	13000.0	37.5	62.5	3.50
9	Jun-15	10.5	2004.4	13.5	83.0	15770.0	51.5	65.0	7.87
10	Jun-22	10.5	2004.4	13.5	83.0	15770.0	51.5	65.0	7.87
11	Jun-29	10.5	2004.4	13.5	83.0	15770.0	51.5	65.0	7.87
12	Jul-06	10.5	2004.4	13.5	83.0	15770.0	51.5	65.0	7.87
13	Jul-13	9.8	1855.9	12.5	83.9	15950.0	52.5	65.0	8.59
14	Jul-20	4.8	920.5	6.2	42.0	7975.6	26.3	32.5	8.66
15	Jul-27	0.0	0.0	0.0	95.8	18200.0	65.0	65.0	#DIV/0!
16	Aug-03	8.6	1633.2	11.0	85.4	16220.0	54.0	65.0	9.93
17	Aug-10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	#DIV/0!
18	Aug-17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	#DIV/0!
19	Aug-24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	#DIV/0!
20	Aug-31	4.7	884.1	6.0	45.9	8729.5	29.1	35.0	9.87
21	Sep-07	4.65	884.1	6.0	45.9	8,730	29.1	35.0	9.87

Appendix 5. Arrow Lakes Reservoir estimated total kokanee spawner numbers (peak counts expanded by 1.5 times)

Upper Arrow	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Hill channel[1]	78,024	102,597	122,400	151,826	133,951	199,820	142,755	92,567	97,731	72,060	241,508	267,243	155,405	24,342	43521	33,812	42,568
Hill Creek other[2]	22,915	39,506	14,696	43,236	21,328	86,370	67,050	29,880	15,840	9,993	45,091	38,091	31,163	5,535	40750	50,419	40,687
Hill Creek egg take												12,220	-	-	1490	15,145	6,000
Bridge channel[1]	13,000	10,643	14,263	17,262	4,237	54,260	14,500	4,740	3,600	2,340							
Alkokolex																	
Bannock	0	128	53	0		1,200											
Blanket	30	2,255	530	4,818	227	240											
Cranberry	6,750	6,300	9,975	4,715	1,046	40,920	2,445	1,677	389	0	359	NS	78	11	5		149
Crawford	90	2,130	1,500	3,246		4,523											
Drimmie	3,300	8,775	7,425	7,646	953	27,015	18,770	6,807	4,359	3,360	16,218	13,077	8,535	479	1,949	6,434	1,547
Halfway	7,050	7,058	12,638	8,850		46,050	4,305	3,150	1,913	620	650	7,235	2,333	272	2,061	7,500	1,452
Jordan	375	683	5,850	3,488		2,400	2,385	3,945	1,995	30	645	2,948	2,250	-	17	300	293
Kuskanax	9,675	8,700	26,775	33,450		63,600	11,595	7,980	2,820	312	1,928	7,305	3,833	9	1,253	3,998	1,044
McDonald	17,076	5,997	23,790	10,260	7,151												
McKay	375	1,406	11,130	281		9,120	28,877	1,938	1,031	0	2,973	1,527	918	99	830	486	539
MacKenzie																	
Mulvehill	0	0	0	39													
St. Leon	2,067	2,364	5,396	6,300	3,618	1,050	3,306	240	90	6	51	63	48	3	29	172	3
Thompson	1,530	3,518	2,966	2,651													
Tonkawatla	975	3,773	10,950	4,203		25,350	8,805	1,875	8,145	1,950	1,845	4,560	4,590	-	360	1,928	780
Upper Index streams only	20,025	24,533	46,838	49,946	*35,336*	136,665	34,670	17,937	9,092	4,292	18,795	27,617	14,700	759	5,262	17,932	4,043
Upper Index tribs+SPChanı	120,964	166,636	183,934	245,008	190,615	422,855	244,475	140,384	122,663	86,345	305,394	345,171	201,268	30,636	91,023	117,308	93,298
Upper Arrow Total	163,232	205,833	270,337	302,271	225,950	561,918	304,793	154,799	137,912	90,671	311,267	354,268	209,152	30,749	92,262	120,194	95,062
Lower Arrow	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2,009**	**2,010**	**2,011**	**2,012**	**2,013**	**2014**	**2,015**
Burton	105,450	114,750	181,500	190,950		179,700	113,850	56,100	24,075	18,075	36,600	75,960	3,362	9,503	37,005	29,348	34,350
Caribou	50,100	63,600	105,150	61,800		120,750	81,000	23,400	16,650	12,600	29,775	27,488	3,248	14,393	26,625	20,850	22,583
Deer	16,875	11,838	16,977	25,916	19,170	32,273	12,542	10,938	11,477	34,500	17,804	10,553	22,154	3,368	15,834	25,575	6,651
Dog	396																
Eagle	6,029	5,624	0	345	0	13,875	0	0	0	4088	116	506	137	480	227	1,980	0
Fauquier		872	62	273	0												
Heart	803	1,038	285	767	92												
Mosquito	61,500	58,350	101,400	61,800		117,600	106,050	47,700	43,650	31,875	61,668	42,147	20,033	17,625	49,772	34,575	53,745
Little Cayuse	1,305			2													
Octopus	5,955	3,249	1,065	4,814	4,271		1,184	680	740	4,710	3,179	NS	1,121	-	66	1,983	327
Taite	23,220	11,792	12,012	21,741	510	17,400	11,976	6,834	5,132	10,289	7,251	3,888	2,181	1,136	714	12,912	19,544
Lower Arrow Index Total	233,925	248,538	405,027	340,466	*307,000*	450,323	313,442	138,138	95,852	97,050	145,847	156,147	48,795	44,888	129,236	110,348	117,329
Lower Arrow Total	271,633	271,113	418,451	368,408		481,598	326,602	145,652	101,723	116,136	156,392	160,541	52,233	46,503	130,242	127,223	137,200
Columbia tribs u/s REV																	
Overall Arrow Index Total	354,889	415,174	588,961	585,474	*500,000*	873,178	557,917	278,522	218,514	183,395	451,241	501,318	250,063	75,524	220,259	227,656	210,627
Total Arrow	434,865	476,946	688,788	670,679	*500,000*	1,043,516	631,395	300,451	239,634	206,807	467,658	514,809	261,385	77,252	222,504	247,417	232,262

1. Hill Creek and Bridge Creek represent total counts so were not subject to expansion factors. Additional data for Hill for the years 1979-87 available in Hill Creek electronic data records.

NOTE: Italicized numbers indicate ground count, all others except Hill and Bridge were counted from the air.

All peak counts (except complete counts at Hill and Bridge) have been expanded by 1.5x to represent total spawning escapement.

2. Hill Creek "other" is based on a combination of fence counts, electronic counters and ground counts for the spawning channel AND the creek downstream (see Hill Creek reports).

Expansion factor, where applicable, has been built into the estimate.

Note: Index counts in bold red italics (eg 2003)were based on an average of the four previous years as no data was available

Appendix 6. Summary of kokanee adult age proportions for Upper Arrow (Hill Creek Spawning Channel) 2007-2015 and for Lower Arrow (Deer and Taite Creeks) from 2013-2015 based on otolith rating analyses.

		Mean Length		Number of samples by age					Proportion by age					Comments
Year	Description	(mm)	(all ages)	age 2	age 3	age 4	age 5	age 6	age 2	age 3	age 4	age 5	age 6	
2007	Hill Creek all spawners	245	205											
2007	Otolith samples with rating 6 or higher	242	99	30	45	24	0	0	30%	46%	24%	0%	0%	
2008	Hill Creek all spawners	228	203											
2008	Otolith samples with rating 6 or higher	226	97	43	53	1	0	0	44%	55%	1%	0%	0%	
2009	Hill Creek all spawners	241	260											
2009	Otolith samples with rating 6 or higher	240	120	12	103	5	0	0	10%	86%	4%	0%	0%	
2010	Hill Creek all spawners	243	227											
2010	Otolith samples with rating 6 or higher	244	115	17	93	5	0	0	15%	81%	4%	0%	0%	
2011	Hill Creek all spawners	225	205											
2011	Otolith samples with rating 6 or higher	225	100	7	93	0	0	0	7%	93%	0%	0%	0%	
2012	Hill Creek all spawners	218	139											
2012	Otolith samples with rating 6 or higher	216	53	7	40	6	0	0	18%	75%	11%	0%	0%	
2013	Hill Creek all spawners	288	176											
2013	Otolith samples with rating 6 or higher	286	73	0	6	66	0	1	0%	8%	91%	0%	1%	one very large mort included
2014	Hill Creek all spawners	305	204											
2014	Otolith samples with rating 6 or higher	305	99	3	92	4	0	0	3%	93%	4%	0%	0%	ages corrected by CL
2015	Hill Creek all spawners	251	201											
2015	Otolith samples with rating 6 or higher	246	96	14	78	4	0	0	15%	81%	4%	0%	0%	(plus 1% age 1+)
For Lower Arrow kokanee														
2013	Deer Creek all spawners sampled	274	30	0	0	25	5	0	0%	0%	83%	17%	0%	
2013	Otolith samples with rating 6 or higher	275	28	0	0	24	4	0	0%	0%	86%	14%	0%	
2014	Deer and Taite Creeks all spawners sampled	296	70											
2014	Otolith samples with rating 6 or higher	299	51	8	34	8	1	0	16%	67%	16%	2%	0%	19 samples not aged
2015	Deer and Taite Creeks all spawners sampled	52	256											
2015	Otolith samples with rating 6 or higher	42	257	4	32	6	0	0	10%	76%	14%			9 samples not aged, 1 CSA<6 not include

The above age proportions are for good quality otolith samples with a CSA Confidence rating of 6 or higher.
Note: 19 of the 70 otolith samples for Deer and Taite Creeks in 2014 were not aged due to missing or broken otolith samples or poor quality samples

Appendix 7. Hill Creek Spawning Channel production data (fry and adult returns by age and year) and fry to adult survival by cohort

Yellow highlighting shows example of which numbers are used in calculating fry survival

Subsequent colors show individual cohorts

Fry	Total fry	Adult Return Data		Age Class Proportions[1]				Returns by Age Class					Brood	Fry	Fry-Adult
Year	Production	Year	Number	2+	3+	4+	5+	2+	3+	4+	5+	Age Data Source	Year	Year	Survival
1983	2,047,503	1983	15,277	-	1.00	-	-	-	15,277	-	-	assumed all age 3 from length frequency	1982	83	3.52%
1984	3,000,000	1984	69,936	-	1.00	-	-	-	69,936	-	-	assumed all age 3 from length frequency	1983	84	1.33%
1985	3,404,652	1985	60,176	-	1.00	-	-	-	60,176	-	-	assumed all age 3 from length frequency	1984	85	8.12%
1986	4,511,267	1986	75,889	-	0.95	0.05	-	-	72,095	3,794	-	estimated from bimodal frequency distribution	1985	86	9.15%
1987	4,399,695	1987	107,528	0.63	0.37	-	-	67,743	39,785	-	-	estimated from bimodal frequency distribution	1986	87	6.30%
1988	4,586,296	1988	298,112	0.30	0.70	-	-	89,434	208,678	-	-	estimated from bimodal frequency distribution	1987	88	5.13%
1989	8,601,185	1989	323,437	-	1.00	-	-	-	323,437	-	-	assumed all age 3 from length frequency	1988	89	2.81%
1990	6,592,040	1990	277,239	-	1.00	-	-	-	277,239	-	-	assumed all age 3 from length frequency	1989	90	4.15%
1991	5,802,397	1991	235,443	-	1.00	-	-	-	235,443	-	-	assumed all age 3 from length frequency	1990	91	3.00%
1992	3,610,373	1992	241,871	-	1.00	-	-	-	241,871	-	-	assumed all age 3 from length frequency	1991	92	2.05%
1993	3,883,792	1993	273,679	-	1.00	-	-	-	273,679	-	-	assumed all age 3 from length frequency	1992	93	0.75%
1994	4,924,652	1994	174,224	-	1.00	-	-	-	174,224	-	-	assumed all age 3 from length frequency	1993	94	1.20%
1995	2,865,029	1995	73,840	-	1.00	-	-	-	73,840	-	-	assumed all age 3 from length frequency	1994	95	1.73%
1996	1,280,288	1996	29,072	-	1.00	-	-	-	29,072	-	-	assumed all age 3 from length frequency	1995	96	5.98%
1997	989,644	1997	58,977	-	1.00	-	-	-	58,977	-	-	assumed all age 3 from length frequency	1996	97	8.65%
1998	1,324,779	1998	42,540	-	1.00	-	-	-	42,540	-	-	assumed all age 3 from length frequency	1997	98	10.86%
1999	1,326,527	1999	100,939	0.20	0.73	0.07	-	20,188	73,685	7,066	-	Andrusak, Arrow fert report	1998	99	9.30%
2000	4,250,501	2000	142,103	0.52	0.46	0.02	-	73,894	65,367	2,842	-	Andrusak, Arrow fert report	1999	00	6.99%
2001	8,888,753	2001	137,096	0.49	0.51	-	-	67,177	69,919	-	-	Andrusak, Arrow fert report	2000	01	3.15%
2002	8,433,296	2002	195,062	0.76	0.24	-	-	148,247	46,815	-	-	estimated from bimodal frequency distribution	2001	02	2.48%
2003	4,100,045	2003	155,279	-	0.94	0.06	-	-	145,962	9,317	-	Carder plus 1 year based on trawl 2+ size	2002	03	3.75%
2004	229,231	2004	286,190	0.05	0.94	0.01	-	14,310	269,019	2,862	-	based on ages by J. DeGisi	2003	04	23.15%
2005	671,233	2005	209,805	0.02	0.93	0.05	-	4,238	194,970	10,596	-	based on ages by J. DeGisi	2004	05	13.51%
2006	5,009,523	2006	122,447	-	1.00	-	-	-	122,447	-	-	default to spawner lfreq	2005	06	5.89%
2007	5,634,460	2007	113,571	0.30	0.46	0.24	-	34,071	52,243	27,257	-	Casselman CSA Confidence rating of 6-9)	2006	07	5.07%
2008	7,042,421	2008	82,061	0.44	0.55	0.01	-	36,107	45,134	821	-	Casselman CSA Confidence rating of 6-9)	2007	08	3.20%
2009	3,829,792	2009	286,599	0.10	0.86	0.04	-	28,660	246,475	11,464	-	Casselman CSA Confidence rating of 6-9)	2008	09	2.99%
2010	20,362,487	2010	317,554	0.15	0.81	0.04	-	47,633	257,219	12,702	-	Casselman CSA Confidence rating of 6-9)	2009	10	0.08%
2011	17,679,762	2011	186,537	0.07	0.93	-	-	13,058	173,479	-	-	Casselman CSA Confidence rating of 6-9)	2010	11	0.54%
2012	11,233,138	2012	29,877	0.18	0.75	0.11	-	5,378	22,408	3,286	-	Casselman CSA Confidence rating of 6-9)	2011	12	0.66%
2013	2,069,081	2013	85,761	-	0.07	0.92	0.01	-	6,003	78,900	858	Casselman CSA Confidence rating of 6-9)	2012	13	0.65%
2014	3,876,915	2014	99,375	0.03	0.93	0.04	-	2,981	92,419	3,975	-	Casselman CSA Confidence rating of 6-9)	2013	14	
2015	5,079,496	2015	89,255	0.15	0.80	0.04		13,388	71,404	3,570	-	Casselman CSA Confidence rating of 6-9)			

Appendix 8. Equipment and Data Processing Specifications.

Echosounder Specifications and Field Settings

Category	**Parameter**	**Value**
Echosounder Transceiver	Manufacturer	Simrad EK60
	Frequency	120 kHz
	Max power	100 W
	Pulse duration	0.256 ms
	Band width	8.71 kHz
	Absorption coefficient	4.43 dB.km^{-1}
	Sound speed	1447 m.sec^{-1}
	Water column temperature	10.0 °C
Transducer	Type	split-beam
	Depth of face	0.75 m
	Orientation, survey method	vertical, mobile, tow foil
	Sv, TS transducer gain	27.0 dB
	Angle sensitivity	23.0 dB
	nominal beam angle	7.0 degrees
	Data collection threshold	-70 dB
	Ping rate	6 – 8 pps

Data Processing Specifications: SONAR 5 software version 6.0.0

Data conversion	Amplitude/ SED thresholds	-70 dB (40 Log R TVG)
	Sv, TS gain (correction)	-27.0 dB from field calibration
Single target filter	analysis threshold	-61 to -24 dB (forty 1dB bins)
	Min echo length	0.7 – 1.3
	Max phase deviation	0.30
	Max gain compensation	3 dB (one way)
Fish tracking	Minimum no. echoes	3
	Max range change	0.30 m
	Max ping gap	1
Density determination	Integration method	20 log r density from Sv/Ts
	Echo counting method*	40 log r density based on SED
	Fish size distributions	From in situ single echo detections

- Note: echo counting was the main method used for determining fish densities since fish densities were relatively low for the majority of fish layers.

Appendix 9. Habitat areas for kokanee surveys.

a) Water level and limnetic habitat areas in Arrow Reservoir during acoustic surveys.

Survey Dates		Water level	Habitat area >20 m depth (km^2)		
Year	Month / day	(m)	Upper Arrow	Lower Arrow	Total
2004	Oct 3	430.04	194	94	289
2005	Oct 21	430.30	194	93	287
2006	Oct 19	430.50	194	93	287
2007	Oct 17	432.80	196	96	292
2008	Sept 28	437.50	199	100	299
2009	Oct 14-17	433.19	196	96	292
2010	Oct 4-7	434.50	197	96	293
2011	Sept 25-28	436.80	199	99	298
2012	Oct 11-13	434.26	197	96	293
2013	Oct 1-4	432.02	195	95	290
2014	Oct 19-26	432.50	195	95	290
2015	Oct 7-19	428.58	193	91	284

Note: some corrections have been made to this table to fix discrepancies from rounding

Appendix 9 – continued

b) Habitat area estimates by depth stratums used for acoustic population estimates.

Depth (m) from surface	Revelstoke Reach	Upper Arrow	Narrows	Lower Arrow
full pool	6437	22,582	5,500	12,193
1		22,456		12,092
2		22,330		11,991
3		22,205		11,890
4		22,079		11,789
5		21,953		11,688
6		21,827		11,587
7		21,702		11,486
8		21,576		11,385
9		21,450		11,284
10		21,324		11,183
11		21,198		11,082
12		21,073		10,981
13		20,947		10,880
14		20,821		10,779
15		20,695		10,678
16		20,570		10,577
17		20,444		10,476
18		20,318		10,375
19		20,192		10,274
20		20,055		10,173
21		19,992		10,086
22		19,929		10,000
23		19,866		9,913
24		19,803		9,827
25		19,739		9,740
26		19,676		9,653
27		19,613		9,567
28		19,550		9,480
29		19,487		9,394
30		19,424		9,307
31		19,360		9,220
32		19,297		9,134
33		19,234		9,047
34		19,171		8,961
35		19,108		8,874
36		19,045		8,787
37		18,981		8,701
38		18,918		8,614
39		18,855		8,528
40		18,792		8,441

Depth (m) from surface	Upper Arrow	Lower Arrow
41	18,729	8,354
42	18,665	8,268
43	18,602	8,181
44	18,539	8,095
45	18,476	8,008
46	18,413	7,921
47	18,350	7,835
48	18,286	7,748
49	18,223	7,662
50	18,160	7,575
51	18,068	7,511
52	17,977	7,447
53	17,885	7,384
54	17,794	7,320
55	17,702	7,256
56	17,611	7,192
57	17,519	7,129
58	17,427	7,065
59	17,336	7,001
60	17,244	6,937
61	17,153	6,874
62	17,061	6,810
63	16,969	6,746
64	16,878	6,682
65	16,786	6,619
66	16,695	6,555
67	16,603	6,491
68	16,512	6,427
69	16,420	6,364
70	16,328	6,300
71	16,237	6,236
72	16,145	6,172
73	16,054	6,109
74	15,962	6,045
75	15,870	5,981
76	15,779	5,917
77	15,687	5,853
78	15,596	5,790
79	15,504	5,726
80	15,413	5,662

Data interpolated from Canadian Hydrographic Service charts: # 3056, 3057 and 3058,
Areas are in Hectares (Ha.); Full pool elevation reference 440.24 m

Appendix 10. Summaries of fish density (number/ha) by transect for age 0+ and age 1-3+ fish during October 2015 acoustic surveys.

Transect Number	All ages	Age 0	Age 1-3
1	335	317	19
2	765	728	37
3	585	554	31
4	281	241	40
5	366	300	66
6	144	130	14
7	234	202	32
8	137	118	19
9	282	256	26
10	179	162	17
11	679	611	68
12	1183	1048	135
13	504	424	80
14	432	350	82
15	303	258	45
16	653	573	80
17	648	574	74
18[a]	1646	1493	152
19[b]	911	838	73
20[b]	991	761	229
Upper[c]	331	301	30
Lower[c]	692	610	81

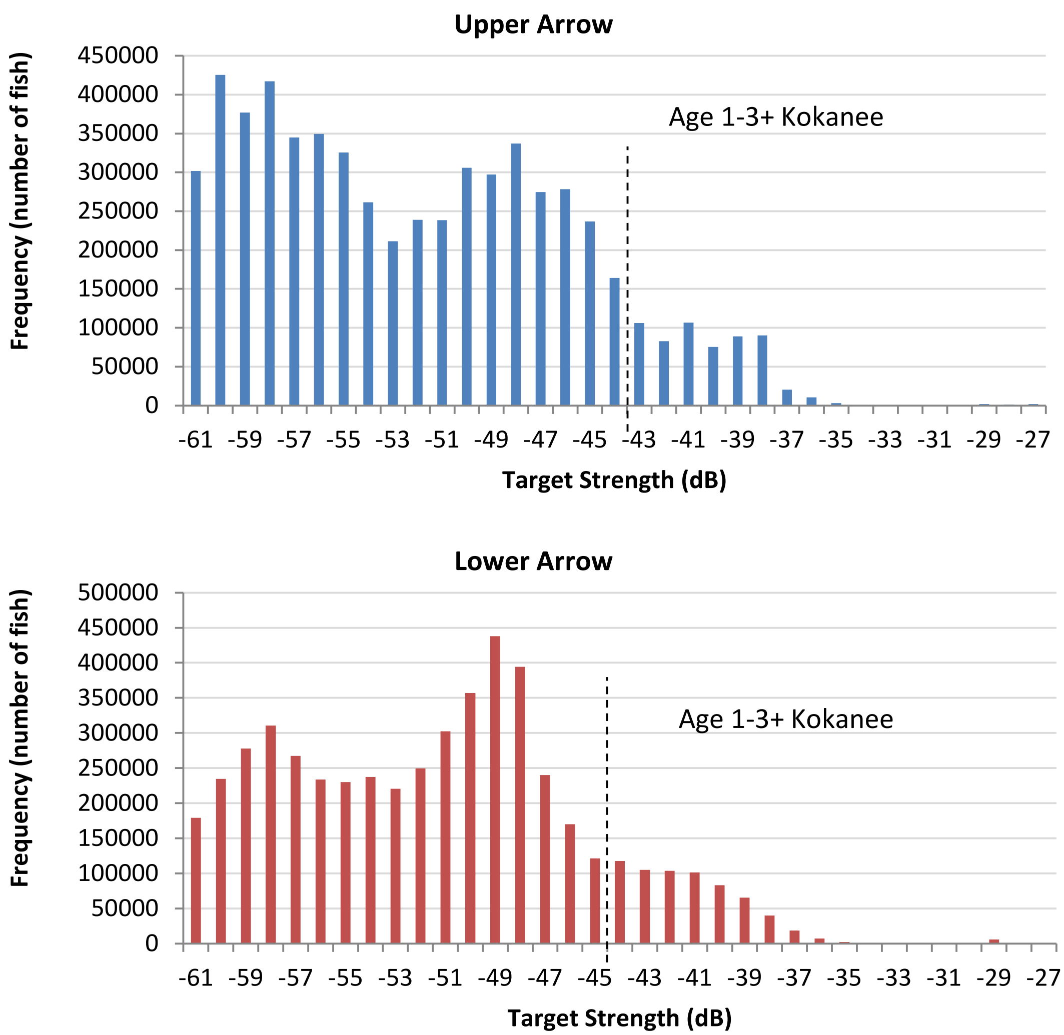
Transect 18 is used with #11-17 to estimate Lower Arrow abundance
Transects 19 and 20 are in the Narrows and used for qualitative information only. T19 and 20 were not completed in 2014.
Basin averages do not include transects 19 and 20 in the Narrows

Appendix 11. Total transect fish density (number/ha) 2003 to 2015.

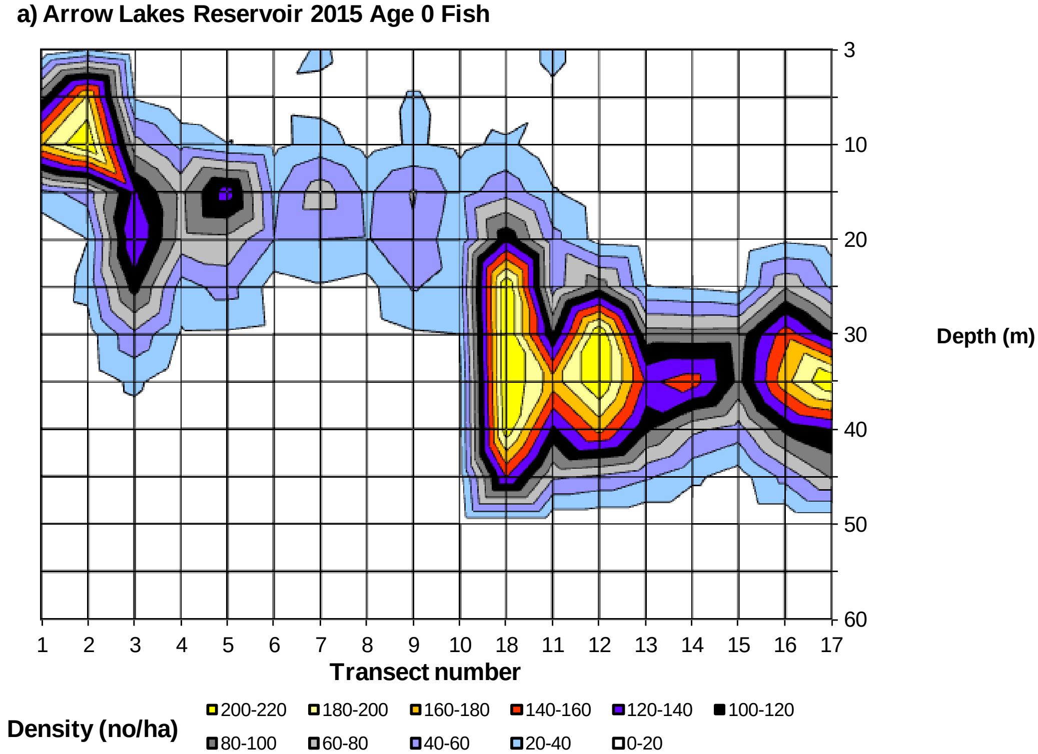
Transect	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Upper Arrow													
1	300	160	160	301	498	379	217	361	241	145	268	388	335
2	480	566	285	359	275		286	718	671	489	259	360	765
3	330	260	142	274	115		220	426	908	375	160	369	585
4	184	253	77	275	206	362	147	332	425	186	171	182	281
5	214	180	139	224	78		166	282	195	181	112	229	366
6	561	217	348	218	162	192	125	550	401	117	55	171	144
7	574	304	185	255	168		133	655	315	110	92	196	234
8	629	359	149	337	104	253	634	512	708	158	80	147	137
9	439	304	210	367	223		554	351	429	162	131	221	282
10	284	240	254	318	324	310	382	271	229	168	81	237	179
Narrows													
20	898	564	497	672	872	618	1164	979	138	556	1161	813	990
19	613	664	422	1668	429	1004	1433	2064	424	770	735	1114	911
Lower Arrow													
18	540	624	249	638	227	622	855	2188	198	398	651	731	1646
11	391	490	357	363	323	387		795	334	358	397	818	679
12	173	238	92	255	75	216	356	569	119	121	155	364	1183
13	302	162	197	294	161		371	344	121	179	231	339	504
14	729	368	234	296	344	138	248	314	118	196	186	293	432
15	500	331	255	528	196	227	245	278	373	405	247	514	303
16	844	266	285	480	222	193	398	420	452	294	225	528	653
17	938	693	231	269	241	149	379	438	249	311	274	335	648
Upper	400	284	195	293	215	299	286	446	452	209	141	250	331
Lower	552	397	238	390	224	276	407	668	246	283	296	490	756

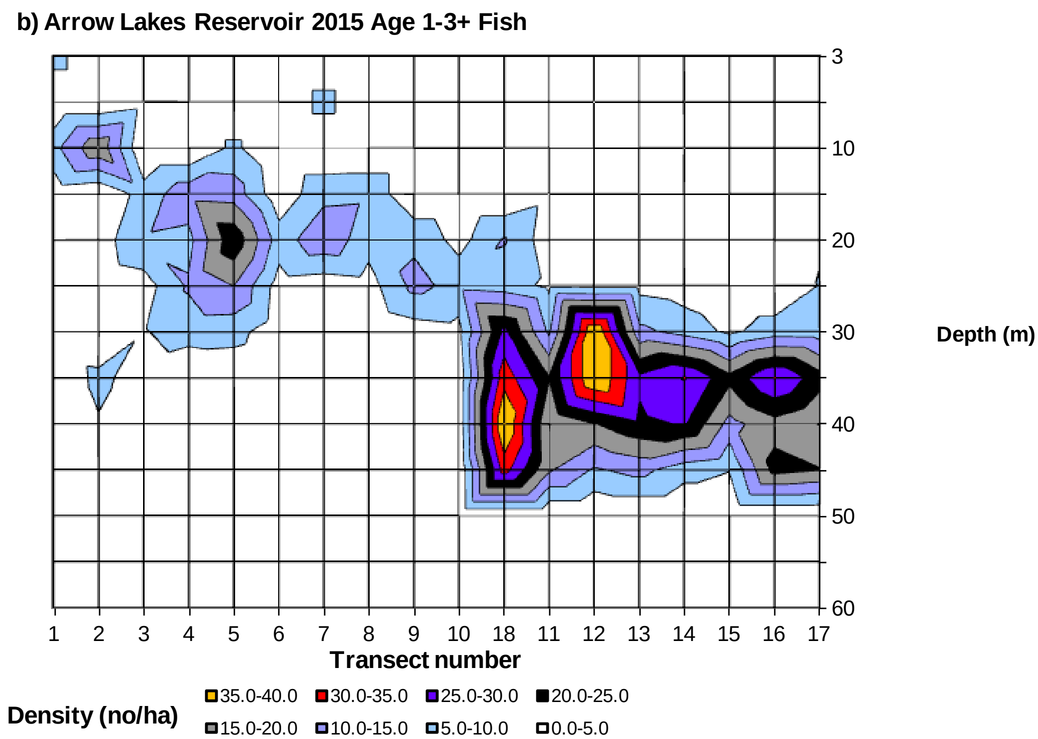
Note: Upper Arrow is represented by transects 1-10
Lower Arrow is represented by transects 11-18
Narrows area is represented by transects 19-20 and not included in annual kokanee population as it includes inknown proportions of other species and represents a very small habitat area.

Appendix 12. Cumulative target strength (TS) frequency distributions (all transects) for a) Upper Arrow and b) Lower Arrow Reservoir used for establishing cut-off points to separate fry from age 1-3+ kokanee.



Appendix 13. Contour plot showing depth and distribution of the night time kokanee layer in Arrow Reservoir based on hydroacoustic surveys in October 2015. Note darker and hotter colours indicate higher fish density in no·ha^{-1} as shown by the legend





Appendix 14. Maximum likelihood estimates and bounds for a) all fish in Upper and Lower Arrow and for b) age 1-3+ kokanee and c) age 0+ fish in Upper and Lower Arrow during October 2015 based on Monte Carlo Simulations.

a) Statistics for 2015 kokanee of all ages (> –61 dB) for Zone 1 in Upper Arrow (Transects 1-10) and Zone 2 in Lower Arrow (Transects 11-18).

Zone	Depth	N	Mean	SE	Area	StratumPop	CV	Statistic	Abundance
1	3-5	10	5.0	2.9	20,570	102,899	0.3	LB=	4,472,912
1	5-10	10	36.8	18.1	20,192	743,599	0.3	MLE=	6,414,831
1	10-15	10	83.0	41.3	19,803	1,643,918	0.3	UB=	8,344,918
1	15-20	10	69.8	12.6	19,487	1,359,805	0.3		
1	20-25	10	59.1	13.4	19,171	1,132,071	0.3		
1	25-30	10	38.5	10	18,855	726,635	0.3		
1	30-35	10	19.6	5.1	18,539	363,060	0.3		
1	35-40	10	9.1	2.6	18,223	165,339	0.3		
1	40-45	10	5.6	1.8	17,794	99,952	0.3		
1	45-50	10	4.3	1.2	17,336	74,275	0.3		
2	3-5	8	5.6	3.8	10,577	59,305	0.4	LB=	4,801,249
2	5-10	8	3.6	1.8	10,274	36,836	0.4	MLE=	5,928,571
2	10-15	8	5.5	3.3	9,827	53,884	0.4	UB=	7,072,683
2	15-20	8	12.8	6.3	9,394	120,134	0.4		
2	20-25	8	29.3	14.8	8,961	262,116	0.4		
2	25-30	8	70.6	27	8,528	601,766	0.4		
2	30-35	8	176.3	43.9	8,095	1,427,139	0.4		
2	35-40	8	240.3	40.9	7,662	1,840,789	0.4		
2	40-45	8	138.7	20.7	7,320	1,015,518	0.4		
2	45-50	8	73.4	17.1	7,001	514,018	0.4		

b) Statistics for 2015 age 0+ kokanee (-61 to –44.1 dB) for one Zone 1 in Upper Arrow (Transects 1-10) and (-61 to –45.1 dB) for Zone 2 in Lower Arrow (Transects 11-18)

Zone	Depth	N	Mean	SE	Area	StratumPop	CV	Statistic	Abundance
1	3-5	10	4.3	2.9	20,570	88,342	0.4	LB=	4,009,457
1	5-10	10	35.9	18.2	20,192	725,107	0.4	MLE=	5,831,659
1	10-15	10	79.7	39.4	19,803	1,578,226	0.4	UB=	7,721,301
1	15-20	10	64.4	11.5	19,487	1,255,514	0.4		
1	20-25	10	50.7	12.2	19,171	971,063	0.4		
1	25-30	10	32.9	9.5	18,855	619,624	0.4		
1	30-35	10	16.9	4.6	18,539	312,906	0.4		
1	35-40	10	7.6	2.3	18,223	137,893	0.4		
1	40-45	10	4.9	1.6	17,794	86,506	0.4		
1	45-50	10	3.6	1.2	17,336	62,444	0.4		
2	3-5	8	5.6	3.8	10,577	59,305	0.4	LB=	4,185,869
2	5-10	8	2.5	1.8	10,274	25,925	0.4	MLE=	5,237,535
2	10-15	8	4.7	3	9,827	45,844	0.4	UB=	6,288,409
2	15-20	8	12	6.3	9,394	112,750	0.4		
2	20-25	8	26.2	13.8	8,961	235,155	0.4		
2	25-30	8	67.4	26.4	8,528	574,741	0.4		
2	30-35	8	161.7	39.7	8,095	1,308,732	0.4		
2	35-40	8	211	38	7,662	1,616,224	0.4		
2	40-45	8	117.3	18.5	7,320	858,574	0.4		
2	45-50	8	58.1	14.1	7,001	406,668	0.4		

c) Statistics for 2014 age 1-3+ kokanee (> –44 dB) for one zone in Upper Arrow (Transects 1-10) and one zone in Lower Arrow (Transects 11-18)

Zone	Depth	N	Mean	SE	Area	StratumPop	CV	Statistic	Abundance
1	3-5	10	0.7	0.7	20,570	14,557	0.5	LB=	419,907
1	5-10	10	0.9	0.7	20,192	18,492	0.5	MLE=	573,122
1	10-15	10	3.3	2.0	19,803	65,691	0.5	UB=	726,916
1	15-20	10	5.4	1.7	19,487	104,291	0.5		
1	20-25	10	8.4	2.1	19,171	161,009	0.5		
1	25-30	10	5.7	1.6	18,855	107,011	0.5		
1	30-35	10	2.7	0.9	18,539	50,154	0.5		
1	35-40	10	1.5	0.6	18,223	27,446	0.5		
1	40-45	10	0.8	0.4	17,794	13,447	0.5		
1	45-50	10	0.7	0.3	17,336	11,832	0.5		
2	3-5	8	0.0	0.0	10,577	-	0.4	LB=	569,812
2	5-10	8	1.1	0.7	10,274	10,911	0.4	MLE=	687,939
2	10-15	8	0.8	0.6	9,827	8,041	0.4	UB=	805,717
2	15-20	8	0.8	0.4	9,394	7,383	0.4		
2	20-25	8	3.0	1.2	8,961	26,960	0.4		
2	25-30	8	3.2	0.9	8,528	27,025	0.4		
2	30-35	8	14.6	4.9	8,095	118,407	0.4		
2	35-40	8	29.3	3.6	7,662	224,565	0.4		
2	40-45	8	21.4	3.3	7,320	156,945	0.4		
2	45-50	8	15.3	3.2	7,001	107,351	0.4		

Appendix 15. Preliminary estimates of age specific abundance, mean weight and biomass density (kg·ha^{-1}) for kokanee in a) Upper Arrow and b) Lower Arrow Reservoirs based on acoustic and trawl surveys during 1993-2014.

a) Upper Arrow Reservoir

	Age specific population estimates				Mean weight by age group (g)				Pelagic area	Biomass Density by age group (kg/ha)				Total
year	Age 0	Age 1	Age 2	Age 3	Age 0	Age 1	Age 2	Age 3	(ha)	Age 0	Age 1	Age 2	Age 3	In-lake
1993	1,552,000	358,714	266,143	23,143	3.3	32	107	118	19,803	0.26	0.58	1.44	0.14	2.42
1994	2,516,000	259,429	194,571	-	2.3	30	86		19,550	0.29	0.40	0.85	0.00	1.55
1995	1,361,000	360,769	108,231	-	3.1	33	89		19,739	0.21	0.60	0.49	0.00	1.30
1996	982,000	136,800	91,200	-	1.7	19	55		19,613	0.08	0.13	0.26	0.00	0.47
1997	738,000	135,625	298,375	-	2.2	31	59		19,803	0.08	0.21	0.88	0.00	1.17
1998	1,316,000	248,000	496,000	-	3.8	62	130		19,929	0.25	0.77	3.24	0.00	4.26
1999	2,450,000	302,000	1,208,000	-	4.9	110	241		19,803	0.61	1.68	14.70	0.00	16.99
2000	6,410,000	884,615	265,385	-	4.8	97	159		19,803	1.55	4.34	2.13	0.00	8.01
2001	10,190,000	2,502,632	667,368	-	3.1	52	125		19,171	1.65	6.76	4.36	0.00	12.77
2002	8,760,000	2,769,437	888,310	52,254	2.5	32	81		19,613	1.10	4.48	3.68	0.00	9.26
2003	4,220,000	2,712,056	701,944	-	2.7	38	72		19,676	0.57	5.25	2.58	0.00	8.40
2004	3,210,000	362,535	1,027,183	40,282	3.4	30	74	77	19,487	0.57	0.56	3.90	0.16	5.19
2005	2,265,400	497,300	430,993	66,307	2.6	53	88	98	19,424	0.30	1.36	1.96	0.33	3.96
2006	4,394,000	1,577,455	350,545	-	3.6	54	162		19,424	0.82	4.42	2.93	0.00	8.17
2007	3,207,100	646,510	418,330	38,030	3.0	47	110	100	19,613	0.49	1.55	2.35	0.19	4.58
2008	4,609,000	791,424	445,176	-	2.9	52	133		19,929	0.68	2.08	2.98	0.00	5.73
2009	3,440,600	796,000	1,194,000	-	3.0	47	121		19,613	0.53	1.90	7.37	0.00	9.80
2010	6,882,000	599,657	1,099,371	49,971	3.0	37	97	107	19,676	1.04	1.13	5.41	0.27	7.85
2011	6,644,000	2,020,288	209,653	19,059	1.8	30	80	95	19,866	0.59	3.02	0.85	0.09	4.55
2012	3,608,000	429,811	159,189	-	2.5	34	72		19,676	0.45	0.75	0.58	0.00	1.79
2013	2,113,000	273,000	273,000	-	1.8	41	168		19,550	0.19	0.57	2.35	0.00	3.11
2014	4,215,900	386,280	257,520	-	2.7	57	110		19,550	0.59	1.13	1.45	0.00	3.16
2015	5,831,659	506,480	66,642	-	3.7	31	83		19,297	1.10	0.82	0.29	0.00	2.21
Pre-fert	1,410,833	249,890	242,420	3,857	2.7	34	88	118	19,739	0.20	0.45	1.19	0.02	1.86
Fert era (all yrs)	4,850,039	1,062,205	568,389	15,641	3.0	50	116	95	19,598	0.75	2.46	3.52	0.06	6.80
Fert era (02-15)	4,528,619	1,026,302	537,275	18,993	2.8	42	104	95	19,600	0.64	2.07	2.76	0.07	5.55

Note: values in blue font represent best estimates in the absence of trawl data in 2007

Appendix 15 continued.

b) Lower Arrow Reservoir

year	Age specific population estimates Age 0	Age 1	Age 2	Age 3	Mean weight by age group (g) Age 0	Age 1	Age 2	Age 3	Pelagic area (ha)	Biomass Density by age group (kg/ha) Age 0	Age 1	Age 2	Age 3	Total In-lake
1993	1,435,000	307,136	247,864	-	2.0	43	113		9,827	0.29	1.34	2.86	0.00	4.49
1994	1,662,000	258,523	166,604	2,872	2.6	42	97	112	9,480	0.45	1.16	1.70	0.03	3.34
1995	1,222,000	194,084	243,916	-	2.9	42	92		9,740	0.36	0.84	2.30	0.00	3.51
1996	920,000	252,778	447,222	-	1.8	30	61		9,567	0.18	0.78	2.83	0.00	3.79
1997	753,000	125,803	233,197	-	1.6	35	77		9,827	0.12	0.45	1.84	0.00	2.41
1998	1,360,000	385,882	434,118	-	1.8	69	132		10,000	0.25	2.66	5.72	0.00	8.62
1999	1,418,000	200,556	521,444	-	4.9	103	238		9,827	0.70	2.11	12.63	0.00	15.44
2000	3,275,000	518,636	259,318	37,045	4.9	57	174	172	9,827	1.65	3.03	4.60	0.65	9.93
2001	5,210,000	685,607	575,421	48,972	3.8	56	125	169	8,961	2.21	4.26	8.02	0.92	15.41
2002	4,800,000	1,597,453	1,218,396	54,151	2.9	29	109		9,567	1.45	4.89	13.83	0.00	20.17
2003	1,835,000	1,150,541	775,946	53,514	3.9	36	117	137	9,653	0.74	4.28	9.41	0.76	15.19
2004	1,554,000	494,615	748,989	42,396	4.1	28	87	109	9,394	0.68	1.45	6.90	0.49	9.52
2005	1,206,400	148,667	237,867	104,067	3.8	62	104	128	9,307	0.49	0.99	2.67	1.43	5.58
2006	1,594,700	584,588	206,325	34,388	4.6	68	169	202	9,307	0.79	4.28	3.75	0.75	9.56
2007	1,136,500	267,979	267,979	36,543	3.3	48	122	140	9,567	0.39	1.34	3.42	0.53	5.69
2008	1,833,652	95,513	620,835	-	4.0	40	164		10,000	0.73	0.38	10.17	0.00	11.28
2009	2,601,425	447,692	522,308	-	3.7	56	156		9,567	1.01	2.63	8.49	0.00	12.14
2010	4,738,000	504,680	412,920	229,400	3.9	29	115	142	9,653	1.92	1.50	4.92	3.37	11.71
2011	1,256,000	410,000	569,444	45,556	2.4	28	77	90	9,913	0.30	1.16	4.44	0.42	6.32
2012	2,059,000	127,609	127,609	331,783	4.2	55	91	110	9,653	0.89	0.73	1.20	3.79	6.61
2013	2,039,000	309,833	183,083	14,083	2.9	73	145	275	9,480	0.62	2.39	2.80	0.41	6.21
2014	3,701,400	369,987	165,313	-	3.0	55	126		9,480	1.16	2.14	2.19	0.00	5.49
2015	5,237,535	570,843	107,338	9,758	2.6	29	74	89	9,134	1.46	1.80	0.87	0.09	4.23
Pre-fert	1,225,333	254,034	295,487	479	2.12	44	95	112	9,740	0.28	1.21	2.87	0.01	4.36
Fert era (all yrs)	2,676,212	499,106	442,384	61,274	3.69	50	129	147	9,546	1.01	2.32	5.90	0.85	10.03
Fert era (03-15)	2,368,662	421,734	380,458	69,345	3.56	47	119	142	9,547	0.86	1.93	4.71	0.93	8.43

Note: values in blue font represent best estimates in the absence of trawl data in 2007

Appendix 16. Estimation and comparison of egg to spawner survival for the spawner index Tributaries of Arrow Lakes Reservoir. Upper Arrow Index streams include Drimmie, Halfway, Kuskanax, and Hill Creek is presented separately. Lower Arrow index streams include Burton, Caribou, Deer, and Mosquito.

Spawner / Brood Yr	Spawner Count						Size and Fecundity[2]					Egg Deposition (millions)								Egg to Spawner Survival Index[3]				
	Upper Arrow				Lower Arrow	Combined Basins	Hill Creek Spawning Channel					Upper Arrow				Lower Arrow	Combined Basins			Upper Arrow			Lower Arrow	Combined Basins
	HC + index	Index	Hill Creek Total	Hill Creek SC	Index	All[1]	Length	Fecund	Retention	Net Fec	%Female	HC + index	Index	Hill Creek Total	Hill Creek SC	Index	All[1]	Brood Yr	Spawner Yr	HC + index	Index	Hill Creek Total	Index	All[1]
1988	409,862	111,750	298,112	150,000	271,500	681,362	204	184		184	50%	37.8	10.3	27.5	13.8	25.0	49.1							
1989	429,187	105,750	323,437	150,000	181,500	610,687	213	207		207	50%	44.3	10.9	33.4	15.5	18.7	45.2							
1990	325,689	48,450	277,239	180,000	260,250	585,939	213	170	32	138	50%	22.5	3.3	19.1	12.4	18.0	33.7							
1991	285,993	50,550	235,443	75,000	291,750	577,743	218	219	13	206	49%	28.9	5.1	23.8	7.6	29.4	42.1							
1992	261,971	20,100	241,871	75,000	86,250	348,221	223	263	33	230	50%	30.1	2.3	27.8	8.6	9.9	20.9	88	92	1.1%	0.2%	1.8%	0.3%	0.7%
1993			273,679	75,000			241	248	31	217	52%			30.9	8.5			89	93			1.8%		
1994			174,224	75,000			240	302	51	251	51%			22.3	9.6			90	94			1.4%		
1995	84,839	11,385	73,454	16,328	147,953	232,792	235	274	1	273	51%	11.8	1.6	10.2	2.3	20.6	24.5	91	95	0.7%	0.2%	1.0%	0.5%	0.6%
1996	34,172	5,100	29,072	25,030	161,175	195,347	207	172	8	164	52%	2.9	0.4	2.5	2.1	13.7	16.3	92	96	0.3%	0.2%	0.3%	1.6%	0.9%
1997	63,959	4,982	58,977	22,566	24,636	88,595	209	182	6	176	50%	5.6	0.4	5.2	2.0	2.2	4.6	93	97			0.7%		
1998	48,162	5,622	42,540	19,087	184,920	233,082	250	226	12	214	44%	4.5	0.5	4.0	1.8	17.4	19.7	94	98			0.4%		
1999	120,964	20,025	100,939	78,024	233,925	354,889	297	424	36	388	41%	19.2	3.2	16.1	12.4	37.2	52.8	95	99	3.1%	1.3%	4.4%	1.1%	1.5%
2000	166,636	24,533	142,103	102,400	248,538	415,174	302	469	2	467	47%	36.6	5.4	31.2	22.5	54.6	82.4	96	00	6.5%	5.6%	6.7%	1.8%	2.5%
2001	183,934	46,838	137,096	122,400	405,027	588,961	259	379	7	372	41%	28.1	7.1	20.9	18.7	61.8	87.6	97	01	7.6%	10.7%	6.9%	18.7%	12.8%
2002	245,008	49,946	195,062	151,826	340,466	585,473	213	212	5	207	39%	19.8	4.0	15.7	12.3	27.5	43.8	98	02	10.5%	9.4%	10.9%	2.0%	3.0%
2003			155,279	133,951			214	233	9	224	48%			16.7	14.4			99	03			1.3%		
2004	422,855	136,665	286,190	199,820	450,323	873,178	206	189	4	185	35%	27.4	8.8	18.5	12.9	29.2	50.9	00	04	1.5%	2.5%	1.3%	0.8%	1.1%
2005	244,475	34,670	209,805	142,755	313,442	557,916	212	214	5	209	48%	24.5	3.5	21.0	14.3	31.4	49.2	01	05	0.9%	0.5%	1.1%	0.5%	0.6%
2006	140,384	17,937	122,447	91,649	138,138	278,522	259	240	8	232	48%	15.6	2.0	13.6	10.2	15.4	27.6	02	06	0.9%	0.4%	1.0%	0.5%	0.6%
2007	122,663	9,092	113,571	97,731	95,852	218,514	247	236	4	232	46%	13.1	1.0	12.1	10.4	10.2	21.6	03	07			0.8%		
2008	86,345	4,292	82,053	72,068	97,050	183,395	228	236	4	232	38%	7.6	0.4	7.2	6.4	8.6	15.3	04	08	0.4%	0.05%	0.6%	0.3%	0.4%
2009	305,394	18,795	286,599	241,508	145,847	451,241	241	258	7	251	50%	38.3	2.4	36.0	30.3	18.3	51.0	05	09	1.7%	0.5%	2.0%	0.5%	0.9%
2010	345,171	27,617	317,554	267,243	156,147	501,318	243	272	5	267	43%	38.2	3.2	35.1	30.7	17.9	51.8	06	10	2.8%	1.4%	3.1%	1.0%	1.8%
2011	201,268	14,701	186,567	155,405	48,797	250,065	225	267	5	262	44%	23.2	1.7	21.5	17.9	5.6	25.2	07	11	1.8%	1.5%	1.8%	0.5%	1.2%
2012	30,637	760	29,877	24,342	44,890	75,527	218	255	4	251	47%	3.6	0.1	3.5	2.9	5.3	8.2	08	12	0.5%	0.2%	0.5%	0.5%	0.5%
2013	91,024	5,263	85,761	43,521	129,236	220,260		252	3	249	54%	12.0	0.7	11.3	5.9	17.4	23.9	09	13	0.3%	0.2%	0.3%	0.7%	0.4%
2014	117,308	17,932	99,376	33,812	110,348	227,656	305	438	5	433	41%	18.2	3.2	15.0	6.0	19.7	28.9	10	14	0.3%	0.6%	0.3%	0.6%	0.4%
2015	93,298	4,043	89,255	42,568	117,329	210,627	251	314	5	309	42%	11.3	0.5	10.8	5.5	15.2	21.2	11	15	0.5%	0.2%	0.5%	2.1%	0.8%
Average (All)	**194,448**	**31,872**	**166,699**	**102,287**	**187,411**	**381,859**	**236**	**262**	**12**	**251**	**46%**	**21.0**	**3.3**	**18.3**	**11.3**	**21.2**	**35.9**			**2.3%**	**2.0%**	**2.1%**	**1.9%**	**1.7%**
SD	125,807	36,220	94,033	67,783	111,693	207,484	29	79	13	78	5%	12.2	3.1	9.8	7.6	14.1	20.8			2.9%	3.2%	2.6%	4.2%	2.9%
2xSE	50,323	14,488	35,541	25,620	44,677	82,994	11	30	5	30	2%	4.9	1.2	3.7	2.9	5.6	8.3			1.4%	1.5%	1.1%	2.0%	1.4%
Average (10 yr)	**153,349**	**12,043**	**141,306**	**106,985**	**108,363**	**261,712**	**246**	**277**	**5**	**272**	**45%**	**18.1**	**1.5**	**16.6**	**12.6**	**13.4**	**27.5**			**1.0%**	**0.6%**	**1.1%**	**0.7%**	**0.8%**
SD	100,916	8,632	93,587	86,939	37,942	125,566	26	61	1	61	5%	11.9	1.1	11.0	10.3	5.4	14.0			0.9%	0.5%	0.9%	0.5%	0.5%
2xSE	63,825	5,460	59,190	54,985	23,997	79,415	17	39	1	39	3%	7.5	0.7	7.0	6.5	3.4	8.8			0.6%	0.4%	0.6%	0.4%	0.3%
Average (5 yr)	**106,707**	**8,540**	**98,167**	**59,930**	**90,120**	**196,827**	**250**	**305**	**4**	**301**	**46%**	**13.7**	**1.2**	**12.4**	**7.6**	**12.6**	**21.5**			**0.7%**	**0.5%**	**0.7%**	**0.9%**	**0.7%**
SD	61,779	7,377	56,376	53,932	40,103	69,350	39	78	1	78	5%	7.4	1.2	6.6	5.9	6.7	7.9			0.6%	0.6%	0.6%	0.7%	0.3%
2xSE	55,257	6,598	50,424	48,239	35,869	62,029	39	70	1	70	5%	6.7	1.1	5.9	5.3	6.0	7.1			0.6%	0.5%	0.6%	0.6%	0.3%

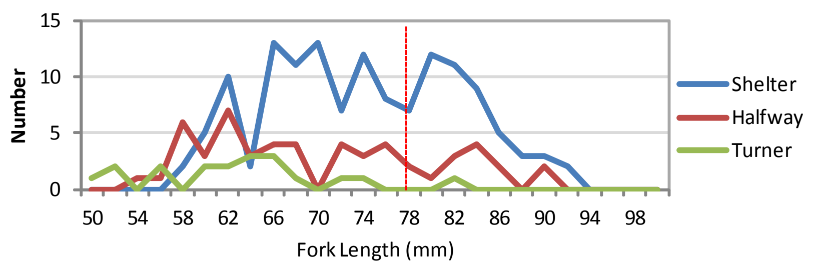
[1] Includes all Upper and Lower Arrow index tributaries including Hill Creek spawning channel (but not surplus eggs to SC in Hill Creek)

[2] Blue values estimated to result in reported egg deposition in regional files

[3] Assumes age 3+ spawners

Appendix 17. Fry length frequency analyses for Upper Arrow trawl catches used to estimate the number of large fry in Upper Arrow in 2015.

	Number of fry captured by trawl location			
FL mm	Shelter	Halfway	Turner	total
50	0	0	1	1
52	0	0	2	2
54	0	1	0	1
56	0	1	2	3
58	2	6	0	8
60	5	3	2	10
62	10	**7**	2	19
64	2	3	**3**	8
66	**13**	4	**3**	**20**
68	11	4	1	16
70	**13**	0	0	13
72	7	4	1	12
74	12	3	1	16
76	8	4	0	12
78	7	2	0	9
80	**12**	1	0	13
82	11	3	1	**15**
84	9	**4**	0	13
86	5	2	0	7
88	3	0	0	3
90	3	2	0	5
92	2	0	0	2
94	0	0	0	0
96	0	0	0	0
98	0	0	0	0
100	0	0	0	0
Regular fry	86	41	18	145
Large fry	49	13	1	63
Total fry	135	54	19	208
% Large	36.3%	24.1%	5.3%	30.3%



Option 1: no entrained fry in Beaton				
Location	transects	Fry abundance	% large	No. Large fry
Beaton	1 and 2	1,402,849		
Shelter Bay	3 and 4	1,594,566	36%	578,828
Halfway	5, 6 and 7	1,308,122	24%	315,257
Turner Cr	8, 9 and 10	1,080,523	5%	57,268
Total Upper Arrow		5,386,060	18%	951,353

Option 2: similar proportion in Beaton as Shelter Bay				
Location	transects	Fry abundance	% large	No. Large fry
Beaton	Trans 1,2	1,402,849	36%	509,234
Shelter Bay	Trans 3,4	1,594,566	36%	578,828
Halfway	Trans 5,6,7	1,308,122	24%	315,257
Turner Cr	Trans 8,9,10	1,080,523	5%	57,268
Total Upper Arrow		5,386,060	27%	1,460,587

Suggests large fry comprise from 18-27% of Upper Arrow total fry population.

Appendix 18. Arrow May-Oct average water temperature (°C) at 2m. Data extracted from profile data. Years represented by red points are incomplete for all stations and months, with long-term monthly averages substituted in data gaps. 2014 omitted due to instrument failure.