ARROW LAKES RESERVOIR NUTRIENT RESTORATION PROGRAM
YEAR 18 (2016) REPORT

by

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EXECUTIVE SUMMARY

This report contains a summary of results from the 18th year of the nutrient restoration program on the Arrow Lakes. 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 response to changes in the lakes caused by upstream impoundments, we added a total of 40 tonnes of phosphorus and 240 tonnes of nitrogen to Arrow Lakes Reservoir off the Columbia Ferry in 2016. We also conducted monthly or bi-monthly monitoring of lower trophic levels and assessed the status of kokanee.

In 2016, mean daily outflow from lower Arrow from April to November was only slightly higher than the 1997–2016 average, but flows were higher than average in June and early July. Secchi disc measurements in the main body of the reservoir were comparable to 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 phosphorus results in 2016 were within the range of previous years. Total phosphorus concentrations averaged 2.8 µg/L and total dissolved phosphorus concentrations averaged 2.1 µg/L. These results are indicative of oligotrophic conditions. Epilimnetic dissolved inorganic nitrogen averaged 98 µg/L, which indicates that the lake was not nitrogen limited at any point in the season, and was also within the range of previous years.

The biovolume of phytoplankton that were edible to desirable zooplankton was below average but greater than the previous year, while the density of the inedible community was less than 2015 and below the long-term average. *Daphnia* sp., which are the preferred food source of kokanee, first appeared in the samples in April in Upper Arrow and in May in Lower Arrow, peaking in August and maintaining detectable numbers through to November. Overall, the annual biomass of zooplankton was higher than average, and increased from 2015. The density of *Mysis diluviana* was near to average in Upper Arrow, and lower than average in Lower Arrow.

The 2016 kokanee in-lake fry abundance estimate was similar to 2015 and well above average in Upper Arrow at 5.7 million, while the estimate of 3.7 million fry in Lower Arrow was down from 2015 but still above average. The age 1–3 population increased to near average for Upper Arrow at 1.6 million, which was the highest number since 2011 and a substantial increase over 2015. In Lower Arrow the age 1–3 population was 0.8 million, which was only 75% of the post-fertilization average yet still the highest number abundance since 2011. Spawner numbers declined slightly from 2015 in both basins, and were estimated at ~80,000 (44% of average) and 100,000 (52% of average) in Upper Arrow and Lower Arrow index streams, respectively. Mean spawner length declined to 238 mm, or just below average for Hill Creek, and the dominant age at maturity shifted to age 2 for the first time since 2002. Fork length of all in-lake age classes captured in the trawl increased over from 2015, with the exception of Upper Arrow fry. The increase in size coincided with an increase in abundance of age 1–3 kokanee which lead to in-lake biomass density nearly tripling in Upper Arrow to 6.3 kg/ha and increasing ~40% in Lower Arrow to 7.1 kg/ha.

Hill Creek Spawning Channel egg to fry survival was 57% in 2016, which was a substantial decline from 2015 but still well above average. The decrease in survival led to a reduction in channel fry output to 2.6 million down from 4.4 million in 2015. Egg to spawner survival has been improving since the very poor survival observed in the 2009 and 2010 brood year cohorts and was well above average, particularly for in Upper Arrow index tributaries. Outflow rates from Lower Arrow declined from a post-fertilization record high in 2015 to near average in 2016, which correlated with an improvement in annual kokanee survival to near average in 2016. As a result, age 1 and 2 abundances increased to the highest in 4–5 years, which suggests the potential for an increase in kokanee spawner numbers in 2017 and 2018 should in-lake conditions and kokanee survival remain average or better. The decrease in spawner size, fecundity and numbers in 2016 led to a reduction in the system-wide egg deposition to 19 million, which could result in a decrease in age 0 numbers in 2017 compared to 2016.

Raw data for 2016 are in appendices or on file at Ministry of Forests, Lands and Natural Resource Operations and Rural Development (FLNRORD) in Nelson, B.C.

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 (*Oncorhynchus nerka*; Stockner and MacIsaac 1996; Ashley *et al.* 1999; Mazumder and Edmundson 2002; Hyatt *et al.* 2004; Perrin *et al.* 2006). Nutrient additions have also been used in Scandinavia as a technique for improving Arctic char (*Salvelinus alpinus*) and brown trout (*Salmo trutta*) populations (Milbrink *et al.* 2008; Rydin *et al.* 2008). Prior to nutrient additions, systems such as the 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 was taken with the addition of nutrients (nitrogen and phosphorus in the form of liquid fertilizer) to increase the production of *Daphnia* spp., a main food source for kokanee, which in turn is a keystone species in these lakes. Nutrient addition to the Arrow Lakes Reservoir began in 1999.

The objectives of the nutrient restoration program are outlined in the Fish and Wildlife Compensation Program's Large Lakes Plan. The program follows habitat based actions, one of which is to apply seasonally adjusted nutrients to mimic natural inputs of nutrients to sustain productivity at levels sufficient to support fisheries and ecosystem objectives. Details of the plan are found in the link below:

http://fwcp.ca/app/uploads/2016/07/Large-Lakes-Action-Plan-Web-FNL-June-20121.pdf

The Arrow Lakes Reservoir

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,2009b; Utzig and Schmidt 2011). ALR is now a warm, monomictic water body with isothermal temperatures from late fall to early spring and stratification during the summer months. In addition to nutrient losses, wide seasonal variations in reservoir levels have contributed to oligotrophication of ALR. Modeling of hydraulic alterations caused by annual hydro facility water regulation by Matzinger *et al.* (2007) predicted that further hydraulic modifications, such as deep water withdrawal or increased reservoir levels within the growing season, could reduce lake productivity by up to 40%. A further impact to ALR fish production has been the introduction of the freshwater shrimp *Mysis diluviana* (formerly *M. relicta;* Audzijonyte and Vainola 2005) in 1968 (Sebastian *et al.* 2000), which occurred after the perceived success of their 1949 introduction into Kootenay Lake (Thompson, 1999). *M. diluviana* are known to be a competitor with kokanee for macrozooplankton.

In response to these numerous perturbations, the ALR kokanee 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 status of ALR and the events leading to initial nutrient additions to 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 often a 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) summarizes ALR sport fish statistics and demonstrated improved growth and condition of 2003 rainbow trout and bull trout, attributed to increased kokanee abundance (Arndt 2004a). Schindler *et al.* (2009a) compared trophic level data from a number of years prior to nutrient additions with data from the first eight years of nutrient additions and concluded that it 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. Of course, 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 reliable dataset of kokanee that dates to the early 1970s, primarily based on kokanee spawner abundance from several index streams and the Hill Creek spawning channel. The current ALR nutrient addition and monitoring program can therefore demonstrate trends over four decades of monitoring. Spawner escapement approaching one million was estimated for the 1960s and early 1970s based on run reconstruction from the Upper Columbia (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, Natural Resource Operations and Rural Development (MoFLNRORD). Most of the ALR work was 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 program 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 (1999–2016) 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, 2009b, 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)
- The 17th year, 2015, Bassett et al. (2018)

This report describes the 18th year (2016) of the program and includes a summary of results and analysis of monitoring for climate, 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 methods used for monitoring 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 2016.

In 2016, 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 2016 was 40.1 tonnes of phosphorus and 240.8 tonnes of nitrogen (Table 1). Weekly nutrient dispensing began the week of April 25th and finished the week of September 5th. 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 9.93:1 in the late summer (Appendix 3). Phosphorus loading ranged from 7.6 to 20.3 mg/m^2 and nitrogen loading ranged from 5.1 to 85.4 mg/m^2 in 2016 (Figure 1). The planned seasonal loading of fertilizer was intended to approximate pre-impoundment spring freshet conditions for phosphorus (P) loading, and the loads were adjusted in-season to compensate for biological uptake of dissolved inorganic nitrogen (DIN), depending on the conditions. The planned proportion of nitrogen in the weekly loads started low 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 nitrogen depletion, or low N:P ratios (Smith, 1983; Pick and Lean, 1987). Actual nutrient addition was altered from the planned schedule due to low nitrogen results in the June water sampling session: total nitrogen (TN), dissolved inorganic nitrogen (DIN), and the N:P (DIN: total dissolved phosphorus (TDP)) were all significantly low for that time of year. Water clarity (indicated by Secchi depth) in the Narrows was also abnormally low for early June. The schedule was therefore moved forward one week to increase the nitrogen to phosphorus ratio (Figure 1).

Table 1. Total tonnes of nitrogen and phosphorus additions from fertilizer to Upper Arrow between April and September, 1999–2016.

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
2016	40.1	240.8

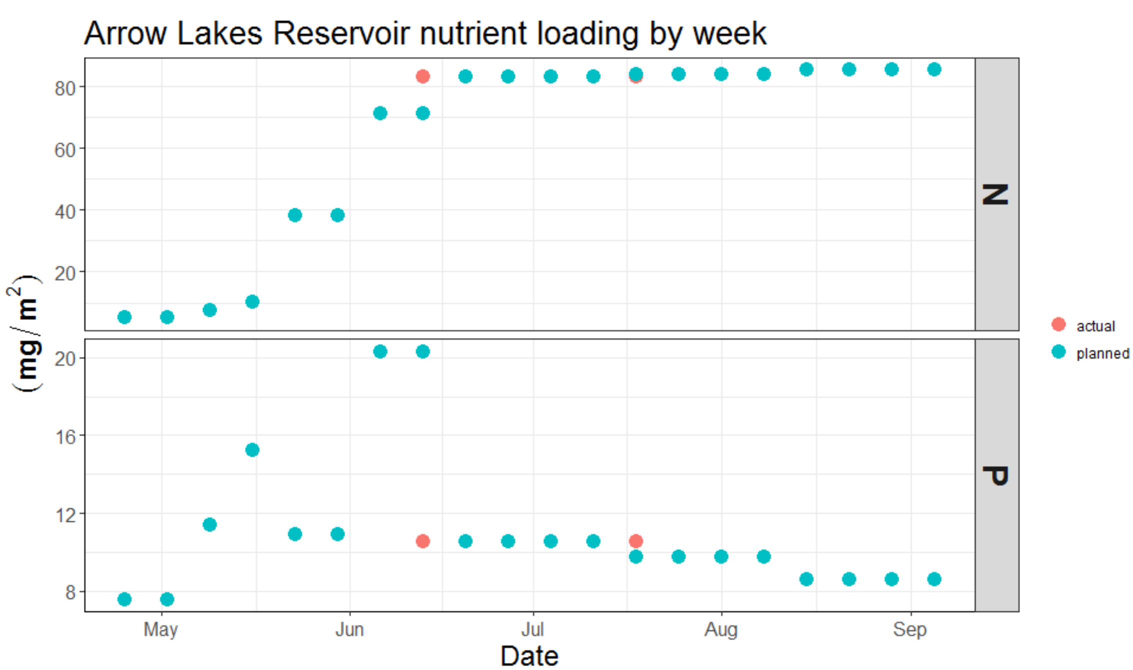


Figure 1. Phosphorus and nitrogen loading to Upper Arrow (mg/m^2/week) from fertilizer (N:Nitrogen, P:Phosphorus), April–September, 2016. Planned (blue) and actual (red).

Nutrient application

In 2016, fertilizer was dispensed from the Columbia ferry via dispensing bars off of the stern. A truck hauling approximately 7,570 litres (2000 US gallons) of fertilizer was driven onto the ferry and the fertilizer dispensed during the regular passenger run from Galena Bay to Shelter Bay (Appendix 4). The number of dispensing trips varied depending on the weekly loading schedule. A maximum of seven trips were required to dispense a full week's load. Often, two to three trips were done in a day, and were timed to go every two to three days. The fertilizer was stored at a tank farm located at the Hill Creek Spawning Channel prior to dispensing.

Diffuser pipes were installed on the stern end 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.* 2003). 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.

Flow

The combined daily mean outflow from Hugh Keenleyside Dam and the Arrow Lakes Generating station were obtained from BC Hydro to represent the total outflow from Lower Arrow. Only flows from the growing season (April to October) were used in yearly comparisons.

Limnology sampling stations

In 2016 there were nine sampling stations on ALR: stations AR 1–3 were located in Upper Arrow, stations AR 4 and AR 5 were in the former river channel that connected the pre-impoundment Upper and Lower Arrow lakes (called the Narrows), and stations AR 6–8 and HL 4 were located in Lower Arrow (Table 2, Appendix 4). Physical hydrology, phytoplankton, chlorophyll, water chemistry, zooplankton, and *Mysis diluviana* samples were collected at stations AR 1–3 and AR 6–8. Physical hydrology, phytoplankton and chlorophyll were measured at stations AR 4 and AR 5. Station HL 4 is close to Syringa Provincial Park and was only monitored for physical hydrology. Monitoring details are described in Appendix 2.

Table 2. Limnological sampling stations for the Arrow Lakes Reservoir Nutrient Restoration Program. EMS Site no. refers to data submitted to the Environmental Monitoring System (MECCS, 2018).

Site ID	EMS Site No.	Site name	Max Depth (m)	UTM NAD 83 Zone 11	
				Northing	Easting
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, dissolved oxygen and conductivity 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. Conductivity, or specific conductance, is a measure of resistance of a solution to electrical flow; in an aqueous solution, the resistance to electrical current declines with increasing ion content (Wetzel, 2001). For graphing purposes, profiles for Upper Arrow were represented by AR 2 and Lower Arrow represented by AR 7. Water transparency was measured at each station using a standard 20 cm Secchi disc (without a viewing chamber). Secchi depth measurements evaluate the transparency of water to light and in some conditions 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; increasing Secchi depths indicate increasing transparency.

Water chemistry

Water chemistry sampling in the epilimnion occurred monthly from April through November in 2016. Water samples were collected using a 2.54 cm (inside diameter) tube sampler to collect an integrated water sample from 0–20 m. Additional discrete epilimnetic water samples were taken at depths of 2, 5, 10, 15, and 20 m at stations AR 2 and AR 7 from June to September using a Niskin bottle sampler. 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 bottle sampler. Water samples were field filtered and preserved where appropriate and immediately placed on ice and shipped within 24 hours of collection to ALS Global 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 AR 7 were analyzed for TP, TDP, OP, and DIN.

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 was 2 µg/L. 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). 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).

Chlorophyll *a* (Chl *a*) samples were collected 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* samples were sent to the Ministry of Environment office at the University of British Columbia, Vancouver. Prior to shipping to the lab, Chl *a* samples were filtered through a mixed cellulose ester or cellulose acetate filter with 0.45 µm pore size. At the time of this report, chlorophyll *a* sample results are not yet available.

Many of the figures in this report illustrate the 2016 against a time series of annual averages. Figures were mostly produced in R (R Core Team 2017). Detailed analyses of the 1997–2015 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, Bassett et al. 2018). All data are on file at the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development 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 April through November using the 0 to 20 m integrated tube sampler. Samples were preserved with 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. Initially, micro-phytoplankton (20–200 μm), including colonial diatoms, dinoflagellates, and filamentous blue-greens, within 5 to 10 random fields were enumerated at 250X magnification. After this, picoplankton (0.2–2.0 μm), including autotrophic blue-greens, and nanoplankton (2–20 μm), including small nanoflagellates, within or touching a 10 to 15 mm transect line were counted at 1560 X magnification. In total, about 175–225 cells were enumerated from each sample to ensure statistical accuracy (Lund et al. 1958). Taxonomic identifications were performed using the keys of Prescott (1978) and Canter-Lund and Lund (1995).). The phytoplankton species list and estimates of each species' biomass (cell biovolume) used for the computation of population and class biomass estimates for ALR in 2016 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.

Zooplankton

Zooplankton samples were collected monthly from April to November using a Clarke-Bumpus sampler with a net mesh of 153 μm. At each of the stations, three replicate oblique tows were made: the closed sampler was let out obliquely while maintaining a boat speed of approximately 5 km/h until 40 m of cord was in the water, or the sampler was at approximately 20–25 m depth. A messenger triggered the opening of the sampler, and it was then raised to the surface at a winch speed of approximately 13 m/min. Tow duration was 3 minutes, 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% reagent alcohol (denatured). 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 400 X magnification). For each replicate, organisms were identified to species with reference to taxonomic keys (Pennak 1989, Brooks 1959, Wilson 1959, Sandercock and Scudder 1996) 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 (µg dry weight) using an empirical length-weight regression from McCauley (1984).

Mysis diluviana

Samples of mysids (*Mysis diluviana*) from Arrow Lakes Reservoir were collected monthly from April to November. Sampling was conducted at dusk or at night ideally 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 m^2 square-mouthed net with 1,000 µm primary mesh, 210 µm terminal mesh, and 100 µm bucket mesh. The net was raised from the lake bottom with a hydraulic winch at approximately 0.3 m/s. The contents of the bucket were rinsed through a filter to remove excess lake water and were then preserved in 70% denatured alcohol (85% ethanol, 15% methanol).

Samples were analyzed for density, biomass (estimated from an empirical length-weight regression, Lasenby 1977), life history stage, and maturity (Reynolds and DeGraeve 1972) by Limnolab in Burnaby, B.C. 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 160 X 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, 2016 and 2018). Spawner numbers were estimated each fall through a combination of aerial counts and visual ground counts as outlined in Sebastian *et al.* (2000). In index streams, two or three aerial or ground spawner counts were conducted around the time of peak kokanee spawner abundance at the Hill Creek Spawning Channel (HCSC). The peak counts for each index creek were expanded by a factor of 1.5 to account for fish not observed (Redfish Consulting Ltd. 1999), while at the spawning channel total counts were conducted using a fish fence and therefore not expanded. 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. The enumeration method for each creek is identified. Note for Hill Creek the enumeration method below the channel is a ground count, while a fish fence is used to enumerate the fish in spawning channel. See Appendix 4 for locations of tributaries.

Upper Arrow Tributaries	Enumeration Method	Lower Arrow Tributaries	Enumeration Method
Drimmie Creek	Ground	Mosquito Creek	Aerial
Hill Creek and spawning channel	Ground & Fish Fence	Caribou Creek	Aerial
Halfway River	Aerial	Burton/Snow Creeks	Aerial
Kuskanax Creek	Aerial	Deer Creek	Ground

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). Spawners were collected opportunistically as fresh carcasses and by dip net from Deer Creek on September 8th and 16th, and Taite Creek on September 15th, 2016 for length and age data to represent Lower Arrow. Mosquito Creek spawner samples collected during the course of another project were also used. 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. Appendix 7** provides further spawner data specific to Hill Creek including spring fry estimates and historic age structure estimates and returns by age class**.**

Hydroacoustic sampling paired with mid-water trawling has been conducted during the new moon period in October using consistent methods since 1993. The 2016 hydroacoustic survey occurred on October 1–4. Acoustic sampling consisted of 18 standard transects: 10 in the Upper Basin and 8 in the Lower Basin (**Appendix 4**). As in previous years, an additional two transects in the Narrows (T19 and T20) were completed in 2016. 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. Acoustic surveys were conducted at night, beginning at least 1 hour after civil sunset, using a Simrad EK60 120kHz echosounder and ER60 software. The transducer was towed on a planer alongside the boat at a depth of 0.75 m, and data were collected continuously along survey lines at 3–8 $pings \cdot s^{-1}$ while cruising at approximately 2 $m \cdot s^{-1}$. Navigation was by radar and GPS. The echosounder system was calibrated in the field at the beginning of the survey following the procedure described by Kongsberg Maritime AS (2008).

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, which is considered suitable based on low fish densities (**Appendices 10 and 11**), high single echo detection probability, and a low amount of false single echo detections (Balk and Lindem, 2011).

Echograms for each transect were analyzed from surface to 50 m depth in 10 equal depth layers (allowing two exclusion zones: surface to 3 m and 0.2 m above the bottom). Fish densities (number/ha) for each transect and depth strata were output in 1-decibel (dB) size groups and compiled on an Excel spreadsheet. Cumulative fish target strength frequency distributions for each basin were evaluated to determine the visible cut-off for separating the fry size targets from the larger targets (age 1–3 kokanee group) in order to generate density and population estimates for each group by basin. The age 1–3 kokanee group were defined as targets >-45 dB in Upper Arrow and >-44 dB to Lower Arrow. A stochastic simulation (a Monte Carlo method) approach was used to estimate confidence bounds; for each depth stratum 30,000 random realizations of normal distribution were calculated with the mean as the stratum mean and the standard deviation as the standard error of the population mean estimate. The 0.05 and 0.95 quantiles were taken as the 95% confidence intervals. Simulations were done in the statistical programming environment R (R studio version 1.0.143; R Core Team, 2017). Confidence intervals were produced for the entire fish population, fry sized fish population, and for the age 1–3 kokanee. Layer density statistics and population estimates for fry and age 1–3 kokanee are shown in **Appendix 12.**

Mid-water trawl sampling was conducted at six stations: three in Upper Arrow (October 28–30, 2016) and three in Lower Arrow (October 4–6, 2016), 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 5 x 5 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.

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 and verified by scale interpretation conducted at the Ministry of Environment Fish Ageing Lab in Abbotsford. Scales were taken from fish with fork lengths >100 mm for aging. Fish fork 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 estimates of abundance by age from acoustic and trawl data **(Appendix 13**). The age 0 fish population was based on acoustic data alone while the combined age 1–3 acoustic population was apportioned into individual age classes according to trawl catch by age group. We acknowledge that trawl selectivity can affect estimates of abundance by age; however, assuming trawl bias remains consistent over time, the method should provide a consistent index of in-lake biomass and biomass density.

Egg deposition for Upper and Lower Arrow index tributaries 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; Redfish Consulting Ltd. 1999; **Appendix 14)**. An index of survival was calculated using the cumulative spawners that returned from each cohort as age 2, 3, 4 and 5. This approach to evaluate survival assumed straying was not relevant and would not affect overall trends. Note that for simplicity Hill Creek survival was calculated using total Hill Creek spawner returns but only spawning channel egg deposition, which assumes zero survival from non-channel spawners. While there would have been some production from non-channel spawners, we expected variable but far lower survival in non-channel habitat, and the channel would have produced the vast majority of fry; as such, the HCSC estimates were presumed to be biased slightly high. The spawner estimates for all other index tributaries (counted by ground or air) are less precise than Hill Creek, however the assumption is that they are consistent and precise enough to serve as a basis for calculation of the survival index and for comparison to Hill Creek. In addition, the expansion factor of 1.5 used to expand the spawner counts for index tributaries may not be accurate, and it also implies that this expansion factor is constant across years. If the counter efficiency is actually density dependent for example (e.g. aerial and ground counts underestimate spawner numbers at low densities), it would affect the reliability of the survival index.

RESULTS

Climate and flows

Mean daily air temperatures for the region in 2016 were higher than average during winter, spring, and fall but not significantly different than the summer average (**Figure 2**). Mean air temperatures in April were unusually high compared to previous years: 11.9°C compared to a 1999–2016 mean of 8.4 °C. Fall and winter average daily precipitation for the region was higher than the long-term average (1992–2016), while spring and summer precipitation was similar to the long-term average (**Figure 3**).

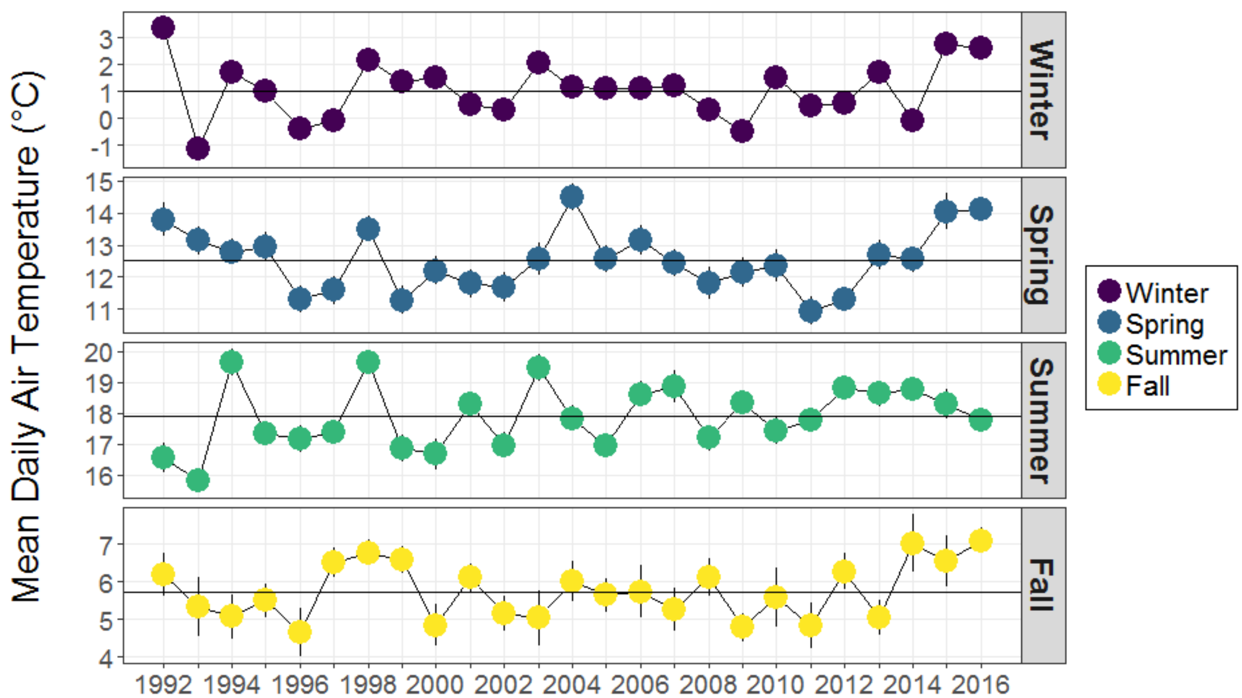


Figure 2. Annual daily mean air temperatures (°C) recorded at the Nelson airport weather station 1992-2016 by season. Note winter data is from respective year (January to March) and December data of previous year. Means ±SE. Solid lines indicate the long-term mean. From Bassett et al. (2018).

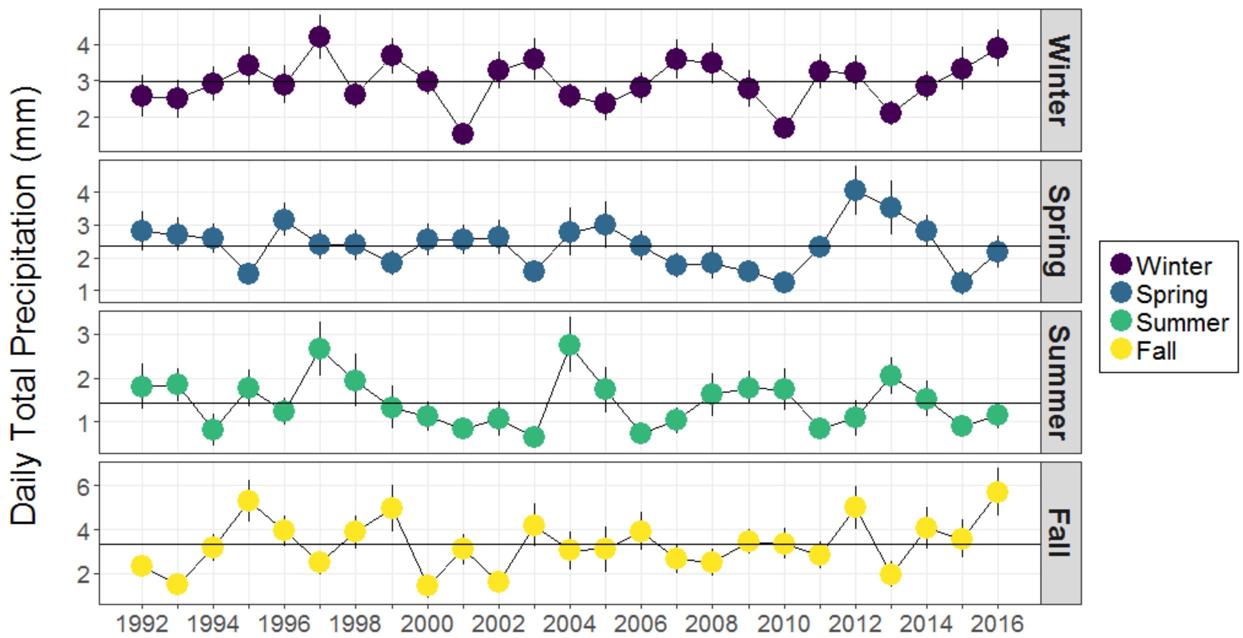


Figure 3. Annual mean total daily precipitation (mm) recorded at the Nelson NE weather station 1992–2016 by season. Note winter data is from respective year (January to March) and December data of previous year. Means ±SE. Solid lines indicate the long-term mean. From Bassett et al. (2018).

Water flow and reservoir elevation

The average April to October mean daily outflow in Arrow Lakes Reservoir in 2016 was 1171 m^3/s, which was slightly above the average long term (1997–2016) daily mean (**Figure 4**). High spring temperatures and low spring precipitation led to a fast freshet in 2016. The seasonal outflow in 2016 was therefore lower than average until June, after which daily outflow was much higher than average until mid-August. Flow was then below average (aside from 12 days at end of September) until the end of October (**Figure 5**). Overall, flows were 89% of normal from April to September (BC Hydro, 2016). Flows were maintained high during the summer of 2016 due to requirements to meet obligations under the Columbia River Treaty related to drought conditions; a full summary of Arrow Reservoir operations is provided in the Fall 2016 Columbia River Operations Summary (BC Hydro, 2016). Though the conditions in the summer of 2016 were hot and dry, they were not as extreme as in 2015.

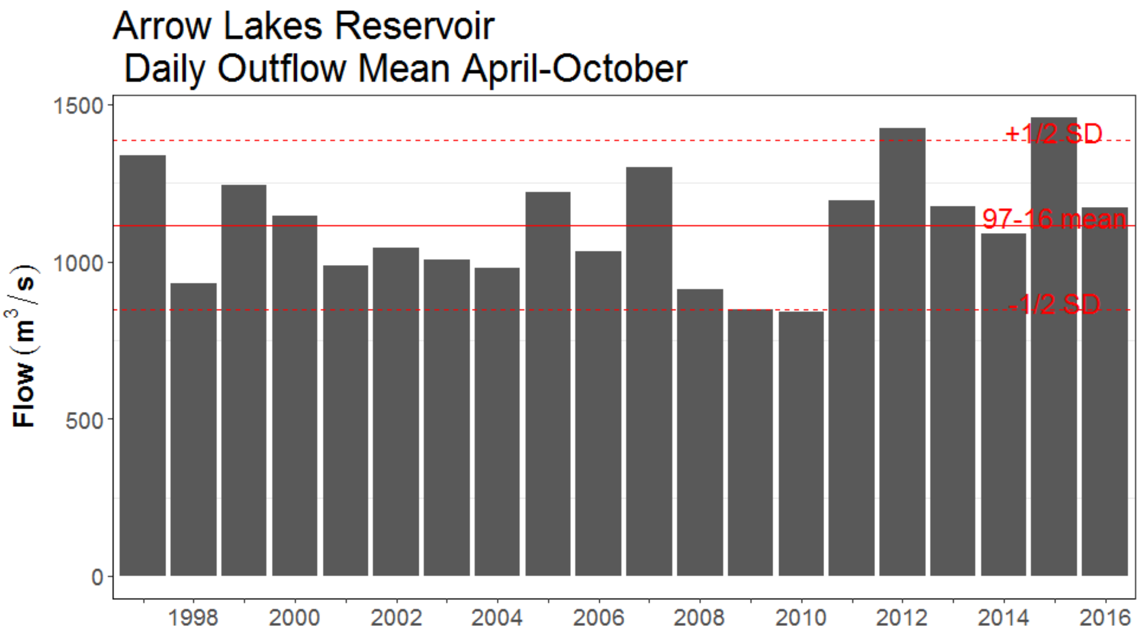


Figure 4. Arrow Lakes Reservoir April-October average daily outflow from Hugh Keenleyside Dam and Arrow Generating Station from 1997 to 2016 with long term average ± 1/2 S.D.

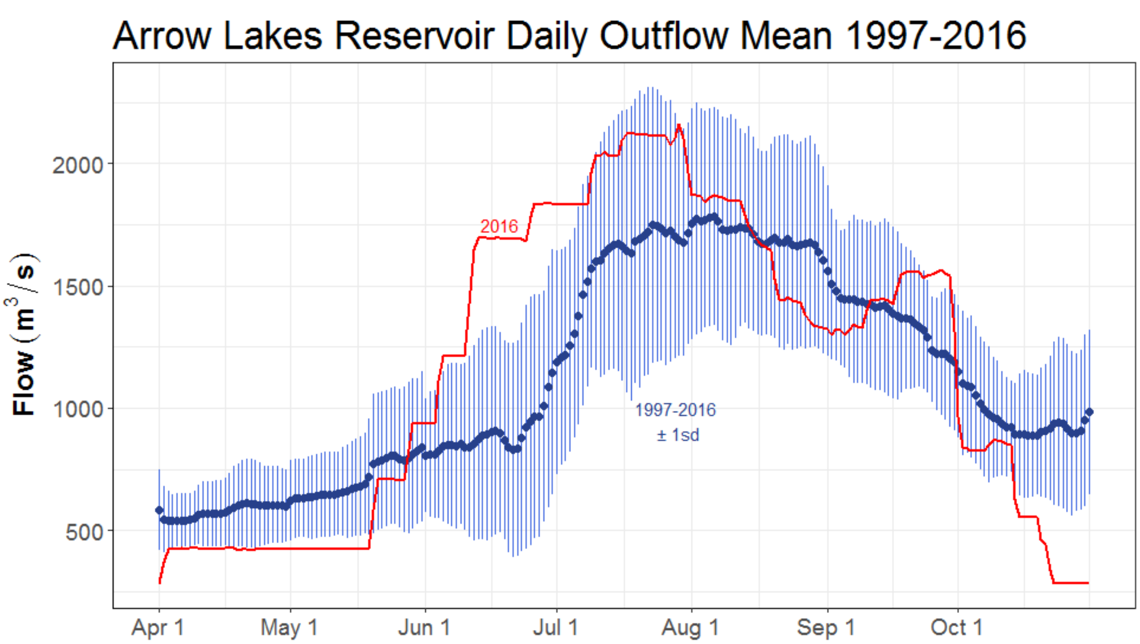


Figure 5. Arrow Lakes Reservoir April-October daily outflow 1997-2016. Blue circles are 1997–2016 daily average, blue vertical lines ± 1 standard deviation and red line is 2016 daily outflow.

Physical Limnology

Profile data

Temperature

Arrow Lakes Reservoir began to stratify in June, and likely at some stations as early as May, then displayed warming surface temperatures through July and August (**Figure 6**). As in previous years, summer stratification occurred with the epilimnion becoming more clearly defined in late summer and early fall. Stratification was maintained until as late as November at some stations. In 2016, hypolimnetic temperatures ranged from 3.5–4°C throughout the year, which is comparable to previous years.

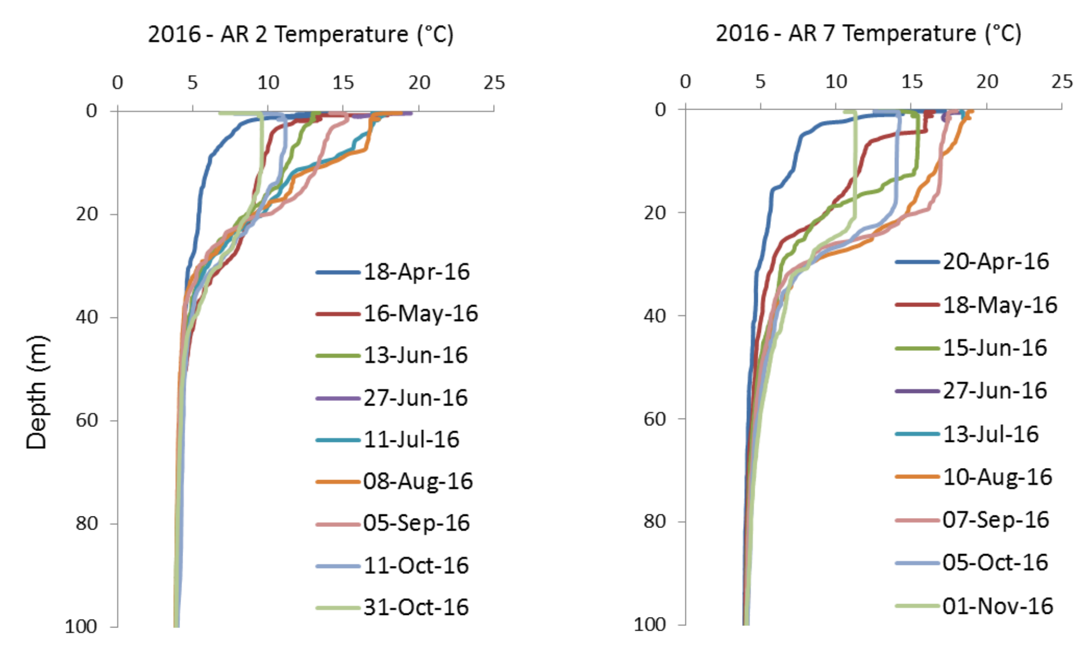


Figure 6. Temperature profiles in Upper (AR2) and Lower (AR7) Arrow basins in 2016. Data is incomplete for June 27, 2016 (AR2 and AR7) and July 13 (AR7 only) due to Seabird battery failure.

Specific Conductivity

Seasonally, conductivity was highest in the spring for both Upper and Lower Arrow, coinciding with freshet (**Figure 7**). Conductivity was lowest in July and August for Upper Arrow and August and September for Lower Arrow. Seasonally, epilimnion conductivity varied more at Upper Arrow compared to Lower Arrow.

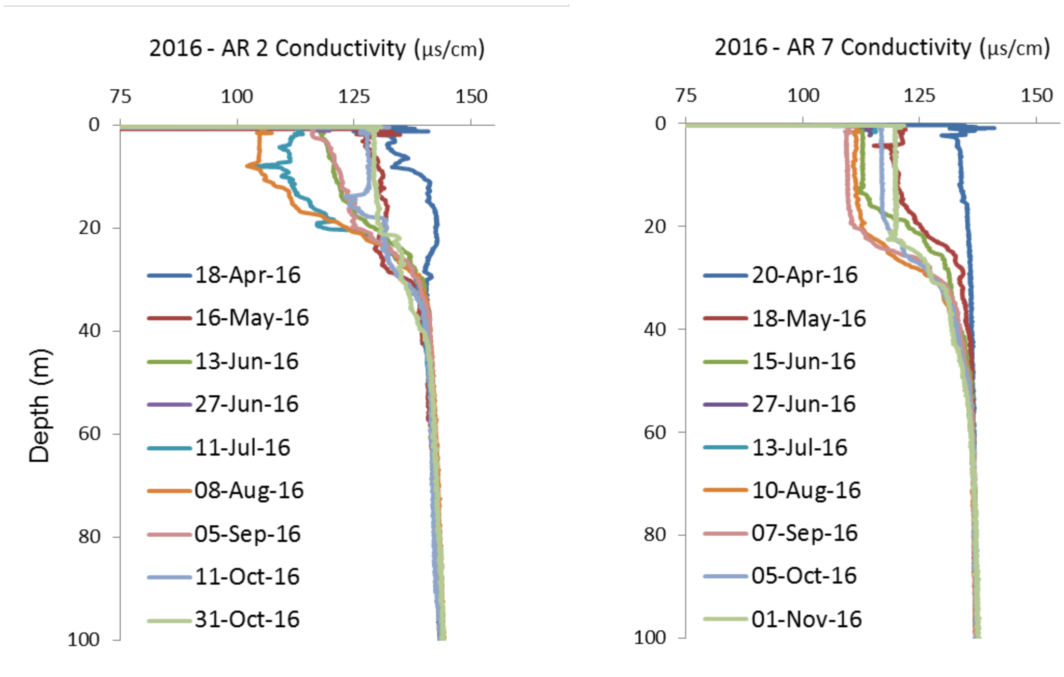


Figure 7. Specific conductivity profiles in Upper (AR2) and Lower (AR7) Arrow basins in 2016. Data is incomplete for June 27, 2016 (AR2 and AR7) and July 13 (AR7 only) due to Seabird battery failure.

Secchi

Secchi disc measurements in Arrow in 2016 show 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 (**Appendix 15**).

In the Upper basin, Narrows and Lower basin, the Secchi depth means in 2016 were slightly above the long term means (**Figure 8**), meaning that water was slightly less clear than basin averages. The exception to this trend was the station at Syringa (HL 4), where the 2016 mean was slightly deeper than the long term mean, meaning the water was slightly clearer in 2016 than on average. Water clarity in all basins was greater (higher Secchi depths) than in 2015.

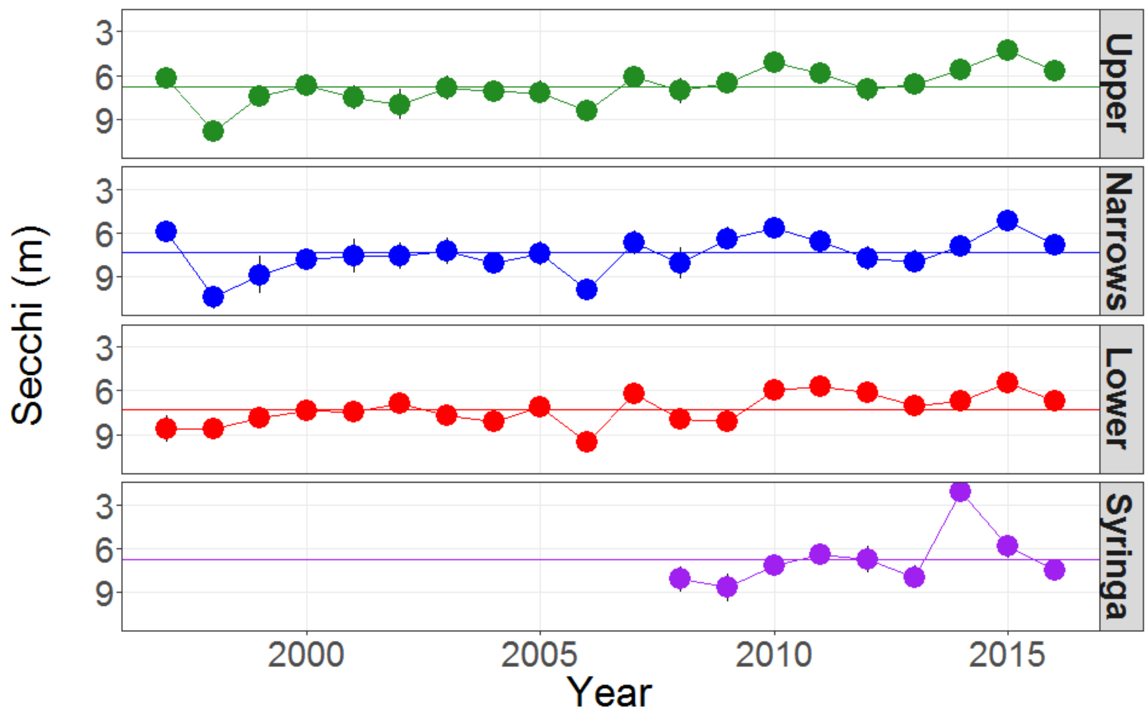


Figure 8. Arrow secchi (m) annual monthly mean by basin (Upper, Narrow, Lower and Syringa) 1997–2016. Means ±SE. Solid lines indicate long term means by basin. Note that the y-axis is inverse.

Water Chemistry

Integrated Epilimnion

Phosphorus

In 2016 in the integrated 0–20 m samples, 36.9% of total phosphorus (TP) values and 64.4% of total dissolved phosphorus (TDP) values were reported at less than the RDL. The annual mean for monthly TP values in 2016 for Upper Arrow was 3.2 µg/L, slightly lower than the 1997–2016 mean of 3.3 µg/L. The mean TP for Lower Arrow was 2.6 µg/L, lower than the Lower Arrow basin 1997–2016 mean of 3.3 µg/L (**Figure 9**). In 2016, TP in Upper Arrow ranged from below the RDL to 6.6 µg/L (which was observed at AR2 in July), in Lower Arrow, TP ranged from below the RDL to 5.0 µg/L (AR8 in July). The annual mean for monthly TDP values in 2016 for Upper Arrow was 2.1 µg/L, lower than the 1997–2016 mean of 2.5 µg/L, Lower Arrow was 2.2 µg/L, lower than the Lower Arrow basin 1997–2016 mean of 2.6 µg/L (**Figure 10**). In 2016, TDP in Upper Arrow ranged from below the RDL to 4.5 µg/L (which was observed in late June at AR2). In Lower Arrow, TDP ranged from below the RDL to 4.4 µg/L (AR8 in June). Monthly phosphorus and nitrogen values for Upper and Lower Arrow are reported in **Appendix**

16 and **17**, respectively. Phosphorus and nitrogen results from the discrete depth sampling are reported in **Appendix 18**.

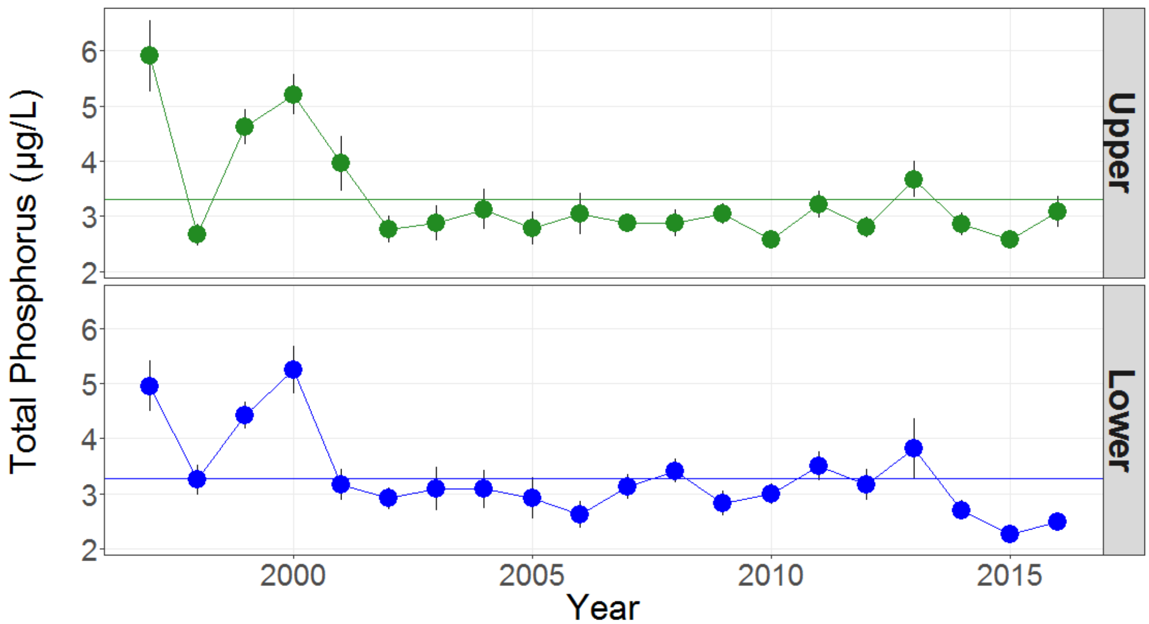


Figure 9. Arrow total phosphorus annual monthly mean by basin (Upper and Lower) 1997-2016. Means ±SE. Solid lines indicate long term means by basin.

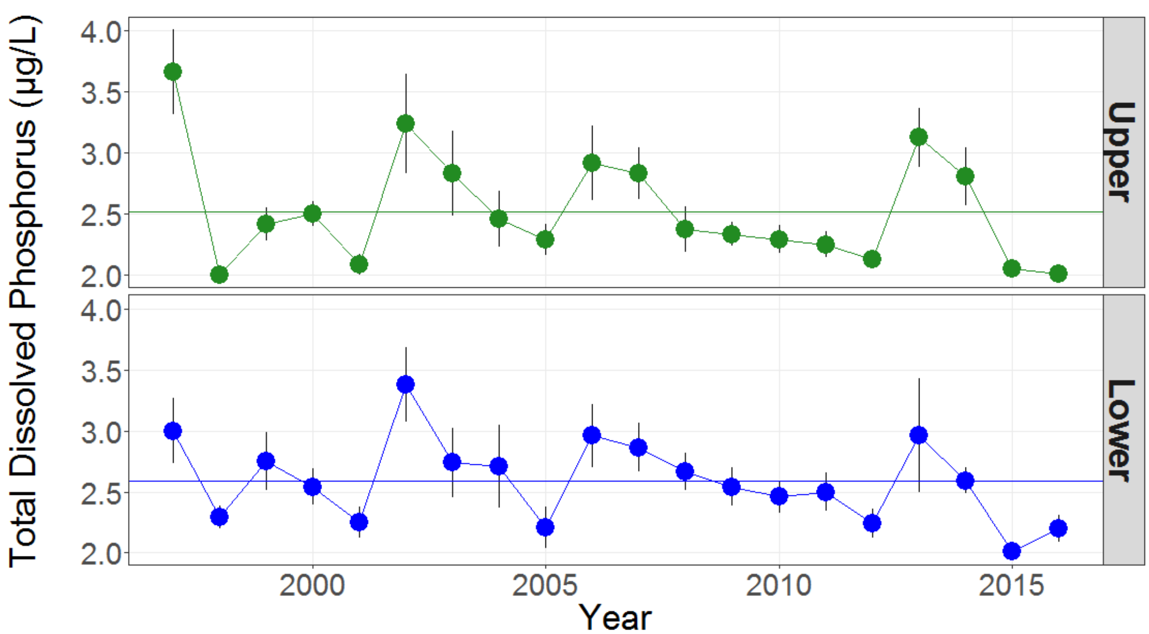


Figure 10. Arrow total dissolved phosphorus annual monthly mean by basin (Upper and Lower) 1997–2016. Means ±SE. Solid lines indicate long term means by basin.

Nitrogen

Total nitrogen (TN) comprises dissolved inorganic forms (i.e., nitrate, nitrite and ammonia) and particulate nitrogen (mainly organic). Dissolved inorganic nitrogen (DIN), consists of nitrite, nitrate and ammonia. The annual mean for monthly TN values in 2016 for Upper Arrow was 161.6 µg/L, lower than the 1997–2016 mean of 189.8 µg/L. Lower Arrow was 136.7 µg/L, lower than the Lower Arrow basin 1997–2016 mean of 183.3 µg/L (**Figure 11**). In 2016, TN in Upper Arrow ranged from 123 (AR3 late July and Aug results) to 235 µg/L (which was observed at AR2 in May), in Lower Arrow, TN ranged from 91 µg/L (AR7 in September) to 171 µg/L (AR6 in July). The annual mean for monthly DIN values in 2016 for Upper Arrow was 115.9 µg/L, lower than the 1997–2016 mean of 128.1 µg/L. Lower Arrow was 80.7 µg/L, lower than the Lower Arrow basin 1997–2016 mean of 97.7 µg/L (**Figure 12**). In 2016, DIN in Upper Arrow ranged from 85 µg/L (observed at AR3 in September) to 175 µg/L (in May at AR1), in Lower Arrow, DIN ranged from 61 µg/L 116 µg/L (AR8 in April). Water chemistry results other than nitrogen and phosphorus for Upper and Lower Arrow are presented in **Appendix 19** and **20**, respectively.

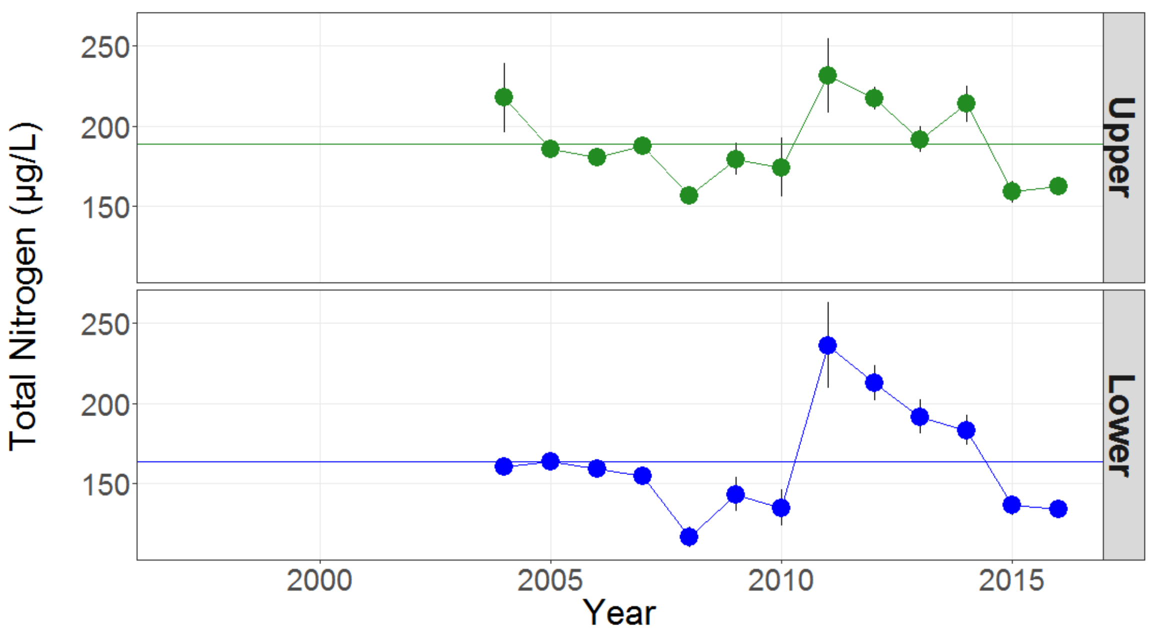


Figure 11. Arrow total nitrogen annual monthly mean by basin (Upper and Lower) 1997–2016. Means ±SE. Solid lines indicate long term means by basin.

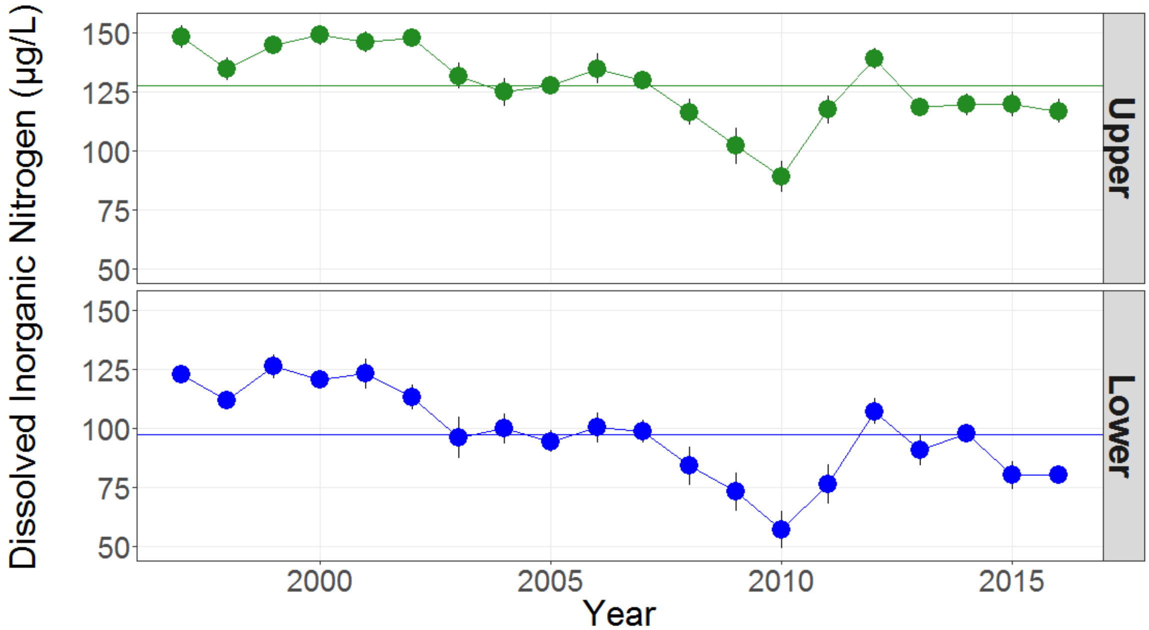


Figure 12. Arrow dissolved inorganic nitrogen annual monthly mean by basin (Upper and Lower) 1997–2016. Means ±SE. Solid lines indicate long term means by basin.

Nitrogen: Phosphorus

The annual mean for monthly N:P ratios in 2016 for Upper Arrow was 58, which was slightly higher than the 1997–2016 mean of 55. Lower Arrow was 38, or slightly lower than the Lower Arrow basin 1997–2016 mean of 41 (**Figure 13**). In 2016, N:P ratios in Upper Arrow ranged from 26 (AR2 in late June) to 88 (which was observed at AR1 in May). In Lower Arrow, N:P ratios ranged from 14 (AR8 in June) to 58 (AR8 in April).

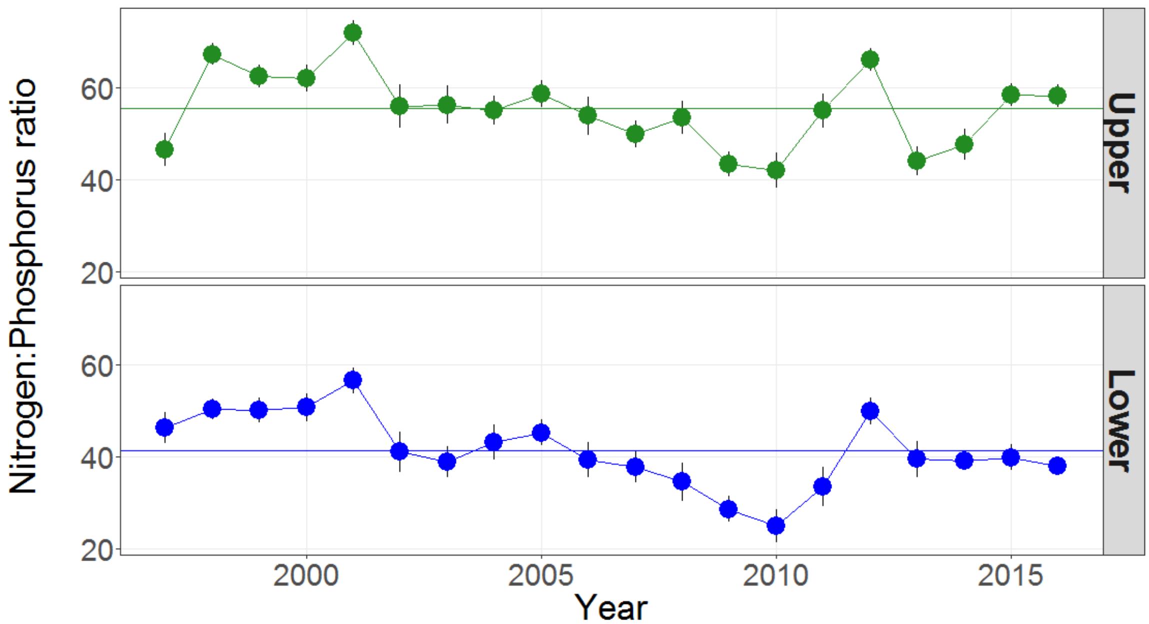


Figure 13. Arrow nitrogen:phosphorus ratio (dissolved, weight:weight) annual monthly mean by basin (Upper and Lower) 1997–2016. Means ±SE. Solid lines indicate long term means by basin.

Phytoplankton

Taxonomic Group

Phytoplankton data by station and month is reported as raw data in **Appendix 21**. Total monthly phytoplankton mean abundance by basin ranged from 1091 cells/mL in April in Upper Arrow to 6508 cells/mL in the Narrows in October (**Figure 14**). Typical of April and May samples, the taxonomic group that dominated the total abundance was chryso- & cryptophytes. Similar to previous summer and early fall samples, the dominant taxonomic group was the Bacillariophytes. Biovolume followed the same patterns as abundance: biovolume was lowest in Upper Arrow in April at 0.100 mm^3/L, and highest in the Narrows in October (**Figure 15**).

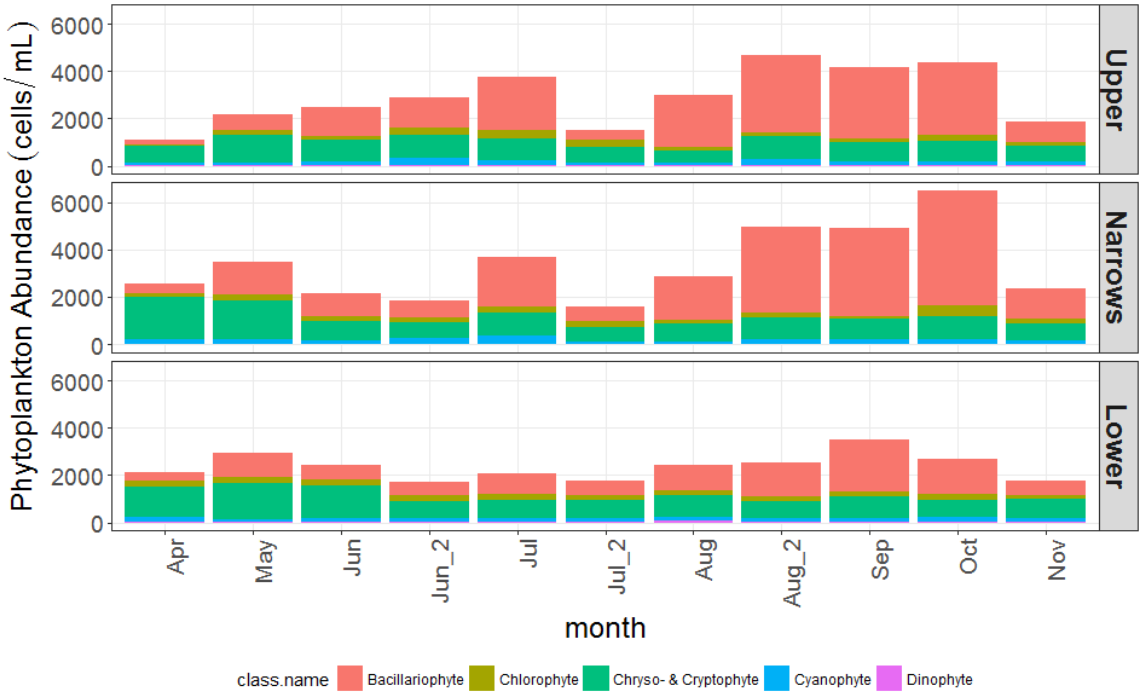


Figure 14. Arrow phytoplankton abundance (cells/mL) by month and basin mean in 2016 by taxonomic group.

Figure 15. Arrow phytoplankton biovolume (mm^3/L) by month and basin mean in 2016 by taxonomic group.

Edible and Inedible Biovolume

In 2016, the biovolume of phytoplankton fluctuated over the course of the sampling period. The phytoplankton community followed a typical trend of building over the course of the growing season, and tapering off as fall conditions of lower nutrients, colder temperatures and shorter photoperiods set in (**Figure 16**). This pattern was more notable in the inedible phytoplankton community since they are not affected by zooplankton grazing pressure. In 2016, the inedible community was generally within previous years' results for each monthly sampling session. The 2016 results in the Narrows in October were slightly higher than what has been observed since 1998. The species that contributed largely to that high result were the bacillariophytes (diatoms); *Diatoma elongatum* and *Fragilaria crotonensis*. Less seasonal variation occurred in the edible community which, as a standing crop metric, is influenced by the top down pressure from zooplankton. Aside from in April, the edible community in 2016 was at or slightly lower than previous monthly observations.

Annually, the edible community showed less variation as the inedible community (**Figure 17**). In 2016 for all basins, the edible mean increased from 2015, and was lower than the long term mean. The annual biovolume of inedible phytoplankton was also slightly below the long-term means for all basins. The lower 2016 results for the edible community may be attributed to the higher zooplankton biomass and that zooplankton were first observed slightly earlier in the year than on average (see zooplankton results).

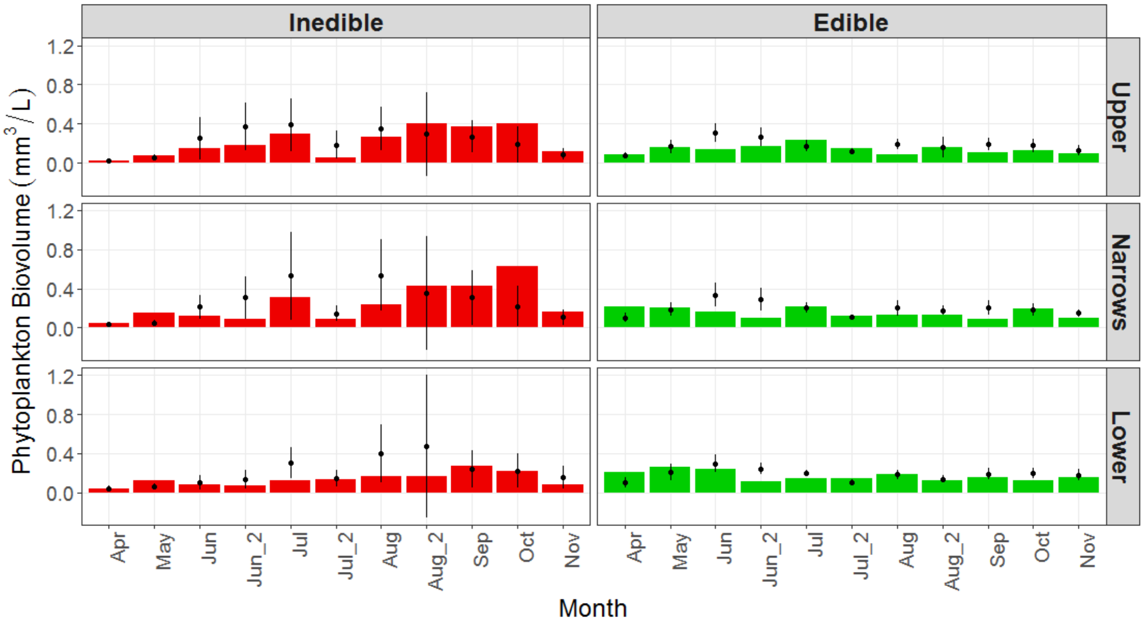


Figure 16. The 2016 phytoplankton mean biovolume (mm^3/L) by month and basin (bars). Inedible (red) and edible (green) phytoplankton. 1998–2015* monthy means by basin are denoted as black points with error bars (Means ± Standard Deviation). *Jul_2 and Aug_2 sampling started in 2012, therefore, Jul_2 and Aug_2 means and standard deviations are from 2012–2015.

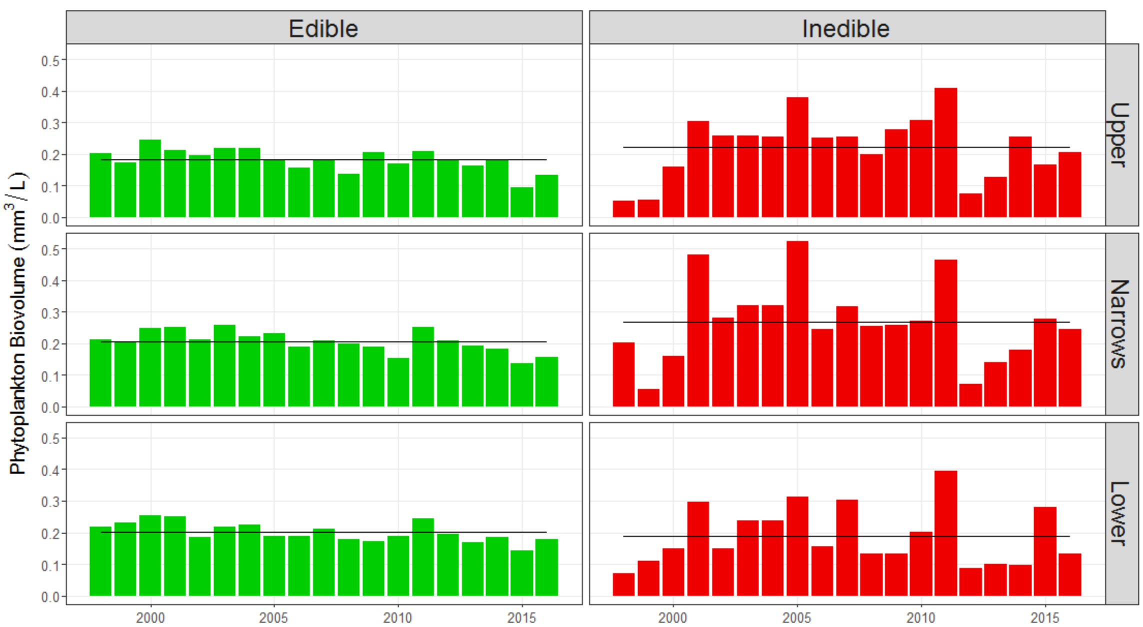


Figure 17. Arrow phytoplankton biovolume (mm^3/L) mean by year (1998–2016). Sampled Apr–Nov*. Inedible (red) and edible (green) phytoplankton. 1998–2016 basin means are denoted as black horizontal lines. *For annual comparisons, Jul_2 and Aug_2 are omitted.

Zooplankton

Density and Biomass

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 2016 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 2016, 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.), and *Leptodora kindtii* (Focke). Other rare species such as *Alona sp.* (Baird) and *Scapholeberis rammneri* (Dumont and Pensaert) were observed sporadically.

Total average zooplankton density in the Upper Arrow in 2016 was dominated by copepods, which comprised 84% of total zooplankton density with a count of 10.87 individuals/L. Other cladocerans comprised 9% of zooplankton density with 1.14 individuals/L, while *Daphnia* spp. contributed only 8% with 0.98 individuals/L (**Figure18**). In the Lower Arrow, copepods contributed to 71% of total zooplankton density (15.63 individuals/L), *Daphnia* spp. 16 % (3.57 individuals/L) and cladocerans other than *Daphnia* spp. 13% (2.91 individuals/L).

Total average zooplankton density in Upper Arrow almost doubled from 2015 to 12.99 individuals/L in 2016 (6.61 individuals/L in 2015). Lower Arrow average zooplankton density also increased to 22.11 individuals/L in 2016 from 18.14 individuals/L in 2015 (**Figure 19**). The average zooplankton biomass in Upper Arrow in 2016 was comprised of 43% copepods (15.41 µg/L), 52% *Daphnia* spp. (18.37 µg/L), and 5% cladocerans other than *Daphnia* spp. (1.82 µg/L; **Figure 20**). In Lower Arrow, the composition favoured *Daphnia* spp., which comprised 71% of zooplankton biomass (65.28 µg/L), while copepods made up 24% (22.32 µg/L), and cladocerans other than *Daphnia* spp. only 5% (4.30 µg/L). The average zooplankton biomass from all stations increased in 2016 compared to the previous year. In Upper Arrow it increased from 11.14 µg/L in 2015 to 35.59 µg/L in 2016 and in Lower Arrow from 34.62 µg/L to 91.89 µg/L (**Figure 21**).

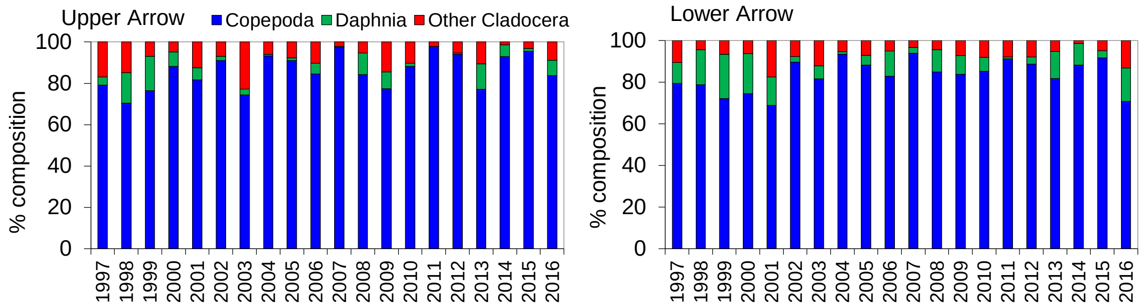


Figure 18. Seasonal composition of zooplankton as a percentage of average density in the Arrow Lakes, 1997 to 2016.

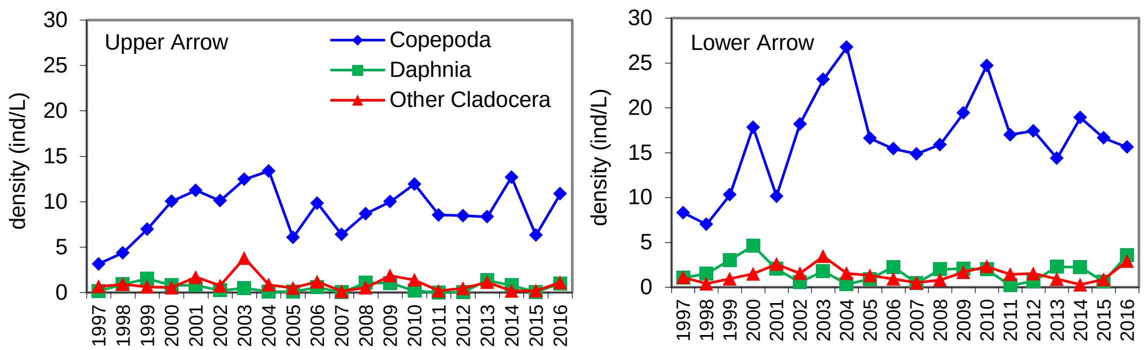


Figure 19. Seasonal average zooplankton density in Arrow Lakes 1997 to 2016.

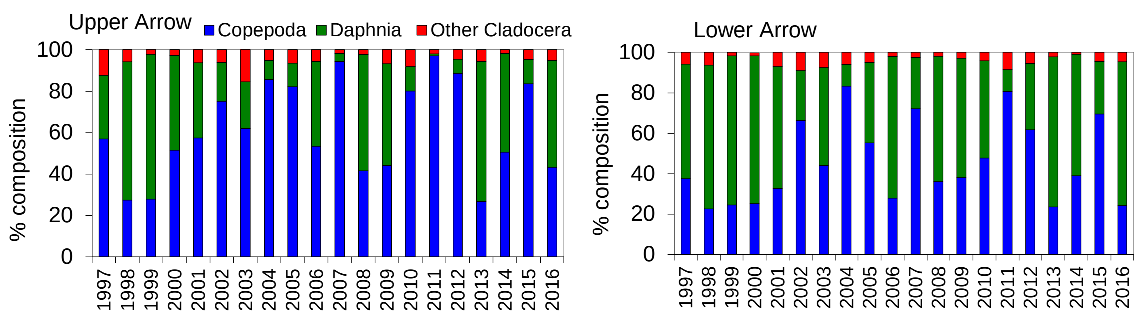


Figure 20. Seasonal composition of zooplankton as a percentage of average biomass in the Arrow Lakes 1997 to 2016.

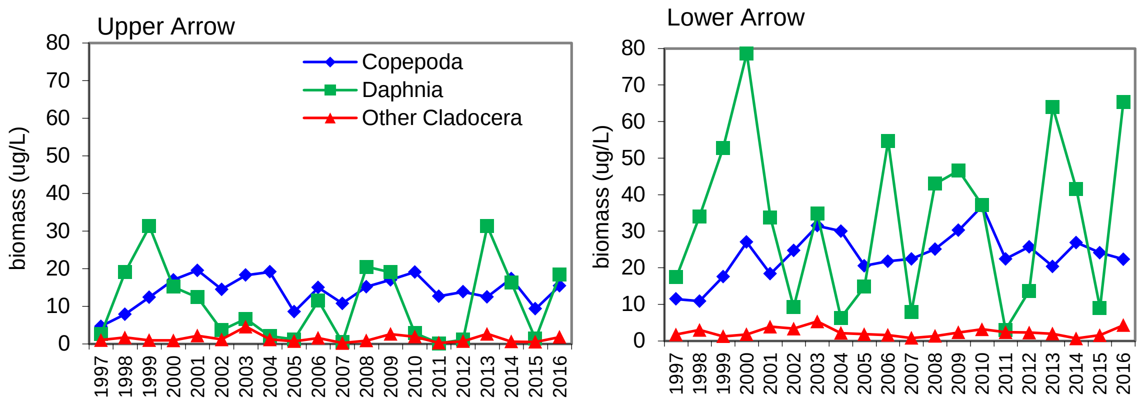


Figure 21. Seasonal average zooplankton biomass in Arrow Lakes 1997 to 2016.

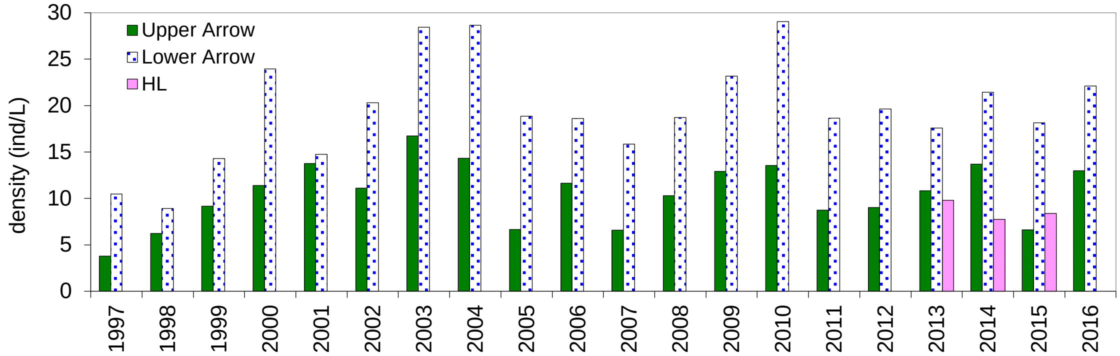
Seasonal and lake patterns

Copepods were the main contributor to the overall zooplankton population throughout the sampling season, with *Daphnia* present in each month from April to November, peaking in August or September and maintaining a population through November. This pattern occurred in both Upper and Lower Arrow in 2016 (**Figure 22** for density and **Figure 23** for biomass). In 2016 copepods dominated the abundance and biomass at the beginning of the sampling season, from April through July, while *Daphnia* dominated in biomass from July through October.

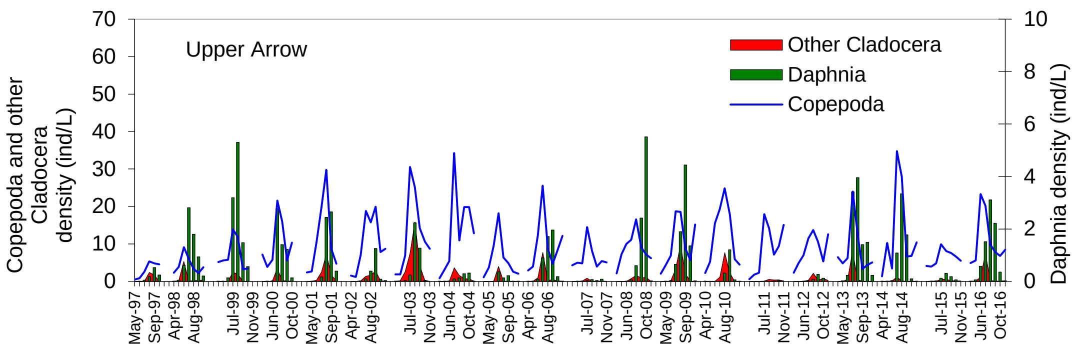
Total zooplankton density was higher in Lower Arrow than Upper Arrow in 2016: a pattern that is repeated in each studied year. Total zooplankton biomass was almost three times higher in Lower Arrow than in Upper Arrow. Like density, biomass has always been higher in Lower Arrow then Upper Arrow since 1997.

The first appearance by month and by basin of *Daphnia* for each year is shown in **Figure 24**. On average, *Daphnia* begin to appear in May in Upper Arrow samples, and June in Lower Arrow samples. 2016 was an "early" year: in Upper Arrow, *Daphnia* were first observed in the April samples and in Lower Arrow *Daphnia* first appeared in May samples. Typically, Upper Arrow *Daphnia* are observed one to two months sooner or simultaneously with Lower Arrow, aside from in 2005 and 2011.

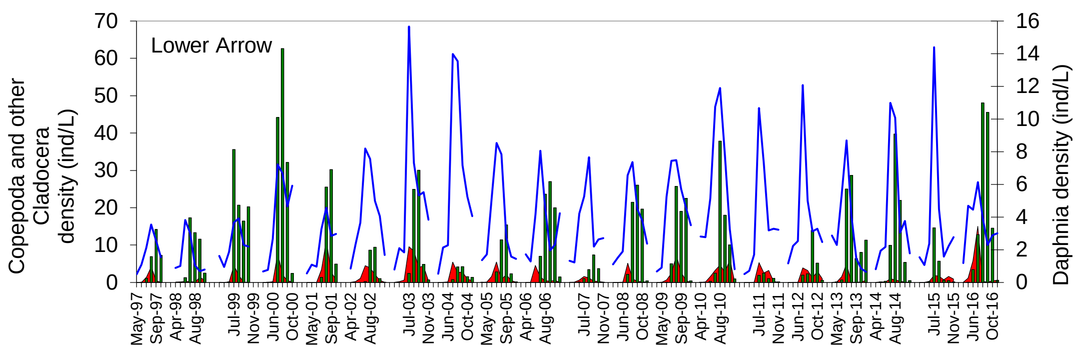
The 2016 monthly results are shown in **Figure 25** for Upper and Lower Arrow density and biomass. Density results varied from station to station in both Lower and Upper Arrow. Biomass results were similar among stations during all months in Upper Arrow, while in Lower Arrow biomass results were similar among stations from April to June, but varied between stations from July through October. The highest density was recorded in July and the highest biomass in August, which were both in Lower Arrow at station AR6.



a) Seasonal average density of total zooplankton in Arrow Lakes Reservoir 1997 to 2016. Note that HL refers to station HL1 in the Beaton Arm **(Appendix 4).**

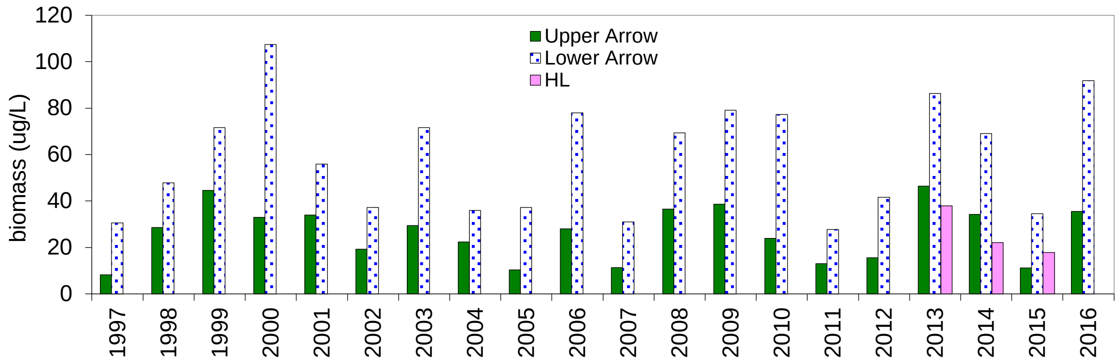


b) Seasonal density of zooplankton in Upper Arrow 1997 to 2016.

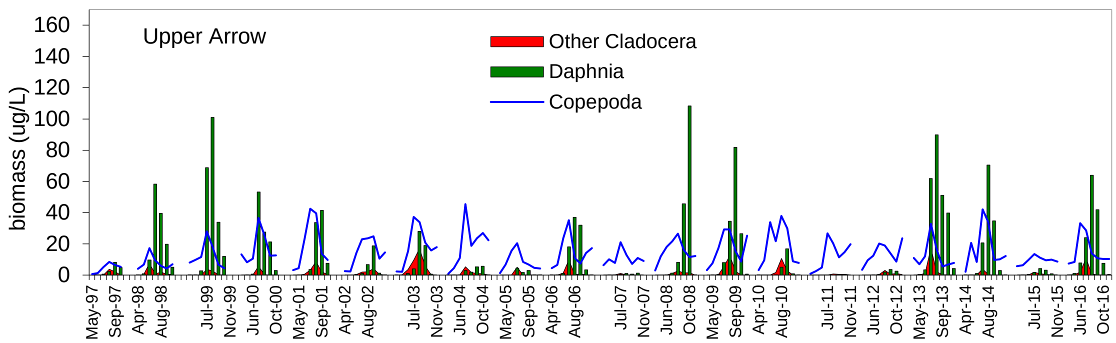


c) Seasonal density of zooplankton in Lower Arrow 1997 to 2016.

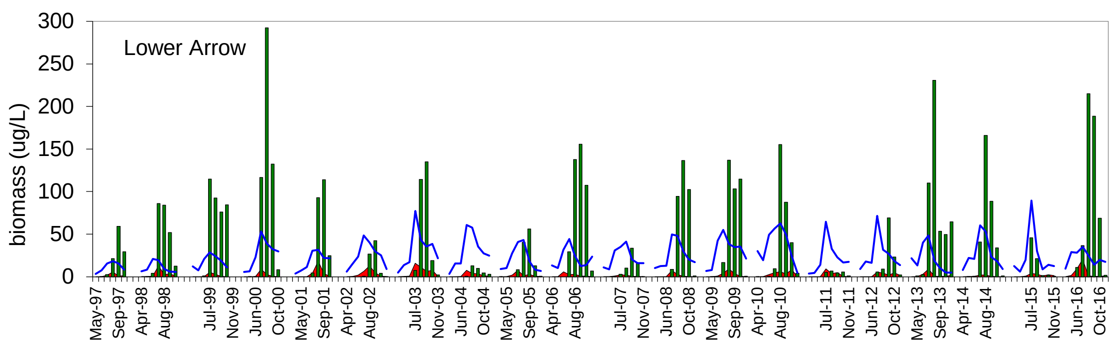
Figure 22. Zooplankton density represented as: **a)** whole lake averages from 1997 to 2016, **b)** density in Upper Arrow and **c)** density in Lower Arrow.



a) Seasonal average biomass of zooplankton in Arrow Lakes 1997 to 2016. Note that HL refers to station HL1 in the Beaton Arm **(Appendix 4).**



b) Seasonal biomass of zooplankton in Upper Arrow 1997 to 2016.



c) Seasonal biomass of zooplankton in Lower Arrow 1997 to 2016.

Figure 23. Zooplankton biomass represented as: **a)** whole lake averages from 1997 to 2016, **b)** biomass in Upper Arrow and **c)** biomass in Lower Arrow in Arrow 1997 to 2016.

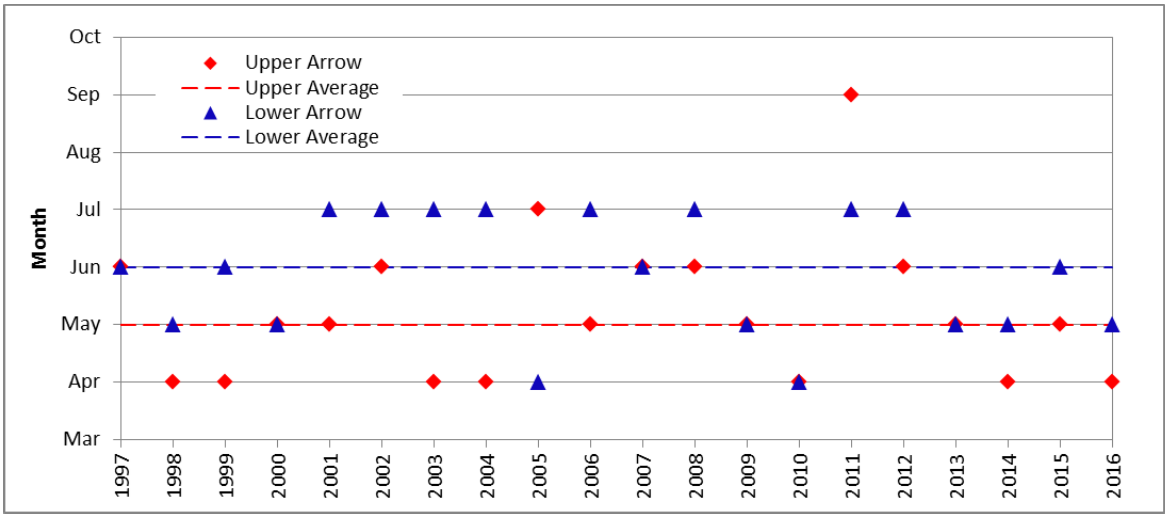


Figure 24. First detectable appearance of *Daphnia* in the season in Upper and Lower Arrow, 1997 to 2016. Triangles indicate the month of first appearance while the dotted lines represent the average first data of appearance from 1997 to 2016.

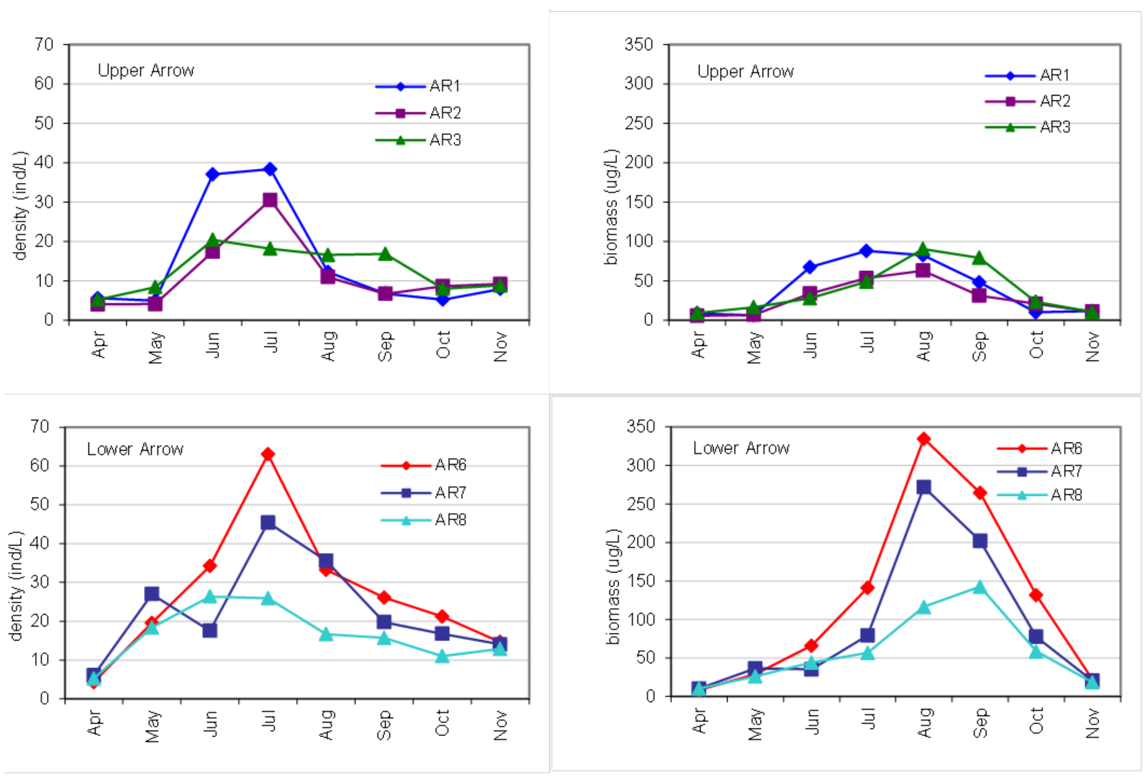


Figure 25. Total zooplankton density and biomass at each station in Arrow Lakes, April to November 2016.

Mysis diluviana

Density of *Mysis diluviana* (mysids) has fluctuated over the course of the studied years. Compared to the previous year, densities of mysids in 2016 increased in Upper Arrow but decreased in Lower Arrow (**Figure 26**). Average densities were higher in Upper than the Lower Arrow, a similar trend that was observed from 2003–2005, 2007 and 2009–2011. In both Upper and Lower Arrow, seasonal average mysid densities during the nutrient addition period (1999–2016) were higher than results from pre-nutrient addition period 1997–1998. The highest densities were observed in 2009 and 2010 in Lower and Upper Arrow, respectively. The peak density in 2016 in Upper Arrow occurred in June at station AR2 with 861.50 ind/L, mainly due to an increased number of juveniles (**Figure 27**). In Lower Arrow the peak density occurred in July at station AR8 with 352 ind/L, also due mainly to an increased number of juveniles (**Figure 28**).

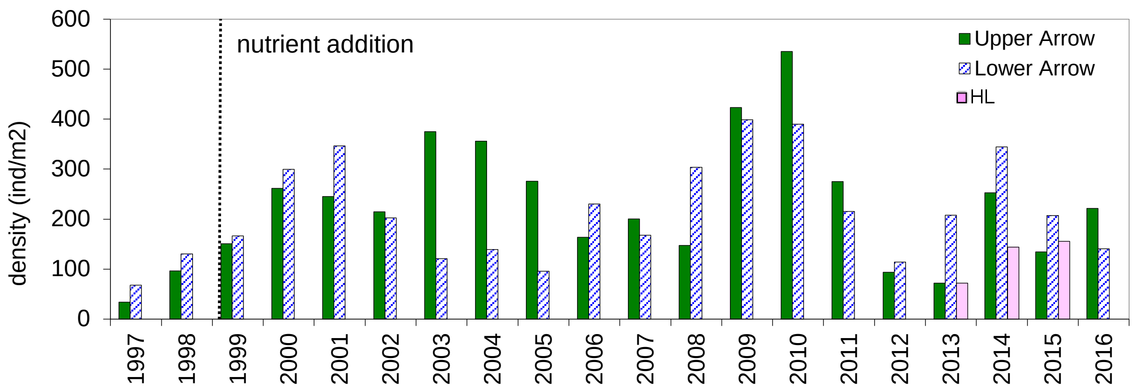


Figure 26. Annual average density of *Mysis diluviana* at pelagic sites in Arrow Lakes Reservoir, 1997 to 2016. Averages calculated from April to November. Note that HL refers to station HL1 in the Beaton Arm (**Appendix 4**).

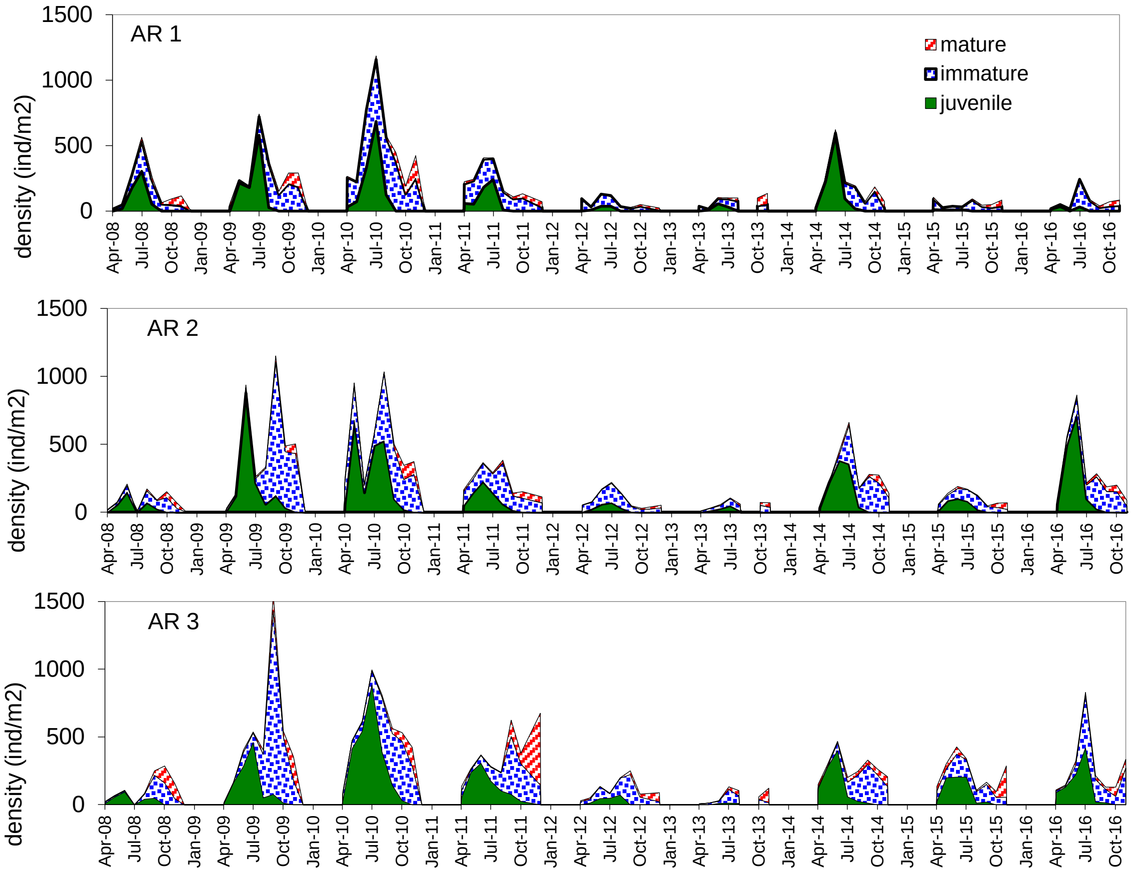


Figure 27. Densities of developmental stages of *Mysis diluviana* at pelagic sites in Upper Arrow stations from 2008 to 2016.

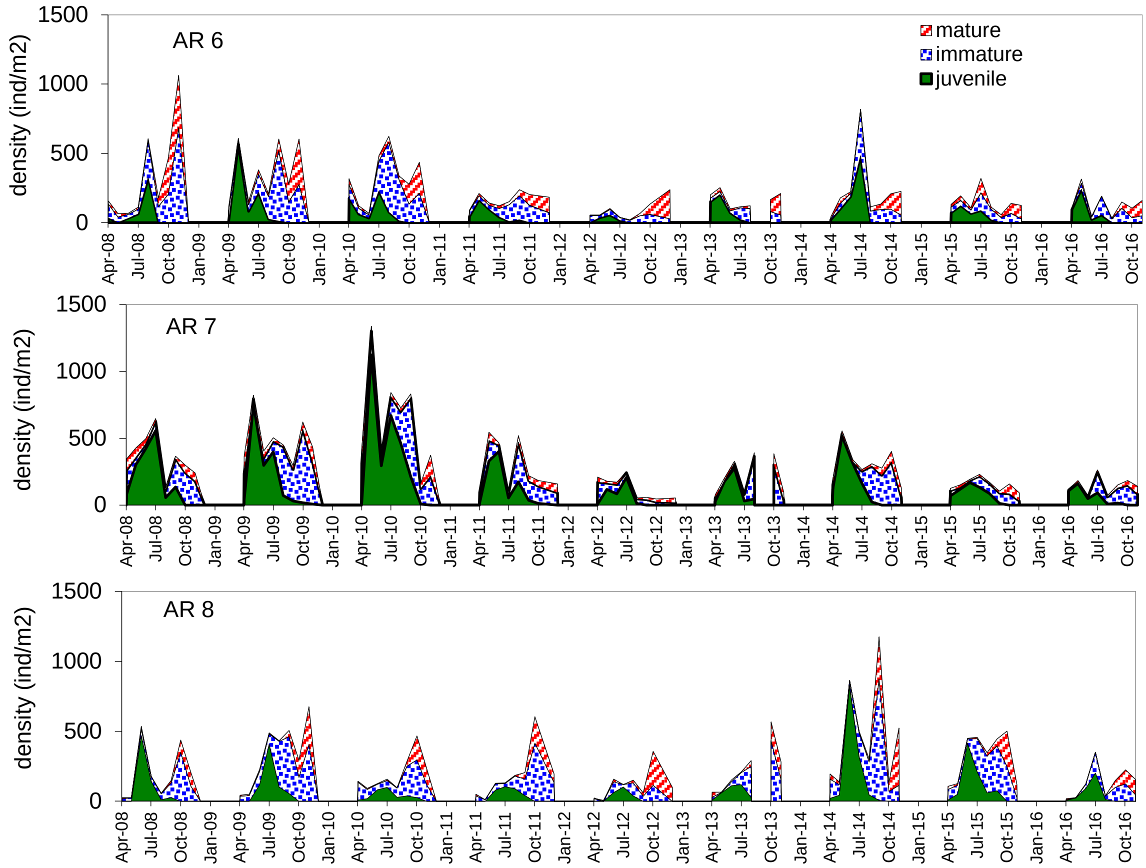


Figure 28. Densities of developmental stages of *Mysis diluviana* at pelagic sites in Lower Arrow stations from 2008 to 2016.

Compared to 2015, average biomass in Upper Arrow increased while in Lower Arrow biomass decreased (**Figure 29**). Biomass was higher in Upper Arrow than in Lower Arrow. Immature and mature developmental stages contributed the most to overall biomass. Peak biomass in 2016 in Upper Arrow occurred in November at sampling station AR3 with 1828.14 mg/m^2, and in Lower Arrow also in November at station AR6 with 1526.73 mg/m^2. The majority of biomass was comprised of mature males and females. The release of juveniles from female brood pouches occurred in early spring and was reflected by an overall density increase from April through July of each year (**Figures 30 and 31**). 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.

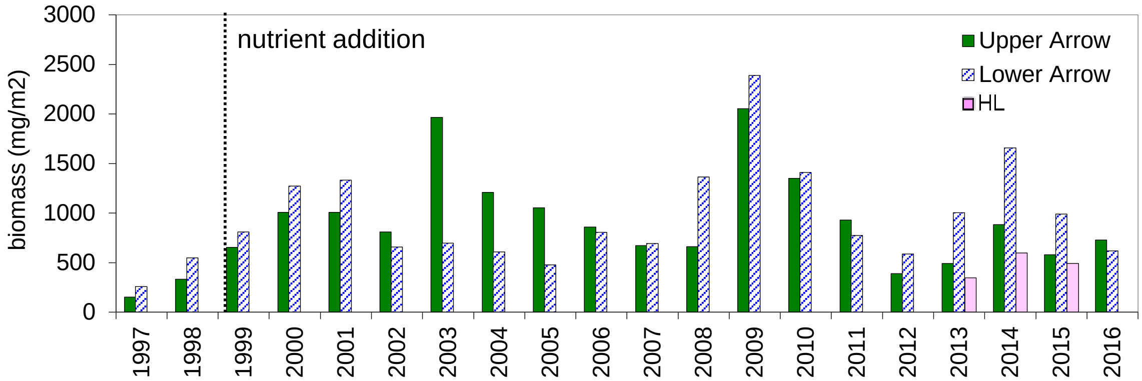


Figure 29. Annual average biomass of *Mysis diluviana* at in Upper and Lower Arrow from 1997 to 2016. Yearly averages were calculated from April to November. Note that HL refers to station HL1 in the Beaton Arm **(Appendix 4).**

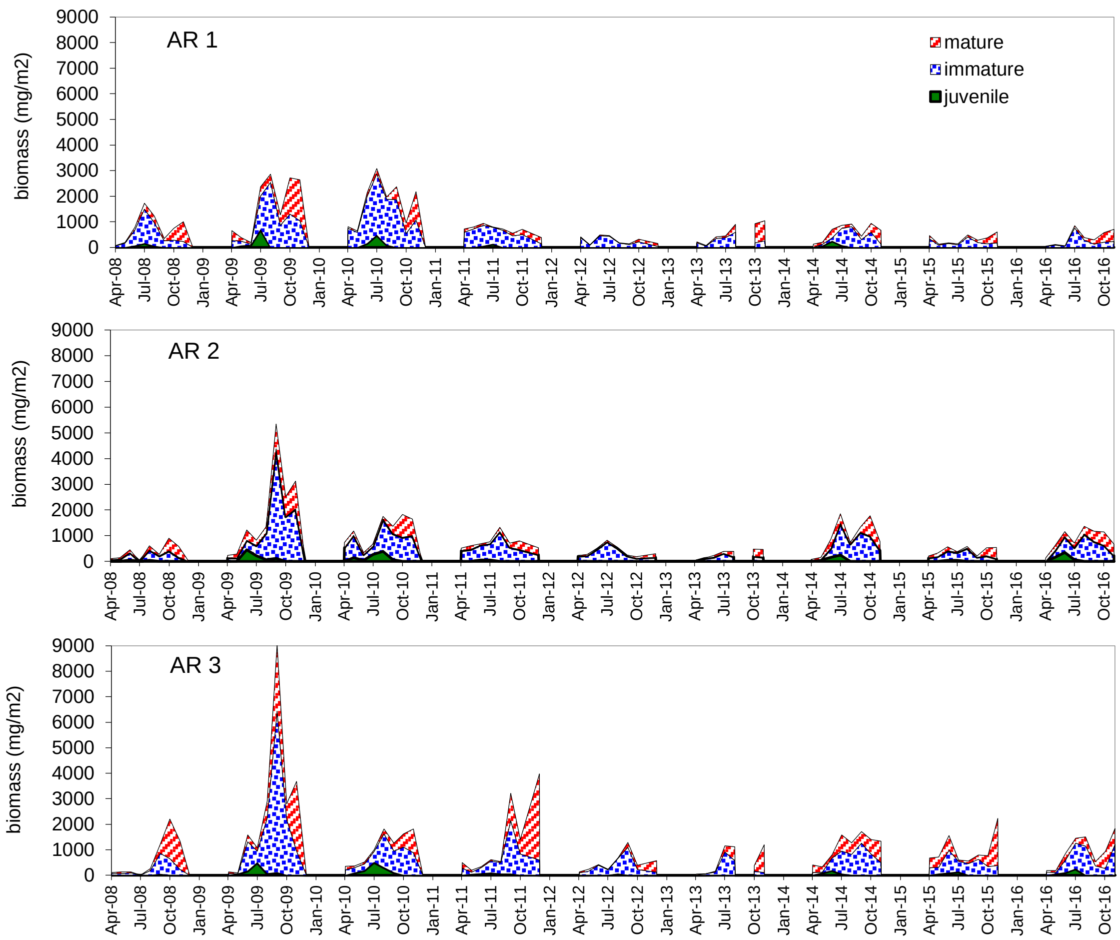


Figure 30. Biomass of developmental stages of *Mysis diluviana* at stations in Upper Arrow, 2008 to 2016.

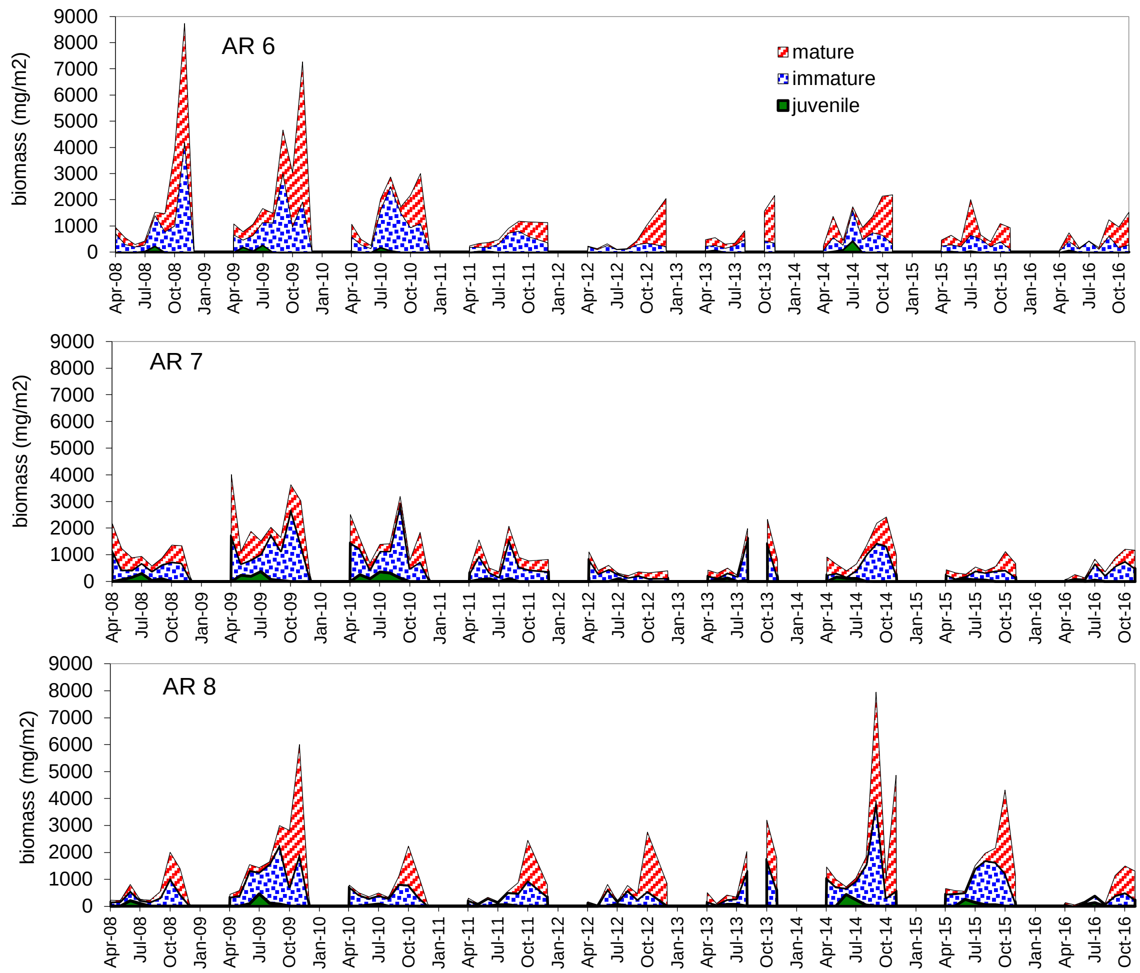


Figure 31. Biomass of developmental stages of *Mysis diluviana* at stations in Lower Arrow, 2008 to 2016.

The monthly results for density and biomass in Upper and Lower Arrow are shown in **Figure 32**. Density results were similar amongst stations in Lower Arrow, while in Upper Arrow density varied from station to station during the whole sampling season. Biomass results varied between stations in both Upper and Lower Upper Arrow. The highest density was recorded in June at station AR2 in Upper Arrow, and the highest biomass in November at station AR3 in Upper Arrow.

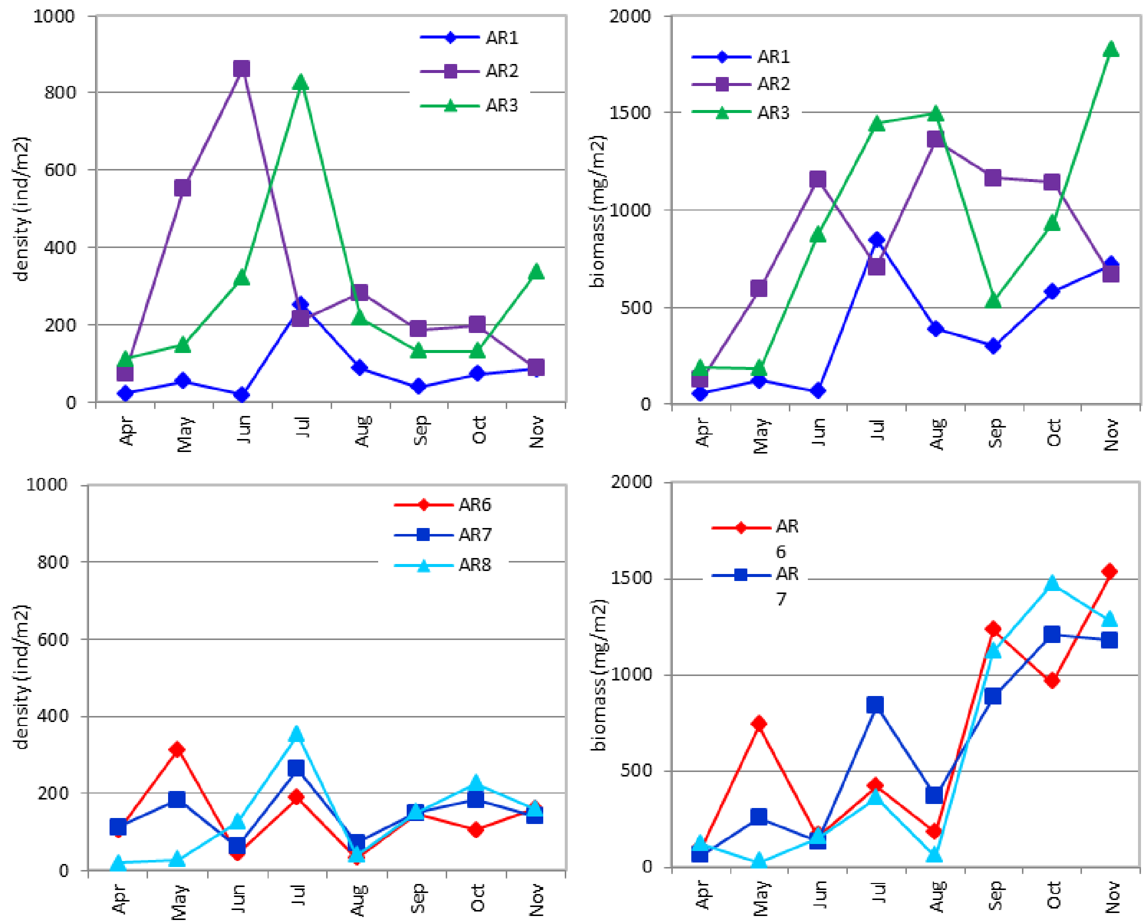


Figure 32. Total mysid density and biomass at each station in Upper and Lower Arrow Lake, April to November 2016.

Kokanee

Pool elevation during the kokanee October 1–4, 2016 survey period averaged 427.75 m (12.5 m below full pool). Pool elevation at the time of the 2016 survey was 6.1 m below the average for fall surveys, even lower than the 2015 survey which was the lowest since 2001. The total area of pelagic habitat (defined as >20 m depth) was estimated at 193 km^2 in Upper Arrow and 91 km^2 in Lower Arrow (**Appendix 9**), or approximately 2% and 5.5% lower than the respective long-term averages for fall surveys, respectively.

Trawl catch

A total of 579 kokanee were captured at the six standard trawl stations in 2016: 268 from Upper Arrow and 311 from Lower Arrow (**Table 4**). The Upper Arrow trawl catch was 125, 112, and 31 for ages 0, 1, and 2, respectively. In Lower Arrow, the trawl sampling produced catches of 135, 101, and 75 for ages 0, 1, and 2, respectively.

Table 4. Kokanee catch statistics from the trawl surveys in October 2016. See Appendix 4 for station locations.

Basin	Station	Hauls	age 0	age 1	age 2	age 3	Total
Upper Arrow	T1 (AR1) Albert Pt.	3	56	66	20	0	142
	T2 (AR2) Halfway R.	3	28	25	6	0	59
	T3 (AR3) Nakusp	3	41	21	5	0	67
	Total of Upper	*9*	*125*	*112*	*31*	*0*	*268*
Lower Arrow	T6 (AR6) Johnston Cr.	3	65	9	23	0	97
	T7 (AR7) Bowman Cr.	3	24	32	29	0	85
	T8 (AR8) Cayuse Cr.	2	46	60	23	0	129
	Total of Lower	*8*	*135*	*101*	*75*	*0*	*311*
Total Arrow	**Both basins**	**17**	**260**	**213**	**106**	**0**	**579**

Kokanee size and age

Length frequencies by basin for both trawl-caught (immature) kokanee and spawners sampled in 2016 are presented in **Figure 33**. Clear single modes were apparent for the age 0 fish in both basins, peaking in the 60–70 mm bins in Upper Arrow whereas in Lower Arrow the peak was confined to the 70 mm bin. The age 1 kokanee in Upper Arrow peaked in the 180 mm bin whereas in Lower Arrow the age 1 fish peaked in the 170 mm bin. In both basins, the age 1 fish exhibited a strong single mode with a component of smaller fish reaching down to the 90 mm bin in Upper Arrow and the 100 mm bin in Lower Arrow. Age 2 trawl caught kokanee showed minimal length overlap with the age 1 fish, and fell within the 190 mm to 220 mm bins in Upper Arrow and the 200 mm to 220 mm bins in Lower Arrow.

Age-specific length frequencies for spawning kokanee from Hill Creek in Upper Arrow and from Deer, Taite, and Mosquito Creeks in Lower Arrow were consistent with trawl age-specific length frequencies for Upper and Lower Arrow, respectively (**Figure 33a, 33b**). Spawners were a mix of age 2 and age 3 in both basins, however Upper Arrow had a greater proportion of age 2 spawners, while Lower Arrow had proportionately more age 3 spawners. Both age classes of spawners were larger in Upper Arrow than in Lower

Arrow; age 2 spawner size peaked in the 230–240 mm bins in Upper Arrow and the 220 mm bin in Lower Arrow, while the age 3 spawners peaked in the 250–260 mm bins in Upper Arrow but only the 230–240 mm bins in Lower Arrow. Mosquito Creek spawners were not aged, but appeared to be of a similar size and age structure as the Deer and Taite Creek spawners, although one larger spawner fell within the 290 mm bin and may have been age 4 or older. A component of age 2 spawners overlapped in size with the age 3 spawners in both basins. The age 2 spawners were slightly larger than age 2 trawled fish, indicating that the larger individuals from this cohort spawned. However, in Lower Arrow 75% of the measured age 2 spawners overlapped in size with immature trawl caught age 2 fish, while only 4% overlapped in Upper Arrow.

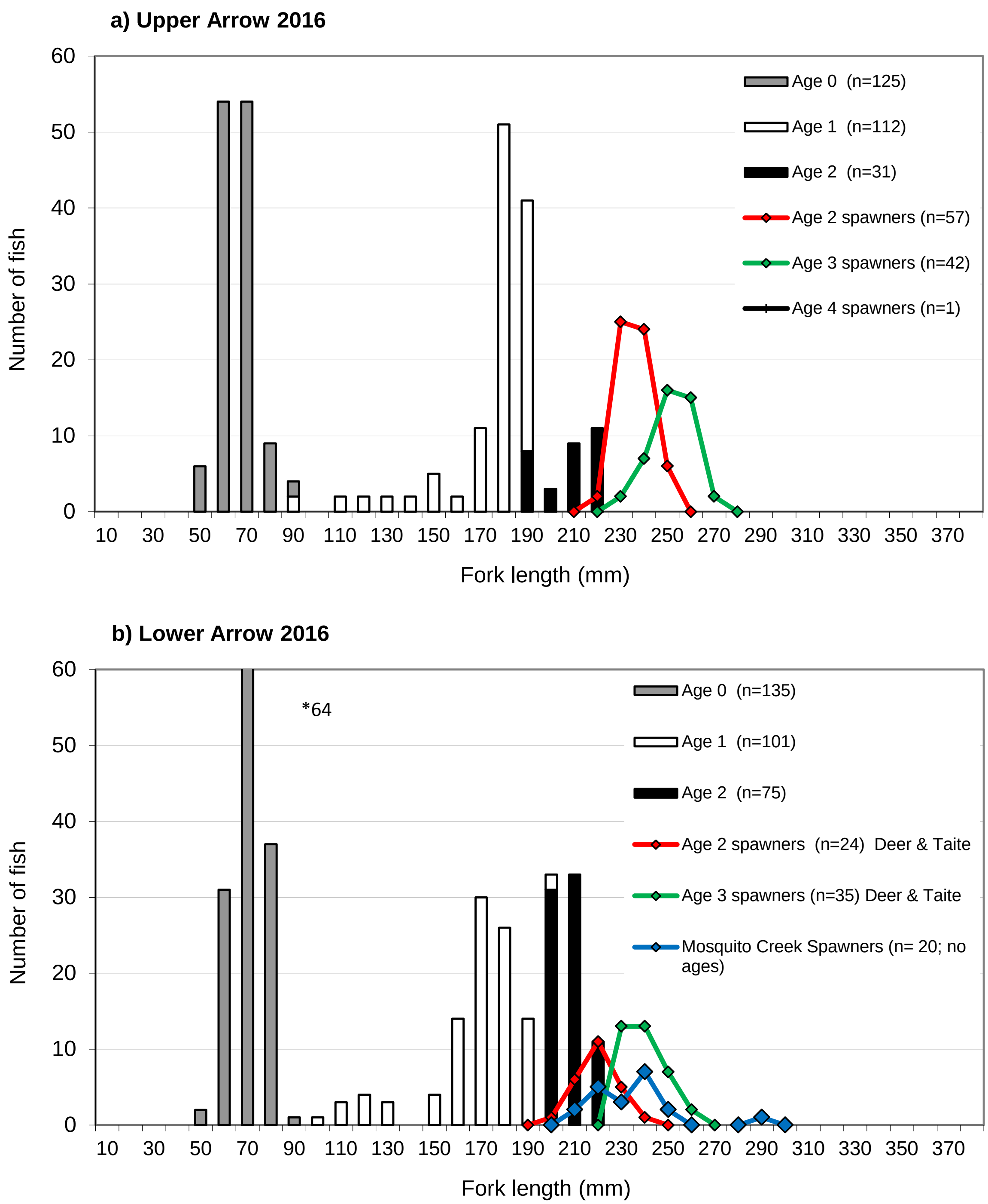


Figure 33. Kokanee length frequency for a) Upper Arrow and b) Lower Arrow basins by age from 2016 trawl sampling with ages verified by scale interpretation. Included are spawner samples collected from Hill Creek (Upper Arrow) and Mosquito, Deer and Taite creeks (Lower Arrow) with ages verified by otolith interpretation (except Mosquito Creek). Fish fork lengths from fall trawl sampling were adjusted to an October 1 standard using empirical growth data from Rieman and Myers (1992).

Kokanee size statistics for trawl caught fish are presented in **Table 5.** In Upper Arrow the average fork length (± 2 SE) adjusted to October 1 was 61 (± 1.3) mm for age 0, 169 (± 3.9) mm for age 1 and 203 (± 4.0) mm for age 2 fish. In Lower Arrow the average fork (± 2 SE) was 65 (± 1.2) mm for age 0, 163 (± 4.2) mm for age 1, and 202 (± 1.5) mm for age 2 fish. No age 3 fish were caught in the trawl for either Upper or Lower Arrow.

Table 5. Kokanee size statistics from the October 2016 trawl surveys corrected to Oct. 1. Fish fork lengths from fall trawl sampling were adjusted to an October 1 standard using empirical growth data from Rieman and Myers (1992).

Survey time	Basin	Metric	Age 0	Age 1	Age 2	Age 3
October 2016	Upper	Ave. length (mm)	61	169	203	
		Length range (mm)	47–85	85–188	182–219	
		Standard deviation	7.4	20.4	11.2	
		Sample size (n)	125	112	31	
October 2016	Lower	Ave. length (mm)	65	163	202	
		Length range (mm)	47–90	98–191	191–216	
		Standard deviation	6.8	20.9	6.5	
		Sample size (n)	135	101	75	

Figure 34 shows trends in the average length at age from trawl-caught kokanee in Upper and Lower Arrow for the past 28 years. The mean length of spawners at Hill Creek has been included to represent Upper Arrow since 1993 while only the last four years of estimates were available from Deer and Taite Creeks for Lower Arrow. The spawner values presented in **Figure 34** are averages which include both age 2 and age 3 spawners.

Age 0 kokanee decreased in length in Upper Arrow and increased in Lower Arrow between 2015 and 2016 (**Figure 34**). Bassett *et al*. (2018) noted an exceptionally large mean length of fry in Upper Arrow in 2015, as well as a non-typical bi-modal age 0 length distribution, and hypothesized that they may have been attributable to increased entrainment of larger fry out of upstream Revelstoke Reservoir. In 2016, the age 0 length distribution in Upper Arrow was more typical and the mean sizes of both Upper and Lower Arrow fry were close to average.

Mean lengths of age 1 kokanee in both basins increased significantly in 2016 over 2015, 169 mm and 163 mm in Upper and Lower Arrow respectively. Age 2 kokanee mean length remained similar to 2015 in Upper Arrow at 203 mm; although very few fish were measured in 2015. Lower Arrow age 2 kokanee increased from an average length of 189 mm in 2015 to 202 mm in 2016.

Upper Arrow mean spawner length (all ages) increased sharply from a low of 218 mm in 2012 to well above average in 2013 and 2014 at 288 mm and 305 mm respectively (**Figure 34**). The average size then declined to 251 mm in 2015, and further again to 238 mm in 2016 in Upper Arrow, slightly below the (1999–2015) post-fertilization average of 244 mm.

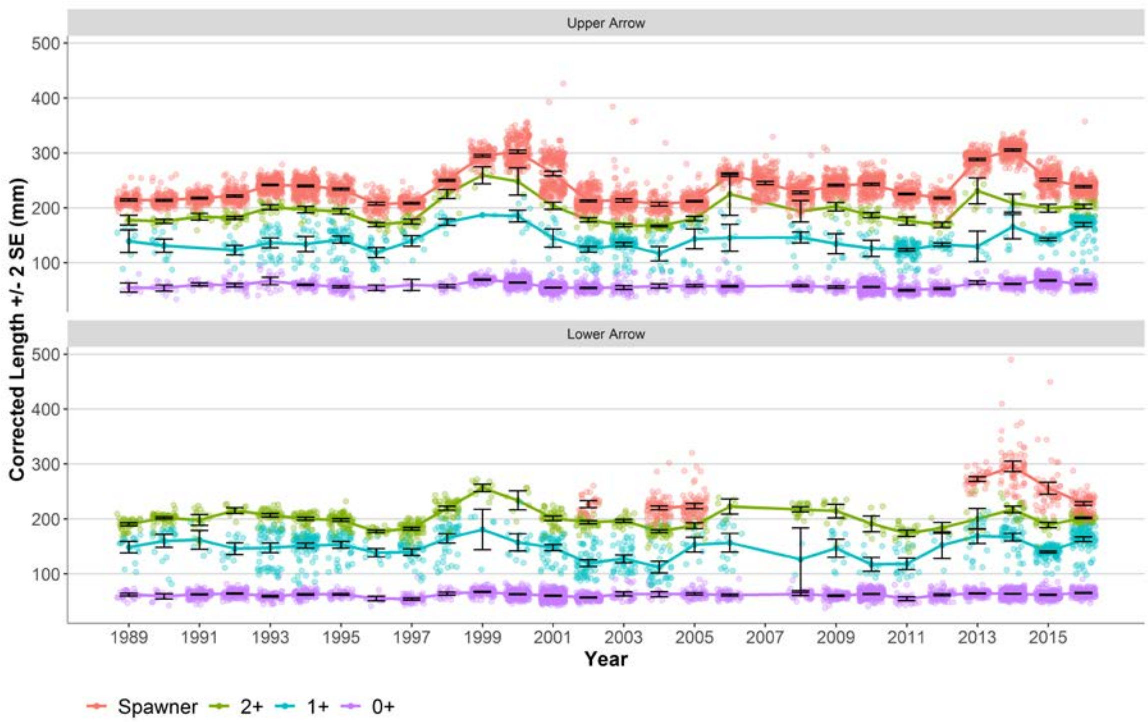


Figure 34. Trends in kokanee length at age for a) Lower Arrow and b) Upper Arrow basins based on trawl survey data (1989–2016). Error bars denote ±2 S.E.; average spawner size was obtained from Hill Creek to represent Upper Arrow and Deer Creek to represent Lower Arrow. Combined data for Deer and Taite Creeks was used to represent Lower Arrow in 2014–2016. Fish fork lengths from fall trawl sampling were adjusted to an October 1 standard using empirical growth data from Rieman and Myers (1992).

Spawner size and age structure

Length frequency distributions show a single mode of spawners returned to Hill Creek in for the previous five consecutive years, including 2016 (**Figure 35**). The dominant age of spawning shifted from age 3 in 2012 to age 4 in 2013, concurrent with a large increase in spawner size. Although spawners in 2014 were even larger than the year prior, the dominant age had shifted back to age 3. In 2015, spawner size declined substantially in both Upper and Lower Arrow while the dominant age at maturity remained age 3. The pattern of a single age class dominating age at maturity appears to have changed in 2016, as otolith ageing revealed more age 2 than age 3 spawners at 58% and 42% respectively for Hill Creek spawners (**Table 6**; Hill Creek spawners). This was the first time since 2002 that the majority of spawners sampled at Hill Creek were age 2.

Lower Arrow spawner sizes were slightly smaller than Upper Arrow in 2013 and 2014, similar in size in 2015, and then slightly smaller again in 2016 (**Figure 35**). In 2014–2015 there was a wider range in the size of spawners in Lower Arrow streams than in Hill Creek. Although the average size was the same or slightly smaller in Lower Arrow, there was a contingent of larger, older individuals in Lower Arrow that were not evident in Hill Creek data. The component of larger spawners was not prominent in 2016 data, although a notable exception of a large 357 mm spawner was measured in Hill Creek in 2016. 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.

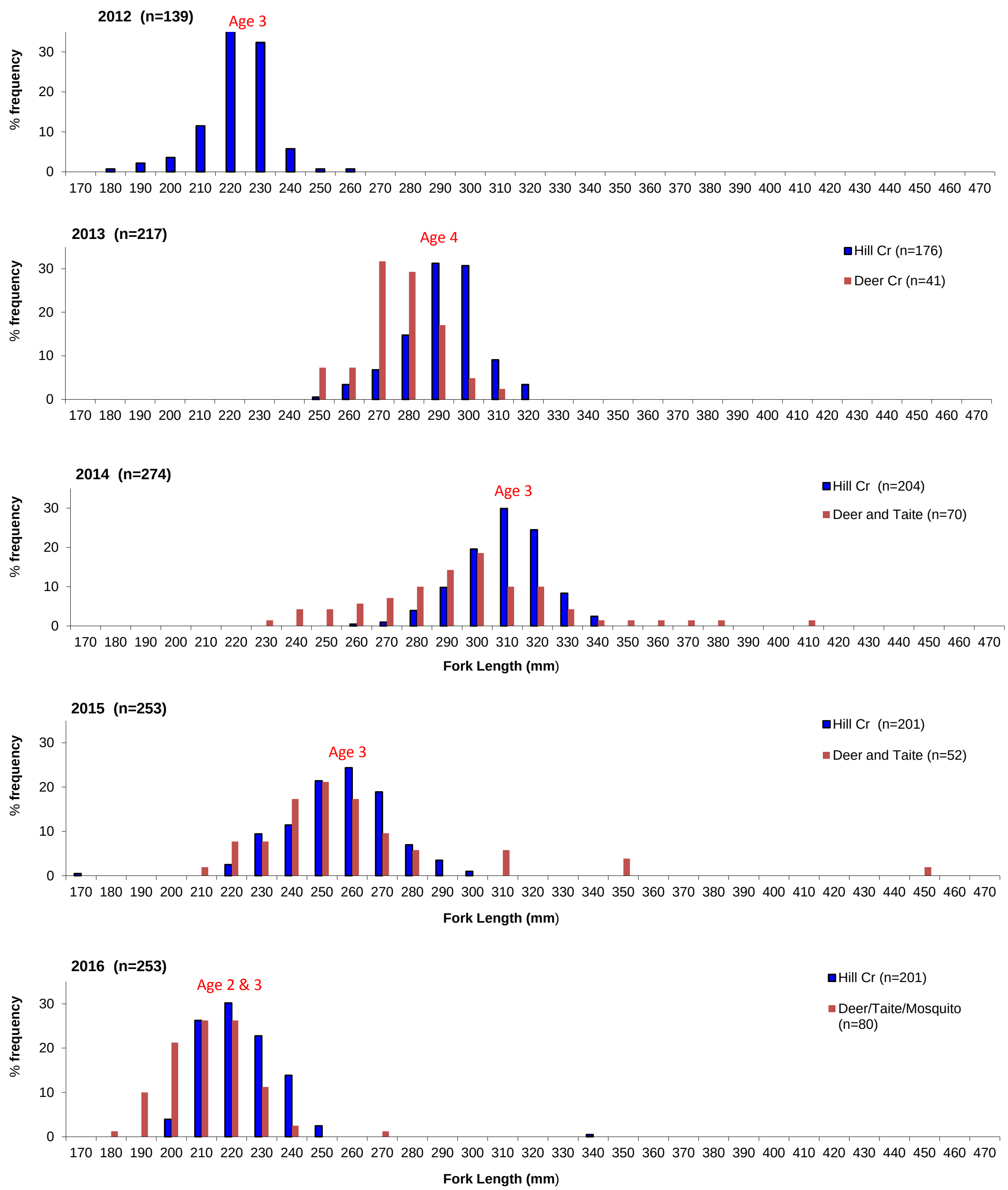


Figure 35. Length frequency distributions and dominant age of modes for Hill Creek kokanee spawners during 2012–2016 representing Upper Arrow tributaries, and for Deer Creek (2013), combined Deer and Taite Creeks (2014–2015), and combined Deer/Taite/Mosquito Creeks (2016) representing Lower Arrow tributaries.

Table 6. Percent age composition for kokanee spawners returning to Hill Creek during the nutrient addition era (1999–2016) based on otolith analyses**.**

Year	Sample	% spawner age by otolith analysis					Comments
	(n)	1	2	3	4	5+	
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		18	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 age 1
2016	99		58	42	0	0	

[1] Otolith ages in 2003 were all shifted by 1 year to coincide with trawl age 2 size
[2] From 2007–2016 otolith analyses followed the Casselmen (1990) method accepting only CSA ratings of 6 or higher

Spawning Escapement

A return of 74,751 spawners to Hill Creek in 2016 represented 48% of average for the nutrient addition period and was down from 56% of average in 2015 (**Figure 36, Appendix 7**). A return of only 8,141 spawners to all other index tributaries in Upper Arrow in 2016 represented only 30% of the fertilization era average, but double the 2015 return to these same tributaries.

Spawner returns to Lower Arrow have been relatively stable since 2013, with counts ranging from 100,000–130,000. The spawner estimate of 103,929 for Lower Arrow tributaries in 2016 was only 56% of the nutrient era average, however it remains an improvement over the recent low returns observed in 2011 and 2012: both years with returns of <50,000 spawners (**Figure 36b, Appendix 7**).

The sum of both Upper and Lower Arrow total returns (i.e., index plus other tributaries) of 210,420 spawners in 2016 (**Appendix 7**) was 50% of the fertilization era average and remained 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).

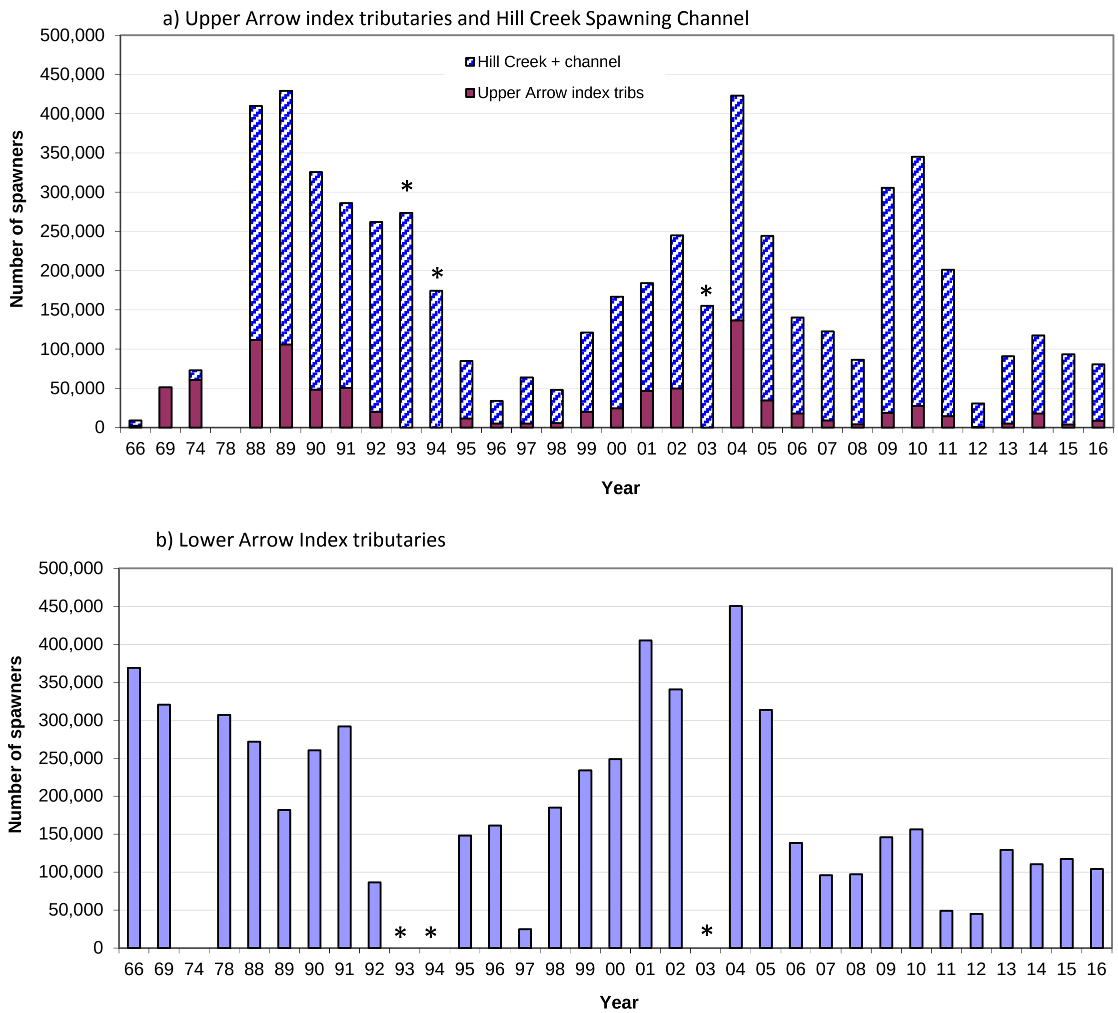


Figure 36. Trends in kokanee spawner returns to: **a)** Hill Creek Spawning Channel and three key index streams (Drimmie, Halfway and Kuskanax) in the Upper Arrow, and; **b)** four index streams (Burton/Snow, Caribou, Deer and Mosquito) in Lower Arrow Reservoir during 1966, 1969, 1974, 1978 and 1988–2016. All index stream counts have been expanded by 1.5 to approximate total run size (Redfish Consulting Ltd. 1999), while the spawning channel was not expanded. *Index streams were not counted in 1993, 1994 & 2003.

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. transects 1–18; omitting 19 & 20 in the Narrows), reservoir fry densities in 2016 ranged from 171–871 fish·ha^{-1}, and averaged 298 fish·ha^{-1} in Upper Arrow and 464 fish·ha^{-1} in Lower Arrow (**Appendix 10**). Upper Arrow fry densities were highest at transect 4 near the Albert Point trawl station **(Figure 37b)** and lowest at transect 7, although they were generally similar across the entire basin relative to other years, including 2015 when relatively higher densities were observed in Beaton Arm and Galena Bay (transects 2 & 3; **Figure 37a**). Lower Arrow fry densities were more variable than Upper Arrow, with far higher densities at transects 18 and 15, relative to the two lowest transect densities at nearby transects 11 and 14.

In 2016, the age 1–3 kokanee densities ranged from 26–200 fish·ha^{-1}, and averaged 86 fish·ha^{-1} in Upper Arrow and 98 fish·ha^{-1} in Lower Arrow (**Appendix 10**). Upper Arrow age 1–3 densities were variable, with the highest densities observed at transects 6 and 9, and lowest at the southernmost transect 10 near Nakusp. Lower Arrow age 1–3 kokanee densities were relatively stable ranging between 92–147 fish·ha^{-1} with the exceptions of transects 11 and 12 which were at only 26 and 32 fish·ha^{-1} respectively.

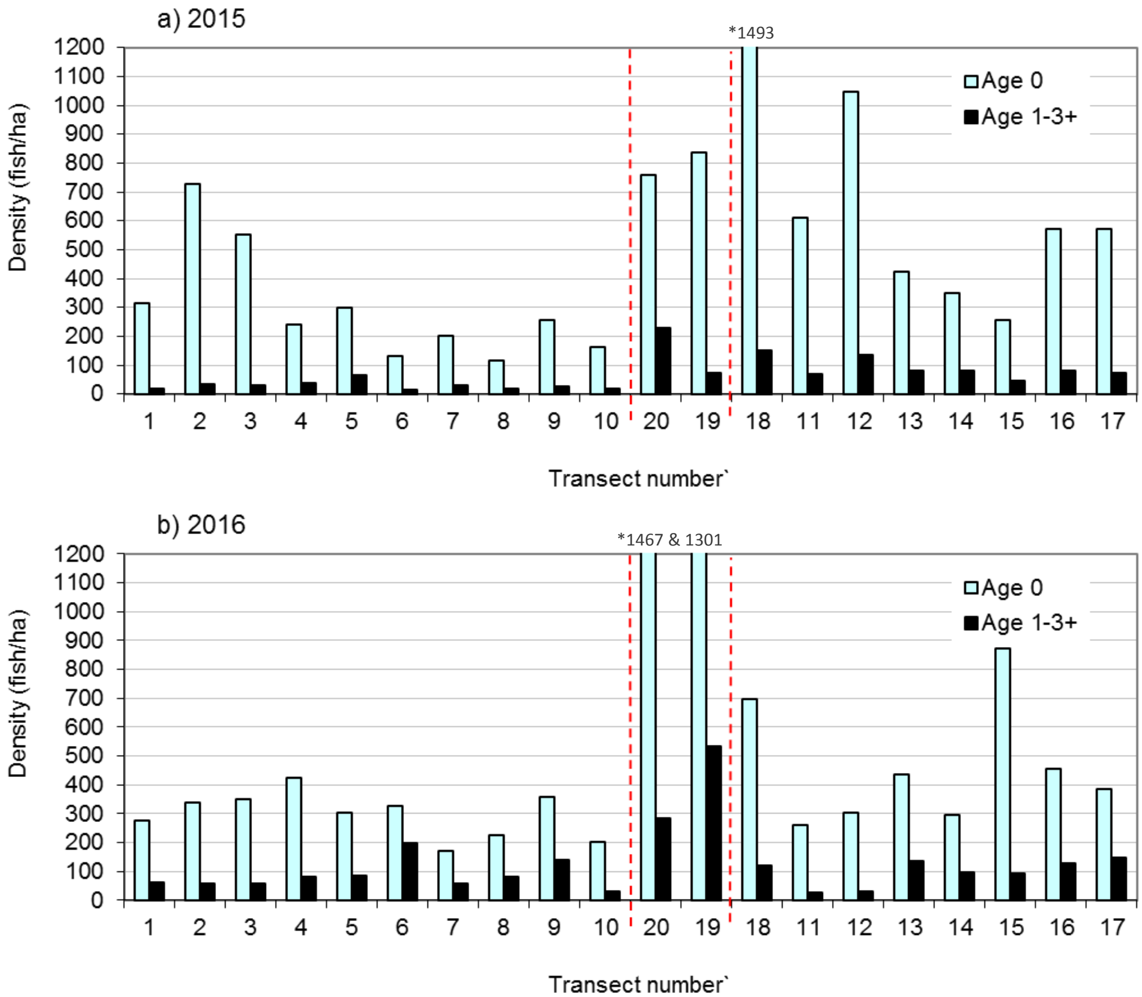


Figure 37. Longitudinal distribution of age 0 and age 1–3 kokanee in ALR during October of **a)** 2015 and **b)** 2016 based on acoustic surveys. Note: Transects 19 and 20 between red dashed lines are in the Narrows between Upper and Lower Arrow and were not used for estimating total kokanee abundance.

In-lake Abundance

Annual hydroacoustic estimates for kokanee during fall surveys have ranged from 5–20 million and averaged 10.3 million since nutrient additions began in 1999 (**Table 7**). In 2013, an estimate of 5.2 million (4.4–6.0 M) was the second lowest for the 17 year period of nutrient addition and the lowest since 2005. The total estimate increased to near average at 9.1 million (8.1–10.1 M) in 2014, and again to slightly above average in 2015 at 12.3 million (10.1–14.6 M). In 2016, the total kokanee abundance remained above average and was estimated at 11.8 million (10.2–13.4 M).

Table 7. 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, 1999–2016 (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)
18	2016	October	7.3 (5.9-8.7)	4.5 (3.7-5.3)	11.8 (10.2-13.4)
Nutrient Era mean (± 1 S.D.)			*6.5 (3.6-9.5)*	*3.7 (2.0-5.5)*	*10.3 (5.8-14.7)*

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).

Figure 38 illustrates the acoustic kokanee population estimates by basin for age 0 and age 1–3 kokanee alongside the expanded spawner counts from index streams. After a recent low spawner escapement in 2012 led to a post-fertilization low of only 2.1 million age 0 kokanee in Upper Arrow in 2013, age 0 numbers recovered to above average in 2015 and 2016 at 5.8 and 5.7 million, respectively. Age 1–3 kokanee numbers remained consistently low from 2012 to 2015 in Upper Arrow, with estimates ranging between only 550,000 and 650,000 fish; however, in 2016, the age 1–3 kokanee population nearly tripled the 2015 estimate and reached 1.6 million, near the post-fertilization average.

In Lower Arrow, low numbers of spawners observed in 2011 and 2012 lead to below average age 0 abundance in 2012 and 2013, before age 0 abundance increased to above average in 2014 and a post-fertilization high of 5.2 million in 2015 **(Figure 38b).** In 2016, fry numbers declined to 3.7 million, which was still well above the post-fertilization average of 2.7 million. Similar to Upper Arrow, age 1–3 kokanee numbers in Lower Arrow descended into a sustained low abundance period beginning in 2012, however the dramatic improvement observed in Upper Arrow in 2016 failed to materialize in

Lower Arrow. While the age 1–3 kokanee population in lower Arrow has increased year over year since the low of 506,000 in 2013, the 2016 estimate of 758,000 remained below the post fertilization average of ~1 million.

Evaluation of individual age class abundance for the age 1–3 kokanee group, derived by applying the trawl age structure to the population estimates, reveals that both age 1 and age 2 kokanee numbers increased substantially in Upper Arrow from 2015, by factors of 2.5 and 5.2 respectively **(Appendix 13).** In Lower Arrow, the age 1 kokanee numbers decreased by 24%, however the age 2 numbers increased 3 fold over 2015.

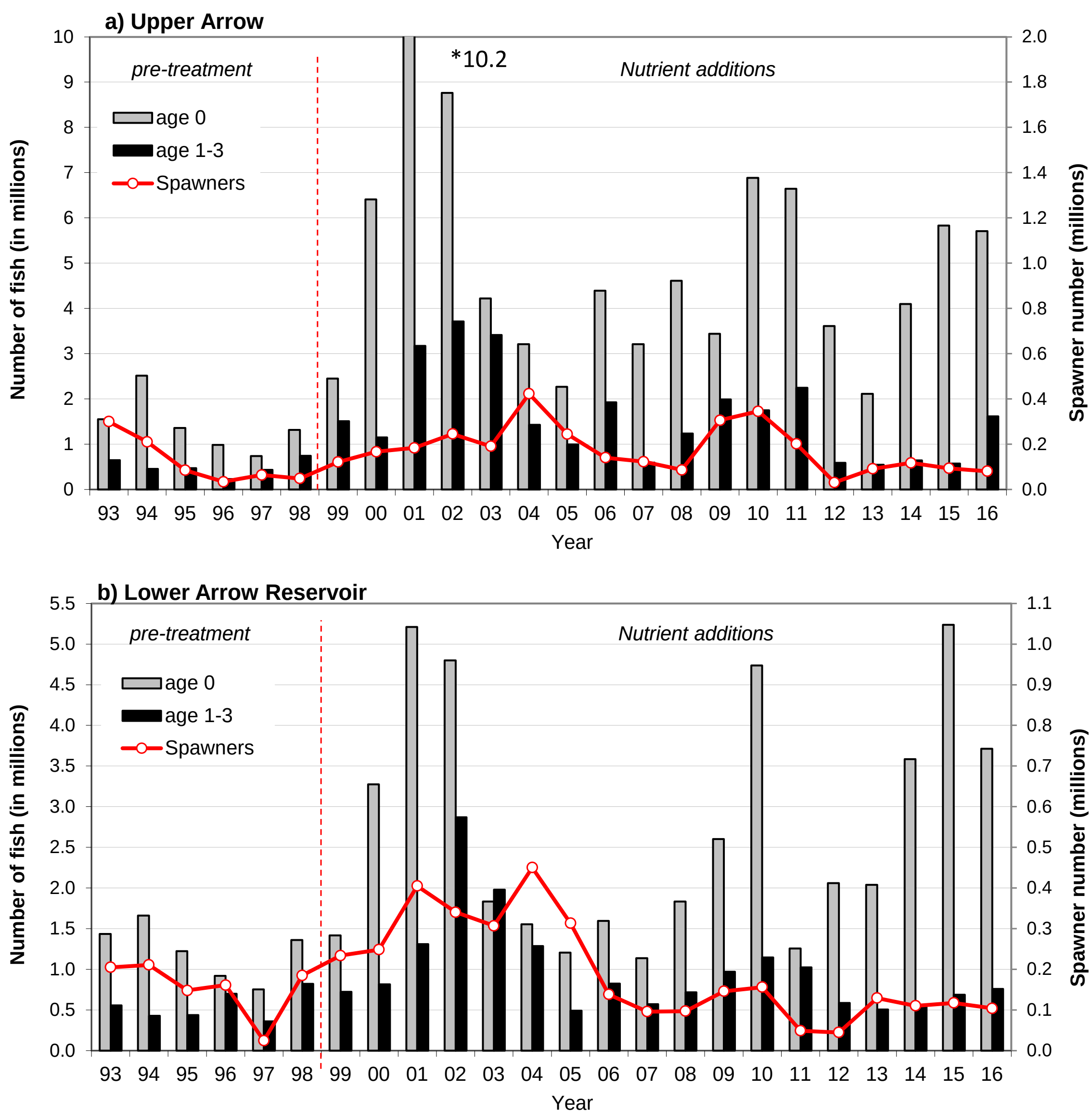


Figure 38. Trends in age 0 and age 1–3 in-lake kokanee abundance as well as index stream kokanee spawner abundance for **a)** Upper Arrow and **b)** Lower Arrow Reservoir based on fall hydroacoustic and spawner surveys during 1993–2016. Note that the y-axis for spawner numbers is on the right.

Biomass

Since 2013, kokanee standing crop 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 six years of data, biomass density averaged 1.9 $kg \cdot ha^{-1}$ in Upper Arrow and 4.0 $kg \cdot ha^{-1}$ in the more productive Lower Arrow. Average kokanee biomass during the nutrient addition era has increased to 5.0 $kg \cdot ha^{-1}$ (2.7 times pre-nutrient era) in Upper Arrow and to 6.5 $kg \cdot ha^{-1}$ (1.6 times pre-nutrient era) in Lower Arrow **(Figure 39**).

Similar to spawner numbers shown above, kokanee biomass reached a nutrient era low in 2012 in both basins (**Figure 39**). Biomass increased over the next 2 years but then declined again in 2015, largely due to the weak cohort of age 2 kokanee that year (progeny of the low 2012 brood year) as well as a decrease in size at age for older age classes. In 2016, kokanee biomass density estimates increased substantially to 6.3 kg/ha in Upper Arrow and 7.1 kg/ha in Lower Arrow, slightly above the nutrient era average for both basins and the highest estimate since 2009 in Upper Arrow and 2010 in Lower Arrow. **Appendix 13** identifies the biomass density estimates by age class across all years.

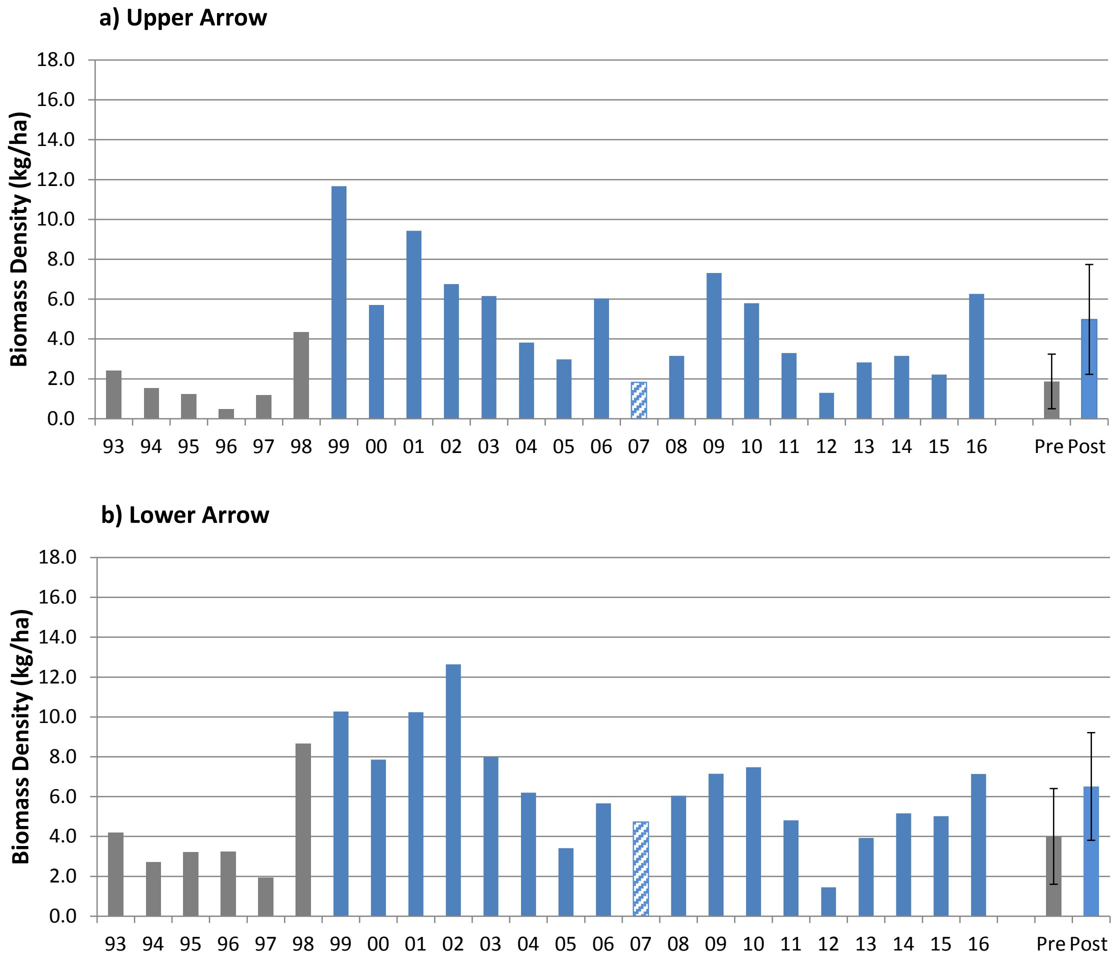


Figure 39. In-lake biomass density (kg.ha-1) trends for kokanee in **a)** Upper Arrow and **b)** Lower Arrow reservoirs based on fall acoustic and trawl survey data 1993–2016. Error bars on pre- and post-nutrient era averages denote era standard deviation. Note: no trawling occurred in 2007; age structure and mean weights were derived by averaging the values for 2006 and 2008.

Hill Creek production

Production statistics for the Hill Creek Spawning Channel (HCSC) are presented in **Table 8**. A peak in spawner returns, fecundity and egg deposition during 2009–2011 resulted in record levels of annual fry production averaging ~16 million during 2010–2012 (compared to ~5.7 million annually from 1999 to 2009). This period was immediately followed by the lowest adult return on record in 2012 and overall spawner returns have remained below average ever since. Current operational objectives, in place since the fall of 2014 for HCSC, are aimed at maintaining channel fry production near 3.8 million/yr. This target was based on the post-fertilization median fry output from the channel from the spring of 2000 to the spring of 2014. As a result, the proportion of fish allowed access into the spawning channel was reduced to <50% of the run compared to an average of 80% of the run since 1999. Resulting fry production from the spawning channel declined from a fertilization era average of 7.2 million annually (1999–2011) to an average of 3.5 million from the spring of 2013 to 2016. In 2016, the egg deposition estimate for the spawning channel was 4.5 million based on 41,344 adults or 19,432 females (47.0% female) with a net fecundity of 283 eggs/female (**Table 8**). The 2016 egg deposition was lower than the previous three years and a decrease in egg to fry survival in 2016 resulted in the below target fry emigration of 2.6 million from the HCSC.

Table 8. Kokanee production statistics for Hill Creek spawning channel 1987–2016.

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
2016	41,344	283	4	47	4.51	2.57	57
Pre fert ave[5]	78,037	236	19	50	7.85	3.18	40
Fert era ave[6]	113,527	287	7	44	12.92	6.20	50

1. Refers only to fish in spawning channel
2. Derived by fish sampling at channel; may be different that actual proportion allowed into channel due to females removed for hatchery egg supply
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

Kokanee survival

Cohort survival

Bassett *et al*. (2018) presented the relationship of fry to adult survival from Hill Creek Spawning Channel (HCSC) fit with a power model for the first 13 years of the nutrient addition era (i.e., 1999 to 2011 brood years; R^2=0.66). The 2009 to 2011 brood years differed from previous years as an attempt was made to test the fry output capacity from the spawning channel, and the resulting output was very high (~20, 17.5 and 11 million fry out respectively, **Table 8**). The 2009 brood year (2010 fry year) cohort had by far the lowest fry to adult survival to date at only 0.08% followed the 2010 and 2011 cohorts, which only showed slight improvements in survival to 0.54% and 0.66% respectively, remaining well below the fertilization era average of 6.6%. The egg to emergent fry survival remained above average all three of these 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 for those cohorts led Bassett *et al.* (2018) to speculate that in-lake rearing capacity may have been exceeded at those production levels, resulting in significant declines in adult returns; they also noted that this alone was not conclusive as it did not consider other factors which may have limited survival of these cohorts, such as record high flows in 2012 and a large scale die-off, also in 2012.

In order to better understand cohort survival trends, it is useful to evaluate survival from other tributaries and between basins in addition to focussing on the spawning channel. As emergent fry estimates were not available for any non-channel spawning habitat, survival from the egg stage to spawner was estimated and compared for both Upper Arrow (all except Hill Creek) and Lower Arrow index tributaries and for the HCSC. Cohort survival has been calculated by summing the cumulative returns at age 2–5 for each age class. We acknowledge that the absolute survival estimates for the index streams in Upper and Lower Arrow are not as accurate or precise as the Hill Creek Spawning Channel estimates. However, the trend in our measured survival likely reflects the actual survival trends.

Figure 39 illustrates the trends in egg to spawner survival for Upper and Lower Arrow index tributaries and for the HCSC since the period of (mostly) continuous spawner counts 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 for their respective brood years of 1989, 1990, and 1999. Survival spiked in both basins for the cohorts in-lake at the onset of nutrient restoration in the late 1990's, with index estimates reaching 15% for Upper Arrow tributaries and 7–8% for Lower Arrow tributaries and the HCSC. The Upper Arrow 1997 brood year estimate was suspiciously high which may reflect an issue with either the spawner estimate in 1997 or the return year counts in 2000 (as age 2) and/or 2001 (as age 3), although it likely still reflects very good survival for that brood year. After the initial increase at the onset of fertilization, survival to spawn declined sharply by 2001 and remained low until another period of increased survival in the mid to late 2000's, in particular for HCSC. This was a period of lower abundance and biomass following the substantial increase in numbers and biomass immediately following fertilization, and illustrates 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 2008 increasing noticeably compared to the years immediately before. Survival for the 2009 cohort declined dramatically for all tributaries to the worst on record, with survival rates of only 0.05% for HCSC and Upper Arrow index tributaries, and only slightly better for Lower Arrow tributaries at 0.12%. Upper Arrow tributaries and HCSC improved only slightly but remained very low for the 2010 and 2011 cohorts, while Lower Arrow survival improved substantially for the 2011 cohort. Survival estimates for the Upper Arrow index tributaries increased dramatically in 2012 and 2013 to >4%, far exceeding survival estimates for HCSC or Lower Arrow tributaries. Lower Arrow tributary survival remained moderately high for the 2012 and 2013 cohorts, while HCSC increased to 2.5% for the 2013 cohort, which was above average and higher than the previous six years. Cohort survival has averaged near 2% over the last 5 years for Upper Arrow tributaries compared to ~1% for HCSC and Lower Arrow tributaries, and averaged over 10 years the Upper Arrow tributaries are equivalent to HCSC at ~1.5% while the Lower Arrow Tributaries averaged 0.9%. It is possible that at very low abundance the index tributary escapement estimates become less reliable and vulnerable to underestimation, which might at least partly explain the dramatically better survival in Upper Arrow index tributaries for the 2012 and 2013 cohorts, compared to the enhanced habitat of the HCSC.

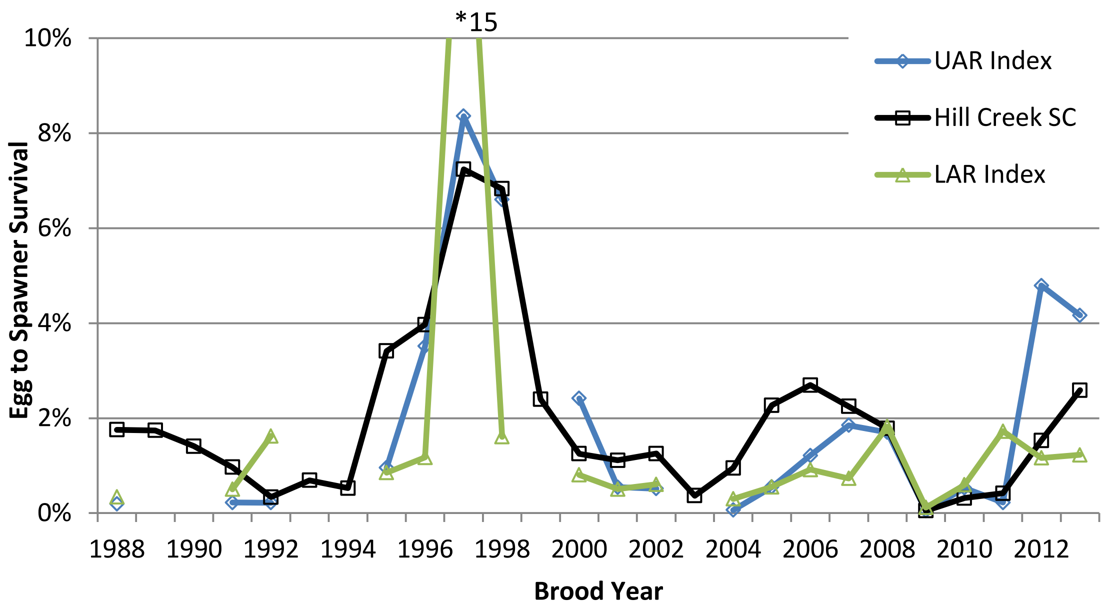


Figure 39. Egg to spawner survival index trends for Upper Arrow (UAR) and Lower Arrow (LAR) index spawning tributaries and for Hill Creek Spawning Channel from 1988 to 2013. Missing data points are a result of no spawner count data for 1993, 1994, and 2003 in any index tributaries except Hill Creek. Hill Creek survival is calculated using only channel eggs but total HC returns, so assumes zero survival from non-channel spawners. Note that the 2013 cohort estimates only include survival up to age 2 and age 3 spawners in 2015 and 2016 respectively, and the estimates may increase slightly if any age 4 spawners return in 2017.

Annual survival

In previous reporting, an index of survival from fry to age 1 was approximated using the proportion of age 1–3 kokanee relative to the fry population from the year prior; based on the premise that age 1 kokanee are most likely to comprise the largest proportion of the age 1–3 population most years. In this report, we have refined the index using the trawl age structure (from the age 1–3 catch) applied to the acoustic age 1–3 estimate, to derive an age 1 population estimate to calculate survival. In addition, we have added an index of age 1 to age 2 survival, where the age 2 value is the sum of the trawl age structure derived age 2 abundance estimate in addition to the age 2 spawner estimate from the same year. See **Appendix 7** (returns by age class) for the age 2 spawner numbers by year, and **Appendix 13** for the acoustic and trawl derived in-lake estimates of age 1 and 2 abundance.

Table 9 shows the survival index estimates for age 0–1 and age 1–2 as proportions and also converted to the equivalent standard (z) score in order to demonstrate the deviation of each value relative to the mean, which is also illustrated in **Figure 40.** Also presented is an annual index of survival in **Table 9** and in **Figure 40**, which is the average of the age 0–1 and age 1–2 survival values for each year. The intent of the annual index is to present a simplified annual value, however it also may moderate any (unquantified but expected) impact of varying trawl selectivity between age 1 and age 2 catches on any given year. Only data collected using equivalent trawl methodology since 2000 are presented, as the age structure from trawl data prior to 2000 are not directly comparable due to a change in net mesh size around that period.

Table 9. Kokanee survival index trends for Arrow Lakes Reservoir from 2000 to 2016. The year is labelled by the latter year as each value includes data from two consecutive years.

	Survival Index (proportional)		Survival Index (standardized)		
	age 0 to 1	age 1 to 2	age 0 to 1	age 1 to 2	*Annual Index*[1]
2000	0.36		1.23		
2001	0.27	1.53	0.45	1.26	*0.86*
2002	0.28	1.14	0.56	0.55	*0.55*
2003	0.30	0.37	0.70	-0.89	*-0.10*
2004	0.14	0.44	-0.59	-0.75	*-0.67*
2005	0.13	0.79	-0.74	-0.10	*-0.42*
2006	0.58	1.05	3.02	0.38	*1.70*
2007	0.11	0.27	-0.87	-1.08	*-0.97*
2008	0.21	1.78	0.00	1.74	*0.87*
2009	0.20	1.83	-0.11	1.82	*0.86*
2010	0.17	1.25	-0.37	0.75	*0.19*
2011	0.21	0.67	-0.01	-0.33	*-0.17*
2012	0.08	0.12	-1.13	-1.34	*-1.24*
2013	0.13	0.65	-0.70	-0.36	*-0.53*
2014	0.19	0.53	-0.19	-0.59	*-0.39*
2015	0.14	0.27	-0.64	-1.06	*-0.85*
2016	0.14	0.84	-0.60	0.00	*-0.30*
Ave	*0.22*	*0.85*			
SD	*0.12*	*0.54*			

[1] Annual index is the average of age 0-1 and age 1-2 survival for each year

Figure 40 illustrates that the survival trend has been variable with good kokanee survival in 2001, 2006, 2008 and 2009 and poor survival in 2004, 2007, 2012, and 2015. The annual survival index was the highest on record in 2006 at nearly 2 SD above average, driven primarily by excellent survival from age 0 to 1 but also slightly above average survival from age 1 to 2. The following year, survival plunged dramatically for both age 0–1 and age 1–2 to approximately 1 SD below the mean. The annual survival was the worst on record in 2012, when both the age 0–1 and age 1–2 values were >1 SD below the mean. Kokanee survival has remained below average since 2012 although returned to near average in 2016.

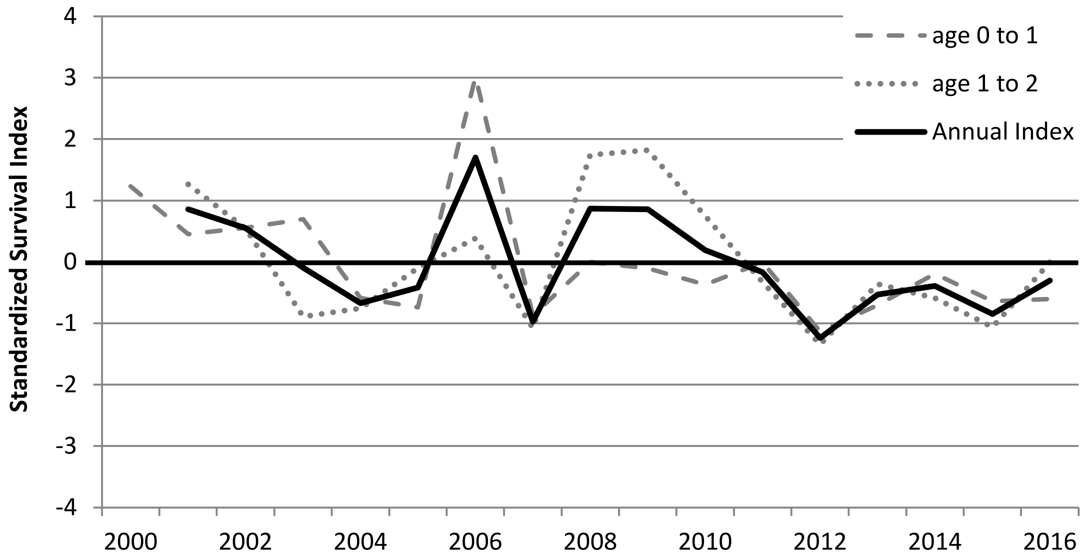


Figure 40. Standardized kokanee survival index trends for Arrow Lakes Reservoir (combined basins) relative to the long-term mean survival. The year is labelled by the latter year as each value includes data from two consecutive years.

DISCUSSION

Lake conditions in 2016

Though less extreme than the dry and high flows summer in 2015, 2016 was still a relatively dry summer with above average early summer flows and a fast April melt. Bio-available ambient phosphorus remained lower than average, though the nitrogen to phosphorus ratio was close to average. Overall density and biomass of phytoplankton was slightly below average, which was mainly driven by fewer diatoms. This pattern was more pronounced in Upper Arrow than Lower Arrow. This lower standing crop of phytoplankton was likely related to an early appearance of *Daphnia*, followed by a higher than average density and biomass of *Daphnia* for the rest of the summer.

Kokanee status leading up to 2016

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 then age 2 fish in 2015. In addition to poor kokanee growth and low fecundity in 2012, Bassett *et al.* (2016, 2018) reported a large scale die off of kokanee in Upper

Arrow in the spring of 2012, which had a dramatic and lasting impact on the kokanee population, and may have been linked to the infectious hematopoietic necrosis virus (IHNV).

Bassett *et al.* (2016) speculated that record high flows (represented by outflow data from Hugh Keenleyside Dam) led to a shorter water residence time in 2012 which may have resulted in zooplankton being flushed out of Upper Arrow Reservoir at a high enough rate that their availability as food for kokanee declined. Further, Bassett *et al.* (2018) suggested that results from 2015 monitoring provided more evidence to support the notion that high flushing during the growing season negatively affects zooplankton and kokanee productivity in the Arrow system, particularly in Upper Arrow, as 2015 was another extremely high flow year. The average April to October outflow from Arrow in 2015 was the highest for the fertilization era at 1456 $m3.s^{-1}$, which was even greater than 2012 (**Figure 4**).

Bassett *et al.* (2015) described poor growth conditions for kokanee which resulted in delayed maturation of the 2009 fry cohort, which primarily spawned at age 4 in 2013. The absence of age 3 spawners in 2012 contributed to the 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 the large-scale die-off event in 2012. 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 (Bassett et. al, 2018). The 2010 fry cohort from Hill Creek was estimated at >20 million yet culminated in only 15,350 spawners returning. Although spawner size increased in 2013, their fecundity did not increase as much as expected (**Appendix 23**). However, by 2014 both spawner length and fecundity increased to near maximum levels for Arrow Reservoir at 30 cm and 438 eggs/female, and the total index stream egg deposition increased from a very low level of ~8 million in 2012 to ~30 million by 2014.

Egg to emergent fry survival was excellent in the spring of 2015, estimated at 81% for the Hill Creek Spawning Channel (HCSC). 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 (Basset *et al.*, 2018). If correct, this would artificially inflate survival estimates to fall fry for 2015. Regardless, the fall fry estimates overall were still above average.

The slightly above average fall fry abundance of 8 million in 2014 led to approximately one million age 1 fish for both basins combined in 2015. This translated to a survival rate of ~14% for fry to age 1 kokanee in 2015, which was below the long-term average although still resulted in an increase in age 1 abundance over the previous two years.

Age 2 kokanee in Arrow reached the lowest abundance on record at ~174,000 fish for the combined basins in 2015 (**Appendix 13**), although this cohort was the progeny of the record low spawner returns in 2012. Regardless, the survival from 2014 age 1 to age 2 in 2015 was very poor, which is contrary to the expectation of increased survival rates at low abundance for a species widely understood to exhibit density dependant compensation in survival and growth. Similarly, growth was also less than expected given the low densities, as mean length at age decreased in 2015.

In summary, the kokanee population has experienced challenging conditions since 2012, with two extremely high flow years in 2012 and 2015, as well as a large scale die off in 2012 which dramatically reduced the abundance of the age 2 cohort in particular. There is also evidence that regional weather patterns may have led to poor productivity in 2011, which was one of the coldest spring seasons in recent history (**Figure 2**). Zooplankton metrics (namely *Daphnia* spp. biomass) were very low in Arrow Reservoir (**Figure 23**) but also in nearby Revelstoke and Kinbasket Reservoirs (Bray, 2017), despite generally low kokanee biomass estimates (FLNRO data on file) among all three systems (suggesting bottom-up limitation as opposed to top down). As each of these events were in close temporal proximity, the resulting cumulative impact was a prolonged period of reduced outcomes for most kokanee population metrics (i.e. well below nutrient restoration period averages since 2012).

Kokanee survival

The kokanee survival data presented in **Figure 39** and **40** demonstrates the trend of poor survival in recent years improved in 2016. Under the premise that reservoir flow rate/water residence time affects reservoir productivity and kokanee survival, the annual kokanee survival index (presented above in **Table 9** and **Figure 40)** is plotted against reservoir outflow in **Figure 41** to identify how flow rate may have influenced kokanee survival. The negative relationship demonstrates declining kokanee survival with increasing outflow, which is particularly evident for the two highest outflow years in 2012 and 2015. It is noteworthy that while 2012 was characterized by exceptionally high rainfall in the spring which led to higher outflow, 2015 was characterized by very dry and warm weather throughout the majority of the growing season. The runoff for the entire Columbia River (Canada and US) was only 67% of normal between April and October of 2015, making it the third driest year on record (BC Hydro, 2015). The expectation under such conditions would be for lower flows (and better conditions for kokanee survival), however the opposite occurred as the average outflow ended up as the highest on record (1997–2016) at 1458 m^3/s. The increased outflow was due to the Columbia River Treaty stipulation that water releases increase from Arrow Reservoir under dry conditions (BC Hydro, 2016). **Figure 41** identifies that the mean daily outflow in 2016 was near average and the kokanee survival index fell very close to the value predicted by the linear regression.

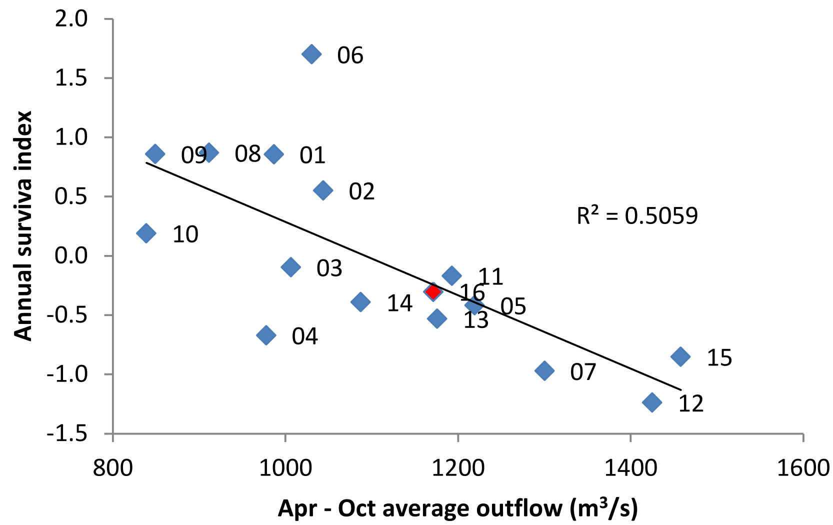


Figure 41. Relation of the annual kokanee survival index to the April to October average daily outflow (m^3/s) at Hugh Keenleyside Dam for Arrow Reservoir from 2001 to 2016. Each point is labelled by year, and the red point identifies 2016 within the cluster of points. Note that an abnormal and large scale kokanee mortality event occurred in the spring of 2012 which affected the survival estimates presented.

While flow rate/water residence time can affect kokanee survival, other factors are also relevant. Basset *et al.* (2018) discussed the role of disease and predation, although with the exception of the 2012 mortality event, neither was supported by the available data as key factors affecting the poor survival outcomes in recent years. Another well-established factor influencing survival is kokanee density, and Bassett *et al*. (2018) presented the relationship of Hill Creek Spawning Channel fry output and survival to adult fit with a power model (R^2=0.66) for the first 13 years of the nutrient addition era. The relationship illustrated that cohort survival decreased with increasing fry density, with the high density end of the relationship defined by the 2009 to 2011 brood years- the period during which an attempt was made to test the fry output capacity from the spawning channel and the resulting output was very high (~20, 17.5 and 11 million fry out respectively**, Table 8**).

In order to better understand the influence of density on the poor survival and weak spawner returns from the three large cohorts (brood years 2009–2011), the egg to spawner survival data presented in **Figure 39** have been plotted against cohort egg deposition (as a proxy for density) in Upper Arrow in **Figure 42**. Utilizing egg deposition in relation to survival, as opposed to the similar relation of fry to adult survival shown by Basset *et al.* (2018) for Hill Creek spawning channel alone, allows for the full extent of spawner data across both Upper and Lower Arrow to be incorporated (as emigrant fry estimates are only available for HCSC). **Figure 42** suggests that density has an influence on cohort survival, which decreases with increasing density. The four most recent cohorts are labelled by the brood year (2009–2013). Survival was worse than predicted by density for all years except 2013. It is important to consider the sum of events/circumstances encountered by each of these cohorts during the 4–6 year period between the egg stage and spawning as age 2–4 adults. For example, each of the 2009–2011 brood year cohorts would have been in-lake during the 2012 mortality event and the 2012 high flow rate growing season, and the 2011–2013 cohorts would have been present during the 2015 high flow rate growing season. The 2009 cohort at age 2 during the mortality event in 2012 was the age class reported to be most heavily impacted by the widespread mortality event that occurred over a period of 2–3 weeks. If density was the only factor affecting survival (i.e. all other factors were neutral) the regression model predicts a survival rate of ~0.42% for Upper Arrow for the abundant 2009 cohort, which would have culminated in ~140,000 spawners in that basin, as opposed to the 0.05% survival and ~17,000 spawners observed.

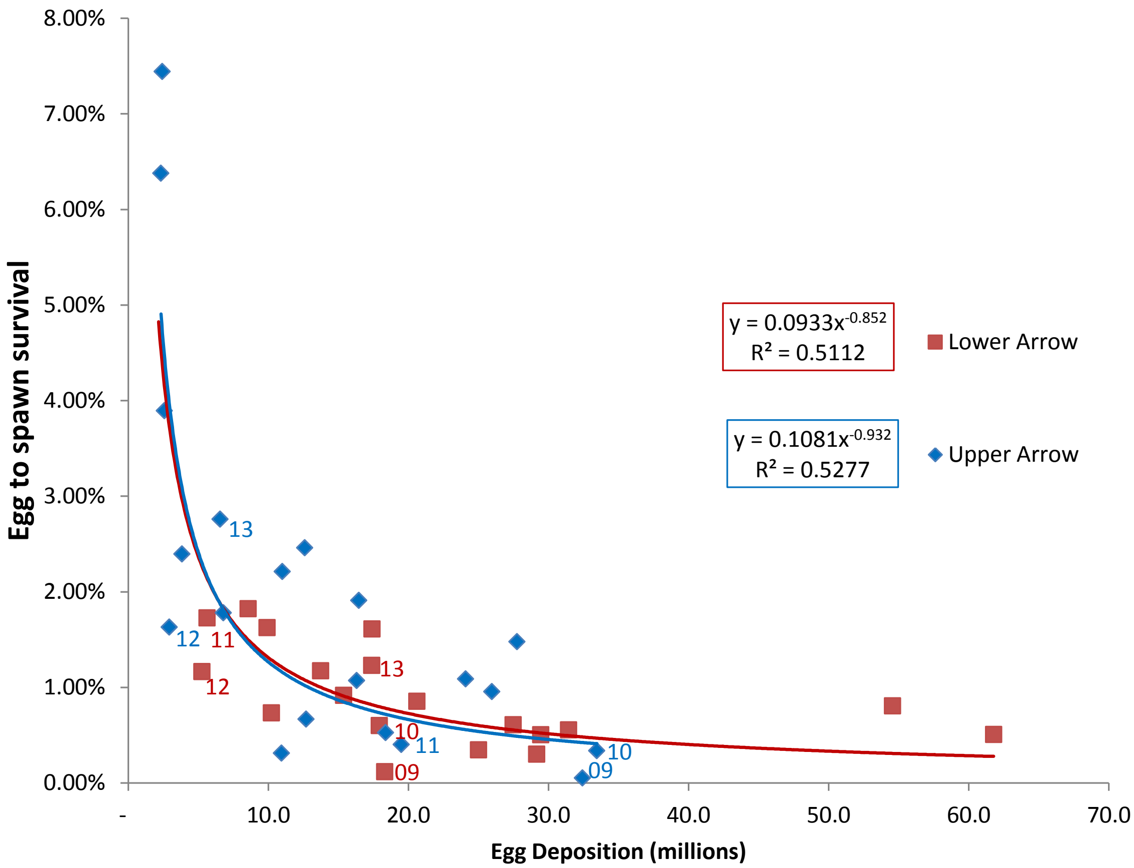


Figure 42. Relation of egg deposition to egg to spawner survival for Upper Arrow (including Hill Creek spawning channel) and Lower Arrow index spawning tributaries from 1988 to 2013. Some data points are omitted as a result of no spawner count data for 1993, 1994, and 2003 in any index tributaries except Hill Creek. The y-axis has been capped at 8% which obscures one very high survival value for lower Arrow at 15.5% at 2.2 million eggs. The 2013 cohort estimates only include survival up to age 2 and age 3 spawners in 2015 and 2016 respectively, and the estimates may increase slightly if any age 4 spawners return in 2017.

Kokanee status in 2016

An increase in length at age coinciding with a return to average survival and increasing abundance by age class resulted in a substantial increase in biomass in 2016, indicating that in-lake conditions improved for kokanee relative to 2015. Fall fry abundance was above average in both basins, providing the basis for an increase in kokanee adult abundance moving forward. Age 1 and 2 abundances were the highest in 4–5 years, which suggests the potential for a significant increase in kokanee spawner numbers in 2017 and 2018 should in-lake conditions and kokanee survival remain average or better. Spawner numbers declined slightly; combined with a decrease in size and fecundity resulting in decreased egg deposition, this is likely to result in a decrease in age 0 numbers in 2017 compared to 2016.

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.

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.

Bassett, M., E.U. Schindler, R. Fox, L. Vidmanic, T. Weir and D. Sebastian. 2018. Arrow Lakes Reservoir Nutrient Restoration Program Year 17 (2015) Report. Fisheries Project Report No. RD 151, Ministry of Forests, Lands and Natural Resource Operations, Province of British Columbia. 133p.

BC Hydro. 2015. Columbia River Operations Summary, Fall 2015. GDS14-120.

BC Hydro. 2016. Columbia River Operations Summary, Fall 2016. BCH16-403.

Bray, K. 2017. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 8 (2015). BC Hydro, Environment. Study No. CLBMON-3 and CLBMON-56.

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, 360p.

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

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

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

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

Koerselman, W. and A.F.M. Meuleman. 1996. The vegetation N:P ratio: a new tool to detect the nature of nutrient limitation. Journal of Applied Ecology 33(6):1441–1450.

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

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

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*). Canadian Journal of Fish and Aquatic Sciences 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. Environmental Biology of Fishes 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, B.C.

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 American Journal of Fisheries Management 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, 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.

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 and 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.

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

R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

RStudio Team. 2017. RStudio: Integrated Development for R. RStudio Inc., Boston, MA, URL: http://www.rstudio.com/.

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

Reynolds, J.B. and G.M. DeGraeve. 1972. Seasonal population characteristics of the opossum shrimp, *Mysis relicta*, in southeastern Lake Michigan, 1970-71. Proceedings of the 15th Conference on Great Lakes Research. 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. Transactions of the American Fisheries Society 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. Aquatic Science 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.

Sebastian, D., H. Andrusak, G. Scholten and L. Brescia. 2000. Arrow Lakes Reservoir Fish Summary. Stock Management Report. 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.

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, 227p.

Stockner, J. G., and E.A. MacIsaac. 1996. British Columbia lake enrichment program: two decades of habitat enhancement for sockeye salmon. Regulated Rivers Research and Management 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.*

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.

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, B.C.

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

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

APPENDICES

Appendix 1. List of personnel involved in the 2016 Arrow Lakes Reservoir project.

Project Focus	Personnel	Affiliation
Project co-ordination, management and scientific liaison	Marley Bassett	Resource Management, MoFLNRO[1], Nelson
Report compilation	Marley Bassett Rob Fox Kristen Peck	Resource Management, MoFLNRO, Nelson
Report editing and review	Marley Bassett Eva Schindler Rob Fox Kristen Peck Steve Arndt Tyler Weir Dale Sebastian Mike Hounjet	Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Victoria British Columbia Conservation Foundation Columbia Basin Trust, Castlegar
Fertilizer schedule, loading	Marley Bassett Eva Schindler Ken Ashley	Resource Management MoFLNRO, Nelson Resource Management MoFLNRO, Nelson BC Institute of Technology Rivers Institute
Fertilizer supplier	Gerry Kroon Alan Jelfs	Agrium, Calgary 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 Dave Heagy Chris Price	Kootenay Wildlife Services Ltd. Resource Management, MoFLNRO, Nelson Resource Management, MoFLNRO, Nelson BC Parks, MoE[2] BC Parks, MoE
Physical limnology, water sampling data analysis and reporting	Marley Bassett Rob Fox	Resource Management, MoFLNRO, Nelson
Chemistry analysis	ALS Global staff	ALS Global, Burnaby BC
Chlorophyll analysis	Shannon Harris Allison Hebert	MoE, Vancouver
Phytoplankton analysis	Dr. John Stockner	Eco-Logic Ltd.
Zooplankton and Mysid analysis and reporting	Dr. Lidija Vidmanic	Limno-Lab Ltd., Vancouver
Kokanee acoustic surveys	Tyler Weir David Johner Sam Albers	Fish, Wildlife and Habitat Management, MoFLNRO, Victoria
Kokanee trawling	Don Miller and staff	Kootenay Wildlife Services Ltd., Nelson
Kokanee aerial spawner surveys	Marley Bassett Eva Schindler Albert Chirico Mark Homis	Resource Management MoFLNRO, Nelson Resource Management MoFLNRO, Nelson MoE, Nelson Highland Helicopters, Nakusp

(cont'd)

Project Focus	**Personnel**	**Affiliation**
Kokanee ground spawner surveys	Steve Arndt Rob Fox Eva Schindler Kristen Murphy Ryan Craft Karen Bray A. Korsa	Resource Management MoFLNRO, Nelson British Columbia Conservation Foundation BC Hydro
Kokanee analysis and Reporting	Tyler Weir David Johner Dale Sebastian	Fish, Wildlife and Habitat Management, MoFLNRO, Victoria British Columbia Conservation Foundation
Kokanee scale ageing	Morgan Davies Carol Lidstone	BC Provincial Aging Lab - FFSBC Birkenhead Scale Analyses
Regional support	Jeff Burrows Matt Neufeld	Resource Management, MoFLNRO, Nelson
FWCP Technical Committee	Jeff Burrows Tyler Weir Guy Martel Karen Bray Misun Kang Michael Zimmer	Resource Management, MoFLNRO, Nelson Fish, Wildlife and Habitat Management, MoFLNRO, Victoria BC Hydro, Vancouver BC Hydro, Revelstoke Ktunaxa Nation Okanagan Nation Alliance
FWCP Board	John Krebs Dave Tesch Trevor Oussoren Kim Cox Misun Kang Adam Neil Howie Wright David White Grant Trower Rick Morley	Resource Management, MoFLNRO, Cranbrook Environmental Sustainability Division, MoE, Victoria BC Hydro BC Hydro Ktunaxa Nation Representative Secwepemc Nation Representative Okanagan Nation Alliance Representative Public Representative Public Representative Public Representative
Contract administration	Crystal Klym Lorraine Ens Eva Schindler	FWCP[3], BC Hydro, Castlegar FWCP, BC Hydro, Burnaby Resource Management, MoFLNRO, Nelson
Administration	Crystal Klym Lorraine Ens Jen Bellhouse Diedre Kilback Disa Westerhaug	FWCP FWCP British Columbia Conservation Foundation Resource Management, MoFLNRO Corporate Services Branch, MoFLNRO, Nelson

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

Appendix 2. Arrow Lakes Reservoir physical, chemical, plankton, and kokanee sampling program for 2016.

Parameter sampled	Sampling frequency	Locations	Sampling technique
Temperature, dissolved oxygen, specific conductance	Monthly: April to November	HL 4, AR 1–8	SeaBird profiles from surface to 5 m off the bottom
Transparency	Monthly: April to November (twice a month in June, July, and August)	HL 4, AR 1–8	Secchi disk (without viewing chamber)
Epilimnion water chemistry Turbidity, pH, TP, TN, NO_3, NO_2, TIC, TDP, OP, TOC, alkalinity, silica	Monthly: April to November	AR 1–3 and AR 6–8	Integrated sampling tube at 0–20 m
TP, TN, NO_3, NO_2, TDP, OP	Twice monthly in June, July and August	(AR1–3 and AR6–8 in mid-June) AR 3 and AR 8	Integrated sampling tube at 0–20 m
Total and Dissolved Metals	June and September	AR 1–3 and AR 6–8	Integrated sampling tube at 0–20 m
Discrete Epilimnion Water Chemistry TP, NO_3, NO_2, TDP, OP, silica	Monthly: June to September	AR 2 and AR 7	Niskin water samples at 2, 5, 10, 15 and 20 m
Hypolimnion Water Chemistry Turbidity, pH, TP, TN, NO_3, NO_2, TIC, TDP, OP, TOC, alkalinity, silica	Monthly: May to October	AR 1–3 and 6–8	Discrete water sample with Niskin sampler 5 m off the bottom
TP, TN, NO_3, NO_2, TDP, OP	Mid-June	AR1–3 and AR6–8	
Chlorophyll *a* (not corrected for phaeophytin)	Monthly: April to November (twice monthly in June, July and August)	AR 1–8	Integrated sampling tube at 0–20 m
	Monthly: June to September	AR 2 and 7	Discrete samples with Niskin sampler at 2, 5, 10, 15 and 20 m
Phytoplankton	Monthly: April to November (twice monthly in June, July and August)	AR 1–8	Integrated sampling tube at 0–20 m
Macrozooplankton	Monthly: April to November (twice monthly in June)	AR 1–3 and 6–8	Three oblique Clarke-Bumpus net hauls (3-minutes each) from about 20–0 m (150 µm net)

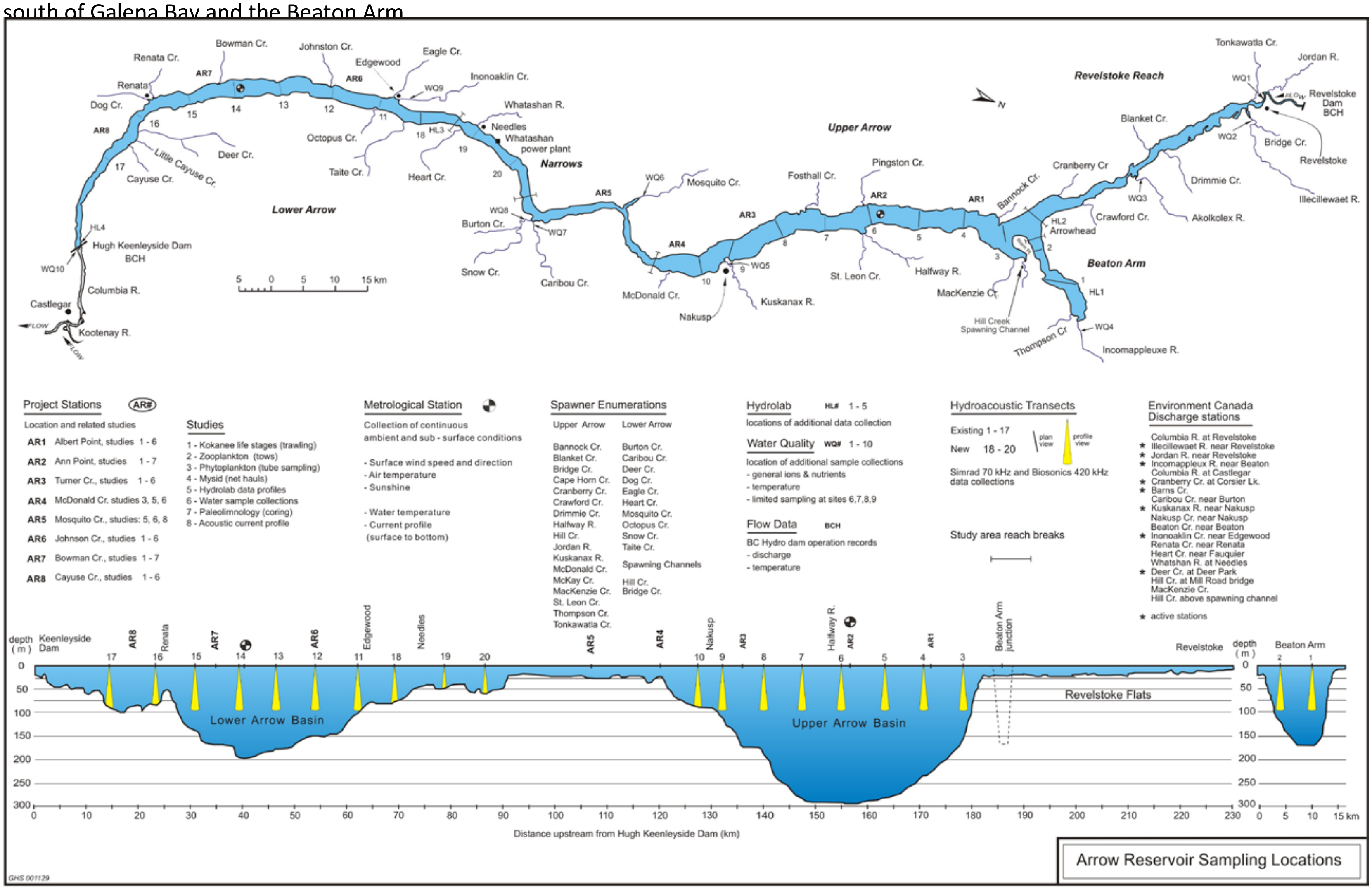
(cont'd)

Parameter sampled	Sampling frequency	Locations	Sampling technique
Mysid net sampling	Monthly: April to November (twice monthly in June)	AR 1–3 and 6–8	Two replicate hauls with the mysid net from 5 m above bottom to the surface
Kokanee acoustic sampling	Fall survey	TR 1–20	Standard Simrad and Biosonics hydroacoustic procedure at 20 transects in Upper and Lower Arrow
Kokanee trawling	Fall trawl series	AR 1–3 and AR 6–8	Standard trawl series using oblique hauls in Upper and Lower Arrow
Aerial kokanee spawner counts	September	See Table 3 for index sites and Appendix 5 for all sites surveyed	Three standardized helicopter flights appr. one week apart to identify peak spawner numbers
Ground kokanee spawner counts	September		Two-three ground counts appr. one week apart to identify peak spawner numbers

Appendix 3. Arrow Lakes Reservoir nutrient loading from fertilizer during 2016– 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-25	7.6	1440.2	9.7	5.1	970.0	0.0	9.7	0.67
2	May-02	7.6	1440.2	9.7	5.1	970.0	0.0	9.7	0.67
3	May-09	11.4	2167.7	14.6	7.7	1460.0	0.0	14.6	0.67
4	May-16	15.2	2895.2	19.5	10.3	1950.0	0.0	19.5	0.67
5	May-23	10.9	2078.6	14.0	38.3	7280.0	21.0	35.0	3.50
6	May-30	10.9	2078.6	14.0	38.3	7280.0	21.0	35.0	3.50
7	Jun-06	20.3	3860.3	26.0	71.2	13520.0	39.0	65.0	3.50
8	Jun-13	10.5	2004.4	13.5	83.0	15770.0	51.5	65.0	7.87
9	Jun-20	10.5	2004.4	13.5	83.0	15770.0	51.5	65.0	7.87
10	Jun-27	10.5	2004.4	13.5	83.0	15770.0	51.5	65.0	7.87
11	Jul-04	10.5	2004.4	13.5	83.0	15770.0	51.5	65.0	7.87
12	Jul-11	10.5	2004.4	13.5	83.0	15770.0	51.5	65.0	7.87
13	Jul-18	10.5	2004.4	13.5	83.0	15770.0	51.5	65.0	7.87
14	Jul-25	9.8	1855.9	12.5	83.9	15950.0	52.5	65.0	8.59
15	Aug-01	9.8	1855.9	12.5	83.9	15950.0	52.5	65.0	8.59
16	Aug-08	9.8	1855.9	12.5	83.9	15950.0	52.5	65.0	8.59
17	Aug-15	8.6	1633.2	11.0	85.4	16220.0	54.0	65.0	9.93
18	Aug-22	8.6	1633.2	11.0	85.4	16220.0	54.0	65.0	9.93
19	Aug-29	8.6	1633.2	11.0	85.4	16220.0	54.0	65.0	9.93
20	Sep-05	8.6	1633.2	11.0	85.4	16220.0	54.0	65.0	9.93

Appendix 4. Map of Arrow Lakes Reservoir with sampling locations. Dispensing of nutrients in Upper Arrow occurs from the Columbia ferry just south of Galena Bay and the Beaton Arm.



Appendix 5. Arrow Lakes Reservoir estimated total kokanee spawner numbers 1999–2016 (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	2016
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	41,344
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	23,324
Hill Creek egg take												12,220	-	-	1490	15,145	6,000	10,083
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	914
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	6,755
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	924
Jordan	375	683	5,850	3,488		2,400	2,385	3,945	1,995	30	645	2,948	2,250	-	17	300	293	233
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	462
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	4,085
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	2
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	1,124
Upper Index streams only	20,025	24,533	46,838	49,946	*Incomplete*	136,665	34,670	17,937	9,092	4,292	18,795	27,617	14,700	759	5,262	17,932	4,043	8,141
Upper Index tribs+SPChanr	120,964	166,636	183,934	245,008	*Incomplete*	422,855	244,475	140,384	122,663	86,345	305,394	345,171	201,268	30,636	91,023	117,308	93,298	82,892
Upper Arrow Total	163,232	205,833	270,337	302,271	*Incomplete*	561,918	304,793	154,799	137,912	90,671	311,267	354,268	209,152	30,749	92,262	120,194	95,062	89,248

Lower Arrow	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
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	41,250
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	19,575
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	10,254
Dog	396																	
Eagle	6,029	5,624	0	345	0	13,875	0	0	0	4088	116	506	137	480	227	1,980	0	440
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	32,850
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	1,599
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	15,204
Lower Arrow Index Total	233,925	248,538	405,027	340,466	*Incomplete*	450,323	313,442	138,138	95,852	97,050	145,847	156,147	48,795	44,888	129,236	110,348	117,329	103,929
Lower Arrow Total	271,633	271,113	418,451	368,408	*Incomplete*	481,598	326,602	145,652	101,723	116,136	156,392	160,541	52,233	46,503	130,242	127,223	137,200	121,172
Columbia tribs u/s REV																		
Overall Arrow Index Total	354,889	415,174	588,961	585,474	*Incomplete*	873,178	557,917	278,522	218,514	183,395	451,241	501,318	250,063	75,524	220,259	227,656	210,627	184,390
Total Arrow	434,865	476,946	688,788	670,679	*Incomplete*	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	207,550

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 were not completed in 2003 due to wildfires

Appendix 6. Summary of kokanee adult age proportions for Upper Arrow (Hill Creek Spawning Channel) from 2007 to 2016 and for Lower Arrow (Deer and Taite Creeks) from 2013 to 2016 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+)
2016	Hill Creek all spawners	238	201											
2016	Otolith samples with rating 6 or higher	238	99	57	42	0	0	0	58%	42%	0%	0%	0%	
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%	
2015	Deer and Taite Creeks all spawners sampled	256	52											
2015	Otolith samples with rating 6 or higher	257	42	4	32	6	0	0	10%	76%	14%	0%	0%	9 samples= CSA<6 not included
2016	Deer and Taite Creeks all spawners sampled	227	60											
2016	Otolith samples with rating 6 or higher	227	59	24	35	0	0	0	41%	59%	0%	0%	0%	

The above age proportions are for good quality otolith samples with a CSA Confidence rating of 6 or higher.

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

Highlighting shows example of which numbers are used in calculating fry surivival

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	
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)	2014	15	
2016	4,702,756	2016	71,738	0.58	0.42	-	-	41,608	30,130	-	-	(Casselman CSA Confidence rating of 6-9)	2015	16	

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 6.0.3

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
	echo length	0.7 – 1.3
	Max phase deviation	0.30
	Max gain compensation	3 dB (one way)
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

*Echo counting based on single echo detections was used to generate density estimates based on low densities and high single echo detection probability.

Appendix 9. Habitat areas for kokanee surveys with survey dates.

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	03-Oct	430.0	194	94	289
2005	21-Oct	430.3	194	93	287
2006	19-Oct	430.5	194	93	287
2007	17-Oct	432.8	196	96	292
2008	28-Sep	437.5	199	100	299
2009	Oct 14-17	433.2	196	96	292
2010	Oct 4-7	434.5	197	96	293
2011	Sept 25-28	436.8	199	99	298
2012	Oct 11-13	434.3	197	96	293
2013	Oct 1-4	432.0	195	95	290
2014	Oct 19-26	432.5	195	95	290
2015	Oct 7-19	428.6	193	91	284
2016	Oct 1-4	427.8	193	91	284

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

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 2016 acoustic surveys. Basin averages do not include transects 19 and 20 in the Narrows.

Transect Number	**All ages**	**Age 0**	**Age 1–3**
1	337	275	62
2	398	340	58
3	411	352	60
4	505	425	81
5	389	305	84
6	529	329	200
7	231	171	60
8	309	226	83
9	497	357	140
10	236	204	33
11	286	260	26
12	337	305	31
13	571	436	135
14	394	297	97
15	964	871	92
16	586	457	129
17	534	387	147
18	818	695	122
19	*1836*	*1301*	*535*
20	*1750*	*1467*	*283*
Upper Ave	384	298	86
Lower Ave	525	435	90

Appendix 11. Total transect fish density (number/ha) 2003 to 2016.

Transect	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Upper Arrow														
1	300	160	160	301	498	379	217	361	241	145	268	388	335	337
2	480	566	285	359	275		286	718	671	489	259	360	765	398
3	330	260	142	274	115		220	426	908	375	160	369	585	411
4	184	253	77	275	206	362	147	332	425	186	171	182	281	505
5	214	180	139	224	78		166	282	195	181	112	229	366	389
6	561	217	348	218	162	192	125	550	401	117	55	171	144	529
7	574	304	185	255	168		133	655	315	110	92	196	234	231
8	629	359	149	337	104	253	634	512	708	158	80	147	137	309
9	439	304	210	367	223		554	351	429	162	131	221	282	497
10	284	240	254	318	324	310	382	271	229	168	81	237	179	236
Narrows														
20	898	564	497	672	872	618	1164	979	138	556	1161	813	990	1836
19	613	664	422	1668	429	1004	1433	2064	424	770	735	1114	911	1750
Lower Arrow														
18	540	624	249	638	227	622	855	2188	198	398	651	731	1646	818
11	391	490	357	363	323	387		795	334	358	397	818	679	286
12	173	238	92	255	75	216	356	569	119	121	155	364	1183	337
13	302	162	197	294	161		371	344	121	179	231	339	504	571
14	729	368	234	296	344	138	248	314	118	196	186	293	432	394
15	500	331	255	528	196	227	245	278	373	405	247	514	303	964
16	844	266	285	480	222	193	398	420	452	294	225	528	653	586
17	938	693	231	269	241	149	379	438	249	311	274	335	648	534
Upper	400	284	195	293	215	299	286	446	452	209	141	250	331	384
Lower	552	397	238	390	224	276	407	668	246	283	296	490	756	561

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. Density statistics and abundance estimates with 95% CI 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 2016

a) Statistics for 2016 kokanee of all ages Upper Arrow (-61 to -24 dB; Zone 1 - Transects 1–10) and Lower Arrow (-61 to -24 dB; Zone 2 - Transects 11–18).

Zone	Depth	N	Mean	SE	Area	StratumPop	CV	Statistic	Abundance
1	3-5	10	3.9	2.1	20,570	80,744	0.3	LB=	5,949,414
1	5-10	10	17.3	8.6	20,192	349,020	0.3	MLE=	7,327,608
1	10-15	10	39.8	12.6	19,803	787,759	0.3	UB=	8,690,039
1	15-20	10	51.4	10	19,487	1,001,116	0.3		
1	20-25	10	87.2	19.4	19,171	1,672,253	0.3		
1	25-30	10	98.1	17.5	18,855	1,850,147	0.3		
1	30-35	10	51.6	16.4	18,539	956,372	0.3		
1	35-40	10	21.0	6	18,223	382,262	0.3		
1	40-45	10	8.0	2.5	17,794	143,072	0.3		
1	45-50	10	6.0	2.2	17,336	103,902	0.3		
2	3-5	8	8.5	3.2	10,274	87,145	0.4	LB=	3,687,576
2	5-10	8	4.6	2.3	9,827	45,443	0.4	MLE=	4,464,038
2	10-15	8	4.1	1.1	9,394	38,922	0.4	UB=	5,250,610
2	15-20	8	41.4	23.3	8,961	370,935	0.4		
2	20-25	8	115.5	24.4	8,528	985,202	0.4		
2	25-30	8	137.4	19.7	8,095	1,112,523	0.4		
2	30-35	8	117.3	17.4	7,662	898,336	0.4		
2	35-40	8	64.7	15.2	7,320	473,415	0.4		
2	40-45	8	40.6	14.8	7,001	284,552	0.4		
2	45-50	8	16.0	9.2	6,682	106,927	0.4		
2	55-60	8	8.9	5.6	6,364	56,524	0.4		
2	60-65	8	1.2	1	6,045	6,953	0.4		

Appendix 12 – continued

b) Statistics for 2016 age 0 kokanee in for Upper Arrow (-61 to -45 dB; Zone 1 - Transects 1–10) and for Lower Arrow (-61 to -44 dB; Zone 2 - Transects 11–18).

Zone	Depth	N	Mean	SE	Area	StratumPop	CV	Statistic	Abundance
1	3-5	10	3.9	2.1	20,570	80,744	0.3	LB=	4,727,747
1	5-10	10	16.8	8.4	20,192	339,840	0.3	MLE=	5,705,892
1	10-15	10	35.5	9.8	19,803	703,235	0.3	UB=	6,673,604
1	15-20	10	43.2	7.9	19,487	842,211	0.3		
1	20-25	10	62.6	12.9	19,171	1,201,027	0.3		
1	25-30	10	70.7	11.5	18,855	1,332,251	0.3		
1	30-35	10	36.5	9.6	18,539	676,487	0.3		
1	35-40	10	17.2	4.5	18,223	312,939	0.3		
1	40-45	10	6.7	1.9	17,794	119,486	0.3		
1	45-50	10	5.2	1.9	17,336	89,371	0.3		
2	3-5	8	8.5	3.2	10,274	87,145	0.4	LB=	3,028,845
2	5-10	8	4.6	2.3	9,827	45,443	0.4	MLE=	3,711,254
2	10-15	8	4.1	1.1	9,394	38,922	0.4	UB=	4,400,537
2	15-20	8	39	22.2	8,961	349,741	0.4		
2	20-25	8	98.2	21.3	8,528	837,190	0.4		
2	25-30	8	113.9	17.6	8,095	922,117	0.4		
2	30-35	8	91.3	15.1	7,662	699,270	0.4		
2	35-40	8	48.9	11.1	7,320	357,714	0.4		
2	40-45	8	33.3	11.5	7,001	233,430	0.4		
2	45-50	8	13.2	7.4	6,682	88,186	0.4		
2	55-60	8	6.8	4	6,364	43,111	0.4		
2	60-65	8	1.1	0.9	6,045	6,379	0.4		

c) Statistics for 2016 age 1–3 kokanee Upper Arrow (>-45 dB; Zone 1 - Transects 1–10) and Lower Arrow (>-44 dB; Zone 2 - Transects 11–18).

Zone	Depth	N	Mean	SE	Area	StratumPop	CV	Statistic	Abundance
1	5-10	10	0.5	0.5	20,192	9,179	0.5	LB=	1,107,283
1	10-15	10	4.3	2.9	19,803	84,524	0.5	MLE=	1,613,218
1	15-20	10	8.2	3.2	19,487	158,905	0.5	UB=	2,108,401
1	20-25	10	24.6	8.1	19,171	471,226	0.5		
1	25-30	10	27.5	7.1	18,855	517,895	0.5		
1	30-35	10	15.1	6.8	18,539	279,885	0.5		
1	35-40	10	3.8	1.5	18,223	69,323	0.5		
1	40-45	10	1.3	0.6	17,794	23,586	0.5		
2	20-25	8	2.4	1.2	8,961	21,194	0.4	LB=	579,248
2	25-30	8	17.4	5.6	8,528	148,013	0.4	MLE=	757,741
2	30-35	8	23.5	5.9	8,095	190,406	0.4	UB=	935,930
2	35-40	8	26.0	5.1	7,662	199,066	0.4		
2	40-45	8	15.8	4.6	7,320	115,701	0.4		
2	45-50	8	7.3	3.6	7,001	51,122	0.4		
2	50-55	8	2.8	1.9	6,682	18,741	0.4		
2	55-60	8	2.1	1.6	6,364	13,413	0.4		

Appendix 13. 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 1993–2016. *Note: no trawling occurred in 2007, so age structure and mean weights were derived by averaging the values for 2006 and 2008.*

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	358,647	110,353	-	2.3	34	83		19,739	0.16	0.62	0.47	0.00	1.25
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	1.18
1998	1,316,000	248,000	496,000	-	2.3	62	137		19,929	0.15	0.78	3.42	0.00	4.35
1999	2,450,000	302,000	1,208,000	-	3.4		184		19,803	0.42	0.00	11.24	0.00	11.67
2000	6,410,000	884,615	265,385	-	3.3	67	120		19,803	1.08	3.01	1.61	0.00	5.71
2001	10,190,000	2,502,632	667,368	-	2.2	38	94		19,171	1.14	5.00	3.28	0.00	9.43
2002	8,760,000	2,769,437	888,310	52,254	1.7	23	61		19,613	0.75	3.26	2.74	0.00	6.76
2003	4,220,100	2,711,818	701,882	-	1.8	28	54		19,676	0.39	3.84	1.91	0.00	6.15
2004	3,214,200	362,535	1,027,183	40,282	2.4	22	55	57	19,487	0.39	0.41	2.90	0.12	3.82
2005	2,267,200	497,300	430,993	66,307	2.2	39	66	73	19,424	0.26	1.01	1.46	0.25	2.98
2006	4,394,300	1,577,455	350,545	-	2.4	40	123		19,424	0.54	3.27	2.22	0.00	6.03
2007	3,207,100	*513,707*	*82,193*	*-*	*2.2*	*39*	*103*	*0*	19,613	*0.35*	*1.03*	*0.43*	*0.00*	*1.82*
2008	4,609,010	1,099,200	137,400	-	2.0	39	83		19,929	0.45	2.12	0.58	0.00	3.15
2009	3,440,643	796,000	1,194,000	-	2.1	35	91		19,613	0.36	1.40	5.55	0.00	7.31
2010	6,882,369	599,799	1,099,632	49,983	2.0	27	72	80	19,676	0.72	0.83	4.05	0.20	5.80
2011	6,643,880	2,020,636	209,689	19,063	1.2	22	60	71	19,866	0.40	2.20	0.63	0.07	3.30
2012	3,608,011	429,604	159,112	-	1.7	25	54		19,676	0.31	0.55	0.43	0.00	1.29
2013	2,112,840	273,119	273,119	-	2.5	30	153		19,550	0.27	0.42	2.13	0.00	2.82
2014	4,098,416	386,758	257,838	-	2.7	57	110		19,550	0.57	1.13	1.45	0.00	3.15
2015	5,831,659	506,480	66,642	-	3.7	31	83		19,297	1.10	0.82	0.29	0.00	2.21
2016	5,705,892	1,263,499	349,719	-	2.7	58	93		19,297	0.80	3.77	1.69	0.00	6.26
Pre-fert	1,410,833	249,536	242,774	3,857	2	35	88	118	19,739	0.17	0.45	1.22	0.02	1.87
Fert era (all yrs)	4,891,423	1,083,144	520,501	12,660	2	37	92	56	19,582	0.57	1.89	2.48	0.04	4.98
Fert era (03-16)	4,302,544	931,279	452,853	12,545	2.3	35	86	56	19,577	0.49	1.63	1.84	0.05	4.01

b) Lower 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	1,435,000	307,136	247,864	-	3.3	32	107	118	9,827	0.48	1.00	2.71	0.00	4.19
1994	1,662,000	258,523	166,604	2,872	2.3	30	86		9,480	0.40	0.83	1.51	0.00	2.73
1995	1,222,000	162,591	275,409	-	2.3	34	83		9,740	0.28	0.57	2.36	0.00	3.22
1996	920,000	252,778	447,222	-	1.7	19	55		9,567	0.16	0.51	2.58	0.00	3.25
1997	753,000	125,803	233,197	-	2.2	31	59		9,827	0.17	0.39	1.39	0.00	1.95
1998	1,360,000	385,882	434,118	-	2.3	62	137		10,000	0.31	2.41	5.96	0.00	8.68
1999	1,418,000	200,556	521,444	-	3.4		184		9,827	0.50	0.00	9.78	0.00	10.28
2000	3,275,000	518,636	259,318	37,045	3.3	67	120		9,827	1.12	3.56	3.18	0.00	7.85
2001	5,210,000	685,607	575,421	48,972	2.2	38	94		8,961	1.25	2.93	6.05	0.00	10.24
2002	4,800,000	1,628,173	1,241,827	-	1.7	23	61		9,567	0.84	3.93	7.86	0.00	12.64
2003	1,834,700	1,150,773	776,103	53,524	1.8	28	54		9,653	0.35	3.32	4.32	0.00	7.99
2004	1,555,700	494,577	748,931	42,392	2.4	22	55	57	9,394	0.39	1.17	4.38	0.26	6.20
2005	1,206,600	148,667	237,867	104,067	2.2	39	66	73	9,307	0.28	0.63	1.68	0.82	3.41
2006	1,595,600	584,588	206,325	34,388	2.4	40	123		9,307	0.41	2.53	2.73	0.00	5.66
2007	1,136,500	*236,467*	*323,587*	*12,446*	*2.2*	*39*	*103*	*0*	9,567	*0.26*	*0.97*	*3.49*	*0.00*	*4.72*
2008	1,833,890	65,123	651,225	-	2.0	39	83		10,000	0.36	0.25	5.43	0.00	6.05
2009	2,601,425	447,692	522,308	-	2.1	35	91		9,567	0.56	1.62	4.97	0.00	7.15
2010	4,871,913	504,850	413,059	229,477	2.0	27	72	80	9,653	1.03	1.43	3.10	1.91	7.47
2011	1,255,412	410,258	569,803	45,584	1.2	22	60	71	9,913	0.15	0.89	3.44	0.32	4.81
2012	2,058,505	133,436	133,436	320,247	1.7	25	54		9,653	0.36	0.35	0.74	0.00	1.45
2013	2,039,040	332,968	144,769	28,954	2.5	30	153		9,480	0.55	1.05	2.33	0.00	3.93
2014	3,585,520	369,630	165,154	-	2.7	57	110		9,480	1.03	2.22	1.91	0.00	5.17
2015	5,237,535	570,843	107,338	9,758	3.7	31	83		9,134	2.09	1.96	0.97	0.00	5.02
2016	3,711,254	434,840	322,901	-	2.7	58	93		9,134	1.10	2.74	3.30	0.00	7.14
Pre-fert	1,225,333	248,786	300,736	479	2	35	88	118	9,740	0.30	0.95	2.75	0.00	4.00
Fert era (all yrs)	2,734,811	495,427	440,045	53,714	2	37	92	56	9,524	0.70	1.75	3.87	0.18	6.51
Fert era (03-16)	2,465,971	420,337	380,200	62,917	2.3	35	86	56	9,517	0.64	1.51	3.06	0.24	5.44

Appendix 14. Estimation of egg deposition for 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)			
	Upper Arrow				Lower Arrow	Combined Basins	Hill Creek Spawning Channel					Upper Arrow		Lower Arrow	Combined Basins
	HC + index	Index	Hill Creek Total	Hill Creek SC	Index	All	Length	Fecund	Retention	Net Fec	%Female	Index	Hill Creek SC	Index	All [1]
1988	409,862	111,750	298,112	150,000	271,500	681,362	204	184		184	50%	10.3	13.8	25.0	49.1
1989	429,187	105,750	323,437	150,000	181,500	610,687	213	207		207	50%	10.9	15.7	18.7	45.4
1990	325,689	48,450	277,239	180,000	260,250	585,939	213	170	32	138	50%	3.3	12.4	18.0	33.7
1991	285,993	50,550	235,443	75,000	291,750	577,743	218	219	13	206	49%	5.1	7.6	29.4	42.1
1992	261,971	20,100	241,871	75,000	86,250	348,221	223	263	33	230	50%	2.3	8.6	9.9	20.9
1993			273,679	75,000			241	248	31	217	52%		8.5		
1994			174,224	75,000			240	302	51	251	51%		9.4		
1995	84,839	11,385	73,454	16,328	147,953	232,792	235	274	1	273	51%	1.6	2.2	20.6	24.4
1996	34,172	5,100	29,072	25,030	161,175	195,347	207	172	8	164	52%	0.4	2.2	13.7	16.3
1997	63,959	4,982	58,977	22,566	24,636	88,595	209	182	6	176	50%	0.4	2.0	2.2	4.6
1998	48,162	5,622	42,540	19,087	184,920	233,082	250	226	12	214	44%	0.5	1.8	17.4	19.7
1999	120,964	20,025	100,939	78,024	233,925	354,889	297	424	36	388	41%	3.2	12.4	37.2	52.8
2000	166,636	24,533	142,103	102,400	248,538	415,174	302	469	2	467	47%	5.4	22.4	54.6	82.3
2001	183,934	46,838	137,096	122,400	405,027	588,961	259	379	7	372	41%	7.1	18.8	61.8	87.7
2002	245,008	49,946	195,062	151,826	340,466	585,473	213	212	5	207	39%	4.0	12.3	27.5	43.8
2003			155,279	133,951			214	233	9	224	48%		14.4		
2004	422,855	136,665	286,190	199,820	450,323	873,178	206	189	4	185	35%	8.8	9.5	29.2	47.5
2005	244,475	34,670	209,805	142,755	313,442	557,916	212	214	5	209	48%	3.5	13.0	31.4	47.9
2006	140,384	17,937	122,447	91,649	138,138	278,522	259	240	8	232	48%	2.0	10.6	15.4	28.0
2007	122,663	9,092	113,571	97,731	95,852	218,514	247	236	4	232	46%	1.0	10.0	10.2	21.2
2008	86,345	4,292	82,053	72,068	97,050	183,395	228	236	4	232	38%	0.4	6.4	8.6	15.3
2009	305,394	18,795	286,599	241,508	145,847	451,241	241	258	7	251	50%	2.4	30.1	18.3	50.7
2010	345,171	27,617	317,554	267,243	156,147	501,318	243	272	5	267	43%	3.2	30.3	17.9	51.4
2011	201,268	14,701	186,567	155,405	48,797	250,065	225	267	5	262	44%	1.7	17.8	5.6	25.1
2012	30,637	760	29,877	24,342	44,890	75,527	218	255	4	251	47%	0.1	2.8	5.3	8.2
2013	91,024	5,263	85,761	43,521	129,236	220,260	288	252	3	249	54%	0.7	5.9	17.4	23.9
2014	117,308	17,932	99,376	33,812	110,348	227,656	305	438	5	433	41%	3.2	6.0	19.7	28.9
2015	93,298	4,043	89,255	42,568	117,329	210,627	251	314	5	309	42%	0.5	5.4	15.2	21.1
2016	80,461	8,723	71,738	41,344	103,929	184,390	238	283	4	279	47%	1.1	4.5	13.6	19.3
Average (All)	**190,064**	**30,981**	**163,425**	**100,185**	**184,201**	**374,264**	**238**	**263**	**11**	**252**	**46%**	**3.2**	**10.9**	**20.9**	**35.1**
SD	125,276	35,778	94,007	67,517	110,654	206,948	29	77	13	77	5%	3.1	7.5	13.9	20.5
2xSE	49,137	14,033	34,913	25,075	43,402	81,172	11	29	5	29	2%	1.2	2.8	5.4	8.0
Average (10 yr)	**147,357**	**11,122**	**136,235**	**101,954**	**104,942**	**252,299**	**248**	**281**	**5**	**277**	**45%**	**1.4**	**11.9**	**13.2**	**26.5**
SD	103,517	8,423	96,064	89,347	36,473	127,677	28	60	1	60	5%	1.1	10.5	5.4	14.1
2xSE	65,470	5,327	60,756	56,508	23,067	80,750	17	38	1	38	3%	0.7	6.6	3.4	8.9
Average (5 yr)	**82,546**	**7,344**	**75,201**	**37,117**	**101,146**	**183,692**	**260**	**308**	**4**	**304**	**46%**	**1.1**	**4.9**	**14.2**	**20.3**
SD	31,995	6,569	27,202	8,104	32,818	62,641	36	77	1	76	5%	1.2	1.3	5.5	7.7
2xSE	28,617	5,875	24,330	7,249	29,353	56,028	32	69	1	68	5%	1.1	1.2	4.9	6.9

[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

Appendix 15. Arrow Lakes Reservoir secchi depth results - 2016. Basin: U=Upper, N=Narrows, L=Lower and S=Syringa.

Station	Basin	Month	Date	Secchi (m)	Station	Basin	Month	Date	Secchi (m)
AR1	U	Apr	2016-04-18	7.3	AR6	L	Apr	2016-04-20	2.4
AR1	U	May	2016-05-16	3.7	AR6	L	May	2016-05-18	3.4
AR1	U	Jun	2016-06-13	3.1	AR6	L	Jun	2016-06-15	5.8
AR1	U	Jun_2	2016-06-27	3.1	AR6	L	Jun_2	2016-06-27	6.4
AR1	U	Jul	2016-07-11	4.0	AR6	L	Jul	2016-07-13	6.1
AR1	U	Aug	2016-08-08	4.0	AR6	L	Aug	2016-08-10	6.4
AR1	U	Sep	2016-09-05	3.7	AR6	L	Sep	2016-09-07	6.4
AR1	U	Oct	2016-10-11	6.4	AR6	L	Oct	2016-10-05	7.3
AR1	U	Nov	2016-10-31	7.9	AR6	L	Nov	2016-11-01	8.8
AR2	U	Apr	2016-04-18	11.6	AR7	L	Apr	2016-04-20	5.8
AR2	U	May	2016-05-16	3.4	AR7	L	May	2016-05-18	3.4
AR2	U	Jun	2016-06-13	3.7	AR7	L	Jun	2016-06-15	5.5
AR2	U	Jun_2	2016-06-27	4.0	AR7	L	Jun_2	2016-06-27	7.0
AR2	U	Jul	2016-07-11	4.6	AR7	L	Jul	2016-07-13	7.6
AR2	U	Aug	2016-08-08	4.6	AR7	L	Aug	2016-08-10	7.3
AR2	U	Sep	2016-09-05	4.9	AR7	L	Sep	2016-09-07	7.9
AR2	U	Oct	2016-10-11	6.1	AR7	L	Oct	2016-10-05	7.3
AR2	U	Nov	2016-10-31	7.6	AR7	L	Nov	2016-11-01	8.8
AR3	U	Apr	2016-04-18	7.9	AR8	L	Apr	2016-04-20	7.0
AR3	U	May	2016-05-16	4.9	AR8	L	May	2016-05-18	5.8
AR3	U	Jun	2016-06-13	6.4	AR8	L	Jun	2016-06-15	6.7
AR3	U	Jun_2	2016-06-27	5.2	AR8	L	Jun_2	2016-06-27	7.0
AR3	U	Jul	2016-07-11	4.6	AR8	L	Jul	2016-07-13	7.0
AR3	U	Jul_2	2016-07-25	4.6	AR8	L	Jul_2	2016-07-26	7.9
AR3	U	Aug	2016-08-08	5.5	AR8	L	Aug	2016-08-10	8.2
AR3	U	Aug_2	2016-08-23	5.5	AR8	L	Aug_2	2016-08-23	7.3
AR3	U	Sep	2016-09-05	6.1	AR8	L	Sep	2016-09-07	8.2
AR3	U	Oct	2016-10-11	6.4	AR8	L	Oct	2016-10-05	8.8
AR3	U	Nov	2016-10-31	8.8	AR8	L	Nov	2016-11-01	8.5
AR4	N	Apr	2016-04-18	9.1	HL4	S	Apr	2016-04-20	6.1
AR4	N	May	2016-05-16	4.9	HL4	S	May	2016-05-18	5.5
AR4	N	Jun	2016-06-13	7.9	HL4	S	Jun	2016-06-15	7.3
AR4	N	Jun_2	2016-06-27	5.5	HL4	S	Jun_2	2016-06-27	7.0
AR4	N	Jul	2016-07-11	4.9	HL4	S	Jul	2016-07-13	7.0
AR4	N	Jul_2	2016-07-25	5.5	HL4	S	Aug	2016-08-10	7.9
AR4	N	Aug	2016-08-08	6.7	HL4	S	Sep	2016-09-07	8.2
AR4	N	Aug_2	2016-08-23	5.8	HL4	S	Oct	2016-10-05	7.9
AR4	N	Sep	2016-09-05	5.8	HL4	S	Nov	2016-11-01	9.8
AR4	N	Oct	2016-10-11	5.5					
AR4	N	Nov	2016-10-31	8.8					
AR5	N	Apr	2016-04-18	9.1					
AR5	N	May	2016-05-16	4.9					
AR5	N	Jun	2016-06-13	7.9					
AR5	N	Jun_2	2016-06-27	5.8					
AR5	N	Jul	2016-07-11	5.5					
AR5	N	Aug	2016-08-08	6.7					
AR5	N	Sep	2016-09-05	6.1					
AR5	N	Oct	2016-10-11	6.7					
AR5	N	Nov	2016-10-31	8.2					

Appendix 16. Upper Arrow Lakes Reservoir water chemistry results - 2016; nitrogen and phosphorus parameters. DepthCat I=Integrated (0-20m), H=Hypolimnion (5m off the bottom). Data not available is noted as: no data. Reportable detection limits (RDL) for each parameter are identified in row 2.

DepthCat	Station	Basin	Depth	Month	Date Sampled	Ammonia, Total (as N)	Nitrate (as N)	Nitrite (as N)	Nitrate and Nitrite (as N)	Total Nitrogen	Dissolved Inorganic Nitrogen	Orthophosphate-Dissolved (as P)	Phosphorus (P)-Total Dissolved	Phosphorus (P)-Total	Nitrogen/ Phosphorus	Nitrite (as N)	Orthophosphate-Dissolved (as P)	Phosphorus (P)-Total Dissolved	Phosphorus (P)-Total
					RDL	**5.0**	**3.0**	**1.0**	**4**	**30**		**1.0**	**2.0**	**2.0**		**<RDL?**	**<RDL?**	**<RDL?**	**<RDL?**
					Units	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**DIN / TDP**	**Y/N**	**Y/N**	**Y/N**	**Y/N**
I	AR1	U	0-20	Apr	18-Apr-2016	5.0	140.0	1.0	141	153	146	1.0	2.0	2.0	73.0	Y	Y	Y	Y
I	AR1	U	0-20	May	16-May-2016	5.0	169.0	1.0	170	211	175	1.0	2.0	4.9	87.5	Y	Y	Y	N
H	AR1	U	220	May	16-May-2016	5.0	146.0	1.0	147	190	152	1.0	2.0	2.0	76.0	Y	Y	Y	Y
I	AR1	U	0-20	Jun	13-Jun-2016	5.0	112.0	1.0	113	184	118	1.0	2.0	5.1	59.0	Y	N	Y	N
H	AR1	U	220	Jun	13-Jun-2016	5.0	149.0	1.0	150	165	155	1.0	2.0	2.0	77.5	Y	Y	Y	Y
I	AR1	U	0-20	Jun_2	27-Jun-2016	5.0	103.0	1.0	104	199	109	1.0	2.0	5.9	54.5	Y	Y	Y	N
I	AR1	U	0-20	Jul	11-Jul-2016	5.0	90.8	1.1	92	203	97	1.0	2.0	4.4	48.5	N	Y	Y	N
H	AR1	U	220	Jul	11-Jul-2016	5.0	151.0	1.0	152	163	157	1.0	2.0	2.0	78.5	Y	Y	Y	Y
I	AR1	U	0-20	Aug	8-Aug-2016	5.0	95.5	1.2	97	144	102	1.0	2.0	4.2	50.9	N	Y	Y	N
H	AR1	U	220	Aug	8-Aug-2016	5.0	151.0	1.1	152	168	157	1.0	2.0	3.5	78.6	N	N	Y	N
I	AR1	U	0-20	Sep	5-Sep-2016	5.0	85.0	1.0	86	134	91	1.0	2.0	2.9	45.5	Y	Y	Y	N
H	AR1	U	220	Sep	5-Sep-2016	5.0	158.0	1.0	159	164	164	1.0	2.0	2.0	82.0	Y	Y	Y	Y
I	AR1	U	0-20	Oct	11-Oct-2016	5.0	128.0	1.0	129	167	134	1.0	2.0	2.0	67.0	Y	Y	Y	Y
H	AR1	U	220	Oct	11-Oct-2016	5.0	153.0	1.0	154	177	159	1.4	2.0	2.0	79.5	Y	N	Y	Y
I	AR1	U	0-20	Nov	31-Oct-2016	5.0	109.0	1.0	110	140	115	1.0	2.0	2.0	57.5	Y	Y	Y	Y
I	AR2	U	0-20	Apr	18-Apr-2016	5.0	137.0	1.0	138	160	143	1.0	2.0	2.0	71.5	Y	Y	Y	Y
I	AR2	U	0-20	May	16-May-2016	5.0	157.0	1.0	158	235	163	1.0	2.0	3.1	81.5	Y	Y	Y	N
H	AR2	U	290	May	16-May-2016	5.0	149.0	1.0	150	162	155	1.0	2.0	3.3	77.5	Y	Y	Y	N
I	AR2	U	0-20	Jun	13-Jun-2016	5.0	118.0	1.0	119	160	124	1.0	2.0	5.9	62.0	Y	Y	Y	N
H	AR2	U	280	Jun	13-Jun-2016	5.0	151.0	1.0	152	161	157	1.2	2.0	2.0	78.5	Y	N	Y	Y

(cont'd)

DepthCat	Station	Basin	Depth	Month	Date Sampled	Ammonia, Total (as N)	Nitrate (as N)	Nitrite (as N)	Nitrate and Nitrite (as N)	Total Nitrogen	Dissolved Inorganic Nitrogen	Orthophosphate-Dissolved (as P)	Phosphorus (P)-Total Dissolved	Phosphorus (P)-Total	Nitrogen/ Phosphorus	Nitrite (as N)	Orthophosphate-Dissolved (as P)	Phosphorus (P)-Total Dissolved	Phosphorus (P)-Total
I	AR2	U	0-20	Jun_2	27-Jun-2016	5.0	111.0	1.0	112	166	117	1.0	4.5	3.4	26.0	Y	Y	N	N
I	AR2	U	0-20	Jul	11-Jul-2016	5.0	91.8	1.0	93	172	98	1.0	2.0	6.6	48.9	N	Y	Y	N
H	AR2	U	290	Jul	11-Jul-2016	5.0	151.0	1.0	152	187	157	1.2	2.0	2.0	78.5	Y	N	Y	Y
I	AR2	U	0-20	Aug	8-Aug-2016	5.0	106.0	1.0	107	173	112	1.0	2.0	3.4	56.0	Y	Y	Y	N
H	AR2	U	280	Aug	8-Aug-2016	5.0	166.0	1.0	167	175	172	1.0	2.0	3.6	86.0	Y	Y	Y	N
I	AR2	U	0-20	Sep	5-Sep-2016	5.0	92.3	1.0	93	129	98	1.0	2.0	2.8	49.2	Y	Y	Y	N
H	AR2	U	280	Sep	5-Sep-2016	5.0	168.0	1.0	169	174	174	1.8	2.8	2.9	62.1	Y	N	N	N
I	AR2	U	0-20	Oct	11-Oct-2016	5.0	99.2	1.0	100	144	105	1.0	2.0	2.0	52.6	Y	Y	Y	Y
H	AR2	U	284	Oct	11-Oct-2016	5.0	187.0	1.0	188	208	193	1.7	2.4	2.0	80.4	Y	N	N	Y
I	AR2	U	0-20	Nov	31-Oct-2016	5.0	104.0	1.0	105	135	110	1.0	2.0	2.0	55.0	Y	Y	Y	Y
I	AR3	U	0-20	Apr	18-Apr-2016	5.0	132.0	1.0	133	154	138	1.0	2.0	2.0	69.0	Y	Y	Y	Y
I	AR3	U	0-20	May	16-May-2016	5.0	135.0	1.0	136	191	141	1.0	2.0	2.2	70.5	Y	Y	Y	N
H	AR3	U	180	May	16-May-2016	5.0	159.0	1.0	160	169	165	1.0	2.0	2.0	82.5	Y	Y	Y	Y
I	AR3	U	0-20	Jun	13-Jun-2016	5.0	117.0	1.0	118	155	123	1.3	2.0	2.1	61.5	Y	N	Y	N
H	AR3	U	170	Jun	13-Jun-2016	5.0	168.0	1.0	169	173	174	1.1	2.0	2.0	87.0	Y	N	Y	Y
I	AR3	U	0-20	Jun_2	27-Jun-2016	5.0	126.0	1.0	127	178	132	1.0	2.0	3.7	66.0	Y	Y	Y	N
I	AR3	U	0-20	Jul	11-Jul-2016	5.0	94.0	1.0	95	201	100	1.0	2.0	2.3	50.0	Y	Y	Y	N
H	AR3	U	190	Jul	11-Jul-2016	5.0	158.0	1.0	159	178	164	1.0	2.0	2.0	82.0	Y	Y	Y	Y
I	AR3	U	0-20	Jul_2	25-Jul-2016	5.0	109.0	1.0	110	123	115	1.0	2.0	2.6	57.5	Y	Y	Y	N
I	AR3	U	0-20	Aug	8-Aug-2016	5.0	96.0	1.0	97	149	102	1.0	2.0	4.1	51.0	Y	Y	Y	N
H	AR3	U	170	Aug	8-Aug-2016	5.0	167.0	1.0	168	181	173	1.0	2.0	3.1	86.5	Y	Y	Y	N
I	AR3	U	0-20	Aug_2	23-Aug-2016	5.0	82.8	1.0	84	123	89	1.0	no data	2.1	no data	Y	Y	no data	N
I	AR3	U	0-20	Sep	5-Sep-2016	5.0	78.7	1.0	80	128	85	1.1	2.2	2.0	38.5	Y	N	N	N
H	AR3	U	180	Sep	5-Sep-2016	5.0	169.0	1.0	170	179	175	1.1	2.3	2.0	76.1	Y	N	N	Y
I	AR3	U	0-20	Oct	11-Oct-2016	5.0	80.4	1.0	81	141	86	1.0	2.0	2.0	43.2	Y	Y	Y	Y
H	AR3	U	178	Oct	11-Oct-2016	5.0	165.0	1.0	166	179	171	1.0	2.0	2.0	85.5	Y	Y	Y	Y
I	AR3	U	0-20	Nov	31-Oct-2016	5.0	86.9	1.0	88	133	93	1.0	2.0	2.0	46.5	Y	Y	Y	Y

Appendix 17. Lower Arrow Lakes Reservoir water chemistry results - 2016; nitrogen and phosphorus parameters. DepthCat I=Integrated (0-20m), H=Hypolimnion (5m off the bottom). Data not available is noted as: no data. Reportable detection limits (RDL) for each parameter are identified in row 2.

DepthCat	Station	Basin	Depth	Month	Date Sampled	Ammonia, Total (as N)	Nitrate (as N)	Nitrite (as N)	Nitrate and Nitrite (as N)	Total Nitrogen	Dissolved Inorganic Nitrogen	Orthophosphate-Dissolved (as P)	Phosphorus (P)-Total Dissolved	Phosphorus (P)-Total	Nitrogen/ Phosphorus	Nitrite (as N)	Orthophosphate-Dissolved (as P)	Phosphorus (P)-Total Dissolved	Phosphorus (P)-Total
					RDL	**5.0**	**3.0**	**1.0**	**4**	**30**		**1.0**	**2.0**	**2.0**		**<RDL?**	**<RDL?**	**<RDL?**	**<RDL?**
					Units	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**DIN/TDP**	**Y/N**	**Y/N**	**Y/N**	**Y/N**
I	AR6	L	0-20	Apr	20-Apr-2016	5.0	105.0	1.0	106	160	111	1.0	2.0	2.0	55.5	Y	Y	Y	Y
I	AR6	L	0-20	May	18-May-2016	5.0	79.3	1.0	80	141	85	1.0	2.1	2.0	40.6	Y	Y	N	Y
H	AR6	L	160	May	18-May-2016	5.0	150.0	1.0	151	178	156	1.0	2.0	2.0	78.0	Y	Y	Y	Y
I	AR6	L	0-20	Jun	15-Jun-2016	5.0	73.4	1.1	75	128	80	1.0	2.7	2.4	29.4	N	Y	N	N
H	AR6	L	160	Jun	15-Jun-2016	5.0	159.0	1.0	160	180	165	1.0	2.0	2.0	82.5	Y	Y	Y	Y
I	AR6	L	0-20	Jun_2	27-Jun-2016	5.0	81.6	1.0	83	167	88	1.0	2.0	4.3	43.8	Y	Y	Y	N
I	AR6	L	0-20	Jul	13-Jul-2016	5.0	72.3	1.0	73	171	78	1.0	2.0	3.4	39.2	Y	Y	Y	N
H	AR6	L	140	Jul	13-Jul-2016	5.0	151.0	1.0	152	174	157	1.0	2.0	2.0	78.5	Y	Y	Y	Y
I	AR6	L	0-20	Aug	10-Aug-2016	5.0	72.8	1.0	74	133	79	1.0	2.0	2.6	39.4	Y	Y	Y	N
H	AR6	L	155	Aug	10-Aug-2016	5.0	166.0	1.0	167	184	172	1.2	2.0	2.0	86.0	Y	N	Y	Y
I	AR6	L	0-20	Sep	7-Sep-2016	6.6	59.9	1.0	61	129	68	1.0	2.0	2.0	33.8	Y	Y	Y	Y
H	AR6	L	150	Sep	7-Sep-2016	5.0	168.0	1.0	169	188	174	1.0	2.0	2.0	87.0	Y	Y	Y	Y
I	AR6	L	0-20	Oct	5-Oct-2016	5.0	69.4	1.0	70	127	75	1.0	2.0	3.3	37.7	Y	Y	Y	N
H	AR6	L	145	Oct	5-Oct-2016	5.0	173.0	1.0	174	178	179	1.3	2.4	2.0	74.6	Y	N	N	Y
I	AR6	L	0-20	Nov	1-Nov-2016	5.0	75.6	1.0	77	148	82	1.0	2.0	2.0	40.8	Y	Y	Y	Y
I	AR7	L	0-20	Apr	20-Apr-2016	5.0	108.0	1.0	109	151	114	1.0	2.0	2.0	57.0	Y	Y	Y	Y
I	AR7	L	0-20	May	18-May-2016	5.0	71.3	1.0	72	150	77	1.0	2.0	2.0	38.7	Y	Y	Y	Y
H	AR7	L	140	May	18-May-2016	5.0	148.0	1.0	149	168	154	1.0	2.0	2.0	77.0	Y	Y	Y	Y
I	AR7	L	0-20	Jun	15-Jun-2016	5.0	72.0	1.0	73	138	78	1.0	2.8	2.0	27.9	Y	Y	N	Y
H	AR7	L	150	Jun	15-Jun-2016	5.0	157.0	1.0	158	196	163	1.0	2.0	no data	81.5	Y	Y	Y	Y
I	AR7	L	0-20	Jun_2	27-Jun-2016	5.0	90.9	1.0	92	137	97	1.0	2.0	3.8	48.5	Y	Y	Y	N

(cont'd)

DepthCat	Station	Basin	Depth	Month	Date Sampled	Ammonia, Total (as N)	Nitrate (as N)	Nitrite (as N)	Nitrate and Nitrite (as N)	Total Nitrogen	Dissolved Inorganic Nitrogen	Orthophosphate-Dissolved (as P)	Phosphorus (P)-Total Dissolved	Phosphorus (P)-Total	Nitrogen/ Phosphorus	Nitrite (as N)	Orthophosphate-Dissolved (as P)	Phosphorus (P)-Total Dissolved	Phosphorus (P)-Total
I	AR7	L	0-20	Jul	13-Jul-2016	5.0	75.6	1.0	77	157	82	1.0	2.0	2.9	40.8	Y	Y	Y	N
H	AR7	L	145	Jul	13-Jul-2016	5.0	154.0	1.0	155	181	160	1.1	2.0	2.0	80.0	Y	N	Y	Y
I	AR7	L	0-20	Aug	10-Aug-2016	5.0	72.5	1.0	74	137	79	1.0	2.0	3.2	39.3	Y	Y	Y	N
H	AR7	L	150	Aug	10-Aug-2016	5.0	173.0	1.0	174	185	179	1.1	2.0	2.1	89.5	Y	N	Y	N
I	AR7	L	0-20	Sep	7-Sep-2016	5.7	54.6	1.0	56	91	61	1.0	2.0	2.4	30.7	Y	Y	Y	N
H	AR7	L	150	Sep	7-Sep-2016	5.0	173.0	1.0	174	203	179	1.0	2.0	2.0	89.5	Y	Y	Y	Y
I	AR7	L	0-20	Oct	5-Oct-2016	5.0	59.1	1.0	60	101	65	1.0	2.0	2.0	32.6	Y	Y	Y	Y
H	AR7	L	150	Oct	5-Oct-2016	5.0	182.0	1.0	183	192	188	1.7	2.0	2.0	94.0	Y	N	Y	Y
I	AR7	L	0-20	Nov	1-Nov-2016	5.0	75.4	1.0	76	111	81	1.0	2.0	2.0	40.7	Y	Y	Y	Y
I	AR8	L	0-20	Apr	20-Apr-2016	5.0	110.0	1.0	111	156	116	1.0	2.0	2.4	58.0	Y	Y	Y	N
I	AR8	L	0-20	May	18-May-2016	5.0	69.1	1.0	70	129	75	1.0	2.8	2.0	26.8	Y	Y	N	Y
H	AR8	L	90	May	18-May-2016	5.0	139.0	1.0	140	174	145	1.0	2.0	2.0	72.5	Y	Y	Y	Y
I	AR8	L	0-20	Jun	15-Jun-2016	5.0	57.5	1.0	59	150	64	1.0	4.4	2.6	14.4	Y	Y	N	N
H	AR8	L	80	Jun	15-Jun-2016	5.0	148.0	1.2	149	186	154	1.0	2.0	2.0	77.1	N	Y	Y	Y
I	AR8	L	0-20	Jun_2	27-Jun-2016	6.9	86.6	1.0	88	164	95	1.0	2.0	3.8	47.3	Y	Y	Y	N
I	AR8	L	0-20	Jul	13-Jul-2016	5.0	71.9	1.0	73	140	78	1.0	2.0	5.0	39.0	Y	Y	Y	N
H	AR8	L	80	Jul	13-Jul-2016	5.0	154.0	1.0	155	189	160	1.0	2.0	2.0	80.0	Y	Y	Y	Y
I	AR8	L	0-20	Jul_2	26-Jul-2016	5.0	65.7	1.0	67	163	72	1.0	2.0	2.2	35.9	Y	Y	Y	N
I	AR8	L	0-20	Aug	10-Aug-2016	5.0	76.3	1.5	78	154	83	1.0	2.0	3.4	41.4	N	Y	Y	N
H	AR8	L	85	Aug	10-Aug-2016	5.0	168.0	1.0	169	179	174	1.0	2.0	2.0	87.0	Y	Y	Y	N
I	AR8	L	0-20	Aug_2	24-Aug-2016	5.0	56.8	1.0	58	109	63	1.0	no data	2.9	no data	Y	Y	no data	N
I	AR8	L	0-20	Sep	7-Sep-2016	5.0	56.5	1.0	58	109	63	1.0	2.0	2.0	31.3	Y	Y	Y	Y
H	AR8	L	80	Sep	7-Sep-2016	5.0	174.0	1.0	175	255	180	1.0	2.0	2.0	90.0	Y	Y	Y	Y
I	AR8	L	0-20	Oct	5-Oct-2016	5.0	64.3	1.0	65	110	70	1.0	2.0	2.0	35.2	Y	Y	Y	Y
H	AR8	L	65	Oct	5-Oct-2016	5.0	171.0	1.0	172	184	177	1.0	2.0	2.0	88.5	Y	Y	Y	Y
I	AR8	L	0-20	Nov	1-Nov-2016	5.0	77.3	1.0	78	104	83	1.0	2.0	2.0	41.7	Y	Y	Y	Y

Appendix 18. Arrow Lakes Reservoir discrete (D) water chemistry results - 2016; nitrogen and phosphorus parameters. Basin U=Upper, L=Lower, Data not available is noted as: no data. Reportable detection limits (RDL) for each parameter are identified in row 2.

DepthCat	Station	Basin	Depth	Month	Date Sampled	Ammonia, Total (as N)	Nitrate (as N)	Nitrite (as N)	Nitrate and Nitrite (as N)	Total Nitrogen	Dissolved Inorganic Nitrogen	Orthophosphate-Dissolved (as P)	Phosphorus (P)-Total Dissolved	Phosphorus (P)-Total	Nitrogen/ Phosphorus	Nitrite (as N)	Orthophosphate-Dissolved (as P)	Phosphorus (P)-Total Dissolved	Phosphorus (P)-Total
					RDL	5	3	1	4	30	9	1	2	2		<RDL?	<RDL?	<RDL?	<RDL?
					Units	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	DIN/TDP	Y/N	Y/N	Y/N	Y/N
D	AR2	U	2	Jun	13-Jun-2016	5.0	102.0	1.0	103.0	180	108	1.0	2.0	4.3	54.0	Y	Y	Y	N
D	AR2	U	5	Jun	13-Jun-2016	5.0	105.0	1.0	106.0	174	111	1.0	2.0	5.1	55.5	Y	Y	Y	N
D	AR2	U	10	Jun	13-Jun-2016	5.0	118.0	1.0	119.0	174	124	1.0	2.0	4.9	62.0	Y	Y	Y	N
D	AR2	U	15	Jun	13-Jun-2016	5.0	131.0	1.0	132.0	185	137	1.0	2.0	5.0	68.5	Y	Y	Y	N
D	AR2	U	20	Jun	13-Jun-2016	5.0	159.0	1.0	160.0	192	165	1.0	2.0	2.8	82.5	Y	Y	Y	N
D	AR2	U	2	Jul	11-Jul-2016	5.0	46.6	1.0	47.6	148	53	1.0	2.0	3.2	26.3	Y	Y	Y	N
D	AR2	U	5	Jul	11-Jul-2016	5.0	46.3	1.0	47.3	136	52	1.0	2.0	4.7	26.2	Y	Y	Y	N
D	AR2	U	10	Jul	11-Jul-2016	5.0	97.3	1.0	98.3	173	103	1.0	2.0	3.8	51.7	Y	Y	Y	N
D	AR2	U	15	Jul	11-Jul-2016	5.0	134.0	1.0	135.0	182	140	1.0	2.0	2.8	70.0	Y	Y	Y	N
D	AR2	U	20	Jul	11-Jul-2016	6.5	143.0	1.7	144.7	212	151	1.0	2.0	2.4	75.6	N	Y	Y	N
D	AR2	U	2	Aug	8-Aug-2016	5.0	76.9	1.0	78	168	83	1.0	2.0	2.0	41.5	Y	Y	Y	Y
D	AR2	U	5	Aug	8-Aug-2016	5.0	75.5	1.0	77	135	82	1.0	2.0	2.0	40.8	Y	Y	Y	Y
D	AR2	U	10	Aug	8-Aug-2016	5.0	103.0	1.0	104	149	109	1.0	2.0	2.0	54.5	Y	Y	Y	Y
D	AR2	U	15	Aug	8-Aug-2016	5.0	127.0	1.9	129	160	134	1.0	2.0	2.0	67.0	N	Y	Y	Y
D	AR2	U	20	Aug	8-Aug-2016	5.0	159.0	1.8	161	182	166	1.0	2.0	2.0	82.9	N	Y	Y	Y
D	AR2	U	2	Sep	5-Sep-2016	5.0	62.1	1.0	63	118	68	1.0	2.0	2.0	34.1	Y	Y	Y	Y
D	AR2	U	5	Sep	5-Sep-2016	5.0	69.7	1.1	71	115	76	1.0	2.0	2.6	37.9	N	Y	Y	N
D	AR2	U	10	Sep	5-Sep-2016	5.0	84.7	1.2	86	124	91	1.0	2.0	2.0	45.5	N	Y	Y	Y
D	AR2	U	15	Sep	5-Sep-2016	5.0	98.0	1.0	99	124	104	1.0	2.0	2.4	52.0	Y	Y	Y	N
D	AR2	U	20	Sep	5-Sep-2016	5.0	125.0	1.0	126	146	131	1.0	2.0	2.4	65.5	Y	N	Y	N
D	AR7	L	2	Jul	13-Jul-2016	5.0	66.8	1.0	68	131	73	1.0	2.0	2.0	36.4	Y	Y	Y	Y
D	AR7	L	5	Jul	13-Jul-2016	5.0	67.3	1.0	68	129	73	1.0	2.0	2.0	36.7	Y	Y	Y	Y
D	AR7	L	10	Jul	13-Jul-2016	5.0	69.5	1.0	71	129	76	1.1	2.0	3.2	37.8	Y	N	Y	N
D	AR7	L	15	Jul	13-Jul-2016	5.0	79.5	1.0	81	165	86	1.0	2.0	4.6	42.8	Y	Y	Y	N
D	AR7	L	20	Jul	13-Jul-2016	5.0	100.0	1.0	101	157	106	1.0	2.0	2.0	53.0	Y	N	Y	Y
D	AR7	L	2	Aug	10-Aug-2016	5.0	63.5	2.4	66	113	71	1.0	2.0	2.0	35.5	N	Y	Y	Y
D	AR7	L	5	Aug	10-Aug-2016	5.0	66.6	1.0	68	120	73	1.0	2.0	2.0	36.3	Y	Y	Y	Y

(cont'd)

DepthCat	Station	Basin	Depth	Month	Date Sampled	Ammonia, Total (as N)	Nitrate (as N)	Nitrite (as N)	Nitrate and Nitrite (as N)	Total Nitrogen	Dissolved Inorganic Nitrogen	Orthophosphate-Dissolved (as P)	Phosphorus (P)-Total Dissolved	Phosphorus (P)-Total	Nitrogen/ Phosphorus	Nitrite (as N)	Orthophosphate-Dissolved (as P)	Phosphorus (P)-Total Dissolved	Phosphorus (P)-Total
D	AR7	L	10	Aug	10-Aug-2016	5.0	70.0	1.0	71	463	76	1.0	2.0	2.0	38.0	Y	Y	Y	Y
D	AR7	L	15	Aug	10-Aug-2016	5.0	77.4	1.0	78	127	83	1.0	2.0	2.0	41.7	Y	Y	Y	Y
D	AR7	L	20	Aug	10-Aug-2016	6.4	85.9	1.0	87	123	93	1.0	2.0	2.0	46.7	Y	Y	Y	Y
D	AR7	L	2	Sep	7-Sep-2016	5.0	50.9	1.0	52	108	57	1.0	2.0	2.0	28.5	Y	Y	Y	Y
D	AR7	L	5	Sep	7-Sep-2016	5.0	51.4	1.0	52	110	57	1.0	2.0	2.0	28.7	Y	Y	Y	Y
D	AR7	L	10	Sep	7-Sep-2016	5.8	53.6	1.0	55	110	60	1.0	2.0	2.4	30.2	Y	Y	Y	N
D	AR7	L	15	Sep	7-Sep-2016	6.2	56.2	1.0	57	105	63	1.0	2.0	2.3	31.7	Y	Y	Y	N
D	AR7	L	20	Sep	7-Sep-2016	9.2	82.4	2.0	84	131	94	1.0	2.0	2.0	46.8	N	Y	Y	Y

Appendix 19. Upper Arrow Lakes Reservoir water chemistry results - 2016; other parameters. DepthCat I=Integrated (0-20m), H=Hypolimnion (5m off the bottom). Data not available is noted as: no data. Reportable detection limits (RDL) for each parameter are identified in row 2.

DepthCat	Station	Basin	Depth	Month	Date Sampled	pH	Turbidity	Alkalinity, Total (as CaCO3)	Silicate (as SiO2)	Total Inorganic Carbon	Total Organic Carbon
					RDL	**0.1**	**0.1**	**1**	**0.5**	**0.5**	**0.5**
					Units	**pH**	**NTU**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
I	AR1	U	0-20	Apr	18-Apr-2016	7.89	0.4	60.8	3.75	13.8	1.0
I	AR1	U	0-20	May	16-May-2016	7.91	1.3	56.3	3.68	13.6	1.1
H	AR1	U	220	May	16-May-2016	7.88	0.3	60.3	3.44	14.1	0.8
I	AR1	U	0-20	Jun	13-Jun-2016	8.02	2.2	52.1	3.28	11.9	1.1
H	AR1	U	220	Jun	13-Jun-2016	7.92	0.3	59.7	3.61	14.4	0.8
I	AR1	U	0-20	Jun_2	27-Jun-2016	8.07	0.8	49.8	3.27	11.8	1.4
I	AR1	U	0-20	Jul	11-Jul-2016	7.92	1.1	48.7	3.22	11.1	1.4
H	AR1	U	220	Jul	11-Jul-2016	7.95	0.2	62.0	3.70	14.8	0.9
I	AR1	U	0-20	Aug	8-Aug-2016	7.79	1.2	45.0	3.05	10.6	0.9
H	AR1	U	220	Aug	8-Aug-2016	7.82	0.2	61.9	3.58	14.4	0.8
I	AR1	U	0-20	Sep	5-Sep-2016	7.95	1.0	54.7	2.72	12.4	1.0
H	AR1	U	220	Sep	5-Sep-2016	8.00	0.3	67.1	3.79	14.9	0.8
I	AR1	U	0-20	Oct	11-Oct-2016	7.91	0.6	57.2	3.48	13.3	1.7
H	AR1	U	220	Oct	11-Oct-2016	7.94	0.3	63.8	3.81	14.5	1.5
I	AR1	U	0-20	Nov	31-Oct-2016	7.96	0.6	57.3	3.32	13.0	1.0
I	AR2	U	0-20	Apr	18-Apr-2016	7.93	0.3	58.4	3.94	13.6	0.9
I	AR2	U	0-20	May	16-May-2016	7.88	1.1	55.2	3.54	12.9	1.2
H	AR2	U	290	May	16-May-2016	7.82	0.3	60.5	3.54	14.8	0.7
I	AR2	U	0-20	Jun	13-Jun-2016	7.98	2.0	51.1	3.46	12.1	1.3
H	AR2	U	280	Jun	13-Jun-2016	7.89	0.4	59.9	3.63	14.3	0.8
I	AR2	U	0-20	Jun_2	27-Jun-2016	8.02	0.7	50.5	3.58	11.9	1.1
I	AR2	U	0-20	Jul	11-Jul-2016	7.93	0.8	48.4	3.23	11.7	1.2
H	AR2	U	290	Jul	11-Jul-2016	7.93	0.3	62.8	3.75	15.0	1.0
I	AR2	U	0-20	Aug	8-Aug-2016	7.79	0.7	47.3	3.20	14.8	1.1
H	AR2	U	280	Aug	8-Aug-2016	7.78	0.4	60.3	3.71	11.0	0.8
I	AR2	U	0-20	Sep	5-Sep-2016	8.00	0.8	54.0	3.02	12.3	1.1
H	AR2	U	280	Sep	5-Sep-2016	8.00	0.4	67.1	3.99	15.0	0.8
I	AR2	U	0-20	Oct	11-Oct-2016	7.93	0.6	54.9	3.28	12.6	1.5
H	AR2	U	284	Oct	11-Oct-2016	7.88	0.5	65.7	4.25	15.0	1.4
I	AR2	U	0-20	Nov	31-Oct-2016	7.98	0.5	56.2	3.37	12.8	1.2
I	AR3	U	0-20	Apr	18-Apr-2016	7.96	0.3	58.2	3.83	11.9	1.0

(cont'd)

DepthCat	Station	Basin	Depth	Month	Date Sampled	pH	Turbidity	Alkalinity, Total (as CaCO3)	Silicate (as SiO2)	Total Inorganic Carbon	Total Organic Carbon
I	AR3	U	0-20	May	16-May-2016	7.93	0.6	53.4	3.80	15.3	1.4
H	AR3	U	180	May	16-May-2016	7.80	0.3	60.5	3.59	16.3	0.7
I	AR3	U	0-20	Jun	13-Jun-2016	7.96	0.6	49.9	3.61	11.8	1.0
H	AR3	U	170	Jun	13-Jun-2016	7.88	0.6	59.5	4.04	14.7	0.8
I	AR3	U	0-20	Jun_2	27-Jun-2016	7.96	0.5	51.1	3.57	12.4	1.1
I	AR3	U	0-20	Jul	11-Jul-2016	7.94	0.7	49.0	3.34	11.9	1.4
H	AR3	U	190	Jul	11-Jul-2016	7.94	0.2	60.4	3.77	14.8	1.1
I	AR3	U	0-20	Jul_2	25-Jul-2016	not req	not req	not req	not req	not req	not req
I	AR3	U	0-20	Aug	8-Aug-2016	7.79	0.7	47.3	3.03	10.9	1.0
H	AR3	U	170	Aug	8-Aug-2016	7.81	0.2	61.9	3.67	14.3	0.8
I	AR3	U	0-20	Aug_2	23-Aug-2016	not req	not req	not req	not req	not req	not req
I	AR3	U	0-20	Sep	5-Sep-2016	7.97	0.6	50.7	2.53	11.8	1.5
H	AR3	U	180	Sep	5-Sep-2016	7.97	0.3	63.6	3.87	14.7	1.0
I	AR3	U	0-20	Oct	11-Oct-2016	7.88	0.5	54.0	2.90	12.6	2.1
H	AR3	U	178	Oct	11-Oct-2016	7.89	0.5	63.3	4.00	14.5	1.3
I	AR3	U	0-20	Nov	31-Oct-2016	7.97	0.5	55.0	3.03	12.5	1.3

Appendix 20. Lower Arrow Lakes Reservoir water chemistry results - 2016; other parameters. DepthCat I=Integrated (0-20m), H=Hypolimnion (5m off the bottom). Data not available is noted as: no data. Reportable detection limits (RDL) for each parameter are identified in row 2.

DepthCat	Station	Basin	Depth	Month	Date Sampled	pH	Turbidity	Alkalinity, Total (as CaCO3)	Silicate (as SiO2)	Total Inorganic Carbon	Total Organic Carbon
					RDL	**0.1**	**0.1**	**1**	**0.5**	**0.5**	**0.5**
					Units	**pH**	**NTU**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
I	AR6	L	0-20	Apr	20-Apr-2016	7.99	0.56	56.6	4.23	13.7	1.41
I	AR6	L	0-20	May	18-May-2016	7.92	1.17	50.7	4.79	12.2	1.39
H	AR6	L	160	May	18-May-2016	7.99	0.22	57.9	4.05	14.1	0.85
I	AR6	L	0-20	Jun	15-Jun-2016	7.97	0.80	49.0	4.15	11.6	1.29
H	AR6	L	160	Jun	15-Jun-2016	7.98	0.21	58.3	4.13	13.9	0.79
I	AR6	L	0-20	Jun_2	27-Jun-2016	7.97	0.49	47.9	4.12	11.6	1.19
I	AR6	L	0-20	Jul	13-Jul-2016	8.00	0.84	49.0	3.33	12	1.32
H	AR6	L	140	Jul	13-Jul-2016	7.95	0.19	55.3	3.8	14.1	0.87
I	AR6	L	0-20	Aug	10-Aug-2016	7.85	0.51	49.5	3.31	11	1.39
H	AR6	L	155	Aug	10-Aug-2016	7.82	0.23	60.2	4.1	13.7	1.04
I	AR6	L	0-20	Sep	7-Sep-2016	7.86	0.46	46.7	2.73	11.6	1.51
H	AR6	L	150	Sep	7-Sep-2016	7.74	0.20	58.1	4.18	14.1	1.69
I	AR6	L	0-20	Oct	5-Oct-2016	7.84	0.45	50.5	2.75	11.7	1.16
H	AR6	L	145	Oct	5-Oct-2016	7.84	0.19	59.0	4.12	13.7	0.92
I	AR6	L	0-20	Nov	1-Nov-2016	7.70	0.29	51.3	3.14	12.2	1.78
I	AR7	L	0-20	Apr	20-Apr-2016	8.02	0.35	56.8	4.26	13.8	1.19
I	AR7	L	0-20	May	18-May-2016	7.96	0.47	53.4	4.73	12.5	1.43
H	AR7	L	140	May	18-May-2016	8.00	0.23	58.8	3.79	14.2	0.93
I	AR7	L	0-20	Jun	15-Jun-2016	7.94	0.67	48.5	4.24	11.6	1.42
H	AR7	L	150	Jun	15-Jun-2016	7.97	0.26	58.7	4.18	14	0.88
I	AR7	L	0-20	Jun_2	27-Jun-2016	7.94	0.38	48.3	3.98	11.9	1.24
I	AR7	L	0-20	Jul	13-Jul-2016	7.98	0.64	49.0	3.71	12.1	1.6
H	AR7	L	145	Jul	13-Jul-2016	7.89	0.20	55.9	4.1	14	1.03
I	AR7	L	0-20	Aug	10-Aug-2016	7.94	0.43	50.9	3.17	11.3	1.44
H	AR7	L	150	Aug	10-Aug-2016	7.83	0.23	59.0	4.06	13.9	1.02
I	AR7	L	0-20	Sep	7-Sep-2016	7.89	0.44	47.9	2.66	11.6	1.36
H	AR7	L	150	Sep	7-Sep-2016	7.75	0.19	58.9	4.32	14.1	0.86
I	AR7	L	0-20	Oct	5-Oct-2016	7.91	0.55	50.7	2.66	11.4	1.08
H	AR7	L	150	Oct	5-Oct-2016	7.81	0.32	58.3	4.29	13.6	0.87
I	AR7	L	0-20	Nov	1-Nov-2016	7.76	0.32	51.2	2.99	13	1.2
I	AR8	L	0-20	Apr	20-Apr-2016	8.00	0.30	56.6	4.36	13.4	1.75

(cont'd)

DepthCat	Station	Basin	Depth	Month	Date Sampled	pH	Turbidity	Alkalinity, Total (as CaCO3)	Silicate (as SiO2)	Total Inorganic Carbon	Total Organic Carbon
I	AR8	L	0-20	May	18-May-2016	7.98	0.40	54.0	4.56	12.5	1.88
H	AR8	L	90	May	18-May-2016	7.97	0.16	59.1	3.89	13.8	1.42
I	AR8	L	0-20	Jun	15-Jun-2016	7.97	0.51	48.5	4.4	11.2	1.43
H	AR8	L	80	Jun	15-Jun-2016	7.99	0.22	57.2	4.26	13.7	0.77
I	AR8	L	0-20	Jun_2	27-Jun-2016	7.95	0.39	49.3	4.04	11.7	1.39
I	AR8	L	0-20	Jul	13-Jul-2016	7.96	0.43	49.4	3.75	11.9	1.61
H	AR8	L	80	Jul	13-Jul-2016	7.96	0.22	55.3	4.19	13.9	1.03
I	AR8	L	0-20	Jul_2	26-Jul-2016	not req	not req	not req	not req	not req	not req
I	AR8	L	0-20	Aug	10-Aug-2016	7.89	0.34	51.5	3.31	11.7	1.61
H	AR8	L	85	Aug	10-Aug-2016	7.81	0.18	59.9	4.1	13.6	1.12
I	AR8	L	0-20	Aug_2	24-Aug-2016	not req	not req	not req	not req	not req	not req
I	AR8	L	0-20	Sep	7-Sep-2016	7.93	0.39	47.6	2.79	11.6	1.07
H	AR8	L	80	Sep	7-Sep-2016	7.75	0.22	58.0	4.13	13.8	0.86
I	AR8	L	0-20	Oct	5-Oct-2016	7.91	0.37	49.6	2.82	11.2	1.22
H	AR8	L	65	Oct	5-Oct-2016	7.81	0.29	57.4	4.5	13	0.9
I	AR8	L	0-20	Nov	1-Nov-2016	7.69	0.43	51.5	3.03	12.5	1.94

Appendix 21. Arrow Lakes Reservoir phytoplankton results - 2016; Abundance (cells/mL) and biovolume (mm^3/L). Basin: U=Upper, N= Narrows, L=Lower. Class: Bac= Bacillariophyte (Diatoms), ChrCry= Chryso- & Cryptophyte (Flagellates), Din= Dinophyte (Dinoflagellates), Chl= Chlorophyte (Coccoid Greens, Desmids, etc.) and Cya= Cyanophyte (Blue-greens). Edible or inedible to zooplankton (see Appendix 21).

				Abundance cells/mL								Biovolume mm^3/L							
Basin	Station	Month	Date	Bac	ChrCry	Din	Chl	Cya	Total	Edible	Inedible	Bac	ChrCry	Din	Chl	Cya	Total	Edible	Inedible
U	AR1	Apr	18-Apr-16	121.6	689.3	10.1	101.4	141.9	1064.4	963.0	101.4	0.021	0.056	0.005	0.006	0.002	0.090	0.070	0.020
U	AR2	Apr	18-Apr-16	152.1	577.8	10.1	91.2	141.9	973.1	902.2	71.0	0.019	0.055	0.005	0.006	0.002	0.087	0.076	0.011
U	AR3	Apr	18-Apr-16	223.0	790.7	20.3	81.1	121.6	1236.7	1084.6	152.1	0.027	0.078	0.010	0.008	0.002	0.124	0.104	0.020
N	AR4	Apr	18-Apr-16	192.6	1439.5	20.3	172.3	152.1	1976.7	1865.2	111.5	0.030	0.148	0.010	0.018	0.002	0.208	0.184	0.024
N	AR5	Apr	18-Apr-16	557.5	2088.2	20.3	212.9	243.3	3122.2	2706.6	415.6	0.088	0.204	0.010	0.021	0.003	0.327	0.252	0.075
L	AR6	Apr	20-Apr-16	385.2	1652.3	71.0	294.0	192.6	2595.1	2280.8	304.1	0.048	0.211	0.044	0.031	0.003	0.336	0.279	0.042
L	AR7	Apr	20-Apr-16	314.2	1327.9	20.3	212.9	152.1	2027.4	1784.1	233.2	0.037	0.177	0.010	0.033	0.007	0.264	0.226	0.034
L	AR8	Apr	20-Apr-16	446.0	912.3	10.1	223.0	233.2	1824.7	1429.3	395.4	0.050	0.091	0.005	0.022	0.013	0.181	0.128	0.054
U	AR1	May	16-May-16	425.8	932.6	10.1	131.8	121.6	1621.9	1236.7	385.2	0.047	0.094	0.005	0.020	0.002	0.168	0.125	0.042
U	AR2	May	16-May-16	506.8	963.0	10.1	162.2	101.4	1743.5	1287.4	456.2	0.064	0.103	0.005	0.015	0.001	0.189	0.129	0.060
U	AR3	May	16-May-16	1104.9	1621.9	20.3	304.1	162.2	3213.4	2159.1	1054.2	0.127	0.158	0.010	0.038	0.011	0.344	0.213	0.132
N	AR4	May	16-May-16	1459.7	1632.0	10.1	294.0	182.5	3578.3	2169.3	1398.9	0.175	0.140	0.005	0.040	0.012	0.372	0.190	0.177
N	AR5	May	16-May-16	1246.8	1662.5	30.4	263.6	162.2	3365.5	2149.0	1196.2	0.133	0.176	0.025	0.025	0.007	0.366	0.213	0.133
L	AR6	May	18-May-16	1287.4	1044.1	10.1	223.0	10.1	2574.8	1328.0	1246.8	0.165	0.100	0.005	0.030	0.005	0.304	0.139	0.165
L	AR7	May	18-May-16	760.3	1388.8	20.3	263.6	162.2	2595.1	1855.1	719.7	0.100	0.188	0.020	0.042	0.012	0.363	0.238	0.104
L	AR8	May	18-May-16	942.7	2230.1	40.5	202.7	172.3	3588.5	2666.0	902.2	0.117	0.367	0.041	0.023	0.007	0.555	0.409	0.116
U	AR1	Jun	13-Jun-16	2047.7	1226.6	10.1	192.6	141.9	3618.9	1642.2	1966.6	0.246	0.122	0.005	0.031	0.007	0.411	0.165	0.241
U	AR2	Jun	13-Jun-16	567.7	902.2	20.3	162.2	162.2	1814.5	1257.0	557.5	0.075	0.108	0.009	0.017	0.017	0.225	0.138	0.087
U	AR3	Jun	13-Jun-16	1094.8	608.2	10.1	101.4	233.1	2047.7	1145.5	892.1	0.136	0.061	0.005	0.016	0.009	0.227	0.105	0.117
N	AR4	Jun	13-Jun-16	831.3	658.9	10.1	212.9	81.1	1794.3	1034.0	750.2	0.110	0.070	0.005	0.038	0.011	0.233	0.120	0.109
N	AR5	Jun	13-Jun-16	1044.1	1003.6	20.3	223.0	192.6	2483.5	1561.1	912.3	0.128	0.146	0.009	0.042	0.017	0.342	0.212	0.126
L	AR6	Jun	15-Jun-16	517.0	932.6	20.3	192.6	202.7	1865.2	1439.4	425.8	0.069	0.132	0.010	0.036	0.003	0.248	0.189	0.059
L	AR7	Jun	15-Jun-16	1003.6	1571.2	20.3	223.0	182.5	3000.5	2067.9	922.5	0.129	0.186	0.010	0.029	0.007	0.362	0.232	0.125
L	AR8	Jun	15-Jun-16	446.0	1540.8	30.4	304.1	172.3	2493.7	2067.9	405.5	0.055	0.262	0.025	0.040	0.007	0.389	0.316	0.053
U	AR1	Jun_2	27-Jun-16	1601.6	1186.0	20.3	395.3	304.1	3507.4	2209.9	1277.2	0.259	0.122	0.009	0.061	0.014	0.464	0.231	0.223
U	AR2	Jun_2	27-Jun-16	1155.6	932.6	50.7	314.3	314.3	2767.4	1733.4	1013.7	0.154	0.095	0.034	0.035	0.024	0.341	0.169	0.152
U	AR3	Jun_2	27-Jun-16	1206.3	821.1	30.4	172.3	233.1	2463.3	1287.4	1165.7	0.167	0.079	0.024	0.021	0.013	0.304	0.119	0.170

(cont'd)

Basin	Station	Month	Date	Bac	ChrCry	Din	Chl	Cya	Total	Edible	Inedible	Bac	ChrCry	Din	Chl	Cya	Total	Edible	Inedible
N	AR4	Jun_2	27-Jun-16	841.4	790.7	40.6	273.7	273.7	2220.0	1500.3	699.5	0.101	0.050	0.029	0.045	0.019	0.244	0.129	0.095
N	AR5	Jun_2	27-Jun-16	557.5	496.7	20.3	121.6	233.2	1429.3	892.0	537.3	0.077	0.031	0.009	0.020	0.023	0.160	0.072	0.089
L	AR6	Jun_2	27-Jun-16	506.9	557.5	40.6	182.5	131.8	1419.2	932.6	476.4	0.065	0.060	0.029	0.023	0.012	0.189	0.104	0.070
L	AR7	Jun_2	27-Jun-16	699.5	699.5	20.3	212.9	192.6	1824.7	1257.0	557.5	0.093	0.062	0.020	0.028	0.018	0.221	0.117	0.088
L	AR8	Jun_2	27-Jun-16	587.9	881.9	50.7	253.4	192.6	1966.6	1459.7	486.6	0.069	0.066	0.044	0.020	0.018	0.217	0.118	0.069
U	AR1	Jul	11-Jul-16	2483.5	892.0	20.3	395.4	263.6	4054.8	1875.3	2169.3	0.359	0.121	0.020	0.065	0.038	0.603	0.242	0.346
U	AR2	Jul	11-Jul-16	3061.3	963.0	20.3	364.9	192.6	4602.1	2706.6	1895.6	0.393	0.158	0.010	0.084	0.027	0.672	0.304	0.368
U	AR3	Jul	11-Jul-16	1277.2	800.8	20.3	294.0	243.3	2635.6	1611.8	1013.7	0.177	0.091	0.009	0.031	0.028	0.335	0.159	0.171
N	AR4	Jul	11-Jul-16	2149.0	1196.2	20.3	263.6	294.0	3923.0	2270.7	1642.2	0.324	0.111	0.009	0.040	0.049	0.532	0.234	0.293
N	AR5	Jul	11-Jul-16	2027.4	780.5	30.4	263.6	344.7	3446.5	1611.8	1814.5	0.307	0.099	0.025	0.064	0.084	0.580	0.201	0.339
L	AR6	Jul	13-Jul-16	790.7	517.0	10.1	121.6	152.1	1591.5	932.6	658.9	0.110	0.061	0.005	0.021	0.017	0.213	0.108	0.105
L	AR7	Jul	13-Jul-16	952.9	861.6	30.4	354.8	152.1	2351.8	1469.8	841.4	0.135	0.074	0.025	0.093	0.017	0.344	0.160	0.134
L	AR8	Jul	13-Jul-16	871.8	831.2	30.4	365.0	212.9	2311.2	1480.0	800.8	0.125	0.088	0.025	0.089	0.032	0.360	0.172	0.142
U	AR3	Jul_2	25-Jul-16	446.0	669.0	30.4	273.7	111.5	1530.7	1226.6	294.0	0.067	0.073	0.025	0.040	0.007	0.212	0.144	0.053
N	AR4	Jul_2	25-Jul-16	658.9	567.7	30.4	253.4	101.4	1611.8	1094.8	486.6	0.103	0.064	0.024	0.032	0.011	0.234	0.121	0.088
L	AR8	Jul_2	26-Jul-16	608.2	770.4	50.7	192.6	131.8	1753.7	1186.0	547.4	0.086	0.082	0.080	0.039	0.007	0.294	0.142	0.132
U	AR1	Aug	08-Aug-16	2057.8	506.8	30.4	172.3	121.7	2889.0	993.4	1875.3	0.274	0.040	0.025	0.022	0.007	0.368	0.092	0.256
U	AR2	Aug	08-Aug-16	1824.6	506.9	40.6	162.2	141.9	2676.2	902.2	1753.7	0.231	0.047	0.039	0.017	0.007	0.341	0.085	0.226
U	AR3	Aug	08-Aug-16	2686.3	415.6	20.3	172.3	121.7	3416.2	841.4	2564.6	0.342	0.041	0.019	0.026	0.002	0.429	0.088	0.326
N	AR4	Aug	08-Aug-16	1713.2	719.7	20.3	121.6	60.8	2635.6	1054.3	1581.4	0.250	0.091	0.009	0.013	0.001	0.363	0.132	0.232
N	AR5	Aug	08-Aug-16	1976.7	780.5	30.4	192.6	91.2	3071.5	1246.9	1804.4	0.268	0.083	0.024	0.014	0.002	0.391	0.125	0.245
L	AR6	Aug	10-Aug-16	1601.6	1094.8	111.5	344.7	212.9	3365.5	1703.0	1621.9	0.210	0.157	0.085	0.025	0.052	0.529	0.229	0.249
L	AR7	Aug	10-Aug-16	608.2	1165.7	60.8	131.8	172.3	2138.9	1510.4	598.1	0.100	0.205	0.059	0.006	0.017	0.388	0.232	0.110
L	AR8	Aug	10-Aug-16	902.2	547.4	10.1	152.1	141.9	1753.7	851.5	902.2	0.122	0.071	0.005	0.011	0.017	0.226	0.092	0.134
U	AR3	Aug_2	23-Aug-16	3274.2	952.9	20.3	192.6	263.6	4703.6	1490.2	3203.3	0.402	0.118	0.020	0.022	0.018	0.580	0.161	0.404
N	AR4	Aug_2	23-Aug-16	3618.9	881.9	30.4	202.7	202.7	4936.7	1358.3	3547.9	0.424	0.086	0.025	0.034	0.013	0.581	0.132	0.424
L	AR8	Aug_2	24-Aug-16	1409.0	760.3	30.4	182.5	131.8	2514.0	1196.2	1297.5	0.175	0.071	0.025	0.031	0.012	0.314	0.125	0.169
U	AR1	Sep	05-Sep-16	3193.1	587.9	10.1	60.8	202.7	4054.8	902.2	3142.4	0.385	0.044	0.005	0.007	0.012	0.453	0.062	0.387
U	AR2	Sep	05-Sep-16	3446.5	1064.4	10.1	152.1	152.1	4825.2	1459.7	3355.3	0.424	0.088	0.005	0.021	0.002	0.541	0.121	0.415
U	AR3	Sep	05-Sep-16	2503.8	790.7	20.3	192.6	152.1	3659.4	1196.2	2443.0	0.300	0.064	0.020	0.045	0.012	0.442	0.121	0.301
N	AR4	Sep	05-Sep-16	2635.6	942.7	20.3	172.3	223.0	3993.9	1307.6	2655.9	0.298	0.060	0.020	0.019	0.034	0.431	0.086	0.324

(cont'd)

Basin	Station	Month	Date	Bac	ChrCry	Din	Chl	Cya	Total	Edible	Inedible	Bac	ChrCry	Din	Chl	Cya	Total	Edible	Inedible
N	AR5	Sep	05-Sep-16	4774.5	790.7	10.1	101.4	131.8	5808.4	1023.8	4754.2	0.534	0.070	0.005	0.021	0.008	0.639	0.096	0.536
L	AR6	Sep	07-Sep-16	2807.9	973.2	20.3	162.2	223.0	4186.5	1368.5	2767.4	0.349	0.115	0.020	0.034	0.014	0.532	0.154	0.351
L	AR7	Sep	07-Sep-16	1814.5	719.7	20.3	172.3	141.9	2868.8	1044.1	1804.4	0.217	0.086	0.020	0.050	0.017	0.389	0.142	0.227
L	AR8	Sep	07-Sep-16	1946.3	1064.4	40.5	162.2	182.5	3395.8	1520.5	1844.9	0.243	0.115	0.041	0.030	0.012	0.441	0.166	0.240
U	AR1	Oct	11-Oct-16	1571.2	679.2	30.4	233.2	141.9	2655.9	1186.0	1429.3	0.193	0.057	0.025	0.045	0.014	0.333	0.124	0.187
U	AR2	Oct	11-Oct-16	4196.7	1094.8	10.1	253.4	202.7	5757.8	1621.9	4115.6	0.514	0.072	0.005	0.047	0.018	0.656	0.130	0.516
U	AR3	Oct	11-Oct-16	3335.0	831.2	10.1	273.7	223.0	4673.1	1307.7	3335.0	0.470	0.069	0.015	0.059	0.028	0.641	0.127	0.489
N	AR4	Oct	11-Oct-16	3933.1	770.4	10.1	294.0	141.9	5149.5	1378.6	3750.7	0.537	0.060	0.005	0.058	0.022	0.682	0.147	0.526
N	AR5	Oct	11-Oct-16	5838.9	1145.5	10.1	598.1	273.7	7866.2	2311.2	5555.0	0.743	0.062	0.005	0.123	0.036	0.970	0.235	0.735
L	AR6	Oct	05-Oct-16	1469.9	811.0	10.1	324.4	243.3	2858.6	1480.0	1368.5	0.186	0.072	0.005	0.061	0.056	0.379	0.154	0.220
L	AR7	Oct	05-Oct-16	1844.9	770.4	10.1	263.6	182.5	3071.5	1338.1	1733.4	0.236	0.074	0.005	0.049	0.050	0.414	0.153	0.261
L	AR8	Oct	05-Oct-16	1104.9	557.5	10.1	243.3	212.9	2128.7	1003.5	1125.2	0.129	0.025	0.005	0.046	0.050	0.255	0.084	0.171
U	AR1	Nov	31-Oct-16	435.9	638.6	10.1	212.9	131.8	1429.3	1044.1	375.1	0.052	0.060	0.005	0.051	0.008	0.176	0.125	0.050
U	AR2	Nov	31-Oct-16	537.3	638.6	10.1	111.5	141.9	1439.5	932.6	506.9	0.075	0.042	0.005	0.008	0.007	0.137	0.062	0.074
U	AR3	Nov	31-Oct-16	1733.4	719.7	20.3	152.1	192.6	2818.1	1125.2	1672.6	0.217	0.071	0.020	0.028	0.008	0.344	0.111	0.213
N	AR4	Nov	31-Oct-16	1723.3	679.2	20.3	212.9	152.1	2787.7	1155.6	1632.0	0.233	0.057	0.009	0.034	0.012	0.344	0.115	0.229
N	AR5	Nov	31-Oct-16	811.0	750.1	30.4	152.0	162.2	1905.7	1115.0	780.5	0.096	0.043	0.024	0.022	0.022	0.207	0.085	0.107
L	AR6	Nov	01-Nov-16	760.3	577.8	20.3	141.9	121.6	1621.9	881.9	719.7	0.090	0.047	0.009	0.053	0.008	0.206	0.091	0.089
L	AR7	Nov	01-Nov-16	861.6	1034.0	10.1	141.9	182.5	2230.1	1388.8	831.2	0.100	0.150	0.005	0.036	0.013	0.304	0.199	0.103
L	AR8	Nov	01-Nov-16	273.7	790.7	10.1	172.3	212.9	1459.7	1145.5	294.0	0.034	0.124	0.005	0.046	0.023	0.232	0.175	0.052

Appendix 22. Arrow Lakes Reservoir species phytoplankton results - 2016; Edibility to zooplankton by taxonomic group, group alias and species. I= inedible, E= edible, and E/I= either edible or inedible. Assignment made by John Stockner at Eco-Logic Ltd (analyst in 2016).

class name	class alias	species	edibility
Bacillariophyte	Diatoms	*Cyclotella glomerata*	E
Bacillariophyte	Diatoms	*Fragilaria construens*	I
Bacillariophyte	Diatoms	*Navicula sp.*	I
Bacillariophyte	Diatoms	*Synedra acus*	I
Bacillariophyte	Diatoms	*Synedra nana*	I
Bacillariophyte	Diatoms	*Achnanthidium sp.*	E
Bacillariophyte	Diatoms	*Cyclotella stelligera*	E
Bacillariophyte	Diatoms	*Fragilaria capucina*	I
Bacillariophyte	Diatoms	*Asterionella formosa var1*	I
Bacillariophyte	Diatoms	*Diatoma elongatum*	I
Bacillariophyte	Diatoms	*Cymbella sp.*	E
Bacillariophyte	Diatoms	*Cymbella sp. (large)*	I
Bacillariophyte	Diatoms	*Fragilaria crotonensis*	I
Bacillariophyte	Diatoms	*Synedra ulna*	I
Bacillariophyte	Diatoms	*Tabellaria fenestrata*	I
Bacillariophyte	Diatoms	*Tabellaria flocculosa*	I
Bacillariophyte	Diatoms	*Eunotia sp.*	I
Bacillariophyte	Diatoms	*Synedra acus var. angustissima*	I
Bacillariophyte	Diatoms	*Cyclotella comta*	I
Bacillariophyte	Diatoms	*Stephanodiscus sp.*	I
Chlorophyte	Coccoid greens, desmids, etc.	*Chlorella*	E
Chlorophyte	Coccoid greens, desmids, etc.	*Scourfieldia*	E
Chlorophyte	Coccoid greens, desmids, etc.	*Cosmarium sp.*	E
Chlorophyte	Coccoid greens, desmids, etc.	*Cateria sp.*	E
Chlorophyte	Coccoid greens, desmids, etc.	*Monomastix sp*	E
Chlorophyte	Coccoid greens, desmids, etc.	*Monoraphidium*	E
Chlorophyte	Coccoid greens, desmids, etc.	*Stichococcus minutissimus*	E
Chlorophyte	Coccoid greens, desmids, etc.	*Botryococcus sp.*	E

class name	class alias	species	edibility
Chryso- & Cryptophyte	Flagellates	*Chroomonas acuta*	E
Chryso- & Cryptophyte	Flagellates	*Chrysochromulina sp.*	E
Chryso- & Cryptophyte	Flagellates	*Cryptomonas sp.*	E
Chryso- & Cryptophyte	Flagellates	*Kephyrion sp.*	E
Chryso- & Cryptophyte	Flagellates	*Komma sp.*	E
Chryso- & Cryptophyte	Flagellates	*Ochromonas sp.*	E
Chryso- & Cryptophyte	Flagellates	*Pseudokephrion sp.*	E
Chryso- & Cryptophyte	Flagellates	*Small microflagellates*	E
Chryso- & Cryptophyte	Flagellates	*Bitrichia sp.*	E
Chryso- & Cryptophyte	Flagellates	*Chromulina sp1*	E
Chryso- & Cryptophyte	Flagellates	*Chrysococcus*	E
Chryso- & Cryptophyte	Flagellates	*Dinobryon sp*	E
Chryso- & Cryptophyte	Flagellates	*Mallomonas sp2*	E
Chryso- & Cryptophyte	Flagellates	*Isthmochloron*	E
Cyanophyte	Blue-greens	*Merismopedia sp.*	E
Cyanophyte	Blue-greens	*Synechococcus sp. (coccoid)*	E
Cyanophyte	Blue-greens	*Synechococcus sp. (rod)*	E
Cyanophyte	Blue-greens	*Synechocystis*	E
Cyanophyte	Blue-greens	*Lyngbya sp.*	I
Cyanophyte	Blue-greens	*Microcystis sp.*	I
Cyanophyte	Blue-greens	*Aphanothecae sp.*	I/E
Cyanophyte	Blue-greens	*Chroococcus sp.*	I
Dinophyte	Dinoflagellates	*Gymnodinium sp1*	E
Dinophyte	Dinoflagellates	*Gymnodinium sp2*	I/E
Dinophyte	Dinoflagellates	*Peridinium spp.*	E
Dinophyte	Dinoflagellates	*Ceratium*	I

(cont'd)

class name	class alias	species	edibility
Chlorophyte	Coccoid greens, desmids, etc.	*Sphaerocystis sp.*	E
Chlorophyte	Coccoid greens, desmids, etc.	*Clamydocapsa sp.*	E
Chlorophyte	Coccoid Greens, Desmids, etc.	*Ankistrodesmus sp.*	E
Chlorophyte	Coccoid Greens, Desmids, etc.	*Elakatothrix sp3*	E
Chlorophyte	Coccoid Greens, Desmids, etc.	*Gyromitus sp.*	E
Chlorophyte	Coccoid Greens, Desmids, etc.	*Phacus*	E
Chlorophyte	Coccoid Greens, Desmids, etc.	*Pyramimonas*	E
Chlorophyte	Coccoid Greens, Desmids, etc.	*Nephroselmis*	E
Chlorophyte	Coccoid Greens, Desmids, etc.	*Tetraedron*	E
Chlorophyte	Coccoid Greens, Desmids, etc.	*Coelastrum sp.*	I/E
Chlorophyte	Coccoid Greens, Desmids, etc.	*Scenedesmus sp.*	E
Chlorophyte	Coccoid Greens, Desmids, etc.	*Planctosphaeria*	I
Chlorophyte	Coccoid Greens, Desmids, etc.	*Euglena*	I/E
Chlorophyte	Coccoid Greens, Desmids, etc.	*Oocystis sp.*	E
Chlorophyte	Coccoid Greens, Desmids, etc.	*Planctonema sp.*	E

Appendix 23. Empirical relation of average fecundity and average female length from kokanee returning to Hill Creek Spawning Channel.