

Arrow Lakes Reservoir Nutrient Restoration Program 2019 Annual Summary Report

by:

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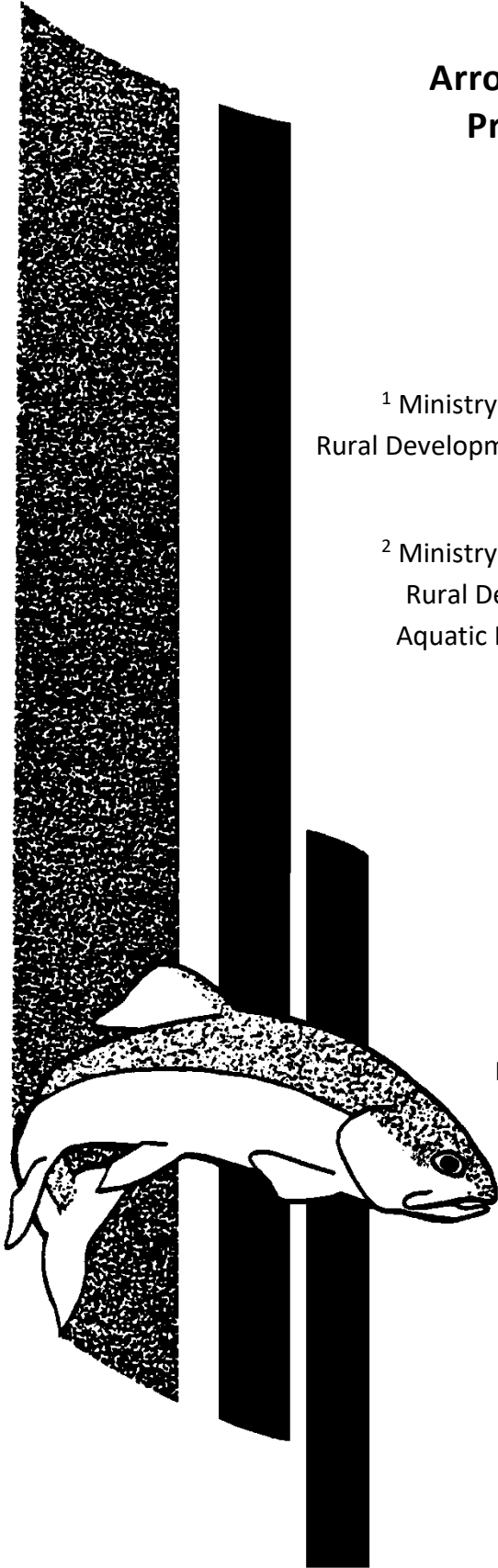
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Contents

| | |
|--|----|
| ACKNOWLEDGEMENTS..... | 2 |
| 1. INTRODUCTION..... | 1 |
| 2. METHODS..... | 1 |
| Study Area..... | 1 |
| Nutrient Additions and Fertilizer Application..... | 1 |
| Reservoir Outflow..... | 2 |
| Limnology Sampling Stations and Timing..... | 3 |
| Physical Limnology and Water Chemistry..... | 3 |
| Phytoplankton..... | 4 |
| Zooplankton..... | 5 |
| Mysis diluviana..... | 5 |
| Kokanee..... | 6 |
| 3. RESULTS..... | 11 |
| Arrow Lakes Reservoir Outflow..... | 11 |
| Secchi..... | 12 |
| Water Chemistry – Integrated Epilimnion..... | 14 |
| Phosphorus..... | 14 |
| Nitrogen..... | 16 |
| Nitrogen: Phosphorus..... | 19 |
| Phytoplankton..... | 20 |
| Zooplankton..... | 22 |
| Mysids..... | 24 |
| Kokanee..... | 25 |
| Trawl catch..... | 25 |
| Kokanee length and age..... | 26 |
| Spawning Escapement..... | 27 |
| In-lake Abundance..... | 29 |
| Biomass..... | 30 |

| | |
|-----------------------------|----|
| Hill Creek production | 32 |
| Kokanee survival | 34 |
| 4. DISCUSSION..... | 36 |
| 5. RECOMMENDATIONS | 40 |
| 6. REFERENCES | 42 |
| 7. APPENDICES | 47 |

1. INTRODUCTION

This is a summary report to highlight the results of the Arrow Lakes Reservoir Nutrient Restoration Program (NRP) in 2019. History of restoration, details on the reservoir and historic responses to nutrient additions are presented in detail in previous reports, most recently in (Bassett *et al.* 2018b).

Limnological data are presented for turbidity, select water chemistry parameters, phytoplankton, zooplankton and mysids. Kokanee data presented include hydroacoustic and trawl data as well as spawner escapement and Hill Creek spawning channel fry production results.

2. METHODS

Study Area

Arrow Lakes Reservoir is located in southeast British Columbia. The reservoir is on the Columbia River and was formed in 1967 when the Hugh Keenleyside Dam (HKD) was constructed on the outlet of the former Lower Arrow Lake. Downstream of HKD, in Castlegar BC, is the confluence with the Kootenay River, from there the Columbia River travels south into Washington State, USA. The Arrow Lakes Reservoir is downstream of Kinbasket Reservoir and Revelstoke Reservoir.

Nutrient Additions and Fertilizer Application

In 2019 agricultural-grade liquid fertilizer of ammonium polyphosphate (10-34-0) and urea ammonium nitrate (28-0-0) was dispensed from the Columbia ferry operated by WaterBridge Ferries, methods are presented in detail in Bassett *et al.* (2018b). The total weight of fertilizer applied in 2019 was 40.5 tonnes of phosphorus and 248.8 tonnes of nitrogen (

Table 1). Application start dates, (N:P) ratio (weight:weight) of the fertilizer, and loading rates (mg/m^2) are presented in Appendix 2. Note: estimates of phosphorus inputs (April to September) (Soluble Reactive Phosphorus – SRP) from the Columbia River to Upper Arrow ranged from 6.6 tonnes to 12.9 tonnes over the 1999 to 2014 period; the range from 2015 to 2018 was 13.7 to 27.7 tonnes; 2019 was not calculated at time of reporting (Data on file, FLNRORD). Tonnes of SRP were estimated by using discharge information and the following concentrations of P – 0.85 $\mu\text{g}/\text{L}$ was used as a post-dam concentration (measured by E. Carmack in 1998) to 2015. A concentration of 2.27 $\mu\text{g}/\text{L}$ was used pre-Mica and pre-Revelstoke; 1.7 $\mu\text{g}/\text{L}$ was used as a concentration post-Mic

and pre-Revelstoke. The calculations occurred during the following time frame: April 11th through September 21st (coincides with timing of spring and summer as described in Pieters et al. 2003). During the years 2016 to 2018 phosphorus samples were collected and the phosphorus concentrations were used to calculate inputs.

Table 1. Total tonnes of phosphorus and nitrogen dispensed from fertilizer to Upper Arrow between April and September 1999-2019.

| 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 |
| 2017 | 41.6 | 229.4 |
| 2018 | 37.9 | 234.3 |
| 2019 | 40.5 | 248.8 |

Reservoir Outflow

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. Flow data for the growing season (April to October) are presented. The cumulative outflow for each 12-month period spanning from October to October is also used for comparison with Kokanee survival data, which are calculated over concurrent 12-month periods.

Limnology Sampling Stations and Timing

In 2019 there were nine sampling stations on ALR: stations AR1–3 were located in Upper Arrow, stations AR4 and AR5 are in the former river channel that connected the pre-impoundment Upper and Lower Arrow Lakes (called the Narrows), and stations AR6–8 and HL4 are located in Lower Arrow (Table 2, Appendix 3).

Table 2. Limnological sampling stations for the Arrow Lakes Reservoir Nutrient Restoration Program. EMS site no. refers to the Environmental Monitoring System (Ministry of ENV) database tracking number where the results of the water chemistry samples are available.

| 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 |
| HL4* | | Arrow Lake @ Syringa | 25 | 5465541 | 436743 |

* Temperature only

Sampling occurred monthly from April through November in 2019. A subset of water and phytoplankton sampling occurred bi-weekly from June through September. Hypolimnetic water samples were collected monthly from May through October. Sampling details for 2019 are presented in Appendix 4.

Physical Limnology and Water Chemistry

Vertical profiles of depth (m), temperature (°C), dissolved oxygen (mg/L), oxygen saturation (%), specific conductance (µS/cm), salinity (PSU), turbidity (NTU), and fluorescence (µg/L) were obtained using a SeaBird SBE 19-plus profiler. At all stations, the profiler logged information every 0.25 seconds from the surface to 5 m off the lake bottom. Due to noise at the surface, only 1 m and deeper data were considered as reliable. Water transparency was also measured at each station using a standard 20 cm Secchi disc (without a viewing chamber) on the shadowy side of the boat without sunglasses. Water chemistry samples were collected using a 2.54 cm (inside diameter) tube sampler to collect an integrated water sample from 0–20 m. A niskin bottle was

used to collect discrete water samples at depths of 2, 5, 10, 15, 20 m and 5 m off the bottom. Water samples were preserved, or field filtered as instructed by the lab, immediately placed on ice and shipped within 24 hours of collection to ALS Global in Burnaby, B.C.

The integrated epilimnetic and hypolimnetic samples were analyzed for Chl a (epilimnetic only), 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 Chl a, TP, TDP, OP, and DIN. Nitrogen to phosphorus ratios were calculated using the dissolved portions of nitrogen and phosphorus: dissolved inorganic nitrogen was the combined concentration of ammonia, nitrate and nitrite ($\mu\text{g/L}$) divided by the total dissolved phosphorus ($\mu\text{g/L}$). If sample results were below the detection limit, they were set equal to the detection limit. Before analysing nitrogen and phosphorus data, within the same sample we removed any values of TDP more than 2 $\mu\text{g/L}$ greater than the TP and any dissolved inorganic nitrogen values more than 20 $\mu\text{g/L}$ greater than total nitrogen. Technically any dissolved components can not be higher than the total components, however the total and dissolved samples are analysed separately so some margin for error was allowed.

Many of the figures in this report illustrate the 2019 against a time series of annual (April–October) averages. Figures were primarily produced in R (R Core Team 2020) or in Excel (MS Office). Detailed analyses of the 1997–2018 data are available in previous annual reports (Pieters *et al.* 1998, 1999, 2000, 2003a, 2003b; Schindler *et al.* 2006a, 2006b, 2007, 2009, 2010, 2011, 2013, 2014; Bassett *et al.* 2015, Bassett *et al.* 2016, Bassett *et al.* 2018a, Bassett *et al.* 2018b) or on file at FLNRORD.

Phytoplankton

Phytoplankton samples were collected from April through November using the 0 to 20m integrated tube sampler. Samples were preserved with Lugol's iodine solution immediately after collection and couriered to Newman Lake, WA for processing by Advanced Eco-Solutions Inc. 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 4–8 hours. Counts were done on an Olympus inverted 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 400X 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 900 X magnification. In total, about 150–225 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).

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 cable was in the water. 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 m² 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

Data collection methods and survey design were identical to previous Kokanee monitoring for this project as reported by Schindler *et al.* (2014) and Bassett *et al.* (2015, 2016, 2018a, and 2018b). Spawner numbers were estimated each fall through a combination of aerial counts and visual ground counts as outlined in Sebastian *et al.* (2000). For index streams, two or three aerial or ground 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 historic spawner enumeration results for all systems including a number of smaller streams are presented by Bassett *et al.* (2018b).

Table 3. Upper and Lower Arrow 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 3 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 for Hill Creek was estimated based on the total number of females allowed into the channel multiplied by 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). Egg deposition for the remainder of the reservoir was determined using the expanded peak counts from index tributaries multiplied by the percent female and fecundity measurements from the HCSC. Spawners were collected opportunistically as fresh carcasses and by dip net from Deer Creek on September 9th and 16th, Octopus Creek on September 17th and 20th and Taite Creek on September 20th, 2019 for length and age data to represent Lower Arrow; these data are not presented herein and are in file with FLNRORD. The age at maturity was determined by Birkenhead Scale Analyses 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).

Hydroacoustic sampling paired with mid-water trawling has been conducted during the new moon period in October using similar methods since 1992. While some changes in hydroacoustic equipment have occurred over time as the technology matured, the equipment (brand, model, frequency) have been identical since 2008. The 2019 hydroacoustic survey occurred September 27-29, which was slightly earlier than normal (typically the survey falls in October), however this is not expected to have any meaningful impact on the comparability of the data. Acoustic sampling consisted of 18 standard transects: 10 in the Upper Basin and 8 in the Lower Basin (Appendix 3). 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/second while cruising at approximately 2 m/second. 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 software following the specifications in Appendix 5. Appendix 6 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, 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 threshold 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. In 2019 the Kokanee fry were determined to be fish between -61 dB and -46 dB, and age 1–3 Kokanee group were defined as targets >-45 dB. 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 1.1.463; R Core Team, 2018). 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 7.

Mid-water trawl sampling was conducted at six stations: three in Upper Arrow (September 21-23, 2019) and three in Lower Arrow (September 25-27, 2019), following standard stepped oblique methods; 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/second. 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 and weight 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). Note that at the time of reporting the scale ageing had not been completed; the ages for trawl captured fish in 2019 are based on length frequency and considered preliminary.

For Arrow Lakes Reservoir, age structure for the older Kokanee age classes (age 1-3) has historically been taken directly from the trawl data catch (Bassett *et al.* 2018b). The same approach has been taken for Kootenay and Okanagan Lakes, where similar quality standardized annual trawl data exist (Peck *et al.* 2019, Sebastian and Scholten *in* Ashley *et al.* 1999). However, for multiple other systems in BC, hydroacoustic data exist but extensive trawl data do not. Accordingly, we developed a new approach to estimating population by age class for age 1-3 Kokanee that does not rely on direct application of trawl age structure. The new method allows for improved comparability across multiple systems regardless of trawl data quality and is assumed to be less affected by small sample sizes and trawl selectivity than the original method. The new method was originally developed for Kinbasket and Revelstoke Reservoirs (Bray *et al.* 2018) and subsequently for Duncan Reservoir and has been refined specific to Arrow Reservoir using the long-term acoustic and trawl datasets. The new method relies on an empirical relation between Kokanee fork length (FL) and acoustic target strength (TS) that was developed from seven consecutive years of acoustic, trawl and gillnet data on Kinbasket Reservoir (Bray *et al.* 2018). The following TS:FL relations were applied to Arrow Reservoir single beam data (1992-2007) (equation 1) and split beam data (equation 2) to convert fork length to acoustic target strength equivalents:

(1) $TS = 21.957 \times \log_{10}(FL) - 67.574$ where TS = target strength (db) and FL = fork length (cm).

(2) $TS = 23.908 \times \log_{10}(FL) - 68.215$ where TS = target strength (db) and FL = fork length (cm).

The partitioning of acoustic data into age groups was done in four steps. First, the trawl length frequency by age data and plots were used to determine where the length cut-offs occurred between age 0 and age 1 fish (defined as the fry cut-off) and between age 1 and 2 (defined as the age 2 cut-off) for each survey year. Cut-offs were typically indicated by valleys between length frequency modes, however where ages were

overlapping, the age data was used in conjunction with length frequency breaks to determine the best length for partitioning age groups. Extensive overlap between age 2 and age 3 fish made separation unreliable, so these fish remained in one group and are referred to as age 2+¹. The second step was to convert the age cut-offs established from trawl data to their acoustic equivalent using the TS:FL relations shown above. The third step was to determine where the fry cut-off occurred on the acoustic size distribution for each survey. The acoustic fry cut-off was typically apparent as an inflection point in the distribution where large numbers of small fry intersect with lower numbers of larger (age 1-3) fish. The acoustic and trawl fry cut-offs were then compared for each survey and their difference (if any) was used as a correction factor (CF). The CF was then applied to (added to) the trawl age 2 cut-off in order to “correct” it to the acoustic size distribution. For example, if the acoustic fry cut-off (AFC) was at -46dB and the trawl fry cut-off (TFC) was -45dB, the correction required to convert trawl cut-offs to the acoustic scale would be $AFC - TFC = CF$ or $((-45) - (-44)) = (-1)$. The correction factor is then added to the trawl derived age 2 cut-off of (for example) -37dB in order to correct it to -38dB on the acoustic distribution.

The final step was to apportion the total survey abundance (which is output in 1dB size increments) into age 0, age 1 and age 2+ groups by using the acoustic fry cut-off and the trawl age 2 cut-off corrected to the acoustic scale. Where there was no visible fry cut-off on the acoustic distribution, we applied the trawl fry cut-off and no correction was applied to the trawl age 2 cut-off.

Biomass estimates for each survey were produced by multiplying the acoustic abundance for each age group by the mean weight for the corresponding age group derived from annual trawl data. Since age 2 and 3 fish were combined for an estimate of age 2+ abundance, the mean weight of combined age 2 and 3 fish was applied to estimate age 2+ biomass (see footnote 1). The total biomass for the survey was the sum of biomass estimates by age group.

Note that as a result of the new approach to estimating age structure, the biomass estimates in this report have been updated from those previously reported for Arrow Reservoir (Bassett *et al.* 2018b). Similarly, the in-lake hydroacoustic abundance

¹ The age 2+ group is dominated by age 2 Kokanee and included very few age 3 most years as the majority of age 3 Kokanee had left the reservoir to spawn prior to the October surveys. Further, the long-term trawl catch identifies that most years there are no age 3 captured in the trawl; see Appendix 8 for the long term timeseries of trawl catch by age and basin.

timeseries (age 0 and age 1-3) have undergone some adjustment as well as other data that rely on estimates of age structure such as cohort survival.

3. RESULTS

Arrow Lakes Reservoir Outflow

The average April to October mean daily outflow in Arrow Lakes Reservoir in 2019 was 881 m³/s, which was well below the both the long term 1997–2019 daily mean and the 2011-2019 daily mean (Figure 1). The average flow over the last nine years (2011-2019) is higher than the initial 14 years (1997-2010) (1195 m³/s and 1059 m³/s; respectively), though largely driven by high flows in 2012 and 2015, seven of nine years were above the long term (1997-2019) mean. The outflow in 2019 was at or lower than average except for late July where a spike of higher flows occurred for approximately a week (Figure 2). Flows decreased and were well below the 1997-2019 daily average in early September and remained low until end of October.

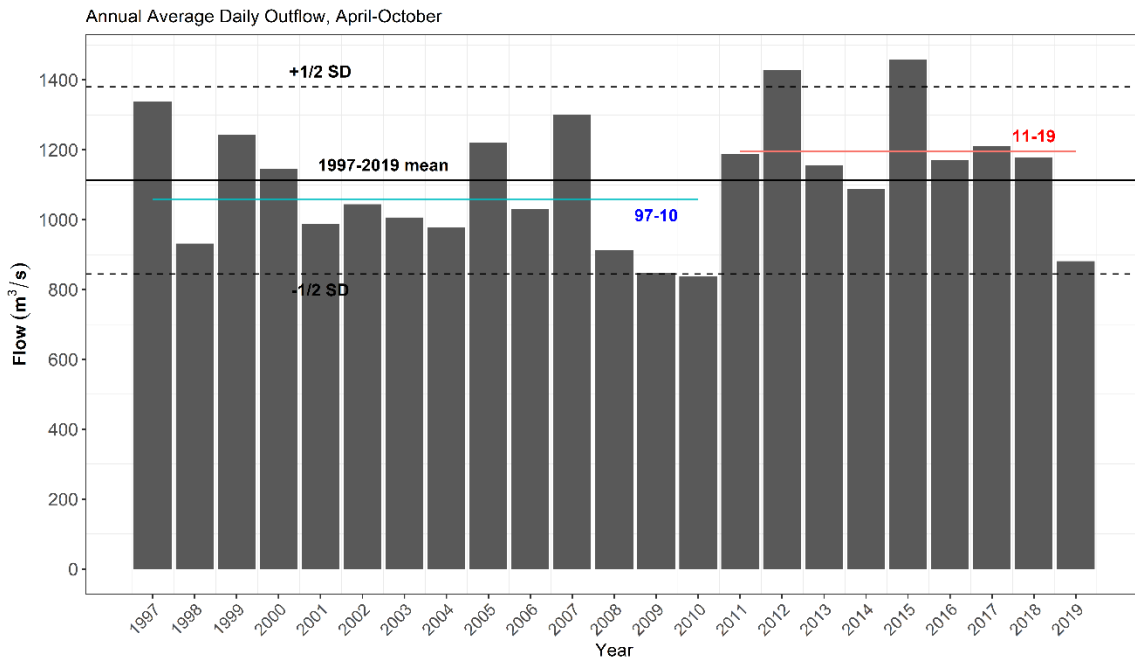


Figure 1. Arrow Lakes Reservoir April-October average daily outflow from Hugh Keenleyside Dam and Arrow Generating Station from 1997 to 2019 with long term mean (black solid line) ± 1/2 S.D (black dashed line). Long term means from 1997-2010 (blue solid line) and 2011-2019 (red solid line).

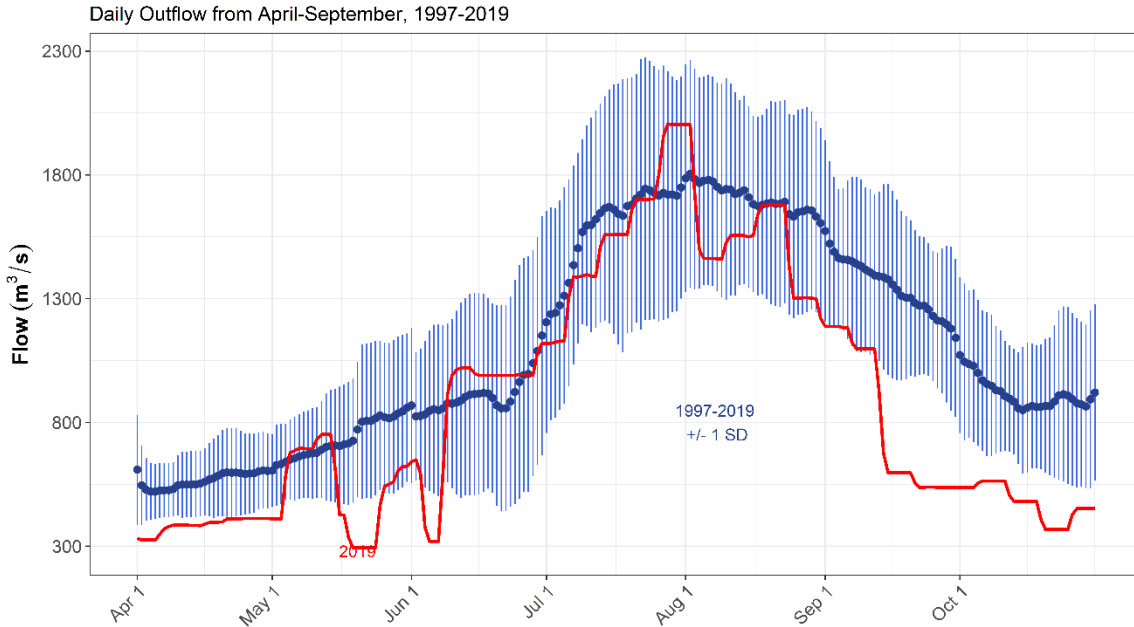


Figure 2. Arrow Lakes Reservoir April-October daily outflow 1997-2019. Blue circles are 1997–2019 daily average, blue vertical lines ± 1 standard deviation and red line is 2019 daily outflow.

Secchi

Secchi disc measurements in Arrow in 2019 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 (Figure 3). In general, the 2019 monthly basin means were close to the 1997-2018 monthly means, however, 2019 Secchi depths were lower (meaning less water clarity) for all basins in the summer, particularly late July to late August. In the Upper basin, Narrows and Lower basin, the Secchi depth means in 2019 were slightly below the long term means (Figure 4), meaning that water was slightly less clear than basin averages. The Secchi depths in 2019 were an increase from 2018, meaning that on average the water was clearer in 2019 than in 2018.

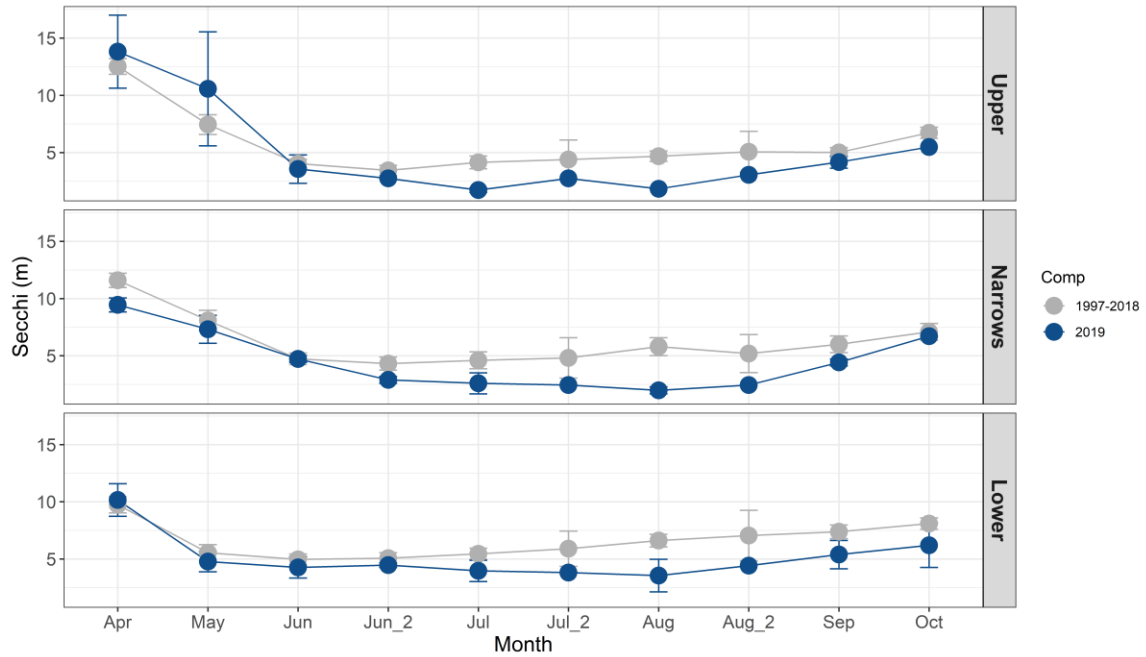


Figure 3. Arrow Secchi (m) monthly mean by basin (Upper, Narrow and Lower) 2019 (blue) and 1997–2018 (grey). Note: Jul_2 and Aug_2 sampling began in 2012. Means \pm SE.

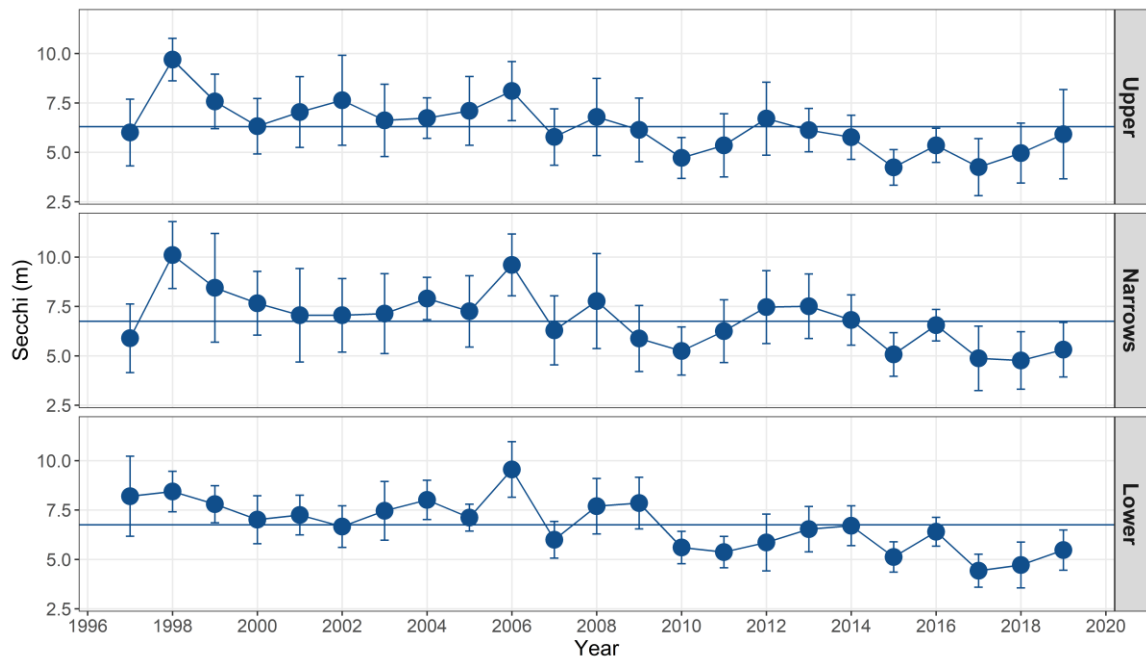


Figure 4. Arrow Secchi (m) annual mean (April – October) by basin (Upper, Narrows and Lower) 1997–2019. Means \pm SE. Solid lines indicate long term means by basin.

Water Chemistry - Integrated Epilimnion

Phosphorus

In Upper Arrow in 2019, the monthly mean total phosphorus (TP) generally followed the previous years (1997-2018) monthly patterns, aside from some higher observations in late June through to August (Figure 5). In Lower Arrow, the 2019 monthly means were close to the 1997-2018 monthly means, aside from some lower results in April through to early June (Figure 5). The annual mean for monthly TP values in 2019 for Upper Arrow was 3.8 $\mu\text{g/L}$, slightly above than the 1997–2018 mean of 3.5 $\mu\text{g/L}$. The mean TP for Lower Arrow was 2.8 $\mu\text{g/L}$, lower than the Lower Arrow basin 1997–2018 mean of 3.4 $\mu\text{g/L}$ (Figure 6). In Upper and Lower Arrow in 2019, the monthly means of total dissolved phosphorus (TDP) were uncoupled from the previous years (1997-2018) monthly means (Figure 7). In general, the 2019 TDP monthly values were lower than historic monthly values. The annual mean for monthly TDP values in 2019 for Upper Arrow was 2.2 $\mu\text{g/L}$, lower than the 1997–2018 mean of 2.5 $\mu\text{g/L}$, Lower Arrow was 2.0 $\mu\text{g/L}$, lower than the Lower Arrow basin 1997–2019 mean of 2.5 $\mu\text{g/L}$ (Figure 8).

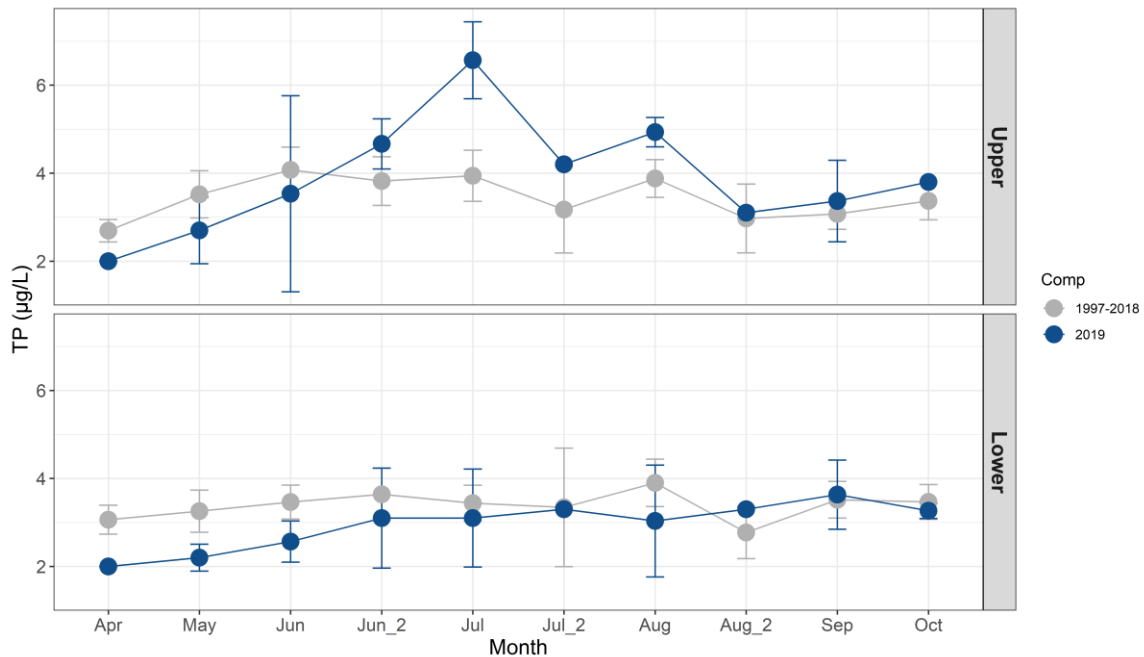


Figure 5. Arrow total phosphorus ($\mu\text{g/L}$) monthly mean by basin (Upper and Lower) 2019 (blue) and 1997–2018 (grey). Note: Jul_2 and Aug_2 sampling began in 2012. Means \pm SE.

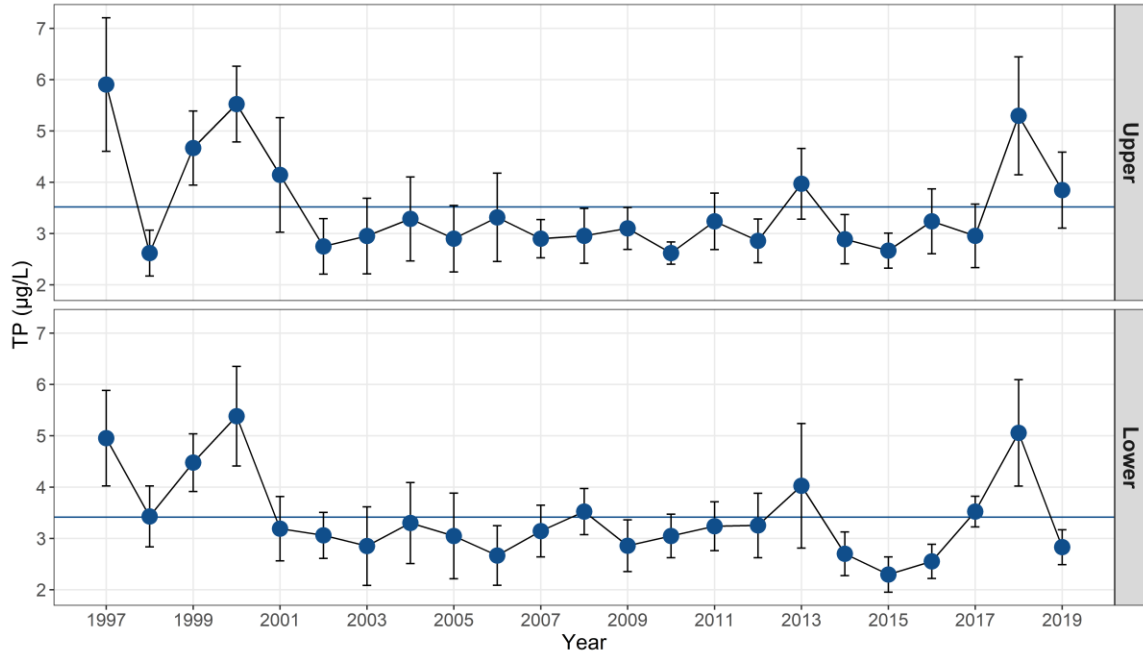


Figure 6. Arrow total phosphorus ($\mu\text{g/L}$) annual mean (April – October) by basin (Upper and Lower) 1997–2019. Means \pm SE. Solid lines indicate long term means by basin.

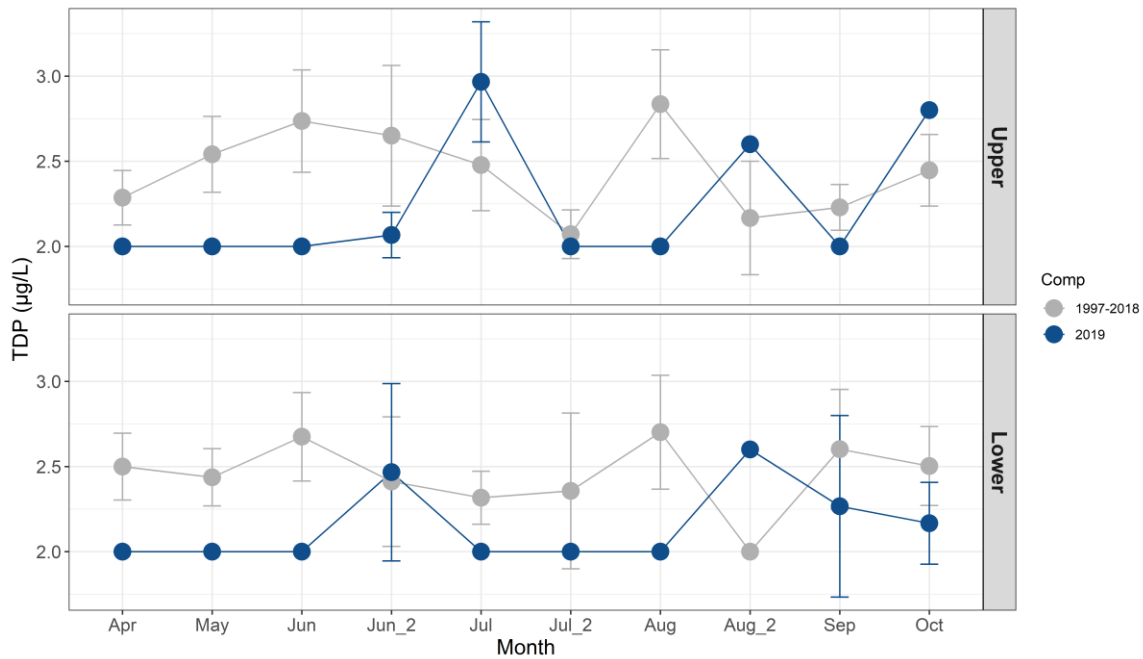


Figure 7. Arrow total dissolved phosphorus ($\mu\text{g/L}$) monthly mean by basin (Upper and Lower) 2019 (blue) and 1997–2018 (grey). Note: Jul_2 and Aug_2 sampling began in 2012. Means \pm SE.

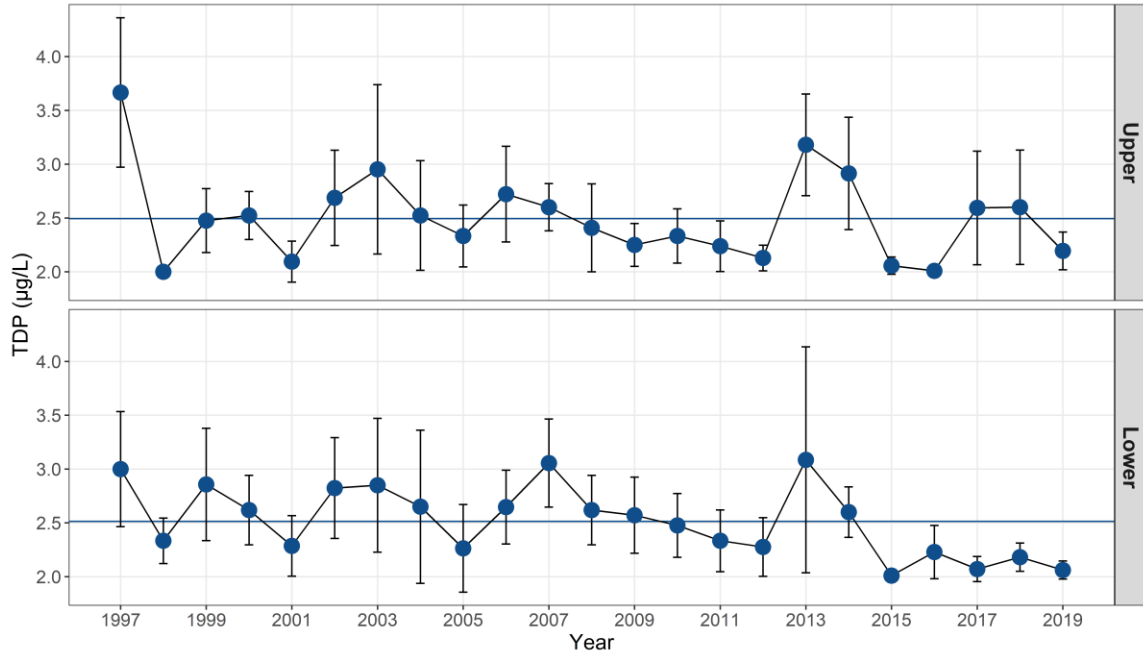


Figure 8. Arrow total dissolved phosphorus ($\mu\text{g/L}$) annual mean (April – October) by basin (Upper and Lower) 1997–2019. Means \pm SE. Solid lines indicate long term means by basin.

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. In both Upper and Lower Arrow, the 2019 TN monthly results were close to historic monthly observations, aside from lower values in 2019 in the spring, and to a less extent in the fall (Figure 9). High TN were observed in Lower Arrow in July, with decreasing values from north to south (data not shown). The annual mean for monthly TN values in 2019 for Upper Arrow was $159.5 \mu\text{g/L}$, lower than the 2004–2019 mean of $188.1 \mu\text{g/L}$. As was the case in Lower Arrow, where the 2019 mean ($132.9 \mu\text{g/L}$) was lower than the 2004–2019 mean ($160.1 \mu\text{g/L}$) (Figure 10). The dissolved component of nitrogen decreased through the 2019 season; a pattern typical of the historical data. However, in 2019, DIN was typically lower each month, particularly in Upper Arrow. Significantly low DIN values were observed in Lower Arrow (August in September), where at times the nitrate results were below RDL. In 2019, for both Upper and Lower Arrow, the annual mean was lower than the historic mean (Figure 11). These lower DIN results have been consistent since 2013 in Upper Arrow and 2015 in Lower Arrow.

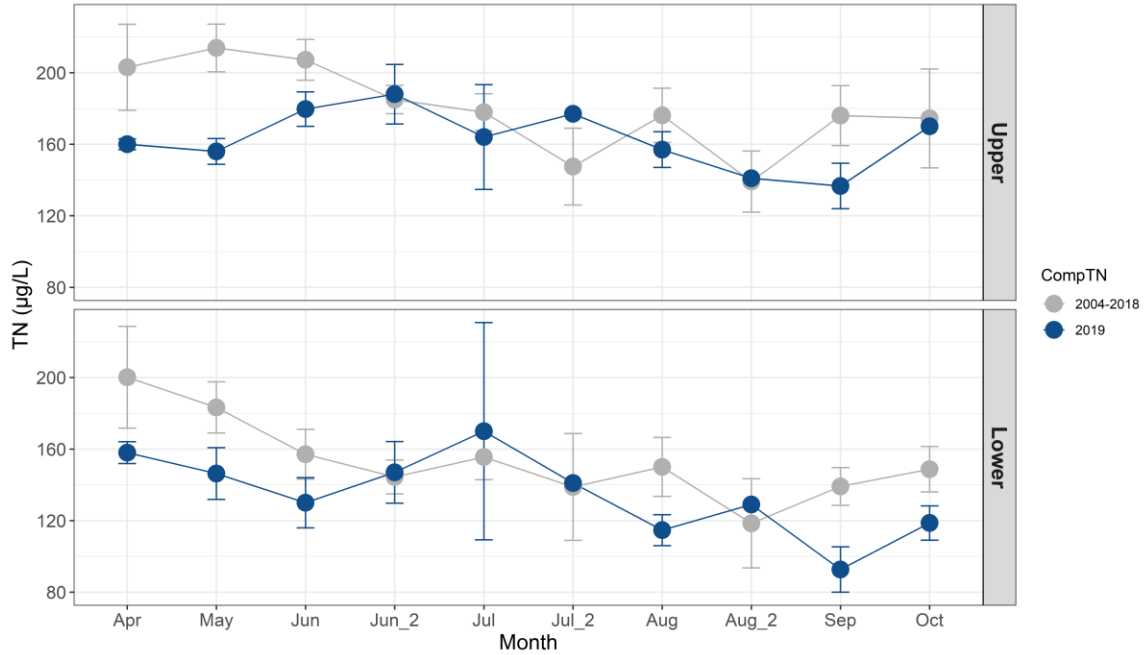


Figure 9. Arrow total nitrogen ($\mu\text{g/L}$) monthly mean by basin (Upper and Lower) 2019 (blue) and 1997–2018 (grey). Note: TN sampling began in 2004 and Jul_2 and Aug_2 sampling began in

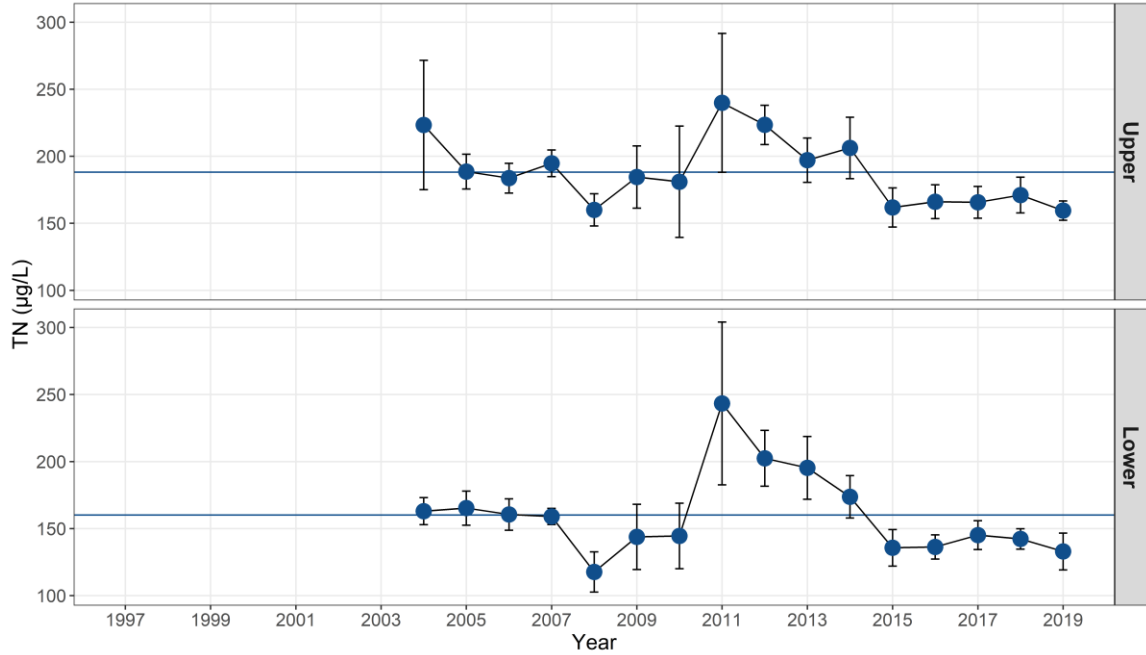


Figure 10. Arrow total nitrogen ($\mu\text{g/L}$) annual mean (April – October) by basin (Upper and Lower) 1997–2019. Means \pm SE. Solid lines indicate long term means by basin. Note: TN sampling began in 2004.

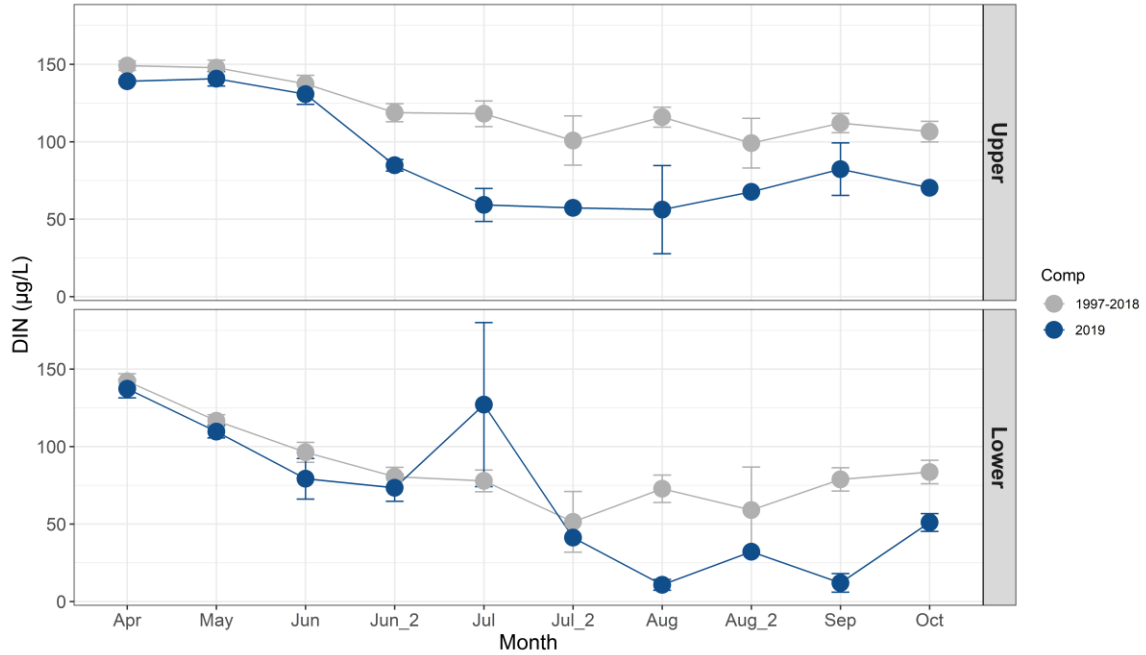


Figure 11. Arrow dissolved inorganic nitrogen ($\mu\text{g/L}$) monthly mean by basin (Upper and Lower) 2019 (blue) and 1997–2018 (grey). Note: Jul_2 and Aug_2 sampling began in 2012. Means \pm SE.

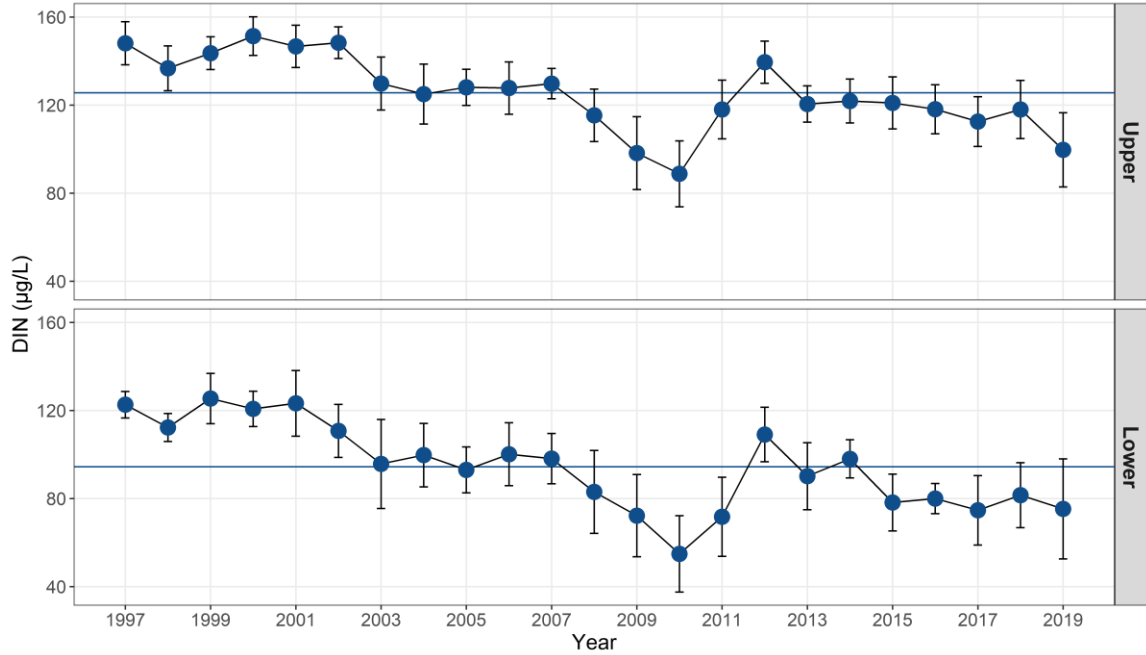


Figure 12. Arrow dissolved inorganic nitrogen ($\mu\text{g/L}$) annual mean (April – October) by basin (Upper and Lower) 1997–2019. Means \pm SE. Solid lines indicate long term means by basin.

Nitrogen: Phosphorus

The nitrogen to phosphorus (NP) ratio in 2019 was generally lower each month than the historic monthly means particularly in Lower Arrow (Figure 13). This was strongly driven by the low nitrate values. The NP ratios were at nitrogen limitation (<14) in Lower Arrow in August and September (data not shown). The annual mean for monthly N:P ratios in 2019 for Upper Arrow was 47.8, which was slightly lower than the 1997–2019 mean of 54.6. Lower Arrow was 37.3 and near the Lower Arrow basin 1997–2018 mean of 40.6 (Figure 14).

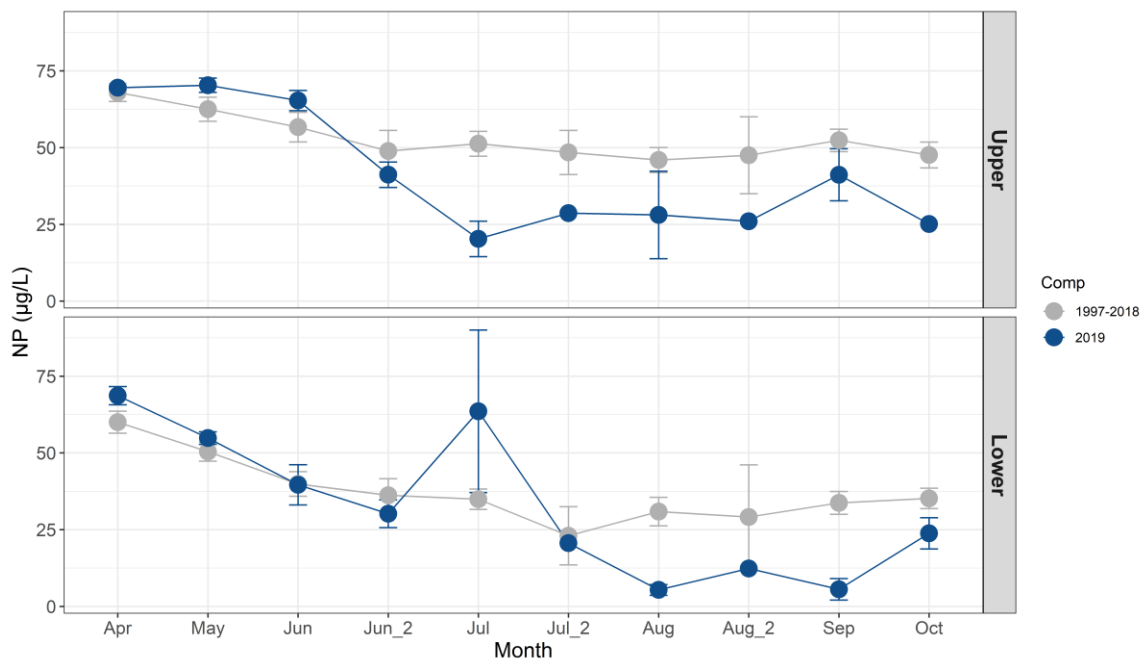


Figure 13. Arrow nitrogen:phosphorus ratio (dissolved, weight:weight) monthly mean by basin (Upper and Lower) 2019 (blue) and 1997–2018 (grey). Note: Jul_2 and Aug_2 sampling began in 2012. Means \pm SE.

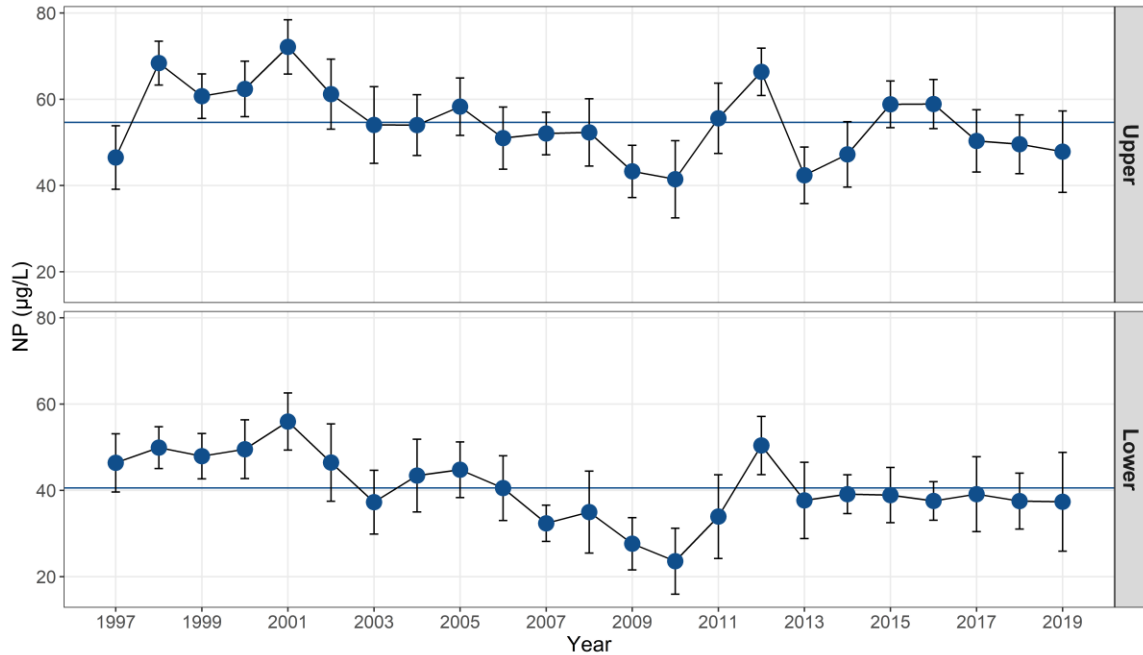


Figure 14. Arrow nitrogen:phosphorus ratio (dissolved, weight:weight) annual mean (April – October) by basin (Upper and Lower) 1997–2019. Means \pm SE. Solid lines indicate long term means by basin.

Phytoplankton

Phytoplankton abundance follows a seasonal pattern of increasing into the summer months and then decreasing into the fall. In 2019, phytoplankton abundances followed this pattern, however were lower in May, September and October for all three basins (Figure 15). Overall in 2019, in all three basins, the annual average was below the long-term average (Figure 16). The 2019 results were compared to 2018 in Upper Arrow May, September and October to obtain a year to year comparison. The decrease in abundance in 2019 compared to 2018 results were as follows: lower Chrysocryptophytes for all three months, lower abundance of Bacillariophytes in May, and lower Cyanophytes for all three months (data on file, FLNRORD).

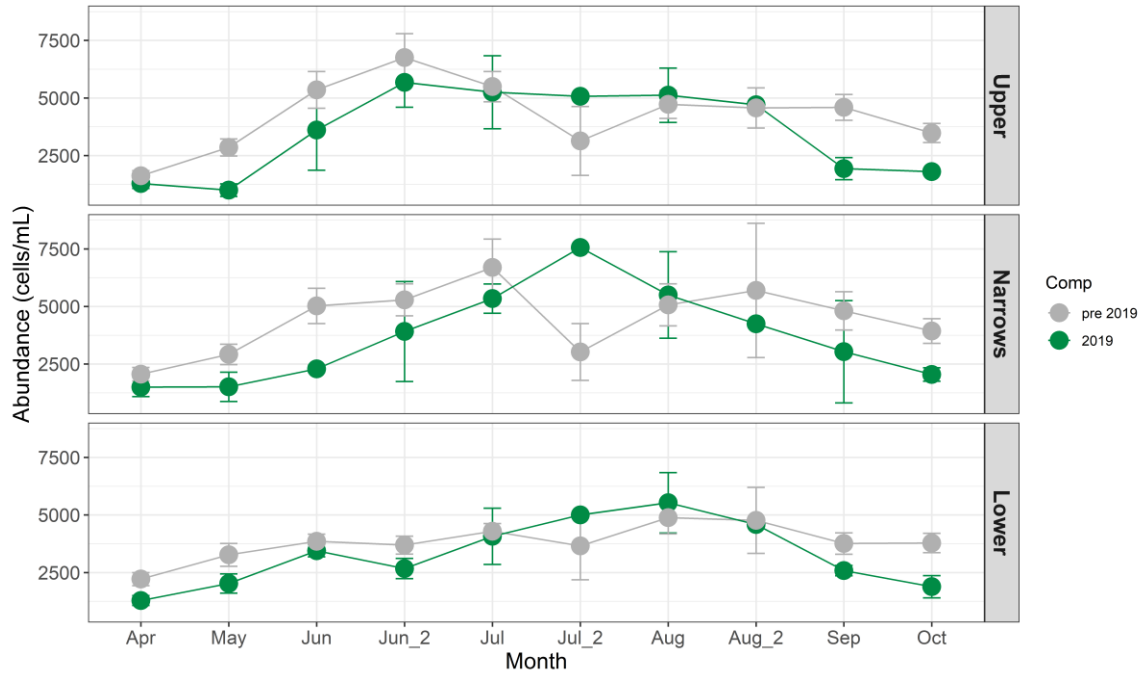


Figure 15. Arrow phytoplankton abundance monthly mean by basin (Upper, Narrows and Lower) 2019 (green) and 1998–2018 (grey). Note: Jul_2 and Aug_2 sampling began in 2012. Means \pm SE.

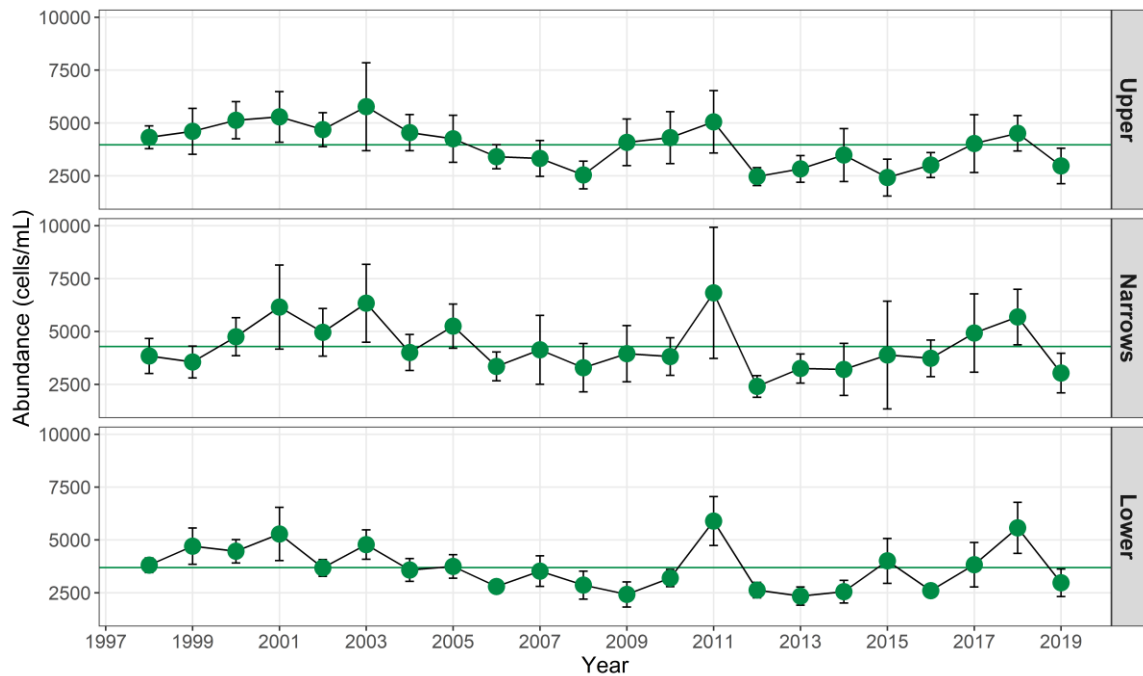


Figure 16. Arrow phytoplankton abundance (cells/ml) annual mean (April – October) by basin (Upper, Narrows and Lower) 1998–2019. Means \pm SE. Solid lines indicate long term means by basin.

Zooplankton

The timing of the appearance of *Daphnia* (the preferred food source to Kokanee) sufficient for Kokanee forage (>0.4 ind/L; Scheuerell *et al.* 2005) was delayed in 2019 in both Upper and Lower Arrow compared to the long term mean (Figure 17). Densities greater than 0.4 ind/L were first observed in Upper Arrow in 2019 in September (mean = August) and in Lower Arrow in 2019 was September, (mean= July) (Figure 18). In Lower Arrow, this is the latest appearance of *Daphnia* in the history of the NRP. The lower densities in July and August, and seasonally late appearances both contributed the lower overall annual biomass in both Upper and Lower Arrow in 2019 (Figure 19). In summary, 2019 was a low-density year, with late emergence of *Daphnia*.

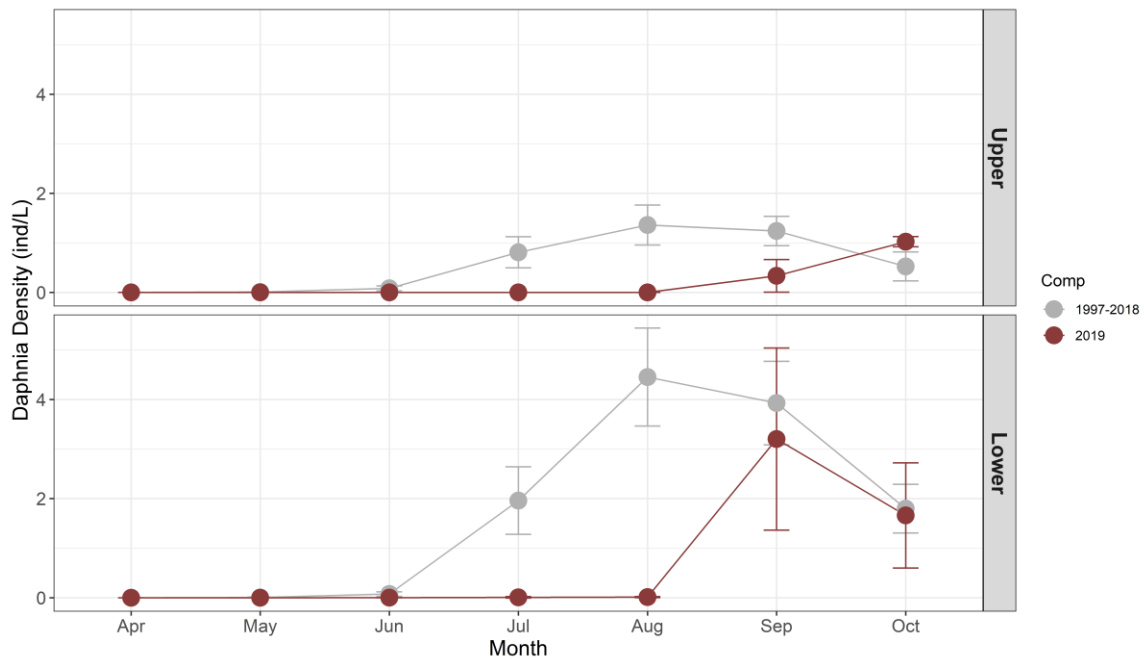


Figure 17. *Daphnia* density (ind/L) monthly mean by basin (Upper and Lower) 2019 (brown) and 1997–2018 (grey) for Arrow Lakes Reservoir. Means \pm SE.

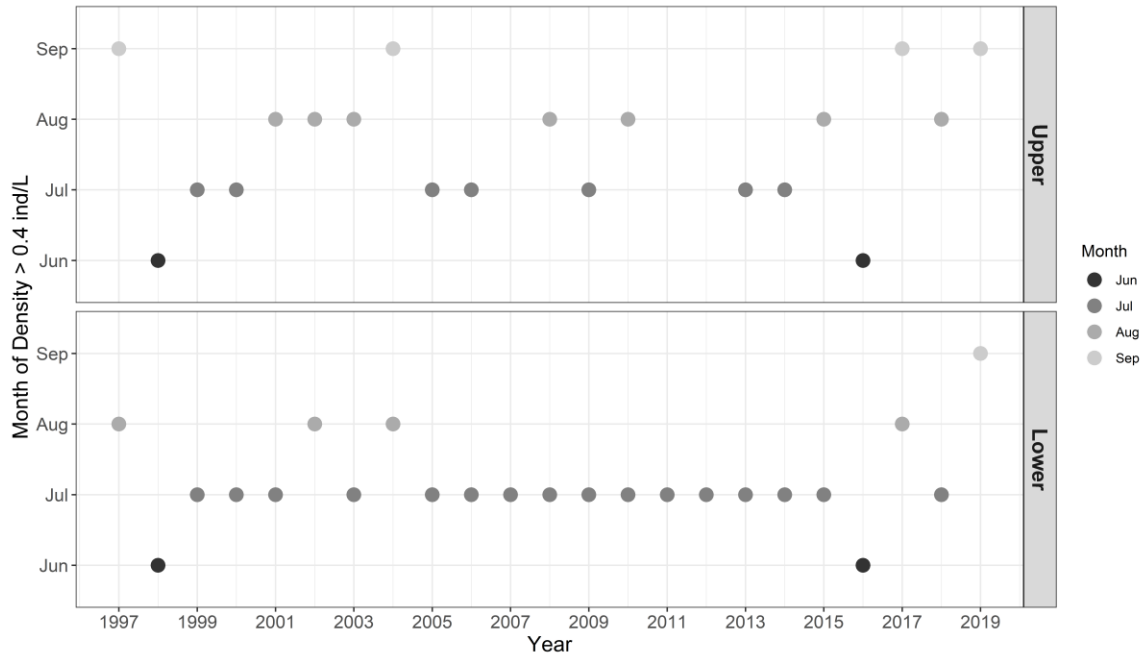


Figure 18. The first month of the year when *Daphnia* densities were greater than or equal to 0.4 ind/L, by basin (Upper and Lower) for Arrow Lakes Reservoir.

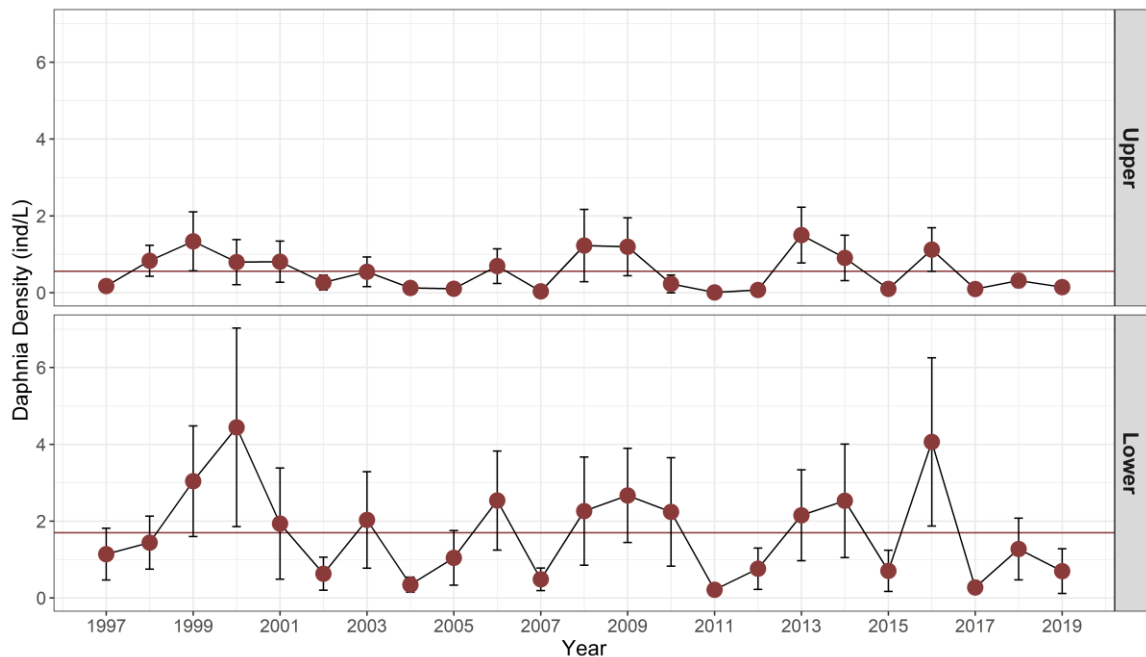


Figure 19. *Daphnia* density (ind/L) annual mean (April – October), by basin for Arrow Lakes Reservoir. Means \pm SE. Solid lines indicate long term means by basin.

Mysids

In 2019, the annual seasonal mean of mysid density was above average in Upper Arrow, and near average in Lower Arrow (Figure 20). The seasonal trend of developmental stages is a pulse of juveniles, then immature individuals, and lastly mature individuals, with overall densities decreasing moving up in maturity (Figure 21). This trend was generally observed in 2019. In Upper Arrow, most individuals were juveniles, and peaked in July, slightly later than in previous years.

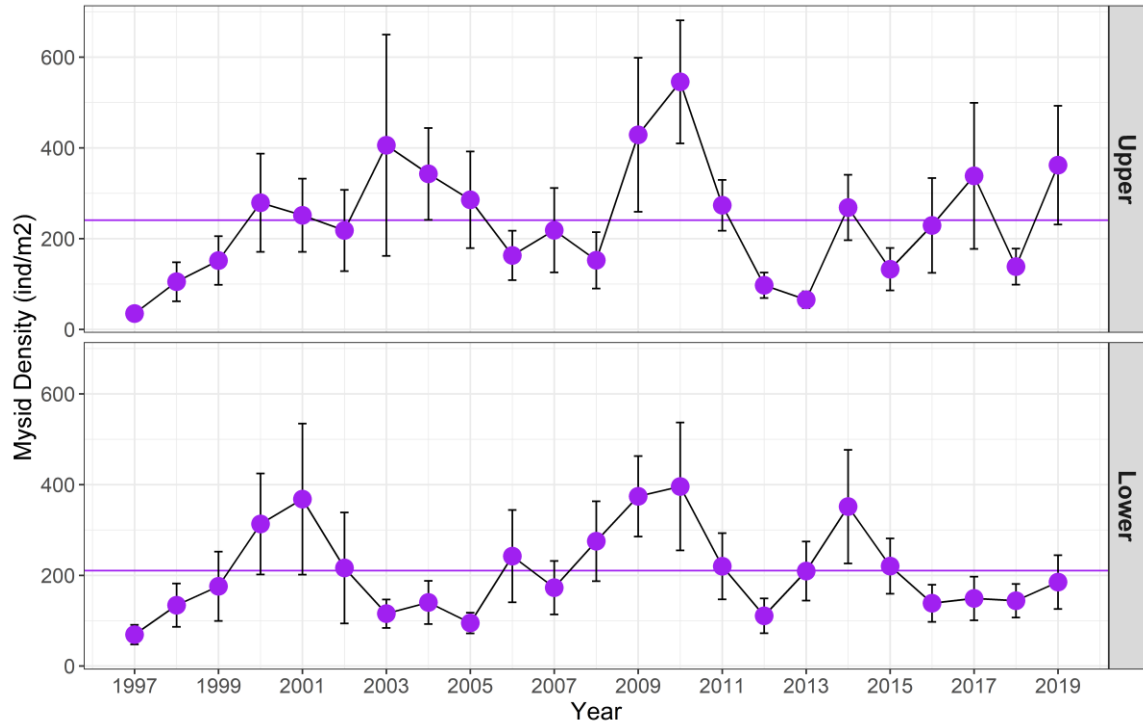


Figure 20. Arrow Mysid density (ind/m²) annual mean (April – October), by basin. Horizontal lines are the basin means for the time series (1997-2019).

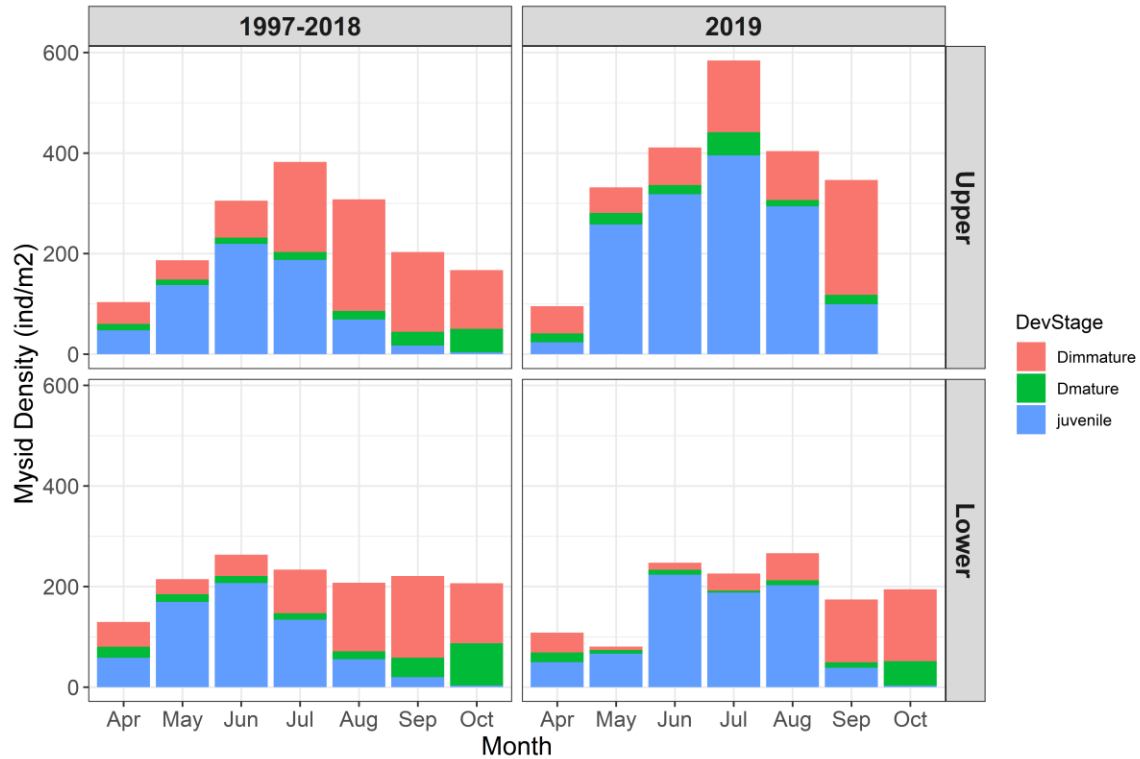


Figure 21. Arrow Mysid density (ind/m²) monthly mean of developmental stage (juvenile, mature and immature individuals) by basin (Upper and Lower) and years (1997-2018 and 2019). Note. No October sampling occurred in 2019 in Upper Arrow.

Kokanee

Pool elevation during the September 27-29, 2020 survey period averaged 435 m (5.2 m below full pool). The total area of pelagic habitat (defined as >20 m depth) was estimated at 19,739 ha in Upper Arrow and 9,740 ha in Lower Arrow (Appendix 6), which were similar to the long-term averages for fall surveys.

Trawl catch

A total of 119 Kokanee were captured at the six standard trawl stations in 2019; 85 from Upper Arrow and 34 from Lower Arrow (Table 4). The Upper Arrow trawl catch was 36, 30, and 19 for ages 0, 1, and 2, respectively. In Lower Arrow, the trawl sampling captured 5, 22, and 7 for ages 0, 1, and 2, respectively. The total combined basin fry catch of 41 was among the lowest on record, and the catch of only 5 fry for Lower Arrow was the lowest on record. The long term timeseries for catch by age by basin is presented in Appendix 8.

Table 4. Kokanee catch statistics from the trawl surveys in October 2019. See Appendix 3 for station locations.

| Basin | Station | Hauls | age 0 | age 1 | age 2 | age 3 | Total |
|--------------------|-----------------------|-----------|-----------|-----------|-----------|----------|------------|
| Upper Arrow | T1 (AR1) Albert Pt. | 3 | 28 | 7 | 1 | 0 | 36 |
| | T2 (AR2) Halfway R. | 3 | 4 | 5 | 9 | 0 | 18 |
| | T3 (AR3) Nakusp | 3 | 4 | 18 | 9 | 0 | 31 |
| | <i>Total of Upper</i> | <i>12</i> | <i>36</i> | <i>30</i> | <i>19</i> | <i>0</i> | <i>85</i> |
| Lower Arrow | T6 (AR6) Johnston Cr. | 4 | 1 | 10 | 0 | 0 | 11 |
| | T7 (AR7) Bowman Cr. | 3 | 2 | 7 | 7 | 0 | 16 |
| | T8 (AR8) Cayuse Cr. | 3 | 2 | 5 | 0 | 0 | 7 |
| | <i>Total of Lower</i> | <i>13</i> | <i>5</i> | <i>22</i> | <i>7</i> | <i>0</i> | <i>34</i> |
| Total Arrow | Both basins | 25 | 41 | 52 | 26 | 0 | 119 |

Kokanee length and age

Kokanee size statistics for trawl caught fish are presented in Table 5. In Upper Arrow the average fork length adjusted to October 1 was 52 mm for age 0, 141 mm for age 1 and 189 mm for age 2 fish. In Lower Arrow the average fork was 55 mm for age 0, 150 mm for age 1, and 209 mm for age 2 fish. Note that at the time of reporting the scale ageing had not been completed; the ages for trawl captured fish in 2019 are based on length frequency and considered preliminary.

Table 5. Kokanee size statistics from the September 2019 trawling at Arrow Lakes Reservoir. Fish fork lengths 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 |
|----------------|-------|-------------------------|-------|--------|---------|
| September 2019 | Upper | Ave. length (mm) | 52 | 141 | 189 |
| | | Length range (mm) | 41–66 | 91–155 | 181–197 |
| | | Standard deviation (mm) | 6.0 | 14.9 | 4.6 |
| | | Sample size | 36 | 30 | 19 |
| September 2019 | Lower | Ave. length (mm) | 55 | 150 | 209 |
| | | Length range (mm) | 48–71 | 91–173 | 190–220 |
| | | Standard deviation (mm) | 9.3 | 25.6 | 11.2 |
| | | Sample size | 5 | 22 | 7 |

Average Kokanee fork length (upper and lower basins combined) decreased for all in-lake age classes as well as spawners in 2019 relative to 2018 (Figure 22). Age 0 Kokanee fork length was the second lowest on record at 52 mm, which was well below the post-NRP average fork length of 60 (± 1.9) mm. Age 1 fork length was 145 mm which was similar to the post-NRP average of 146 (± 18.3) mm. Age 2 fork length was 194 mm which was

smaller than the post-NRP average of 201 (± 9.7) mm. Mean spawner length was 222 mm, also smaller than the post-NRP average of 244 (± 13.5) mm. The spawner values presented in Figure 22 are averages of all age classes of spawners each year.

Kokanee spawner age structure in 2019 was 17% age 2, 80% age 3 and 3% age 4, which was similar to the post-NRP average of 30% age 2, 59% age 3, and 11% age 4 (Appendix 9).

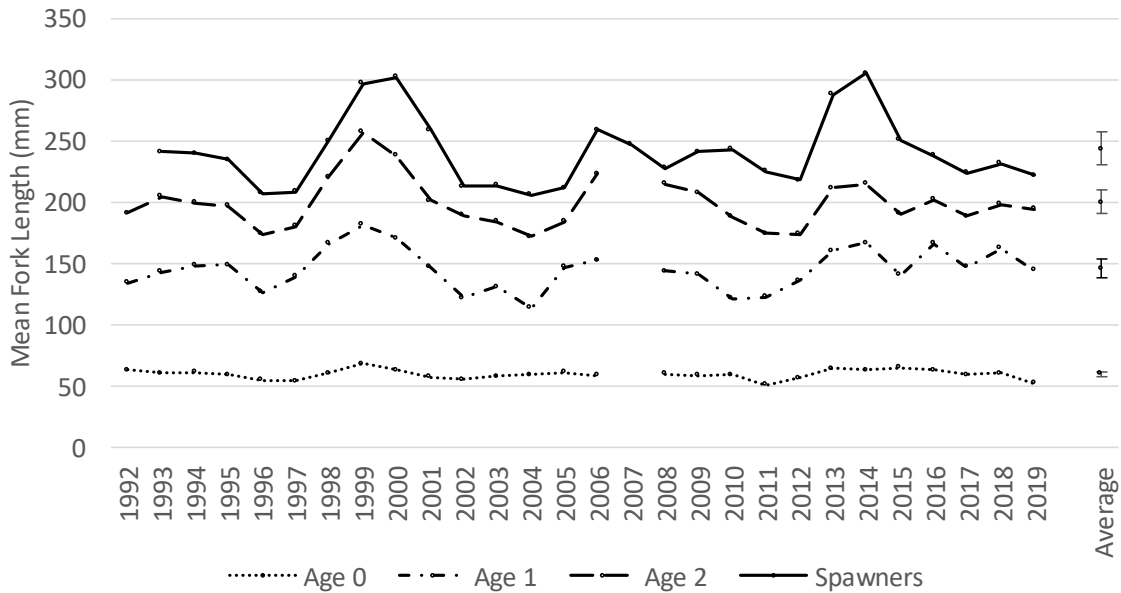


Figure 22. Trends in annual average fork lengths for Arrow Lakes Reservoir Kokanee captured by trawl (age 0-2) and spawners measured at Hill Creek Spawning Channel. The post-NRP (1999-2019) average size is presented (± 2 S.E.). Trawl captured Kokanee fork lengths were adjusted to an October 1 standard using empirical growth data from Rieman and Myers (1992).

Spawning Escapement

A return of 129,766 spawners to Hill Creek in 2019 represented 83% of average for the nutrient addition period and was similar to the 2018 escapement of 133,714 (Figure 23). A return of 34,611 spawners to all other index tributaries in Upper Arrow in 2019 represented 126% of the post-NRP average and was higher than the 2018 return of 21,158 to these same tributaries.

Spawner returns to Lower Arrow were relatively stable from 2013 to 2016 at approximately 100,000 Kokanee. In 2017, escapement more than tripled to ~350,000 spawners, before decreasing again to 90,608 in 2018. The 2019 return to Lower Arrow

index tributaries increased to 142,510, which was 74% of the post-NRP average (Figure 23). The sum of both Upper and Lower Arrow total returns (i.e., index plus other tributaries) of 306,877 spawners in 2019 was 82% of the post-NRP average.

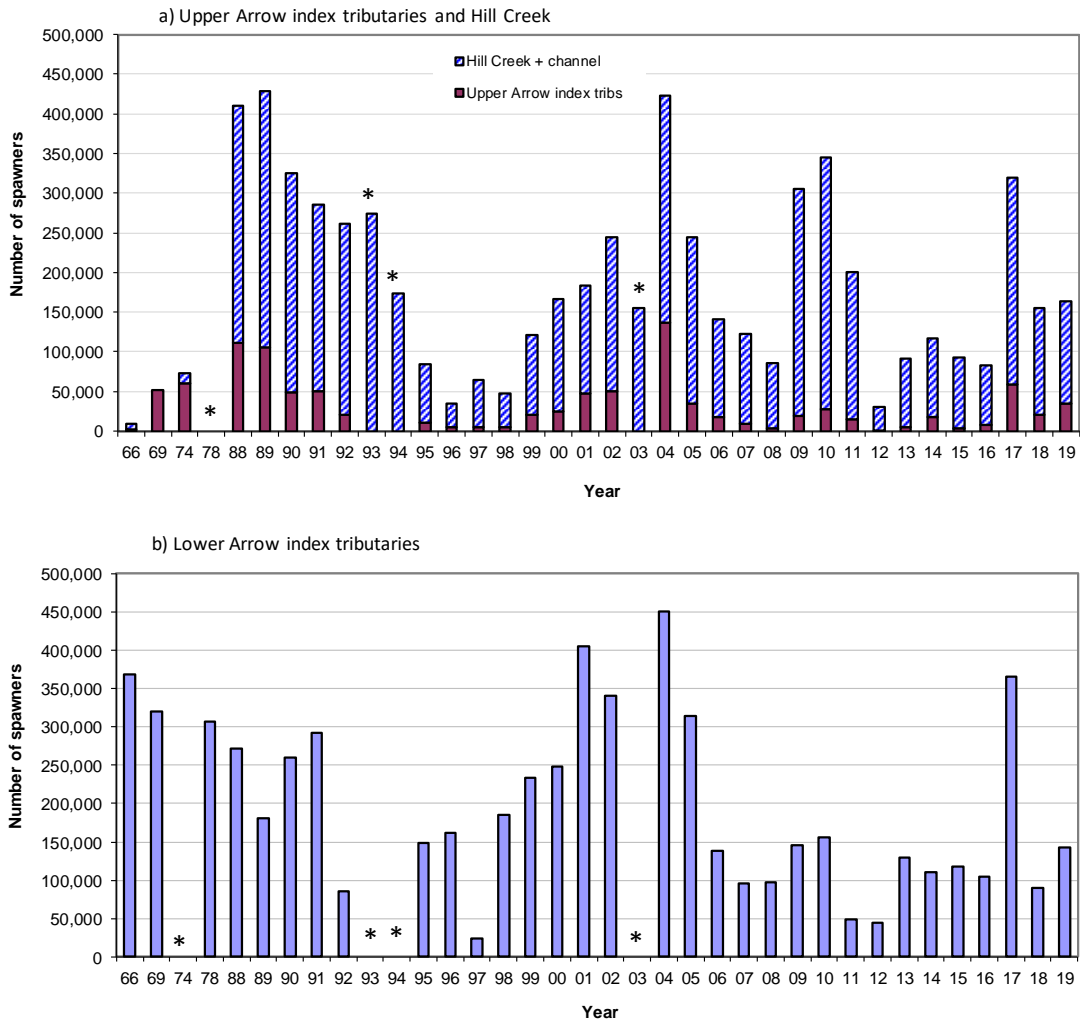


Figure 23. Trends in Kokanee spawner returns to: a) Hill Creek and Spawning Channel and three key index streams (Drimmie, Halfway and Kuskanax) in the Upper Arrow, and; b) four index streams (Burton/Snow, Caribou, Deer and Mosquito) in Lower Arrow Reservoir during 1966, 1969, 1974, 1978 and 1988–2019. 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 1974 (Lower), 1978 (Upper) 1993, 1994 & 2003.

In-lake Abundance

Annual hydroacoustic estimates for Kokanee during fall surveys have ranged from \approx 5-22 million and averaged 9.8 million since nutrient additions began in 1999. The 2019 total Kokanee abundance estimate for both basins combined was among the lowest post-NRP at 4.8 (3.9-5.7) million fish. The age 0 and age 1-3 Kokanee populations for both basins combined were also among the lowest post-NRP, at 3.6 (2.9-4.3) million and 1.2 (1.0-1.4) million respectively. The maximum likelihood estimates, and associated statistics are presented in Appendix 7 for combined basin estimates as well as basin specific estimates.

The 2019 Kokanee age 0 population in Upper Arrow was 2.7 (2.0-3.4) million (Figure 24a), down slightly from the 2018 estimate of 3.2 million and well below the post-NRP average of 4.8 million. Upper Arrow age 1–3 Kokanee were estimated at 0.6 (0.5-0.8) million, which was also down from 2018 and well below the post NRP average of 1.4 million.

In Lower Arrow, the 2019 age 0 population was 0.9 (0.7-1.2) million (Figure 24b), which was the lowest estimate post-NRP and only 34% of average. Lower Arrow age 1–3 Kokanee were estimated at 0.5 (0.4-0.7) million, which was up from the very low estimate of 0.4 million in 2018 but still only 60% of the post NRP average of 0.9 million.

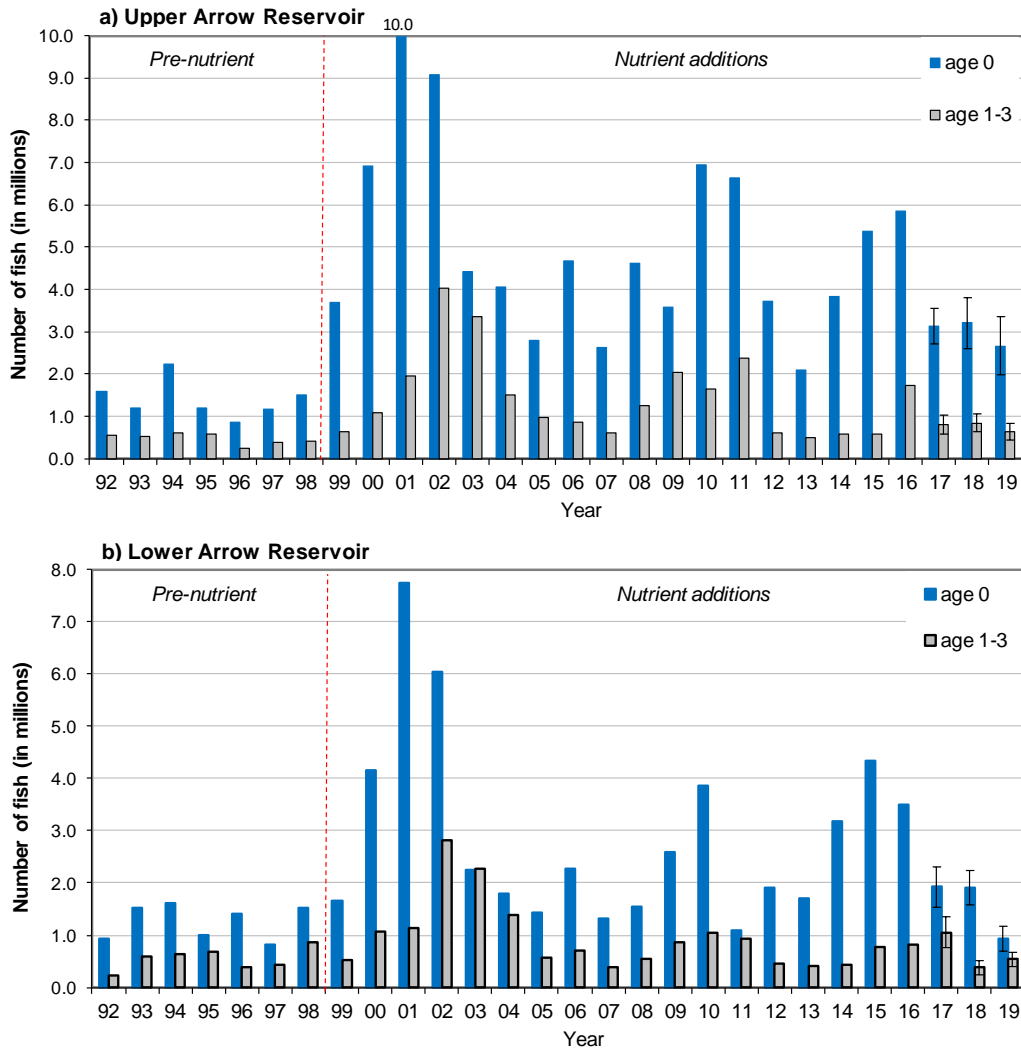


Figure 24. Age 0 and age 1–3 Kokanee abundances with 95% confidence intervals based on fall hydroacoustic surveys for a) Upper Arrow, and b) Lower Arrow Reservoir. These datasets have been recently revised from those previously reported (i.e., Bassett *et al.* 2018b), and confidence intervals were not reproduced prior to 2017.

Biomass

Prior to nutrient additions, biomass density averaged 1.3 kg/ha in Upper Arrow and 3.6 kg/ha in Lower Arrow over 7 years of acoustic surveys (1992-1998). Average Kokanee biomass during the nutrient addition era (post-NRP) increased to 3.9 kg/ha (2.9 times pre-NRP) in Upper Arrow and to 5.7 kg/ha (1.6 times pre-NRP) in Lower Arrow (Figure 25).

Similar to spawner numbers shown above (Figure 23), Kokanee biomass was very low in both basins in 2012 (Figure 25). Biomass increased over the next 2 years but then declined

slightly in 2015 in Upper Arrow due to the weak cohort of age 2 Kokanee (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 6.6 kg/ha in Upper Arrow and 6.8 kg/ha in Lower Arrow, well above the post-NRP averages and the highest estimates since 2003 for both basins. The high in-lake biomass in 2016 translated to an exceptional spawner escapement in 2017 (Figure 23 above). However, despite a wide range of spawner numbers since 2016 fry abundance has been low since 2017 (Figure 24 above), resulting in successive weak cohorts for all age classes by 2019. The low abundance in combination with below average size at age (Figure 22 above) resulted in very low in-lake biomass in 2019. Upper Arrow Kokanee biomass density was only 1.6 kg/ha in 2019, which was among the lowest post-NRP and only slightly above the pre-NRP average. Lower Arrow Kokanee biomass density was also very low in 2019 at 3.3 kg/ha, although it was up slightly from a post NRP low in 2018. Appendix 10 identifies the biomass density estimates by age class across all years.

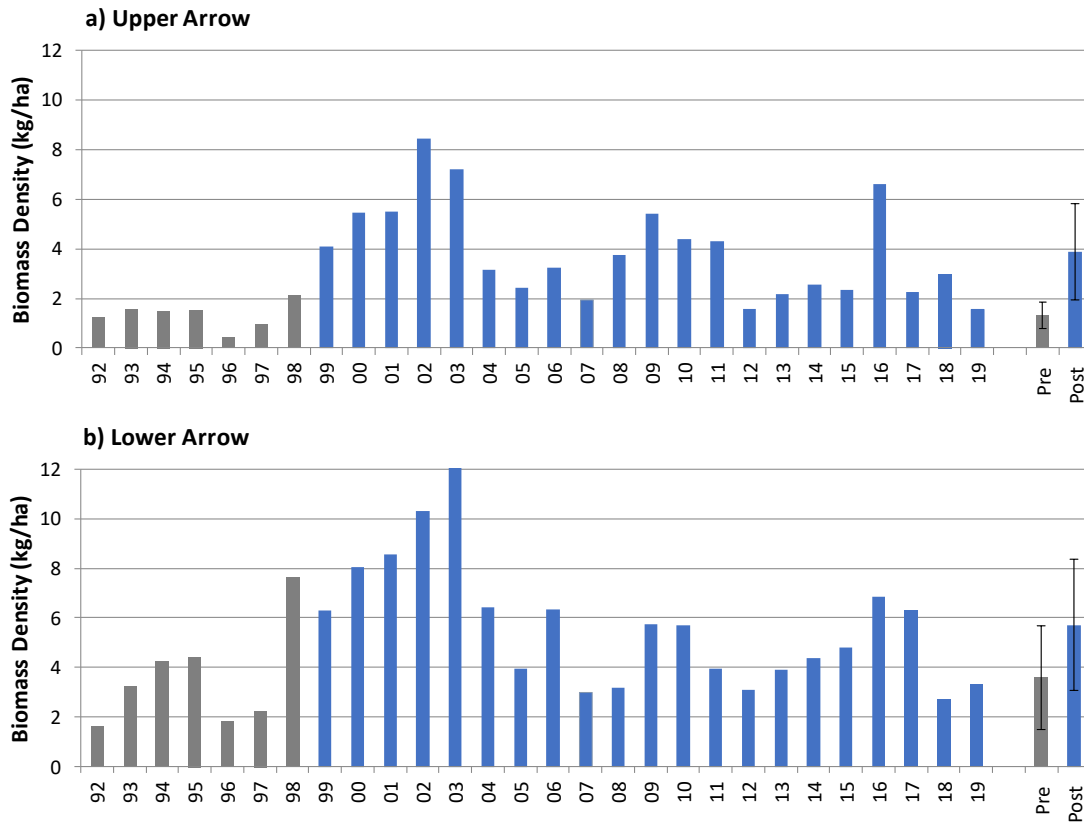


Figure 25. In-lake biomass density (kg/ha) trends for Kokanee in a) Upper Arrow and b) Lower Arrow reservoirs based on fall acoustic and trawl survey data from 1992-2019. Error bars on pre- and post-nutrient averages denote era standard deviation.

Hill Creek production

Current operational objectives, in place since 2014 for the Hill Creek Spawning Channel (HCSC), are aimed at maintaining channel fry production near 3.8 million/yr². This target was based on the median (excluding five outlier years of low (2) and high (3) abundance) fry output between 1984 and 2013. From 2013 to 2019 the proportion of fish allowed access into the spawning channel was reduced to an average of 42% of the run compared to an average of 80%³ of the run from 1999-2012. In 2018, the egg deposition estimate for the spawning channel was 5.59 million based on 21,591 females in the channel with a net fecundity of 259 eggs/female (

Table 6). The 2018 channel spawners produced 3.26 million fry in the spring of 2019, slightly below the target of 3.8 million. In 2019, 26,515 females were allowed into the spawning channel to account for a decrease in fecundity to 242 (net 238) eggs/female. The resulting egg deposition for the fall of 2019 was estimated at 6.31 million.

² The annual spawning channel egg deposition target is determined by dividing the target of 3.8 million fry by the 3-yr rolling egg-emigrant fry survival average. The egg target, in conjunction with in-season fecundity data measured near the start of the return at the channel fence allows for calculation of the annual channel spawner target.

³ The period from 2009-2011 was unique in that Kokanee returning to Hill Creek were allowed unrestricted access to the spawning channel to test the channel fry production capacity. Over those three years an average of 84% of the Hill Creek returns spawned within the spawning channel, similar to the long-term average proportion to that point (1999-2008) of 79%.

Table 6. Kokanee production statistics for Hill Creek spawning channel 1987–2019. The number of kokanee spawners allowed in the channel were capped during 1988 to 1994 and 2013 to 2019. Data courtesy of Steve Arndt, FLNRORD.

| Spawning year | Spawners ¹ | Mean Fecundity | Egg Retention | Females ² (%) | Egg Deposition ³ (millions) | Fry emigration ⁴ (millions) | Egg-to-fry survival (%) |
|-------------------|-----------------------|----------------|---------------|--------------------------|--|--|-------------------------|
| 1987 | 73,437 | 313 | 11 | 45 | 9.92 | 4.36 | 44 |
| 1988 | 150,000 | 240 | 7 | 39 | 13.8 | 7.92 | 57 |
| 1989 | 150,000 | 211 | | 51 | 15.7 | 5.76 | 37 |
| 1990 | 180,000 | 212 | | 35 | 12.4 | 5.49 | 44 |
| 1991 | 75,000 | 218 | | 49 | 7.57 | 2.87 | 38 |
| 1992 | 75,000 | 262 | 11 | 69 | 8.63 | 3.00 | 35 |
| 1993 | 75,000 | 254 | 8 | 52 | 8.54 | 3.43 | 40 |
| 1994 | 75,000 | 302 | 18 | 51 | 9.41 | 2.22 | 24 |
| 1995 | 16,328 | 280 | 9 | 51 | 2.26 | 0.68 | 30 |
| 1996 | 25,030 | 173 | 9 | 52 | 2.15 | 0.69 | 32 |
| 1997 | 22,566 | 182 | | 50 | 1.99 | 0.93 | 47 |
| 1998 | 19,087 | 226 | 9 | 44 | 1.81 | 0.86 | 47 |
| 1999 | 78,024 | 394 | 6 | 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 ⁵ | 199,820 | 189 | 4 | 45 | 9.53 | 0.27 | 2.8 |
| 2005 | 142,755 | 214 | 5 | 48 | 12.99 | 4.66 | 36 |
| 2006 | 92,567 | 240 | 6 | 50 | 10.21 | 5.46 | 52 |
| 2007 | 97,731 | 228 | 4 | 46 | 10.07 | 6.96 | 69 |
| 2008 | 72,068 | 236 | 5 | 38 | 6.41 | 3.76 | 59 |
| 2009 | 241,508 | 259 | 7 | 50 | 30.07 | 20.05 | 67 |
| 2010 | 267,243 | 272 | 7 | 43 | 30.35 | 17.46 | 57 |
| 2011 | 155,405 | 266 | 5 | 44 | 17.88 | 11.05 | 62 |

| | | | | | | | |
|-------------------|---------|-----|---|----|-------|------|----|
| 2012 ⁵ | 24,342 | 255 | 5 | 45 | 2.85 | 2.04 | 71 |
| 2013 ⁶ | 43,521 | 252 | 3 | 47 | 5.85 | 3.63 | |
| 2014 | 33,812 | 436 | 5 | 42 | 6.01 | 4.64 | 77 |
| 2015 | 42,568 | 314 | 5 | 42 | 5.42 | 4.44 | 82 |
| 2016 | 41,344 | 283 | 4 | 49 | 4.51 | 2.57 | 57 |
| 2017 | 47,762 | 235 | 4 | 45 | 5.26 | 3.33 | 63 |
| 2018 | 55,087 | 264 | 5 | 50 | 5.59 | 3.26 | 58 |
| 2019 | 63,030 | 242 | 4 | 43 | 6.31 | | |
| NRP Average | 105,208 | 280 | 5 | 45 | 11.88 | 5.91 | 50 |

¹ Refers only to fish in spawning channel

² Measured from sampling at spawning channel but may be different than actual proportion in channel

³ Potential egg deposition = no of channel females x (fecundity - retention)

⁴ Fry emigration from following spring sampling (excludes non-channel fry production)

⁵ Measured sex ratios in 2004 and 2012 were considered unreliable so average was used

⁶ 2013 spawner numbers and egg deposition were back calculated from fry emigration estimate (Arndt and Barney, 2014)

Kokanee survival

Egg to fall fry

The relationship between egg deposition and egg to fall fry survival during the post-NRP period suggests that egg density explains 57% of the variability in survival to fall fry in Arrow Reservoir (Figure 26). Twenty-four million eggs spawned in the fall of 2016 survived at a rate of 21% to fall fry in 2017, lower than the 26% survival predicted by the regression model (Figure 26, Table 7). In 2017, the high return of spawners deposited 57 million eggs however the survival to fall fry was only 9%, also below the predicted rate of 15%. The result was a fall fry estimate in 2018 that was well below average and similar to the estimate in 2017 (5.1 million). In the fall of 2018, 25 million eggs were deposited, and survival fell even further from the predicted rate at 14% observed compared to 26% predicted. The combination of relatively low egg deposition and very poor survival resulted in the lowest fall fry population since the onset of the NRP at only 3.6 million in 2019 for the combined basins.

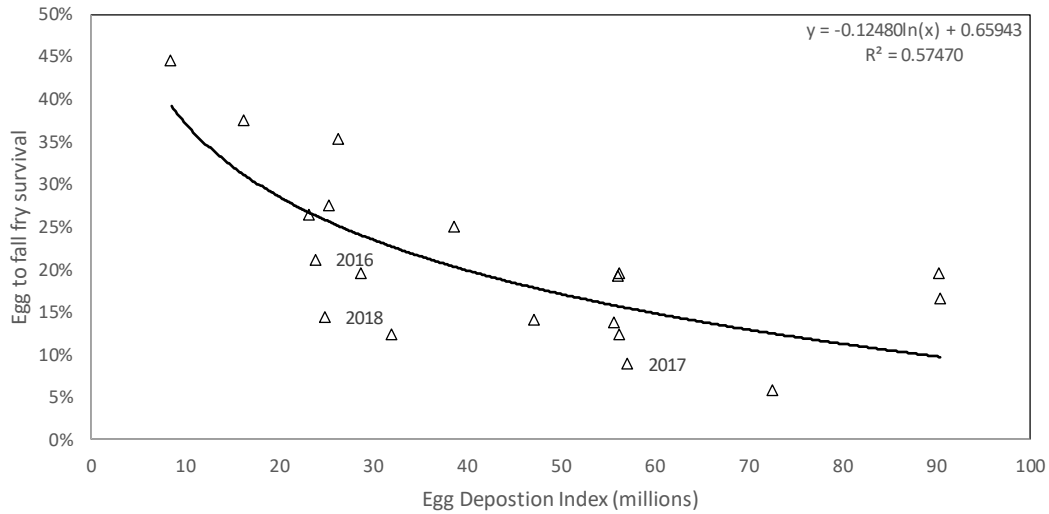


Figure 26. Egg deposition for all index (spawner count) tributaries for Upper and Lower Arrow and egg to fall fry survival for the post-NRP period (1999-2019). The egg deposition estimates include Hill Creek (channel and non-channel eggs) but exclude eggs for any spawners removed for First Nations harvest and/or for provincial hatchery egg supply for stocking of other waterbodies. Year labels identify brood (egg) year.

Table 7. Spawner attributes and estimates of egg deposition and fall fry abundance the following year and the observed egg to fall fry survival as well as the survival predicted by the regression equation in Figure 26 for the post-NRP period (1999-2019).

| Spawning year | Spawner counts ¹ (millions) | Net Fecundity ² | Females ² (%) | Egg Deposition (millions) | Fall Fry Abundance ³ (millions) | Egg-to-fall fry survival (%) | |
|-------------------|--|----------------------------|--------------------------|---------------------------|--|------------------------------|------------------------|
| | | | | | | Observed | Predicted ⁴ |
| 1999 | 0.35 | 388 | 41 | 56.3 | 11.1 | 20 | 16 |
| 2000 | 0.42 | 467 | 47 | 90.5 | 17.7 | 20 | 10 |
| 2001 | 0.59 | 372 | 41 | 90.5 | 15.1 | 17 | 10 |
| 2002 | 0.59 | 207 | 39 | 47.3 | 6.7 | 14 | 18 |
| 2003 ⁵ | | 224 | 48 | | 5.8 | | |
| 2004 ⁶ | 0.87 | 185 | 45 | 72.7 | 4.2 | 6 | 12 |
| 2005 | 0.56 | 209 | 48 | 56.3 | 6.9 | 12 | 16 |
| 2006 | 0.28 | 232 | 50 | 32.0 | 4.0 | 12 | 23 |
| 2007 | 0.22 | 232 | 46 | 23.2 | 6.2 | 26 | 27 |
| 2008 | 0.18 | 232 | 38 | 16.3 | 6.2 | 38 | 31 |
| 2009 | 0.45 | 251 | 50 | 56.2 | 10.8 | 19 | 16 |
| 2010 | 0.49 | 267 | 43 | 55.8 | 7.7 | 14 | 16 |
| 2011 | 0.25 | 262 | 44 | 28.8 | 5.6 | 20 | 24 |
| 2012 ⁶ | 0.08 | 251 | 45 | 8.5 | 3.8 | 45 | 39 |
| 2013 | 0.22 | 249 | 47 | 25.4 | 7.0 | 28 | 26 |
| 2014 | 0.21 | 433 | 42 | 38.8 | 9.7 | 25 | 20 |
| 2015 | 0.20 | 309 | 42 | 26.4 | 9.3 | 35 | 25 |
| 2016 | 0.18 | 279 | 49 | 23.9 | 5.1 | 21 | 26 |
| 2017 | 0.55 | 231 | 45 | 57.2 | 5.1 | 9 | 15 |

| | | | | | | | |
|---------|------|-----|----|------|-----|----|----|
| 2018 | 0.19 | 259 | 50 | 24.9 | 3.6 | 14 | 26 |
| 2019 | 0.26 | 238 | 43 | 26.3 | | | |
| Average | 0.36 | 275 | 45 | 42.9 | 7.6 | 21 | 21 |

¹ All index tributaries for both Upper and Lower Arrow except spawners removed for First Nations and/or for provincial hatchery egg supply for stocking of other waterbodies

² Derived from fish sampling at spawning channel

³ Estimate of fry abundance from the hydroacoustic survey the following fall

⁴ $y = -0.12480\ln(x) + 0.65943$ from egg deposition vs survival regression (Figure 26)

⁵ Counts were incomplete for the fall of 2003 due to forest fires

⁶ Measured sex ratios in 2004 and 2012 were considered unreliable so post-NRP average was used

In-lake

In 2019, cohort survival from fall at age 0 to fall at age 1 was estimated at 17%, which was an improvement over 2018 (12%) but still below the post-NRP average of 22%. Survival from age 1-2 was estimated at 68% in 2019, higher than the post-NRP average of 49% (Figure 27).

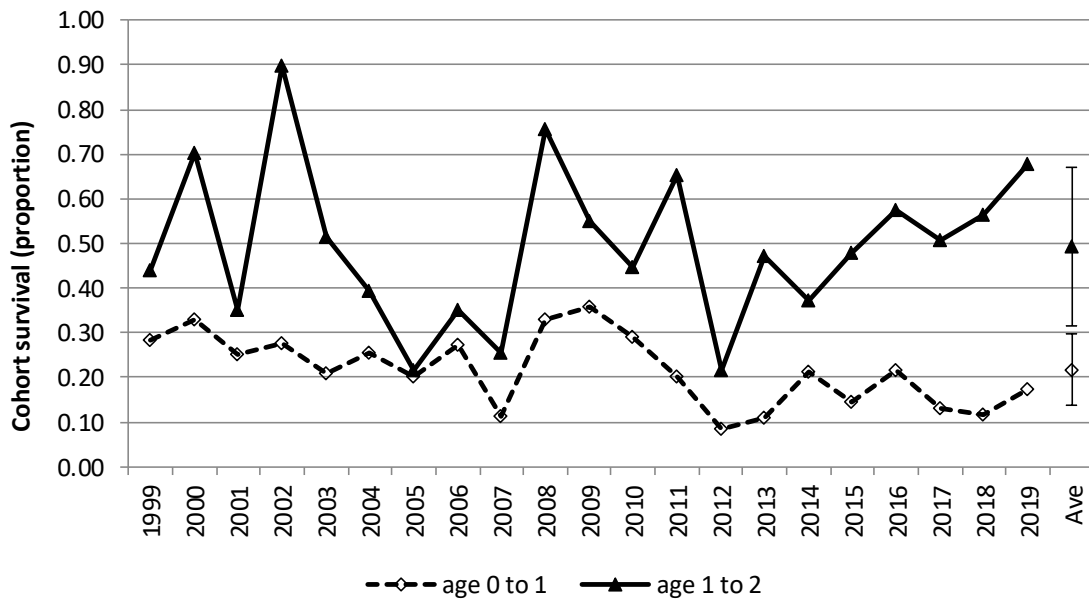


Figure 27. Trends in annual survival for in-lake Kokanee cohorts for Arrow Lakes Reservoir (combined basins) and the post-NRP average and standard deviation. The age 2 cohort includes the component estimated in-lake from fall hydroacoustic surveys as well as the estimate of age 2 spawners the same year. The year is labelled by the latter year as each value includes data from two consecutive years.

4. DISCUSSION

Despite a wide range of Kokanee spawner numbers in 2016, 2017 and 2018 (50%, 183% and 66% of average respectively), the Kokanee fall fry populations were well below average in 2017, 2018 and 2019 (66%, 67% and 56% of average respectively). Egg to fall fry survival was below what was predicted by egg density all three years, but particularly for the eggs deposited in the fall of 2017 and 2018. The mechanism(s) responsible for the low egg to fall fry survival are not directly evident but could be related to environmental conditions during spawning/incubation or could be related to conditions during emigration and early lake entry or in-lake prior to the fall survey. During the incubation period, high flows could impact embryo survival by redd scouring and increasing suspended sediments (Thorne and Ames 1987, Montgomery *et al.* 1996, Newcombe and Jensen 1996, DeVries 1997). Conversely, low flows combined with extreme cold temperatures can cause intergravel freezing and embryo mortality (Cope and Macdonald 1998).

While we have not attempted to investigate all the potential mechanisms that might have influenced the very poor egg to fall fry survival in the past three years, one environmental variable that stands out was the occurrence of exceptionally cold February air temperatures. Mean February air temperatures at the Castlegar Airport (station name: CASTLEGAR A, Lat=49.30, Long=-117.630, elevation=495.6 m; Environment Canada, 2019) averaged -0.2°C from 1992-2019, and for each of the past three years the February air temperature fell below the 25th percentile. Notably, in 2019 the mean February air temperature was by far the lowest across the 1992-2019 period at -5.3°C. As a result, the risk of intergravel freezing was higher in recent years (in February of 2019 particularly), and embryo survival may have been affected during this period.

As environmental extremes and habitat alteration or degradation can have a significant impact on fry production, the Hill Creek Spawning Channel assumes an important role in stabilizing production and/or mitigating steep declines in fry production during years of poor 'wild' production from non-channel habitat. The fry population in Upper Arrow in 2019, while still only 56% of average, was not as low as that of Lower Arrow, which was only 34% of the post-NRP average. Presumably, the marginally better outcome for Upper Arrow was a result of the 3.2 million fry produced from the spawning channel in 2019, where egg to emergent fry survival was not as vulnerable to weather mediated impacts such as intergravel freezing due to controlled flow/water levels. The egg to emigrant fry survival at the spawning channel in 2018-2019 was indeed excellent at 58%.

In addition to a signal that environmental extremes may have impacted fry production, in at least 2019, the in-lake survival from age 0-1 was also relatively poor in recent years, although in 2019 there was an improvement over 2017 and 2018. The rate of water flow through reservoirs has been identified as a factor affecting Kokanee productivity and survival where higher flow generally results in decreased survival (and/or increased entrainment) for Kokanee (Bray *et al.* 2018, Bassett *et al.* 2018b, Biosonics 2013, Baldwin and Polacek 2002). Water flow, represented by outflow data from Hugh Keenleyside Dam, was relatively high consistently from 2011 to 2018, however in 2019 outflow was well below average for the productive season (April to October, Figure 2). As cohort survival is measured over an annual period between acoustic surveys in October of each year, the annual survival data are plotted against the cumulative annual outflow data for the concurrent period (October 1 to Sept 30 the following year) in Figure 28. The below average survival from age 0 to age 1 in 2016-2017 and 2017-2018 appear to be at least partially related to above average cumulative annual outflow over those periods, however the 2018-2019 outflow was the 5th lowest since 2000-2001, yet survival failed to improve to near the 25% predicted by the regression model in Figure 28. While it is apparent that water flow has an important role in driving outcomes for Kokanee in Arrow Lakes Reservoir, clearly one or more other factors also had a substantial impact on in-lake Kokanee survival between October 2018 and October 2019.

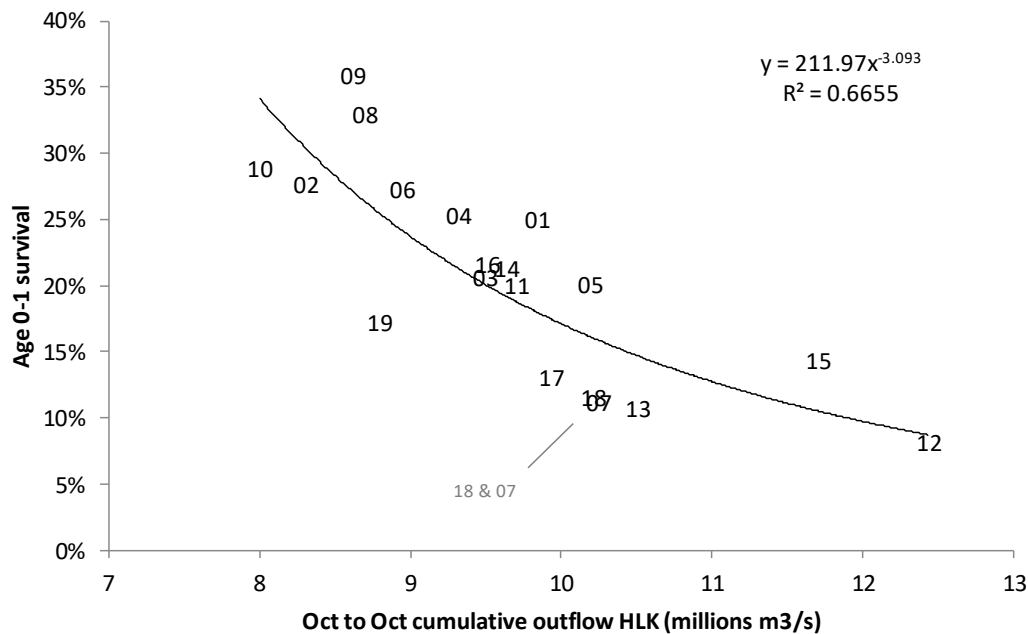


Figure 28. Relation of annual Kokanee cohort survival from fall at age 0 to fall at age 1 and the concurrent October to October cumulative outflow (m3/s) at Hugh Keenleyside Dam for Arrow Reservoir from 2000 to 2019. As each point identifies a value that spans two calendar years the year labels represent the later year. Note that an abnormal and large-scale Kokanee mortality event occurred in the spring of 2012 which may have affected the survival estimates presented.

Consecutive years of poor egg to fall-fry survival and below average in-lake survival from age 0 to age 1 resulted in low numbers for all three in-lake age classes of Kokanee in 2019. As a result, in-lake biomass was very low, an outcome that was amplified by the failure of a substantial density dependant growth response to materialize. The below average density of *Daphnia* in 2019 (Figure 19) was likely a key factor affecting the below average length at age for most Kokanee age classes including spawners in 2019 (Figure 22), and given the low Kokanee densities/biomass it is unlikely that grazing by Kokanee was a primary factor driving down *Daphnia* densities.

The low seasonal average *Daphnia* density was a function of their late appearance in monthly sampling. In Upper Arrow, the first appearance of *Daphnia* (at densities >0.4 ind/L) was later than average (September). Notably, in Lower Arrow *Daphnia* also did not appear in sampling until September, which was the latest on record (Figure 18). The primary mechanism responsible is likely temperature related, as Bray *et al.* (2018) found that winter air temperature affected the timing of the onset of stratification by up to a month at Revelstoke Reservoir and suggested late stratification was likely to delay

the onset of phytoplankton and zooplankton production. Interestingly, Bray *et al.* (2018) identified an early onset of stratification in the spring of 2016 following a mild winter and linked that outcome to the early encounter of *Daphnia* in Revelstoke sampling that year. Similarly, in Arrow Reservoir in 2016 *Daphnia* appeared very early (June), and subsequently the seasonal average densities were above average, particularly in Lower Arrow (Figure 19). Although Arrow zooplankton densities were much higher than those of Kinbasket and Revelstoke, Bray *et al.* (2018) found significant correlations between Arrow zooplankton density and that of Revelstoke and Kinbasket, further demonstrating the importance of environmental/weather related influences on productivity.

Whether the density, biomass and/or time of first appearance of *Daphnia* spp. has any direct impact on in-lake Kokanee survival is uncertain, however the low *Daphnia* densities observed in 2019 and the late timing of first appearance would have affected Kokanee growth and contributed to the small length at age apparent for most age classes. As a result, a strong density dependant growth response did not materialize in 2019, leading to very low Kokanee biomass density estimates.

Looking forward, it is likely that that the Kokanee population will remain in a below-average state for abundance and biomass in 2020 given the small size and low abundance by age for all age classes in 2019. However, if egg to fall fry survival conditions improve to normal or better, the fall fry population should return to near average in 2020, providing the basis for improvement in abundance and biomass for older age classes going forward. Improvement for overall outcomes for Kokanee will also be dependant on favourable flow and climatic/weather driven outcomes in the reservoir.

5. RECOMMENDATIONS

The extremes observed in Arrow Lakes Reservoir monitoring data in 2019, particularly in the *Daphnia* and Kokanee data, suggest several topics that merit further exploration. Although not considered a comprehensive list of all factors relevant to Arrow Lake Reservoir ecosystem dynamics, below are select topics recommended for further review:

- **Air and water temperature dynamics and their influence on zooplankton productivity.** Bray *et al.* (2018) found that a colder winter significantly delayed the onset of summer stratification for Revelstoke Reservoir, and had calculated these data for 2013-2017. Exploration of whether more recent data are available for Revelstoke (to 2019), whether Revelstoke data are a reasonable proxy for Arrow, and how well they correlate with zooplankton dynamics including the timing of first appearance of *Daphnia* is recommended. The potential to estimate timing of stratification using Arrow water profile data should also be evaluated.
- **Weather/climate mediated processes and their relevance to annual outcomes versus localized or lake-specific factors.** The degree to which climatic/weather related factors drive outcomes observed at all trophic levels is an important consideration that requires greater understanding in order to determine the relevance of lake-specific factors (i.e., reservoir operations, spawning channel operations, fertilization amount/timing) on an annual scale, and with respect to evaluating the long-term outcomes of the NRP. Evaluation of trends across multiple systems was initiated for Columbia Basin reservoirs by Bray *et al.* (2018) and this effort should be expanded upon for all trophic levels and systems where comparable data exist.
- **Kokanee egg to fall fry survival.** Egg to fall fry survival was below average for three consecutive years and was exceptionally low in 2019. Survival across this life stage has a dramatic impact on cohort strength in subsequent years; a better understanding of what factors are important in what years would increase our understanding of the overall outcomes for Kokanee.
- **Piscivore consumption rates.** Explore potential to estimate consumption rates on Kokanee by piscivores to improve understanding of the top-down effects in the reservoir.

In 2019, fertilizer additions were kept consistent with the previous three years at ~40 tonnes of phosphorus and 230-250 tonnes of nitrogen. Likewise, fry production from Hill Creek Spawning Channel was maintained at a similar level as the previous six years,

near the target of 3.8 million fry. Despite the stability of these two key management levers, a wide range of outcomes has been observed in zooplankton and Kokanee metrics, demonstrating that other factors have a substantial influence on Arrow Lakes Reservoir productivity. Continuing to maintain stability in these two important variables until a comprehensive review of NRP outcomes occurs will improve our understanding of the relative influence of other factors that affect Arrow Lakes Reservoir ecosystem dynamics.

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7. APPENDICES

Appendix 1. Arrow Lakes Reservoir NRP Personnel by Project focus for the 2019 season. The creel survey is led by Steve Arndt and information is documented in a separate report.

| Project Focus | Personnel - Affiliation |
|--|---|
| Project co-ordination, management and scientific liaison | Marley Bassett - Resource Management, MoFLNRORD Kristen Peck - Resource Management, MoFLNRORD |
| Report compilation | Marley Bassett - Resource Management, MoFLNRORD Tyler Weir - Fish and Aquatic Habitat Branch, MoFLNRORD Rob Fox - Resource Management, MoFLNRORD |
| Report editing and review | Steve Arndt - Resource Management, MoFLNRORD Eva Schindler - Resource Management, MoFLNRORD Mike Hounjet - Columbia Basin Trust, Castlegar |
| Fertilizer schedule, loading | Marley Bassett - Resource Management, MoFLNRORD Kristen Peck - Resource Management, MoFLNRORD Eva Schindler - Resource Management, MoFLNRORD Ken Ashley - BC Institute of Technology Rivers Institute |
| Fertilizer supplier | Alan Jelfs - Agrium |
| Fertilizer application | Crescent Bay Construction - Crescent Bay Construction The Columbia Ferry - Waterbridge ferries |
| Physical limnology, water chemistry, phytoplankton, zooplankton and mysid sampling | Golder Associates Ltd. Staff - Golder Associates Ltd. Marley Bassett - Resource Management, MoFLNRORD Rob Fox - Resource Management, MoFLNRORD Dave Heagy BC Parks, ENV Tom Roos - BC Parks, ENV |
| Chemistry analysis | ALS Global staff - ALS Global |
| Chlorophyll analysis | ALS Global staff - ALS Global |
| Phytoplankton analysis | Advanced Eco-Solutions Inc. |
| Zooplankton and mysid analysis | Dr. Lidija Vidmanic, Limno-Lab Ltd., Vancouver |
| Kokanee acoustic surveys | Tyler Weir - Fish and Aquatic Habitat Branch, MoFLNRORD David Johner - Fish and Aquatic Habitat Branch, MoFLNRORD |
| Kokanee trawling | Golder Associates Ltd. Staff - Golder Associates Ltd. Tyler Weir - Fish and Aquatic Habitat Branch, MoFLNRORD David Johner - Fish and Aquatic Habitat Branch, MoFLNRORD |
| Kokanee aerial spawner surveys | Marley Bassett - Resource Management, MoFLNRORD Eva Schindler - Resource Management, MoFLNRORD Albert Chirico - Environmental Sustainability and Strategic Policy Division, ENV Mark Homis - Highland Helicopters Molly Teather – Resource Management, MoFLNRORD |
| Kokanee ground spawner surveys | Steve Arndt - Resource Management, MoFLNRORD Rob Fox - Resource Management, MoFLNRORD Tim Davis - Resource Management, MoFLNRORD Kristen Murphy - Resource Management, MoFLNRORD Kersti Vaino - Resource Management, MoFLNRORD Molly Teather - Resource Management, MoFLNRORD Aaron MacGregor - Resource Management, MoFLNRORD Julien Gullo- Resource Management, MoFLNRORD Karen Bray - BC Hydro Beth Manson - BC Hydro |
| Kokanee analysis and Reporting | Tyler Weir – Fish and Aquatic Habitat Branch, MoFLNRORD David Johner - Fish and Aquatic Habitat Branch, MoFLNRORD |
| Kokanee scale ageing | Morgan Davies - BC Provincial Aging Lab - FFSBC Carol Lidstone - Birkenhead Scale Analyses |
| Hill Creek Spawning Channel monitoring | Brian Barney – Kingfisher Silviculture Ltd. Steve Arndt – Resource Management MoFLNRORD |
| Regional support | Jeff Burrows - Resource Management, MoFLNRORD Matt Neufeld - Resource Management, MoFLNRORD |

MoFLNRORD – Ministry of Forests, Lands, Natural Resource Operations and Rural Development

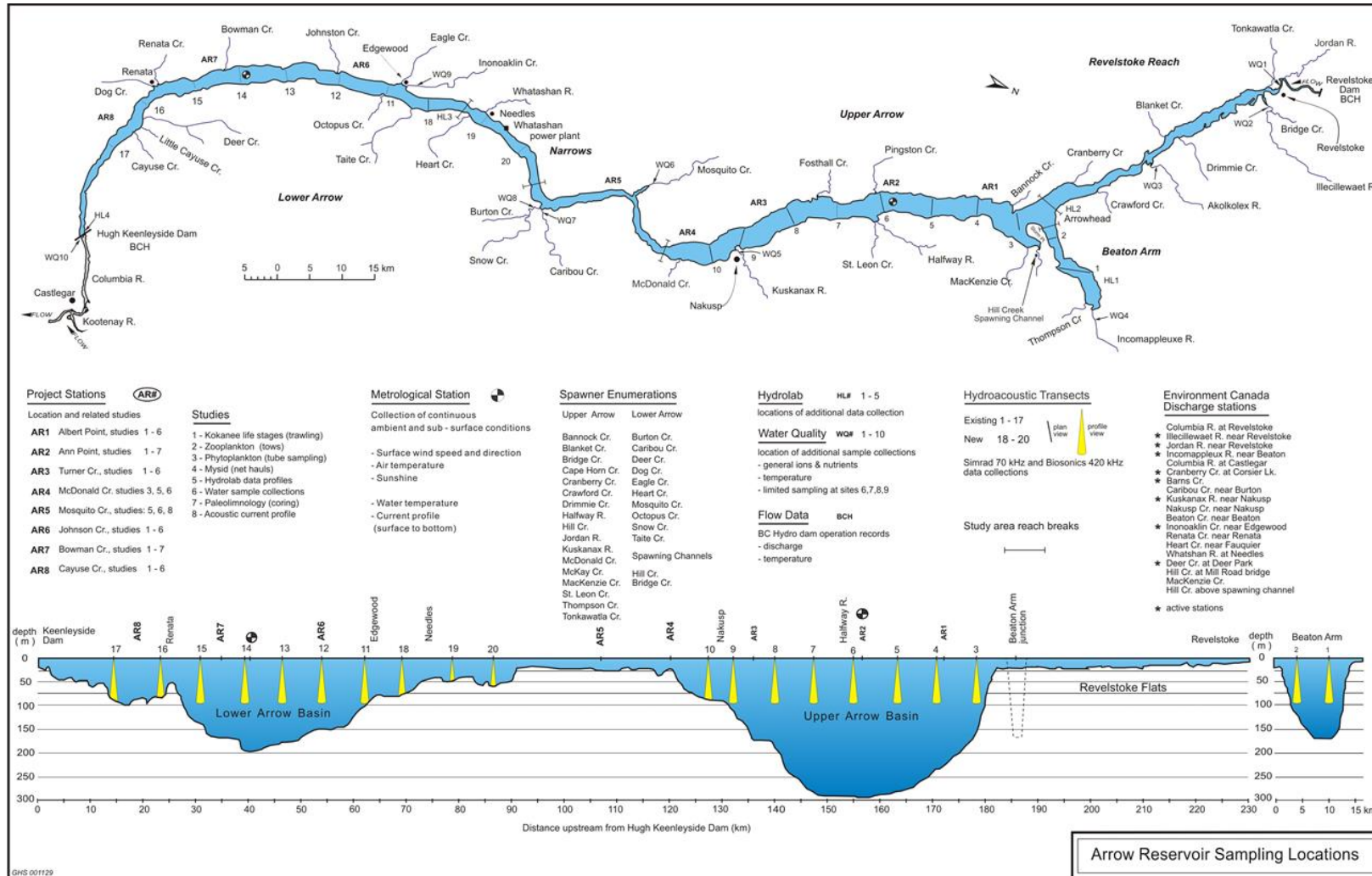
ENV - Ministry of Environment & Climate Change Strategy

FFSBC – Freshwater Fisheries Society of BC

Appendix 2. Arrow Lakes Reservoir nutrient loading from fertilizer during 2019– liquid ammonium polyphosphate (phosphorus: 10-34-0; N-P₂O₅-K₂O) and liquid urea-ammonium nitrate (nitrogen: 28-0-0; N-P₂O₅-K₂O).

| 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 | May-05 | 3.5 | 668.1 | 4.5 | 43.6 | 8290.0 | 28.0 | 32.5 | 12.41 |
| 2 | May-12 | 7.6 | 1440.2 | 9.7 | 5.1 | 970.0 | 0.0 | 9.7 | 0.67 |
| 3 | May-19 | 7.6 | 1440.2 | 9.7 | 5.1 | 970.0 | 0.0 | 9.7 | 0.67 |
| 4 | May-26 | 11.4 | 2167.7 | 14.6 | 7.7 | 1460.0 | 0.0 | 14.6 | 0.67 |
| 5 | Jun-02 | 15.2 | 2895.2 | 19.5 | 10.3 | 1950.0 | 0.0 | 19.5 | 0.67 |
| 6 | Jun-09 | 17.2 | 3266.4 | 22.0 | 74.9 | 14240.0 | 43.0 | 65.0 | 4.36 |
| 7 | Jun-16 | 17.2 | 3266.4 | 22.0 | 74.9 | 14240.0 | 43.0 | 65.0 | 4.36 |
| 8 | Jun-23 | 17.2 | 3266.4 | 22.0 | 74.9 | 14240.0 | 43.0 | 65.0 | 4.36 |
| 9 | Jun-30 | 14.1 | 2672.5 | 18.0 | 78.7 | 14960.0 | 47.0 | 65.0 | 5.60 |
| 10 | Jul-07 | 13.7 | 2605.7 | 17.6 | 83.2 | 15804.0 | 50.2 | 67.7 | 6.07 |
| 11 | Jul-14 | 14.1 | 2672.5 | 18.0 | 78.7 | 14960.0 | 47.0 | 65.0 | 5.60 |
| 12 | Jul-21 | 14.1 | 2672.5 | 18.0 | 78.7 | 14960.0 | 47.0 | 65.0 | 5.60 |
| 13 | Jul-28 | 10.9 | 2078.6 | 14.0 | 82.5 | 15680.0 | 51.0 | 65.0 | 7.54 |
| 14 | Aug-04 | 10.9 | 2078.6 | 14.0 | 82.5 | 15680.0 | 51.0 | 65.0 | 7.54 |
| 15 | Aug-11 | 8.6 | 1633.2 | 11.0 | 85.4 | 16220.0 | 54.0 | 65.0 | 9.93 |
| 16 | Aug-18 | 0.0 | 0.0 | 0.0 | 95.8 | 18200.0 | 65.0 | 65.0 | #DIV/0! |
| 17 | Aug-25 | 7.8 | 1484.7 | 10.0 | 86.3 | 16400.0 | 55.0 | 65.0 | 11.05 |
| 18 | Sep-01 | 7.8 | 1484.7 | 10.0 | 86.3 | 16400.0 | 55.0 | 65.0 | 11.05 |
| 19 | Sep-08 | 7.0 | 1336.2 | 9.0 | 87.3 | 16580.0 | 56.0 | 65.0 | 12.41 |
| 20 | Sep-15 | 7.0 | 1336.2 | 9.0 | 87.3 | 16580.0 | 56.0 | 65.0 | 12.41 |

Appendix 3. 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 4. Arrow Lakes Reservoir physical, chemical, plankton, and Kokanee sampling program for 2019.

| 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 |
| Epilimnion water chemistry Turbidity, pH, TP, TN, NO ₃ , NO ₂ , TIC, TDP, OP, TOC, alkalinity, silica TP, TN, NO ₃ , NO ₂ , TDP, OP | Monthly: April to November Twice monthly in June, July and August | AR 1–3 and AR 6–8 (AR1–3 and AR6–8 in mid-June) AR 3 and AR 8 | Integrated sampling tube at 0–20 m 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 TP, TN, NO ₃ , NO ₂ , TDP, OP | Monthly: May to October Mid-June | AR 1–3 and 6–8 AR1–3 and AR6–8 | Discrete water sample with Niskin sampler 5 m off the bottom |
| Chlorophyll a (not corrected for phaeophytin) | Monthly: April to November (twice monthly in June, July and August) Monthly: June to September | AR 1–8 AR 2 and 7 | Integrated sampling tube at 0–20 m 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 40–0 m (150 µm net) |
| 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 and Appendix 3 | Two standardized helicopter flights appr. one week apart to identify peak spawner numbers |
| Ground Kokanee spawner counts | September | | Two ground counts appr. one week apart to identify peak spawner numbers |

Appendix 5. 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 temperature | column 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 | | |
| conversion | Amplitude/SED thresholds Sv, TS gain (correction) | -70 dB (40 Log R TVG) -27.45 dB from field calibration |
| Single target filter | analysis threshold | -61 to -24 dB |
| | echo length | 0.7 – 1.3 |
| | Max phase deviation | 0.30 |
| Density determination | Max gain compensation | 3 dB (one way) |
| | Echo counting method | 40 log r density based on SED |
| | Fish size distributions | From in situ single echo detections |

Appendix 6. Water levels and habitat areas for hydroacoustic surveys.

a) Water level and limnetic habitat areas in Arrow Reservoir for acoustic surveys from 2010-2019.

| Survey Dates | | Water level (m) | Habitat area >20 m depth (km ²) | | |
|--------------|-------------|--------------------|---|-------------|-------|
| Year | Month / day | | Upper Arrow | Lower Arrow | Total |
| 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 |
| 2017 | Oct 17-19 | 435.2 | 197 | 97 | 295 |
| 2018 | Oct 2-4 | 435.2 | 197 | 97 | 295 |
| 2019 | Sept 27-29 | 435.0 | 197 | 97 | 295 |

Appendix 6. Continued.

b) Habitat areas by depth used for extrapolating acoustic population estimates

| Depth (m) from surface | Revelstoke Reach | Upper Arrow | Narrows | Lower Arrow | Depth (m) from surface | Upper Arrow | Lower Arrow |
|------------------------------|---------------------|----------------|---------|----------------|------------------------------|----------------|----------------|
| full pool | 6437 | 22,582 | 5,500 | 12,193 | 41 | 18,729 | 8,354 |
| 1 | | 22,456 | | 12,092 | 42 | 18,665 | 8,268 |
| 2 | | 22,330 | | 11,991 | 43 | 18,602 | 8,181 |
| 3 | | 22,205 | | 11,890 | 44 | 18,539 | 8,095 |
| 4 | | 22,079 | | 11,789 | 45 | 18,476 | 8,008 |
| 5 | | 21,953 | | 11,688 | 46 | 18,413 | 7,921 |
| 6 | | 21,827 | | 11,587 | 47 | 18,350 | 7,835 |
| 7 | | 21,702 | | 11,486 | 48 | 18,286 | 7,748 |
| 8 | | 21,576 | | 11,385 | 49 | 18,223 | 7,662 |
| 9 | | 21,450 | | 11,284 | 50 | 18,160 | 7,575 |
| 10 | | 21,324 | | 11,183 | 51 | 18,098 | 7,511 |
| 11 | | 21,198 | | 11,082 | 52 | 17,977 | 7,447 |
| 12 | | 21,073 | | 10,981 | 53 | 17,885 | 7,384 |
| 13 | | 20,947 | | 10,880 | 54 | 17,794 | 7,320 |
| 14 | | 20,821 | | 10,779 | 55 | 17,702 | 7,256 |
| 15 | | 20,695 | | 10,678 | 56 | 17,611 | 7,192 |
| 16 | | 20,570 | | 10,577 | 57 | 17,519 | 7,129 |
| 17 | | 20,444 | | 10,476 | 58 | 17,427 | 7,065 |
| 18 | | 20,318 | | 10,375 | 59 | 17,336 | 7,001 |
| 19 | | 20,192 | | 10,274 | 60 | 17,244 | 6,937 |
| 20 | | 20,055 | | 10,173 | 61 | 17,153 | 6,874 |
| 21 | | 19,992 | | 10,086 | 62 | 17,061 | 6,810 |
| 22 | | 19,929 | | 10,000 | 63 | 16,969 | 6,746 |
| 23 | | 19,866 | | 9,913 | 64 | 16,878 | 6,682 |
| 24 | | 19,803 | | 9,827 | 65 | 16,786 | 6,619 |
| 25 | | 19,739 | | 9,740 | 66 | 16,695 | 6,555 |
| 26 | | 19,676 | | 9,653 | 67 | 16,603 | 6,491 |
| 27 | | 19,613 | | 9,567 | 68 | 16,512 | 6,427 |
| 28 | | 19,550 | | 9,480 | 69 | 16,420 | 6,364 |
| 29 | | 19,487 | | 9,394 | 70 | 16,328 | 6,300 |
| 30 | | 19,424 | | 9,307 | 71 | 16,237 | 6,236 |
| 31 | | 19,360 | | 9,220 | 72 | 16,145 | 6,172 |
| 32 | | 19,297 | | 9,134 | 73 | 16,054 | 6,109 |
| 33 | | 19,234 | | 9,047 | 74 | 15,962 | 6,045 |
| 34 | | 19,171 | | 8,961 | 75 | 15,870 | 5,981 |
| 35 | | 19,108 | | 8,874 | 76 | 15,779 | 5,917 |
| 36 | | 19,045 | | 8,787 | 77 | 15,687 | 5,853 |
| 37 | | 18,981 | | 8,701 | 78 | 15,596 | 5,790 |
| 38 | | 18,918 | | 8,614 | 79 | 15,504 | 5,726 |
| 39 | | 18,855 | | 8,528 | 80 | 15,413 | 5,662 |
| 40 | | 18,792 | | 8,441 | | | |

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

Appendix 7. Maximum likelihood population estimates for Kokanee of all ages, age 0, and age 1-3 in 2019 for (a) both Upper and Lower Basin combined, (b) Upper Arrow and (c) Lower Arrow. MLE = maximum likelihood estimate, LB = lower bound, and UB = upper bound.

a) Basins Combined. Zone 1 is Upper Arrow (transects 1-10) and zone 2 is Lower Arrow (transects 11-18)

| Age Class | Zone | Depth | N | Density | Std. Error | Area | Statistic | Abundance |
|-----------|------|-------|----|---------|------------|---------|-----------|-----------|
| All | 1 | 3-5 | 10 | 4.5 | 2.4 | 21450 | LB= | 3,918,102 |
| All | 1 | 5-10 | 10 | 22.6 | 6.5 | 21072.6 | MLE= | 4,792,566 |
| All | 1 | 10-15 | 10 | 43.9 | 15.7 | 20443.7 | UB= | 5,686,301 |
| All | 1 | 15-20 | 10 | 31.8 | 3.8 | 19929 | | |
| All | 1 | 20-25 | 10 | 22.3 | 6.3 | 19613.1 | | |
| All | 1 | 25-30 | 10 | 19.1 | 6.4 | 19297.2 | | |
| All | 1 | 30-35 | 10 | 11.4 | 5 | 18981.3 | | |
| All | 1 | 35-40 | 10 | 5.1 | 2.1 | 18665.4 | | |
| All | 1 | 40-45 | 10 | 3 | 0.5 | 18349.5 | | |
| All | 1 | 45-50 | 10 | 1.8 | 0.4 | 17976.8 | | |
| All | 2 | 5-10 | 8 | 7.9 | 6 | 10981 | | |
| All | 2 | 10-15 | 8 | 3.2 | 1.3 | 10476 | | |
| All | 2 | 15-20 | 8 | 9.3 | 5.8 | 9999.8 | | |
| All | 2 | 20-25 | 8 | 28.9 | 9 | 9566.8 | | |
| All | 2 | 25-30 | 8 | 56.4 | 8.9 | 9133.8 | | |
| All | 2 | 30-35 | 8 | 41 | 9.9 | 8700.8 | | |
| All | 2 | 35-40 | 8 | 9.5 | 3 | 8267.8 | | |
| All | 2 | 40-45 | 8 | 3.4 | 1.5 | 7834.8 | | |
| All | 2 | 45-50 | 8 | 1.7 | 0.8 | 7447.5 | | |
| Age 0 | 1 | 3-5 | 10 | 4.5 | 2.4 | 21450 | LB= | 2,879,949 |
| Age 0 | 1 | 5-10 | 10 | 21.8 | 6.1 | 21072.6 | MLE= | 3,599,021 |
| Age 0 | 1 | 10-15 | 10 | 39.2 | 13.9 | 20443.7 | UB= | 4,316,246 |
| Age 0 | 1 | 15-20 | 10 | 23.9 | 3.7 | 19929 | | |
| Age 0 | 1 | 20-25 | 10 | 14.7 | 4.4 | 19613.1 | | |
| Age 0 | 1 | 25-30 | 10 | 12.7 | 3.9 | 19297.2 | | |
| Age 0 | 1 | 30-35 | 10 | 8 | 3.2 | 18981.3 | | |
| Age 0 | 1 | 35-40 | 10 | 3.5 | 1.2 | 18665.4 | | |
| Age 0 | 1 | 40-45 | 10 | 2.7 | 0.5 | 18349.5 | | |
| Age 0 | 1 | 45-50 | 10 | 1.3 | 0.2 | 17976.8 | | |
| Age 0 | 2 | 5-10 | 8 | 7.9 | 6 | 10981 | | |
| Age 0 | 2 | 10-15 | 8 | 3.2 | 1.3 | 10476 | | |
| Age 0 | 2 | 15-20 | 8 | 7.6 | 5.3 | 9999.8 | | |
| Age 0 | 2 | 20-25 | 8 | 18.6 | 5.6 | 9566.8 | | |
| Age 0 | 2 | 25-30 | 8 | 33.7 | 5.1 | 9133.8 | | |
| Age 0 | 2 | 30-35 | 8 | 21.3 | 4.9 | 8700.8 | | |
| Age 0 | 2 | 35-40 | 8 | 4.9 | 1.6 | 8267.8 | | |
| Age 0 | 2 | 40-45 | 8 | 2.3 | 1.1 | 7834.8 | | |
| Age 0 | 2 | 45-50 | 8 | 1.2 | 0.5 | 7447.5 | | |

Appendix 7a. Continued.

| Size Class | Zone | Depth | N | Density | Std. Error | Area | Statistic | Abundance |
|------------|------|-------|----|---------|------------|---------|-----------|-----------|
| Age 1-3 | 1 | 5-10 | 10 | 0.8 | 0.5 | 21072.6 | LB= | 954,116 |
| Age 1-3 | 1 | 10-15 | 10 | 4.6 | 2.6 | 20443.7 | MLE= | 1,193,279 |
| Age 1-3 | 1 | 15-20 | 10 | 7.9 | 1.7 | 19929 | UB= | 1,434,589 |
| Age 1-3 | 1 | 20-25 | 10 | 7.6 | 2.3 | 19613.1 | | |
| Age 1-3 | 1 | 25-30 | 10 | 6.4 | 2.6 | 19297.2 | | |
| Age 1-3 | 1 | 30-35 | 10 | 3.4 | 1.8 | 18981.3 | | |
| Age 1-3 | 1 | 35-40 | 10 | 1.6 | 0.9 | 18665.4 | | |
| Age 1-3 | 1 | 40-45 | 10 | 0.3 | 0.2 | 18349.5 | | |
| Age 1-3 | 1 | 45-50 | 10 | 0.4 | 0.2 | 17976.8 | | |
| Age 1-3 | 2 | 15-20 | 8 | 1.7 | 1 | 9999.8 | | |
| Age 1-3 | 2 | 20-25 | 8 | 10.3 | 3.6 | 9566.8 | | |
| Age 1-3 | 2 | 25-30 | 8 | 22.8 | 3.9 | 9133.8 | | |
| Age 1-3 | 2 | 30-35 | 8 | 19.6 | 5.2 | 8700.8 | | |
| Age 1-3 | 2 | 35-40 | 8 | 4.7 | 1.7 | 8267.8 | | |
| Age 1-3 | 2 | 40-45 | 8 | 1.1 | 0.5 | 7834.8 | | |
| Age 1-3 | 2 | 45-50 | 8 | 0.5 | 0.4 | 7447.5 | | |

b) Upper Arrow (zone 1; transects 1-10)

| Size Class | Zone | Depth | N | Density | Std. Error | Area | Statistic | Abundance |
|------------|------|-------|----|---------|------------|---------|-----------|-----------|
| All | 1 | 3-5 | 10 | 4.5 | 2.4 | 21450 | LB= | 2,495,908 |
| All | 1 | 5-10 | 10 | 22.6 | 6.5 | 21072.6 | MLE= | 3,304,037 |
| All | 1 | 10-15 | 10 | 43.9 | 15.7 | 20443.7 | UB= | 4,123,782 |
| All | 1 | 15-20 | 10 | 31.8 | 3.8 | 19929 | | |
| All | 1 | 20-25 | 10 | 22.3 | 6.3 | 19613.1 | | |
| All | 1 | 25-30 | 10 | 19.1 | 6.4 | 19297.2 | | |
| All | 1 | 30-35 | 10 | 11.4 | 5 | 18981.3 | | |
| All | 1 | 35-40 | 10 | 5.1 | 2.1 | 18665.4 | | |
| All | 1 | 40-45 | 10 | 3 | 0.5 | 18349.5 | | |
| All | 1 | 45-50 | 10 | 1.8 | 0.4 | 17976.8 | | |
| Age 0 | 1 | 3-5 | 10 | 4.5 | 2.4 | 21450 | LB= | 1,972,311 |
| Age 0 | 1 | 5-10 | 10 | 21.8 | 6.1 | 21072.6 | MLE= | 2,662,101 |
| Age 0 | 1 | 10-15 | 10 | 39.2 | 13.9 | 20443.7 | UB= | 3,351,075 |
| Age 0 | 1 | 15-20 | 10 | 23.9 | 3.7 | 19929 | | |
| Age 0 | 1 | 20-25 | 10 | 14.7 | 4.4 | 19613.1 | | |
| Age 0 | 1 | 25-30 | 10 | 12.7 | 3.9 | 19297.2 | | |
| Age 0 | 1 | 30-35 | 10 | 8 | 3.2 | 18981.3 | | |
| Age 0 | 1 | 35-40 | 10 | 3.5 | 1.2 | 18665.4 | | |
| Age 0 | 1 | 40-45 | 10 | 2.7 | 0.5 | 18349.5 | | |
| Age 0 | 1 | 45-50 | 10 | 1.3 | 0.2 | 17976.8 | | |
| Age 1-3 | 1 | 5-10 | 10 | 0.8 | 0.5 | 21072.6 | LB= | 450,273 |
| Age 1-3 | 1 | 10-15 | 10 | 4.6 | 2.6 | 20443.7 | MLE= | 647,409 |
| Age 1-3 | 1 | 15-20 | 10 | 7.9 | 1.7 | 19929 | UB= | 844,721 |
| Age 1-3 | 1 | 20-25 | 10 | 7.6 | 2.3 | 19613.1 | | |
| Age 1-3 | 1 | 25-30 | 10 | 6.4 | 2.6 | 19297.2 | | |
| Age 1-3 | 1 | 30-35 | 10 | 3.4 | 1.8 | 18981.3 | | |
| Age 1-3 | 1 | 35-40 | 10 | 1.6 | 0.9 | 18665.4 | | |
| Age 1-3 | 1 | 40-45 | 10 | 0.3 | 0.2 | 18349.5 | | |
| Age 1-3 | 1 | 45-50 | 10 | 0.4 | 0.2 | 17976.8 | | |

Appendix 7. Continued.

c) Lower Arrow (zone 2; transects 11-18)

| Size Class | Zone | Depth | N | Density | Std. Error | Area | Statistic | Abundance |
|------------|------|-------|---|---------|------------|--------|-----------|-----------|
| All | 2 | 5-10 | 8 | 7.9 | 6 | 10981 | LB= | 1,137,584 |
| All | 2 | 10-15 | 8 | 3.2 | 1.3 | 10476 | MLE= | 1,479,831 |
| All | 2 | 15-20 | 8 | 9.3 | 5.8 | 9999.8 | UB= | 1,814,807 |
| All | 2 | 20-25 | 8 | 28.9 | 9 | 9566.8 | | |
| All | 2 | 25-30 | 8 | 56.4 | 8.9 | 9133.8 | | |
| All | 2 | 30-35 | 8 | 41 | 9.9 | 8700.8 | | |
| All | 2 | 35-40 | 8 | 9.5 | 3 | 8267.8 | | |
| All | 2 | 40-45 | 8 | 3.4 | 1.5 | 7834.8 | | |
| All | 2 | 45-50 | 8 | 1.7 | 0.8 | 7447.5 | | |
| Age 0 | 2 | 5-10 | 8 | 7.9 | 6 | 10981 | LB= | 700,079 |
| Age 0 | 2 | 10-15 | 8 | 3.2 | 1.3 | 10476 | MLE= | 936,151 |
| Age 0 | 2 | 15-20 | 8 | 7.6 | 5.3 | 9999.8 | UB= | 1,172,034 |
| Age 0 | 2 | 20-25 | 8 | 18.6 | 5.6 | 9566.8 | | |
| Age 0 | 2 | 25-30 | 8 | 33.7 | 5.1 | 9133.8 | | |
| Age 0 | 2 | 30-35 | 8 | 21.3 | 4.9 | 8700.8 | | |
| Age 0 | 2 | 35-40 | 8 | 4.9 | 1.6 | 8267.8 | | |
| Age 0 | 2 | 40-45 | 8 | 2.3 | 1.1 | 7834.8 | | |
| Age 0 | 2 | 45-50 | 8 | 1.2 | 0.5 | 7447.5 | | |
| Age 1-3 | 2 | 15-20 | 8 | 1.7 | 1 | 9999.8 | LB= | 409,054 |
| Age 1-3 | 2 | 20-25 | 8 | 10.3 | 3.6 | 9566.8 | MLE= | 544,927 |
| Age 1-3 | 2 | 25-30 | 8 | 22.8 | 3.9 | 9133.8 | UB= | 682,850 |
| Age 1-3 | 2 | 30-35 | 8 | 19.6 | 5.2 | 8700.8 | | |
| Age 1-3 | 2 | 35-40 | 8 | 4.7 | 1.7 | 8267.8 | | |
| Age 1-3 | 2 | 40-45 | 8 | 1.1 | 0.5 | 7834.8 | | |
| Age 1-3 | 2 | 45-50 | 8 | 0.5 | 0.4 | 7447.5 | | |

Appendix 8. Kokanee catch by age class from fall trawl sampling for a) Upper Arrow Reservoir and b) Lower Arrow Reservoir, 1992-2019. Note that while sampling methodology has been generally similar over time some changes to equipment or approach have occurred over discrete periods. No trawling occurred in 2007. At the time of reporting, the scale ageing had not been completed for 2019 and the ages for trawl captured fish are based on length frequency and considered preliminary.

a) Upper Arrow Reservoir

| year | Age 0 | Age 1 | Age 2 | Age 3 | Age 4 |
|-------------|--------------|--------------|--------------|--------------|--------------|
| 1992 | 33 | 14 | 30 | 3 | |
| 1993 | 20 | 31 | 23 | 2 | |
| 1994 | 60 | 20 | 15 | | |
| 1995 | 42 | 39 | 12 | | |
| 1996 | 7 | 21 | 14 | | |
| 1997 | 3 | 10 | 22 | | |
| 1998 | 22 | 6 | 12 | | |
| 1999 | 95 | 1 | 4 | | |
| 2000 | 267 | 10 | 3 | | |
| 2001 | 361 | 15 | 4 | | |
| 2002 | 130 | 53 | 17 | | |
| 2003 | 52 | 85 | 22 | | |
| 2004 | 21 | 18 | 51 | 2 | |
| 2005 | 22 | 15 | 13 | 2 | |
| 2006 | 107 | 9 | 2 | | |
| 2007 | | | | | |
| 2008 | 49 | 16 | 2 | | |
| 2009 | 43 | 10 | 15 | | |
| 2010 | 337 | 12 | 22 | 1 | |
| 2011 | 108 | 106 | 11 | 1 | |
| 2012 | 115 | 27 | 10 | | |
| 2013 | 22 | 6 | 6 | | |
| 2014 | 128 | 9 | 6 | | |
| 2015 | 208 | 38 | 5 | | |
| 2016 | 125 | 112 | 31 | | |
| 2017 | 47 | 39 | 19 | | |
| 2018 | 92 | 20 | 19 | | |
| 2019 | 34 | 30 | 19 | | |

Appendix 8. Continued

b) Lower Arrow Reservoir

| year | Age 0 | Age 1 | Age 2 | Age 3 | Age 4 |
|-------------|--------------|--------------|--------------|--------------|--------------|
| 1992 | 107 | 14 | 12 | | |
| 1993 | 87 | 57 | 46 | | |
| 1994 | 91 | 90 | 58 | 1 | |
| 1995 | 47 | 49 | 83 | | |
| 1996 | 11 | 13 | 23 | | |
| 1997 | 59 | 41 | 76 | | |
| 1998 | 23 | 48 | 54 | | |
| 1999 | 106 | 5 | 13 | | |
| 2000 | 207 | 14 | 7 | 1 | |
| 2001 | 350 | 56 | 47 | 4 | |
| 2002 | 139 | 59 | 45 | | |
| 2003 | 34 | 43 | 29 | 2 | |
| 2004 | 12 | 35 | 53 | 3 | |
| 2005 | 56 | 10 | 16 | 7 | |
| 2006 | 56 | 17 | 6 | 1 | |
| 2007 | | | | | |
| 2008 | 30 | 2 | 20 | | |
| 2009 | 85 | 12 | 14 | | |
| 2010 | 270 | 11 | 9 | 5 | |
| 2011 | 28 | 18 | 25 | 2 | |
| 2012 | 80 | 5 | 5 | 12 | 1 |
| 2013 | 114 | 23 | 10 | 2 | |
| 2014 | 505 | 47 | 21 | | |
| 2015 | 197 | 117 | 22 | 2 | |
| 2016 | 135 | 101 | 75 | | |
| 2017 | 30 | 55 | 28 | | |
| 2018 | 107 | 3 | 57 | | |
| 2019 | 3 | 22 | 7 | | |

Appendix 9. Percent age composition for Kokanee spawners returning to Hill Creek during the nutrient addition era (1999–2019) based on otolith analyses. From 2007-2019 otolith analyses followed the Casselman (1990) method accepting only CSA ratings of 6 or higher.

| Year | Sample | % by age | | | |
|----------------|--------|----------|----|----|----|
| | | 1 | 2 | 3 | 4 |
| 1999 | 182 | | 20 | 73 | 7 |
| 2000 | 194 | | 52 | 46 | 2 |
| 2001 | 253 | | 49 | 51 | 0 |
| 2002 | 200 | | 90 | 10 | 0 |
| 2003* | 159 | | 94 | 6 | 0 |
| 2004 | 99 | | 5 | 93 | 2 |
| 2005 | 99 | | 2 | 93 | 5 |
| 2006 | 100 | | 0 | 45 | 55 |
| 2007 | 99 | | 30 | 46 | 24 |
| 2008 | 97 | | 44 | 55 | 1 |
| 2009 | 120 | | 10 | 86 | 4 |
| 2010 | 115 | | 15 | 81 | 4 |
| 2011 | 100 | | 7 | 93 | 0 |
| 2012 | 53 | | 15 | 75 | 11 |
| 2013 | 73 | | 0 | 8 | 92 |
| 2014 | 99 | | 3 | 93 | 4 |
| 2015 | 96 | 1 | 16 | 78 | 5 |
| 2016 | 99 | | 58 | 42 | 0 |
| 2017 | 100 | | 53 | 47 | 0 |
| 2018 | 100 | | 55 | 45 | 0 |
| 2019 | 100 | | 17 | 80 | 3 |
| <i>Average</i> | | | 30 | 59 | 11 |

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

Appendix 10. Estimates of age specific abundance, mean weight, and biomass density (kg/ha) for Kokanee in a) Upper Arrow and b) Lower Arrow Reservoirs based on acoustic and trawl surveys during 1992-2019. Age '2+' includes all age 2 and older Kokanee. Note: a comprehensive review of the historic hydroacoustic abundance dataset, as well as a change in methodology for estimating age specific abundances, has resulted in a revised dataset that differs from that reported previously to 2016 by Bassett *et al.* (2018b).

a) Upper Arrow Reservoir

| year | Age specific population estimates | | | Mean weight by age group (g) | | | Pelagic area (ha) | Biomass Density (kg/ha) | | | |
|-------------------|-----------------------------------|-----------|-----------|------------------------------|-------|--------|-------------------|-------------------------|-------|--------|---------------|
| | Age 0 | Age 1 | Age 2+ | Age 0 | Age 1 | Age 2+ | | Age 0 | Age 1 | Age 2+ | Total in-lake |
| 1992 | 1,583,721 | 366,407 | 185,047 | 2.1 | 21 | 69 | 19,424 | 0.17 | 0.40 | 0.66 | 1.2 |
| 1993 | 1,203,150 | 378,257 | 141,229 | 3.3 | 32 | 108 | 19,803 | 0.20 | 0.61 | 0.77 | 1.6 |
| 1994 | 2,229,563 | 509,568 | 100,824 | 2.3 | 30 | 86 | 19,550 | 0.26 | 0.79 | 0.44 | 1.5 |
| 1995 | 1,201,424 | 457,337 | 139,779 | 2.1 | 36 | 82 | 19,739 | 0.13 | 0.83 | 0.58 | 1.5 |
| 1996 | 873,996 | 177,977 | 67,551 | 1.7 | 19 | 55 | 19,613 | 0.07 | 0.17 | 0.19 | 0.4 |
| 1997 | 1,178,353 | 251,182 | 135,442 | 2.2 | 31 | 59 | 19,803 | 0.13 | 0.39 | 0.40 | 0.9 |
| 1998 | 1,504,198 | 272,907 | 151,273 | 1.8 | 69 | 137 | 19,929 | 0.14 | 0.94 | 1.04 | 2.1 |
| 1999 | 3,694,391 | 478,584 | 170,803 | 3.4 | 77 | 184 | 19,803 | 0.64 | 1.87 | 1.59 | 4.1 |
| 2000 | 6,905,691 | 917,240 | 157,858 | 3.3 | 73 | 120 | 19,803 | 1.16 | 3.37 | 0.96 | 5.5 |
| 2001 | 9,963,856 | 1,795,427 | 162,083 | 2.2 | 38 | 94 | 19,171 | 1.12 | 3.59 | 0.80 | 5.5 |
| 2002 | 9,077,738 | 2,519,604 | 1,521,872 | 1.7 | 23 | 61 | 19,613 | 0.78 | 2.97 | 4.70 | 8.4 |
| 2003 | 4,428,749 | 1,829,919 | 1,536,964 | 1.8 | 28 | 54 | 19,676 | 0.41 | 2.59 | 4.19 | 7.2 |
| 2004 | 4,046,119 | 918,484 | 580,434 | 2.4 | 22 | 55 | 19,487 | 0.49 | 1.05 | 1.64 | 3.2 |
| 2005 | 2,788,397 | 811,905 | 157,519 | 1.8 | 39 | 67 | 19,424 | 0.25 | 1.65 | 0.54 | 2.4 |
| 2006 | 4,681,379 | 649,604 | 205,808 | 2.4 | 40 | 123 | 19,424 | 0.57 | 1.35 | 1.30 | 3.2 |
| 2007 ¹ | 2,642,431 | 501,109 | 118,998 | 2 | 39 | 103 | 19,613 | 0.29 | 1.01 | 0.63 | 1.9 |
| 2008 | 4,607,926 | 894,495 | 375,578 | 2.0 | 39 | 83 | 19,929 | 0.45 | 1.73 | 1.57 | 3.8 |
| 2009 | 3,573,408 | 1,520,435 | 509,937 | 2.1 | 35 | 91 | 19,613 | 0.38 | 2.68 | 2.37 | 5.4 |
| 2010 | 6,956,378 | 1,056,955 | 594,147 | 2.0 | 27 | 73 | 19,676 | 0.72 | 1.47 | 2.20 | 4.4 |
| 2011 | 6,641,652 | 1,710,499 | 664,957 | 1.2 | 22 | 61 | 19,866 | 0.40 | 1.86 | 2.03 | 4.3 |
| 2012 | 3,733,245 | 311,971 | 312,578 | 1.7 | 25 | 54 | 19,676 | 0.32 | 0.40 | 0.85 | 1.6 |
| 2013 | 2,091,084 | 321,402 | 181,065 | 2.5 | 30 | 153 | 19,550 | 0.27 | 0.49 | 1.41 | 2.2 |
| 2014 | 3,824,094 | 476,542 | 114,936 | 2.7 | 57 | 110 | 19,550 | 0.53 | 1.39 | 0.65 | 2.6 |
| 2015 | 5,386,060 | 459,864 | 131,031 | 3.7 | 31 | 83 | 19,297 | 1.02 | 0.75 | 0.56 | 2.3 |
| 2016 | 5,843,574 | 1,433,995 | 313,096 | 2.7 | 58 | 93 | 19,297 | 0.82 | 4.27 | 1.51 | 6.6 |
| 2017 | 3,015,281 | 566,544 | 274,189 | 2.4 | 32 | 72 | 19,739 | 0.36 | 0.92 | 1.00 | 2.3 |
| 2018 | 2,984,482 | 410,062 | 424,288 | 1.8 | 48 | 81 | 19,739 | 0.28 | 0.99 | 1.74 | 3.0 |
| 2019 | 2,479,069 | 422,495 | 202,843 | 1.2 | 31 | 72 | 19,739 | 0.16 | 0.67 | 0.74 | 1.6 |

¹No trawling occurred in 2007, mean weights are the average of 2006 & 2008

Appendix 10. Continued.

b) Lower Arrow Reservoir

| year | Age specific population estimates | | | Mean weight by age group (g) | | | Pelagic area (ha) | Biomass Density (kg/ha) | | | |
|-------------------|-----------------------------------|-----------|---------|------------------------------|-------|--------|-------------------|-------------------------|-------|--------|---------------|
| | Age 0 | Age 1 | Age 2+ | Age 0 | Age 1 | Age 2+ | | Age 0 | Age 1 | Age 2+ | Total in-lake |
| 1992 | 936,726 | 180,098 | 41,376 | 2.9 | 38 | 127 | 9,307 | 0.29 | 0.74 | 0.56 | 1.6 |
| 1993 | 1,517,022 | 529,973 | 53,664 | 2.0 | 43 | 113 | 9,827 | 0.31 | 2.31 | 0.62 | 3.2 |
| 1994 | 1,606,038 | 471,475 | 164,093 | 2.6 | 42 | 97 | 9,480 | 0.44 | 2.11 | 1.68 | 4.2 |
| 1995 | 1,003,271 | 477,355 | 203,253 | 3.4 | 43 | 93 | 9,740 | 0.35 | 2.12 | 1.95 | 4.4 |
| 1996 | 1,416,847 | 292,451 | 98,852 | 1.8 | 30 | 61 | 9,567 | 0.27 | 0.90 | 0.63 | 1.8 |
| 1997 | 812,589 | 304,289 | 130,323 | 1.6 | 35 | 77 | 9,827 | 0.13 | 1.10 | 1.03 | 2.3 |
| 1998 | 1,520,025 | 607,596 | 253,572 | 3.8 | 62 | 130 | 10,000 | 0.58 | 3.74 | 3.30 | 7.6 |
| 1999 | 1,652,615 | 381,867 | 145,777 | 3.4 | 77 | 182 | 9,827 | 0.57 | 3.01 | 2.70 | 6.3 |
| 2000 | 4,155,203 | 847,274 | 229,445 | 3.4 | 41 | 132 | 9,827 | 1.45 | 3.50 | 3.08 | 8.0 |
| 2001 | 7,747,118 | 975,495 | 168,030 | 2.6 | 41 | 97 | 8,961 | 2.28 | 4.48 | 1.81 | 8.6 |
| 2002 | 6,040,942 | 2,382,790 | 436,929 | 2.0 | 21 | 81 | 9,567 | 1.25 | 5.32 | 3.72 | 10.3 |
| 2003 | 2,238,558 | 1,296,517 | 983,388 | 2.7 | 26 | 89 | 9,653 | 0.63 | 3.53 | 9.06 | 13.2 |
| 2004 | 1,791,130 | 770,962 | 604,900 | 2.8 | 20 | 65 | 9,394 | 0.54 | 1.66 | 4.22 | 6.4 |
| 2005 | 1,425,175 | 363,227 | 196,484 | 2.6 | 46 | 84 | 9,307 | 0.40 | 1.79 | 1.77 | 4.0 |
| 2006 | 2,260,786 | 502,687 | 204,741 | 3.0 | 51 | 132 | 9,307 | 0.72 | 2.74 | 2.90 | 6.4 |
| 2007 ¹ | 1,328,668 | 280,042 | 109,861 | 3 | 40 | 125 | 9,567 | 0.39 | 1.17 | 1.43 | 3.0 |
| 2008 | 1,546,426 | 415,098 | 132,996 | 2.6 | 29 | 117 | 10,000 | 0.41 | 1.22 | 1.56 | 3.2 |
| 2009 | 2,584,331 | 690,179 | 165,119 | 2.6 | 42 | 118 | 9,567 | 0.69 | 3.01 | 2.03 | 5.7 |
| 2010 | 3,853,611 | 723,161 | 316,489 | 2.7 | 21 | 94 | 9,653 | 1.08 | 1.56 | 3.07 | 5.7 |
| 2011 | 1,083,383 | 460,074 | 482,116 | 1.6 | 20 | 58 | 9,913 | 0.18 | 0.95 | 2.83 | 4.0 |
| 2012 | 1,904,443 | 325,790 | 140,836 | 2.9 | 41 | 79 | 9,653 | 0.57 | 1.38 | 1.15 | 3.1 |
| 2013 | 1,710,837 | 288,330 | 119,062 | 2.8 | 62 | 121 | 9,480 | 0.51 | 1.89 | 1.52 | 3.9 |
| 2014 | 3,185,426 | 335,399 | 104,104 | 3.0 | 56 | 126 | 9,480 | 1.02 | 1.99 | 1.38 | 4.4 |
| 2015 | 4,341,702 | 548,621 | 223,563 | 2.5 | 29 | 76 | 9,134 | 1.21 | 1.73 | 1.85 | 4.8 |
| 2016 | 3,491,826 | 672,466 | 156,886 | 2.8 | 55 | 100 | 9,134 | 1.09 | 4.04 | 1.71 | 6.8 |
| 2017 | 1,913,289 | 661,483 | 434,701 | 2.7 | 36 | 74 | 9,740 | 0.54 | 2.47 | 3.29 | 6.3 |
| 2018 | 1,808,723 | 163,973 | 132,410 | 2.6 | 54 | 98 | 9,740 | 0.48 | 0.91 | 1.33 | 2.7 |
| 2019 | 909,873 | 405,186 | 136,353 | 1.2 | 31 | 72 | 9,740 | 0.12 | 1.65 | 1.57 | 3.3 |

¹No trawling occurred in 2007, mean weights are the average of 2006 & 2008