Arrow Lakes Reservoir Nutrient Restoration Program

(COL-F22-F-3496-DCA)

2021-22 (F22) Activity Report

1 April 2021 to 31 March 2022

Prepared for: Fish & Wildlife Compensation Program (FWCP)

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Executive Summary

Nutrient additions, in the form of liquid agricultural grade fertilizer occurred in Upper Arrow following the same methods as recent years. In total, 39 MT of phosphorus and 200 MT of nitrogen were added to the Reservoir between late April and early September. The annual tonnes of phosphorus from fertilizer additions have been around 40 MT since 2016 (2021 was the 6th year of holding similar loading rates). The 2021 April-October daily mean outflow for Arrow was 1142.5 (m^3/s) and near the 1997-2021 mean. Flows in July and August however were higher than average. Phosphorus and nitrogen values were similar to previous years and in the range of an oligotrophic system. Water clarity, measured as a Secchi depth was average for both basins in 2021. Phytoplankton abundance was higher than average in both basins. Zooplankton, both cladocerans (*Daphnia*) and copepods were at or above average in 2021, as well an early detection compared to previous years was observed in 2021.

Kokanee returns in 2021 were very low totaling only 14,000 in Upper Arrow and 67,000 in Lower Arrow, however the October 2021 hydroacoustic data suggests the spawner return should improve substantially in 2022. The in-lake Kokanee population for the combined basins was 5 million age 0 and 1.2 million age 1-3, which are both below the post nutrient addition average. The Upper Arrow population was closer to the long-term basin average than Lower Arrow, where the age 0 and age 1-3 populations were only 31% and 39% of average respectively. Kokanee cohort survival in 2021 was near average for age 0-1 and was above average for age 1-2+. Kokanee biomass density was 3.3 kg/ha in 2021 which was similar to 2020 however the proportion attributable to in-lake vs. spawner biomass was substantially different; the in-lake Kokanee biomass improved while the spawner biomass declined. Improved survival and positive *Daphnia* outcomes in 2021 should result in improved Kokanee outcomes in 2022.

The angler creel survey was completed with a total of 1,070 anglers interviewed (including repeat contacts) at the three major access locations in the 2021 calendar year. Estimated catch of bull trout, rainbow trout, Kokanee, and burbot combined (including released fish) was 9,200 fish, of which 5,090 were retained for a harvested weight of 4.8 tonnes. This yield is a slight increase from 2020 but less than that from 2001 – 2011, and slightly below expected for the phosphorus added over the last four years. Catch rates were low for burbot and Kokanee, relatively high for rainbow trout, and about average for bull trout. Catches of bull trout and piscivorous rainbow trout (≥ 50 cm) have been relatively low since 2014. The size of harvested Kokanee increased to 24 cm in 2021 but effort and harvest remained relatively low, likely due to dense forest fire smoke over the reservoir from mid to late summer. Relative condition factor (K_n) of bull trout averaged 1.06, this is near the expected value for the phosphorus added over the last four years, and slightly above the expected value based on 2021 Kokanee spawner abundance. Stomach samples collected from bull trout and piscivorous rainbow trout will be analyzed in the coming months.

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Introduction

Arrow Lakes Reservoir has been influenced by the construction of 3 dams – Hugh Keenleyside (1968), Mica (1973) and Revelstoke (1984). Hugh Keenleyside raised maximum water levels inundating the former Upper and Lower Arrow Lakes to form Arrow Lakes Reservoir. The increased water levels impacted high quality spawning and rearing habitat in tributaries. Revelstoke Dam blocked access to spawning and rearing habitat in tributaries upstream of the reservoir, and both Mica and Revelstoke Dams caused long-term changes in light penetration and nutrients in the lentic habitat of Arrow Lakes Reservoir. As a result of decreased upstream nutrient inputs, Kokanee stocks in Arrow Lakes declined substantially by the mid-1990s. To address the nutrient losses in Arrow Lakes Reservoir, a bottom-up approach was taken with the addition of nutrients (nitrogen and phosphorus in the form of liquid fertilizer) to increase phytoplankton populations that are suitable to produce *Daphnia*, the main food source for Kokanee. Nutrients have been added to Upper Arrow since 1999 and are dispensed from Waterbridge ferries, roughly April to September. Columbia Power Corporation contributes 25% of the costs to this project to compensate for fish entrainment through the Arrow Lakes Generating Station as per DFO Authorization No. 5300-10-002. Nutrient addition has been a successful technique used for the enhancement and conservation of sockeye salmon populations as well as being successful in restoring Kokanee populations in lakes and reservoirs altered by hydroelectric construction.

Goals and Objectives and Linkage of FWCP Action Plans and Specific Actions

The goals and objectives of the nutrient restoration program are a priority one habitat-based action (Figure 1) described in the Columbia Region Reservoirs and Large Lakes Action Plan (FWCP, 2019).

8	Habitat-based	**COLRLL.ECO.HB.08.01 Implementation of Kootenay Lake and Arrow Lakes Nutrient Restoration Programs-P1**	**1**	Kootenay Lake Arrow Lakes	Fish	Implement and adaptively manage nutrient restoration programs in Kootenay Lake and Arrow Lakes Reservoir to sustain in-lake productivity at levels sufficient to support secondary productivity (forage for Kokanee).	Successfully demonstrate improved health and productivity of reservoirs.	Directed
9	Habitat-based	**COLRLL.ECO.HB.09.01 Operation of Meadow Creek and Hill Creek spawning channels-P1**	**1**	Kootenay Lake Arrow Lakes	Fish	Support the maintenance and operation of the Meadow Creek and Hill Creek spawning channels to ensure sufficient kokanee production in Kootenay Lake and Arrow Lakes Reservoir.	Improved Kokanee productivity to support a healthy and resilient reservoir ecosystem.	Directed
10	Monitoring and Evaluation	**COLRLL.ECO.ME.10.01 In-season Monitoring of Kootenay Lake and Arrow Lakes Nutrient Restoration Programs-P1**	**1**	Kootenay Lake Arrow Lakes	Fish	Implement in-season monitoring and evaluation of indicators and trends in ecosystem components (e.g. water chemistry, plankton, Kokanee) related to the Kootenay Lake and Arrow Lakes Reservoir nutrient restoration programs.	Improved understanding of indicators and annual trends of in lake productivity.	Directed

- **Habitat-based Actions** – These actions will conserve, restore, and enhance reservoir and large lake habitats. Examples include habitat creation, restoration, and enhancement; enhancing habitat connectivity; nutrient restoration; and invasive species prevention.
- **Monitoring and Evaluation** – These actions will monitor and evaluate reservoir and large lake projects supported by the FWCP to understand the effectiveness of habitat- or species-based actions.

Figure 1. Nutrient Restoration Programs component of the Reservoirs and Large Lakes Action Table – Ecosystems (Aquatic Productivity) in the Columbia Region Reservoirs and Large Lakes Action Plan (FWCP, 2019).

Methods

Methods for nutrient additions and the sampling of various trophic levels for the nutrient restoration programs are identified in the previous year (2019) summary report (Bassett, Weir, & Fox, 2020). The methods for the creel component are listed in (Arndt S. , 2022). In summary, the nutrient addition zone on Arrow Lakes Reservoir is the pelagic area between Shelter Bay and Galena Bay, the passenger ferry (the Columbia) route (Figure 2). The trophic levels monitored as components of the program are physical limnology, phytoplankton, zooplankton, mysids, in – lake Kokanee (hydroacoustics and trawling) and Kokanee spawners, further details are listed in Appendix 2. In 2021, components of monitoring program were reduced to meet the challenges from covid related logistics or from analysis to scale back stations for the zooplankton and mysid data (Thorley & Amies-Galonski, 2022). A summary of data collected for 2021 is in Appendix 2.

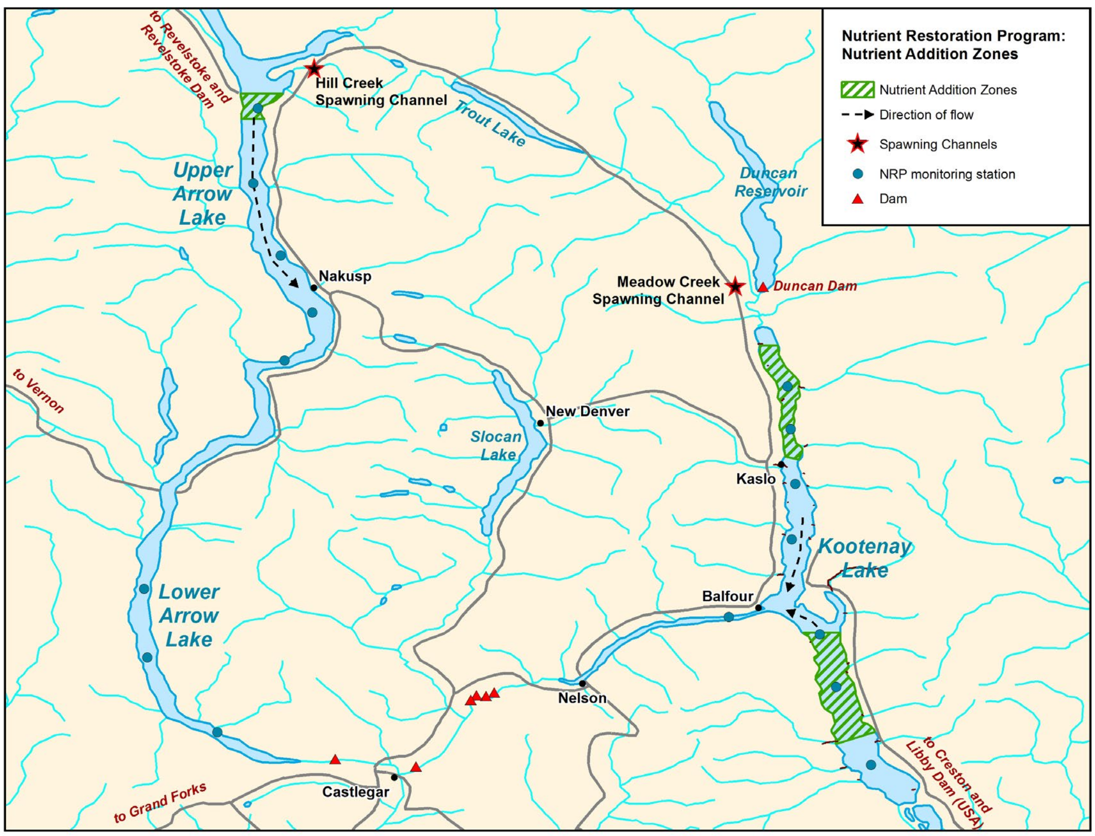

Figure 2. Map of Arrow Lakes Reservoir nutrient addition zone and monitoring stations identified (described in the legend on the map).

Results

Nutrient Loading

Nutrient additions occurred in Upper Arrow following the same methods as recent years. In total, 39 MT of Phosphorus and 200 MT of Nitrogen were added to the Reservoir in the form of liquid agricultural grade fertilizers, 10-34-0 and 28-0-0. The annual tonnes of phosphorus from fertilizer have been approximately 40 MT since 2016.

Flow

The 2021 daily mean outflow (calculated April 1 to Oct 31) for Arrow was 1142.5 (m^3/s), which was near average yet lower than 2020 (Figure 3). The last 9 out of 11 years have been at or above average for flows (Figure 3). The flow regime fluctuated and was notably higher in July and the first half of August (Figure 4). Specifically looking at these warm summer months (July and August), the flows were above average in 2021 and similar to 2020 (Figure 5). There is a significant difference ($p<0.05$) between these two eras, 1997-2010 and 2011-2021, for both the April-October season, and the July-August season.

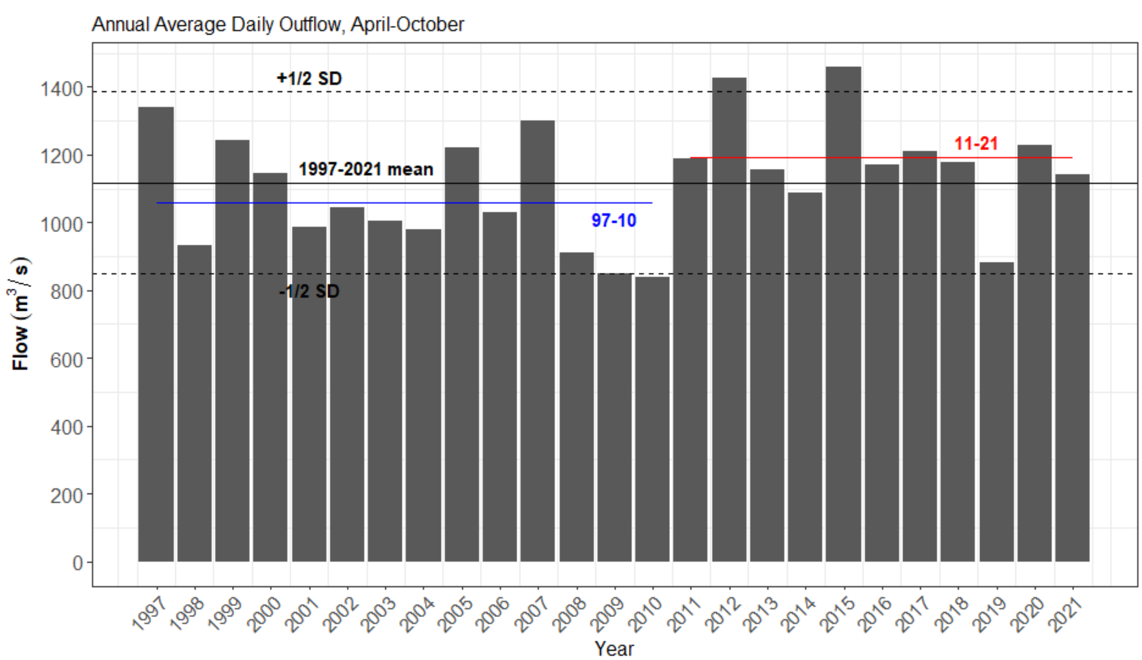

Figure 3. Annual mean of daily outflow (m^3/s) between April and October in Arrow Lakes Reservoir 1997-2021. Solid blue line is 1997-2010 outflow mean and solid red line is 2011-2021 outflow mean. Solid black horizonal line is 1997-2021 mean and dashed black horizonal lines are ±1/2 SD.

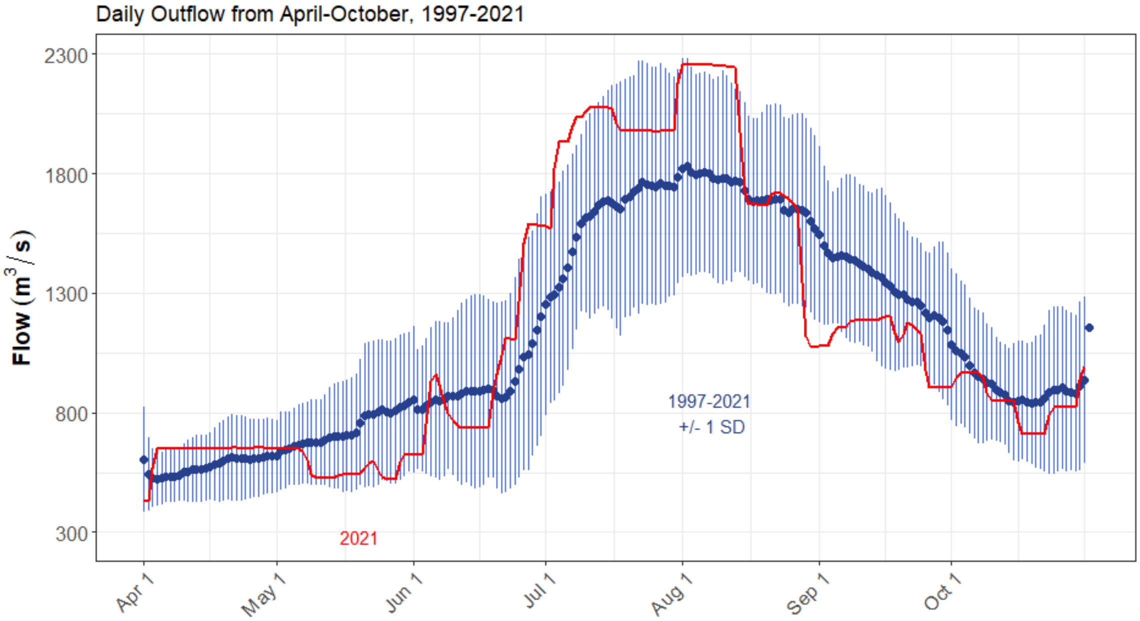

Figure 4. Arrow Lakes Reservoir daily outflow, April-October 1997-2021. Blue circles are 1997–2021 daily average, blue vertical lines ± 1 standard deviation. Red line is 2021 daily outflow.

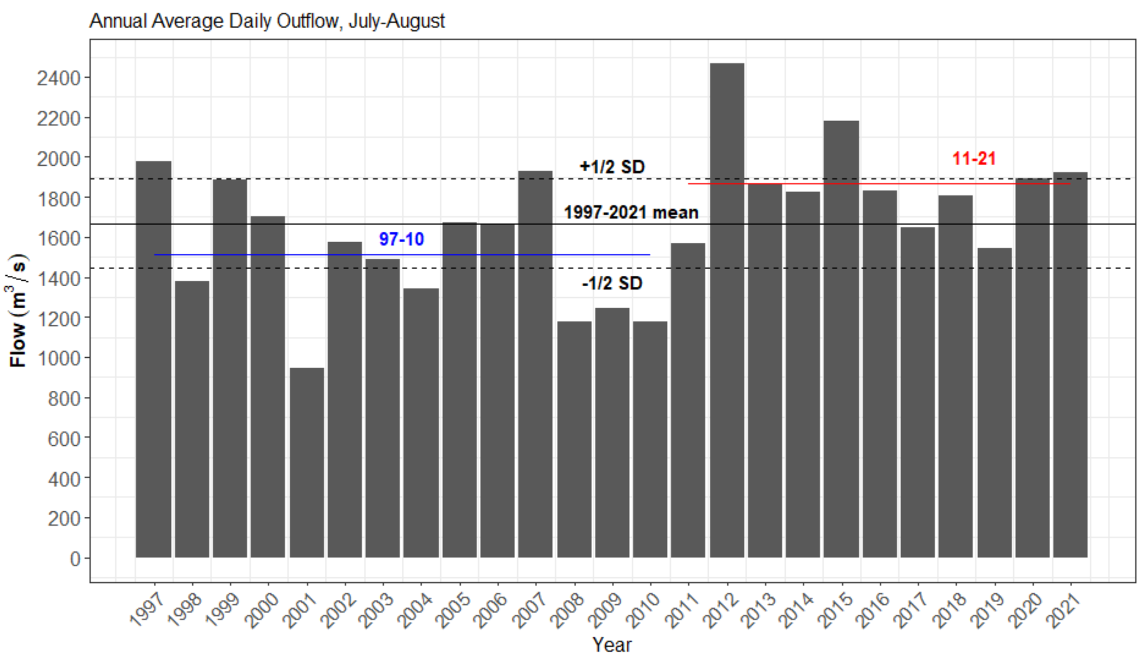

Figure 5. Annual mean of daily outflow (m^3/s) between July and August in Arrow Lakes Reservoir 1997-2021. Solid blue line is 1997-2010 outflow mean and solid red line is 2011-2021 outflow mean. Solid black horizonal line is 1997-2021 mean and dashed black horizonal lines are ±1/2 SD.

Physical Limnology

Secchi depth is a measure of water clarity, where the higher the number, the clearer the water is. In 2021, the mean Secchi in Upper Arrow was 6.4 m while the 1997-2021 average was 6.3 m. The mean Lower Arrow Secchi reading was 6.8 m while the 1997-2021 mean was 6.7 m (Figure 6).

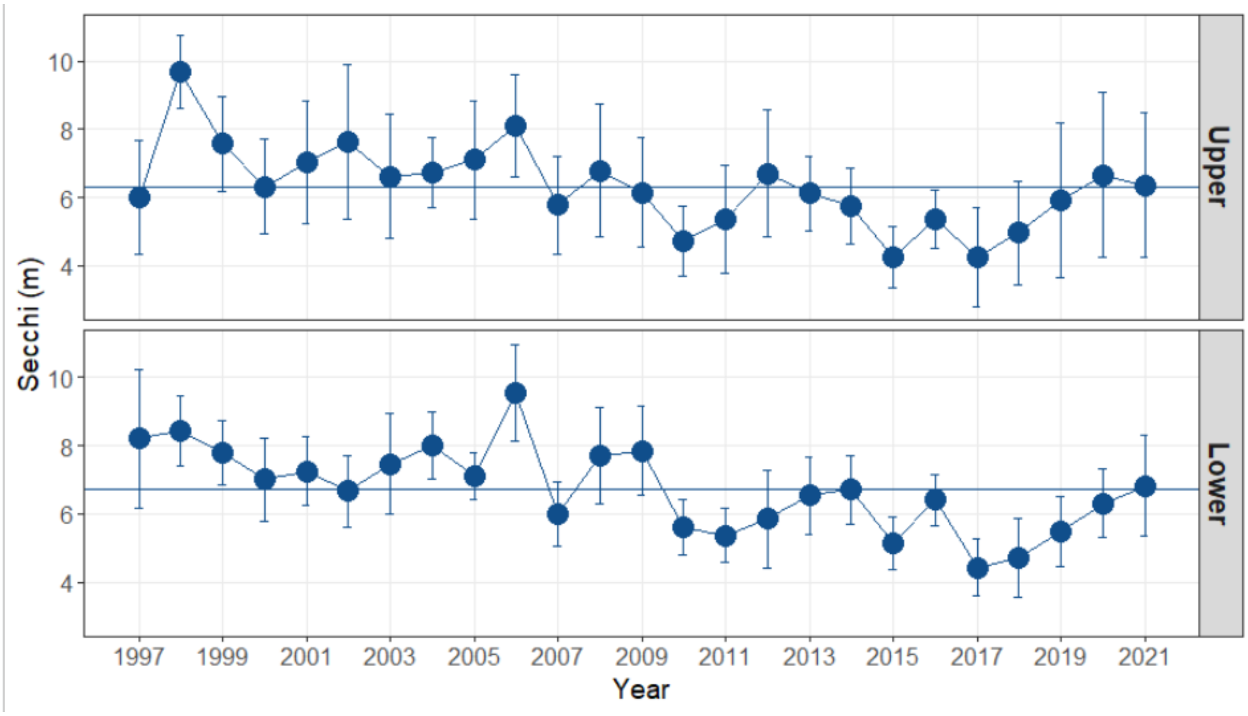

Figure 6. Arrow Secchi (m) annual mean (April – October), by basin. Horizontal lines are long term basin averages. Means ± 2SE.

Water Chemistry: Nutrients

Nutrients of particular interest to the program are nitrogen and phosphorus. The form of phosphorus most readily available for biological uptake is total dissolved phosphorus (TDP). In Upper Arrow, the 2021 mean TDP was 2.2 µg/L, slightly below the long-term mean (Figure 7). In Lower Arrow, the 2021 mean was 2.9 µg/L and above the long-term mean (Figure 7), however the Lower Arrow mean is influenced by a high phosphorus value in October. The phosphorus values observed in Arrow categorize the reservoir as ultra-oligotrophic (Wetzel, 2001). The dissolved components of nitrogen (dissolved inorganic nitrogen; DIN) concentrations in 2021 for Lower Arrow were near the 2004-2021 mean, and Upper Arrow was slightly higher than the 2004-2021 mean (Figure 8). In 2004, the sampling depth was modified to 0-20m from 0-30m. The 0-30 m samples had higher concentrations because 30 m is below the thermocline where higher concentrations of nitrate occur (Schindler, et al., 2007).

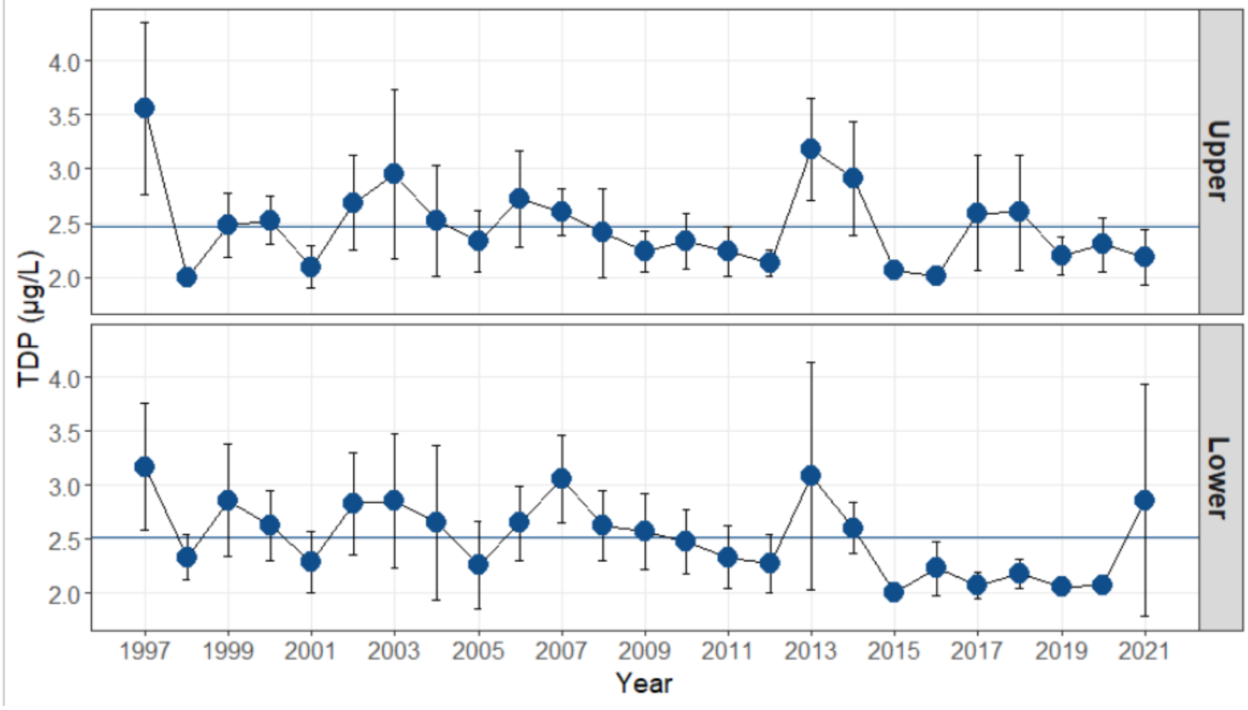

Figure 7. Arrow total dissolved phosphorus (TDP) annual mean (April – October), by basin. Horizontal lines are long term basin averages. Means ± 2SE.

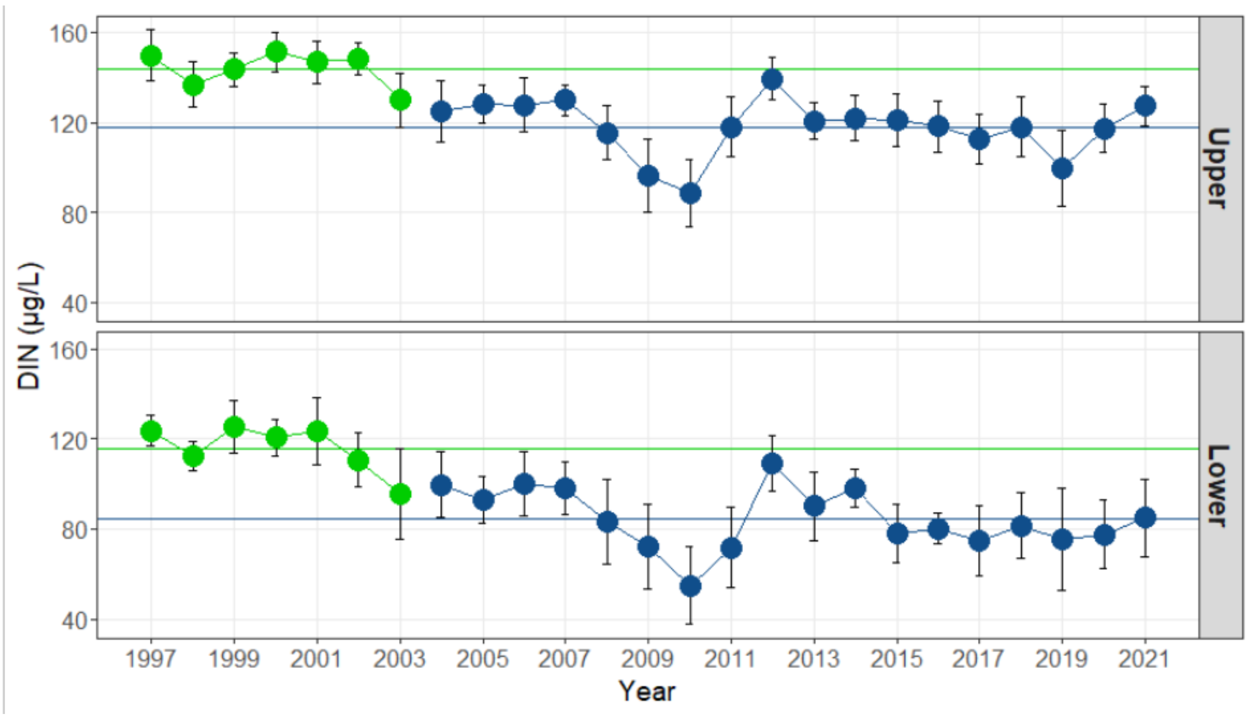

Figure 8. Arrow dissolved inorganic nitrogen (DIN) annual mean (April – October), by basin. Sampling depth 0-30m (green) and 0-20m (blue). Horizontal lines are long term basin averages (by sampling depth). Means ± 2SE.

Total phytoplankton abundance in 2021 was higher than the long term means for both Upper and Lower basins (Figure 9). The 2021 phytoplankton abundance trended seasonally with previous years, apart from higher abundances in July for both basins (Figure 10).

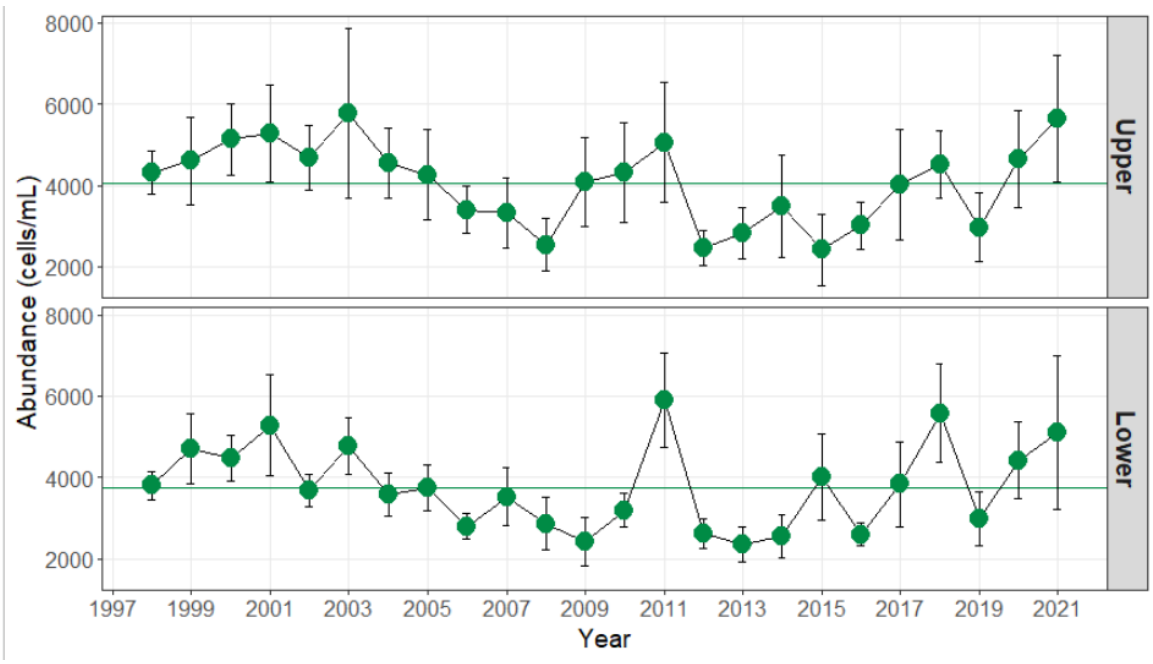

Figure 9. Arrow phytoplankton abundance (cells/ml) annual mean (April – October) by basin. Horizontal lines are long term basin averages. Means ± 2SE.

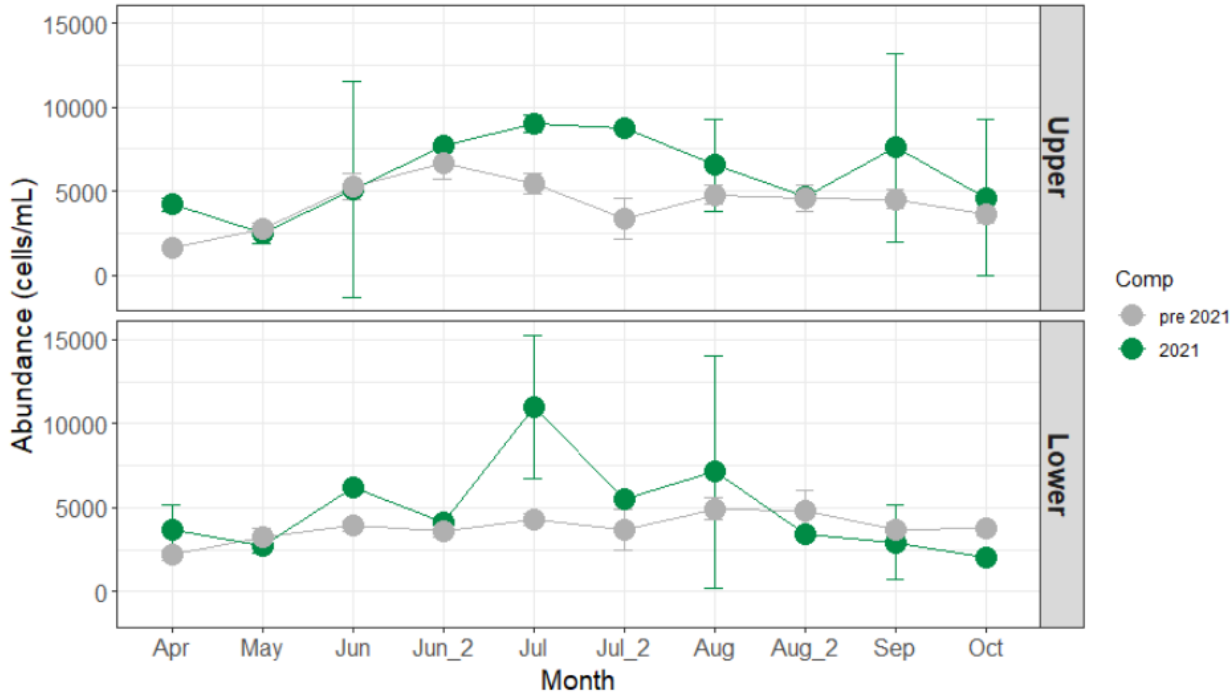

Figure 10. Arrow phytoplankton abundance monthly mean by basin (Upper and Lower) 2021 (green) and 1998–2020 (grey). Jul_2 and Aug_2 sampling began in 2012. Means ±SE.

Zooplankton

Daphnia (the preferred food source of Kokanee) density was higher than average in both Upper and Lower Arrow in 2021 (Figure 11). The annual mean in both basins were driven by high *Daphnia* densities observed in September in the upper basin, and in September and October in the lower basin (Figure 12). The first detection of *Daphnia* at concentrations >0.4 ind/L was in July for both basins, which was the earliest since 2016 in Upper Arrow, and 2018 in Lower Arrow (Figure 13). *Daphnia* first appeared in both basins in June, this was the earliest in Upper Arrow since 2017. Copepods are a smaller and more abundant zooplankton compared to cladocerans (*Daphnia* are the predominant cladoceran species in Kootenay and Arrow) and are a food source to Kokanee when *Daphnia* are in low abundances. The 2021 copepod densities in the upper basin were 9.9 ind/L and in the lower basin were 17.8 ind/L, these results were at or slightly above the long-term basin means (data not shown). In summary, 2021 was a good year for zooplankton in Arrow, particularly for *Daphnia*.

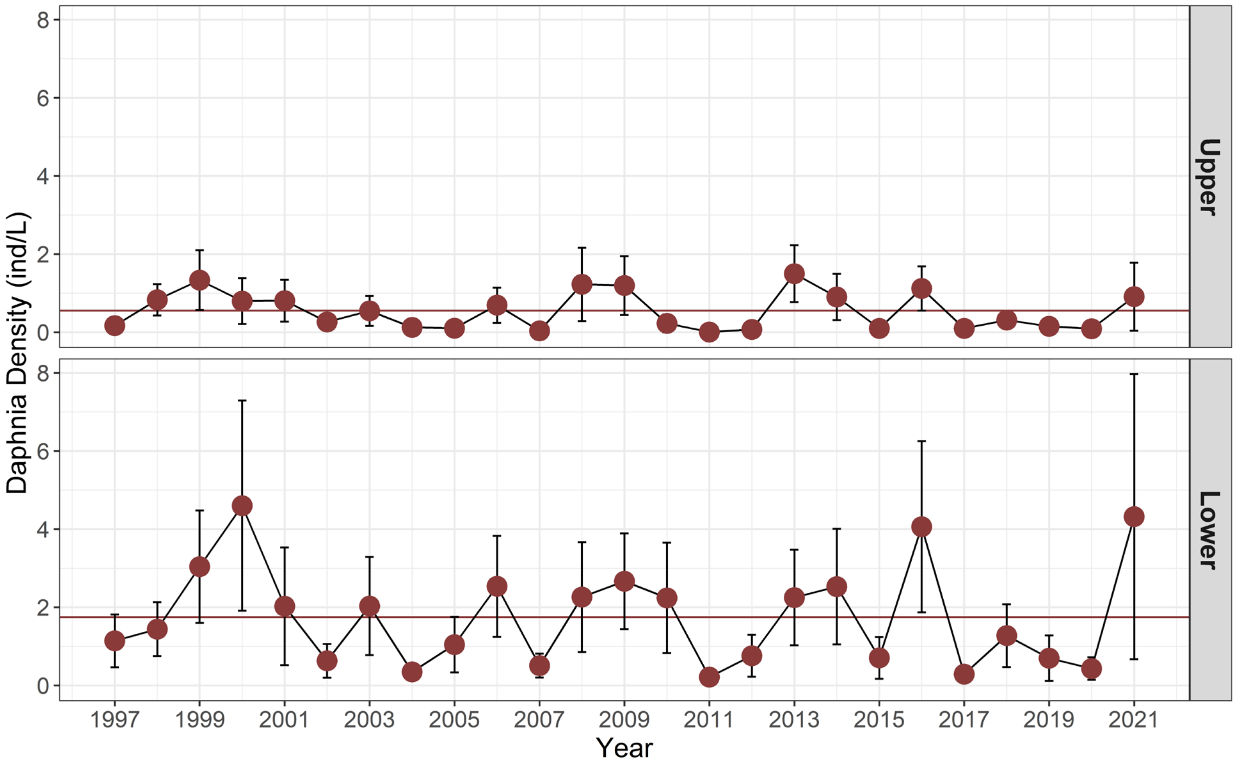

Figure 11. Arrow zooplankton *Daphnia* densities (ind/L) annual mean (April – October), by basin. Means ± 2SE. Horizontal lines are long term basin averages. Means ± 2SE.

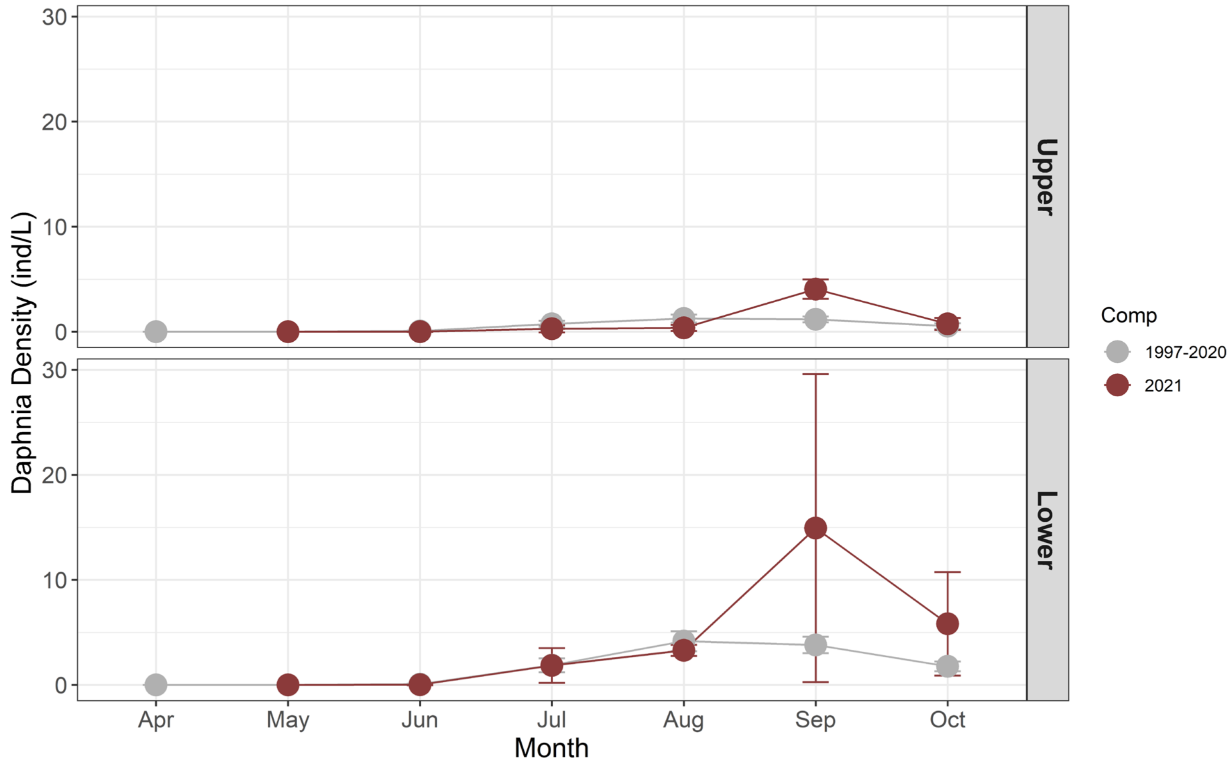

Figure 12. Monthly mean of *Daphnia* densities (ind/L) in Upper and Lower Arrow. Grey dots and error bars are 1997-2019 monthly means; red dots and error bars are 2021 data. No sampling occurred in April of 2021. Means ± 2SE.

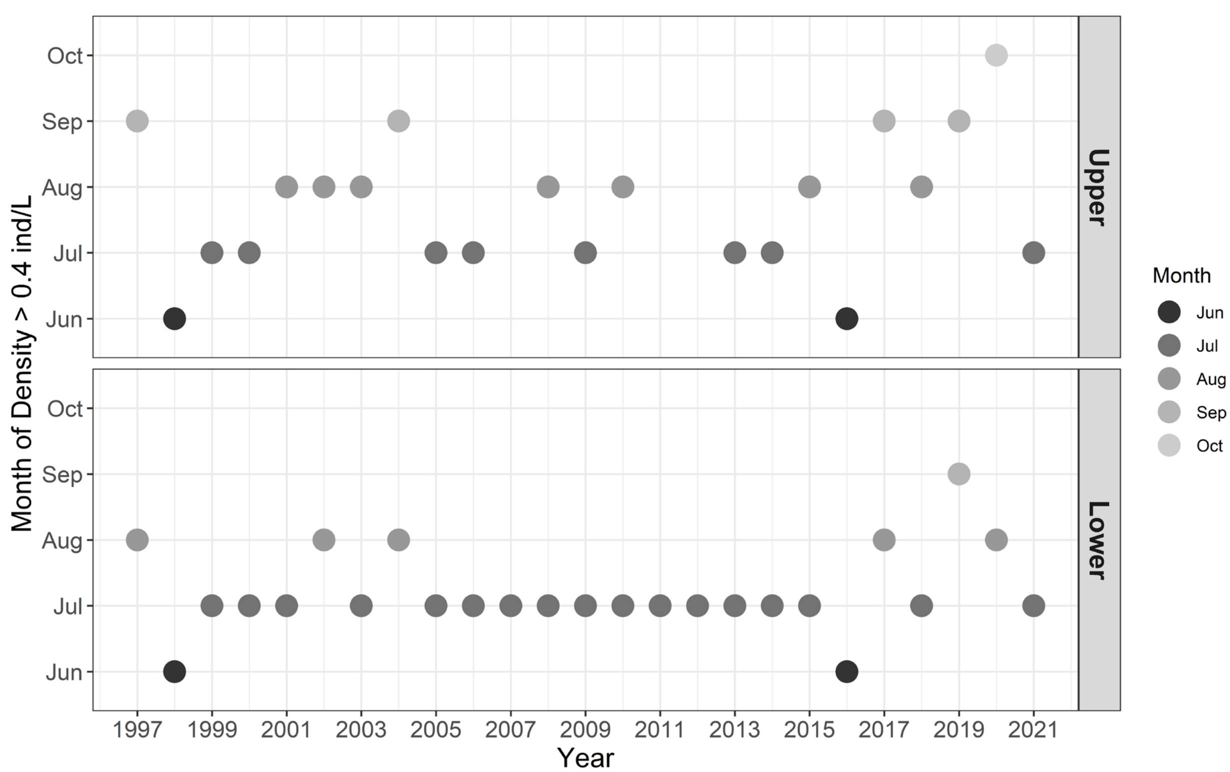

Figure 13. Month of first appearance of *Daphnia* densities above 0.4 ind/L by basin.

Mysids

Mysid densities in both the Upper and Lower basins were below the long term (1997-2021) mean (Figure 14). In Upper Arrow, the 2021 mean was the 2nd lowest in the time series, and lowest since the NRP began in 1999. In Lower Arrow, the 2021 mean was below average, a trend since 2016. In Upper Arrow, the 2021 mysid density seasonal trend was similar to the long-term trend where mysid densities increased from April to a peak in July before decreasing to October, however, the monthly values were all well below average in 2021 (Figure 15). In Lower Arrow, the seasonal trend in 2021 did not follow the long-term trend and mysids peaked in July and August.

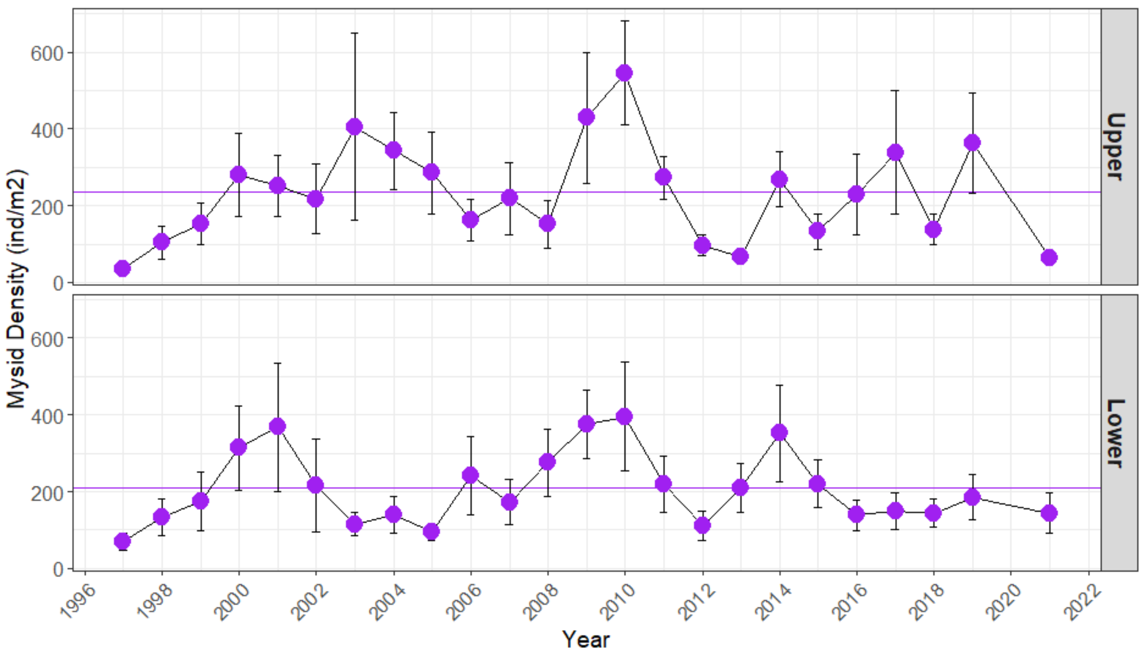

Figure 14. Arrow mysid densities (ind/m²) annual mean (April – October), by basin. The 2020 data is incomplete and not included in analysis. Horizontal lines are long term basin averages. Mean ± 2SE.

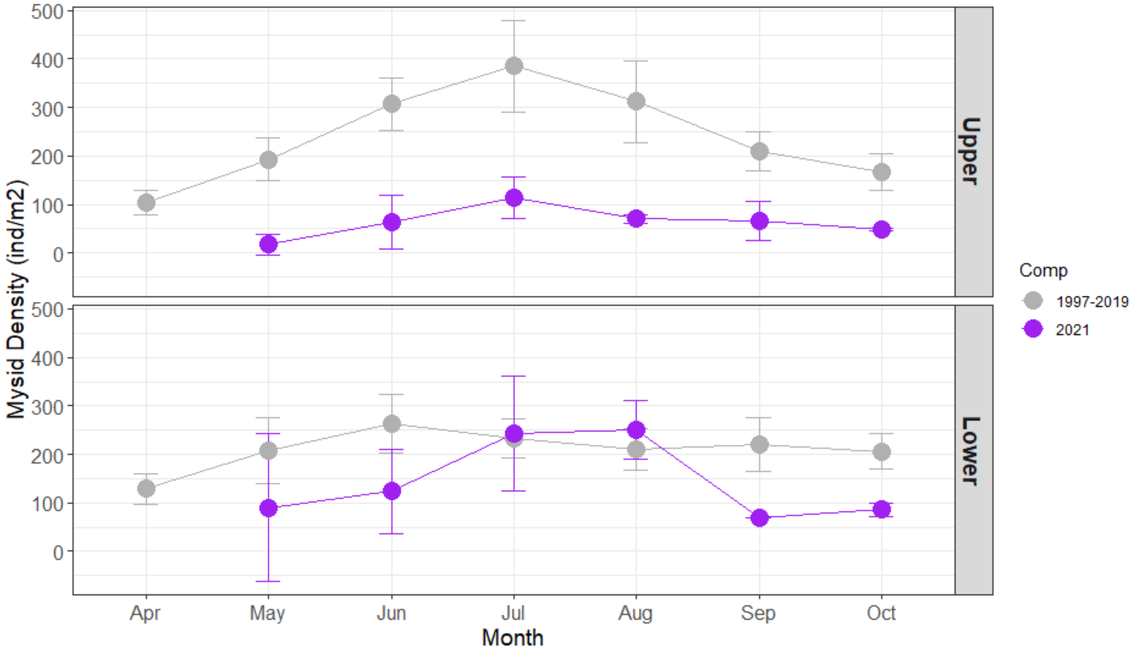

Figure 15. Monthly mean of mysid densities (ind/m²) in Upper and Lower Arrow. Grey dots and error bars are 1997-2019 monthly means; purple dots and error bars are 2021 data. The 2020 data is incomplete and not included in analysis. No sampling occurred in April of 2021. Means ± 2SE.

Kokanee

Escapement

Kokanee returns in 2021 were very low totaling only 14,000 in Upper Arrow and 67,000 in Lower Arrow (Figure 16). Preliminary analysis of hydroacoustic data from the October 2021 survey of Arrow Lakes Reservoir suggests the spawner return should improve substantially in 2022 (not shown).

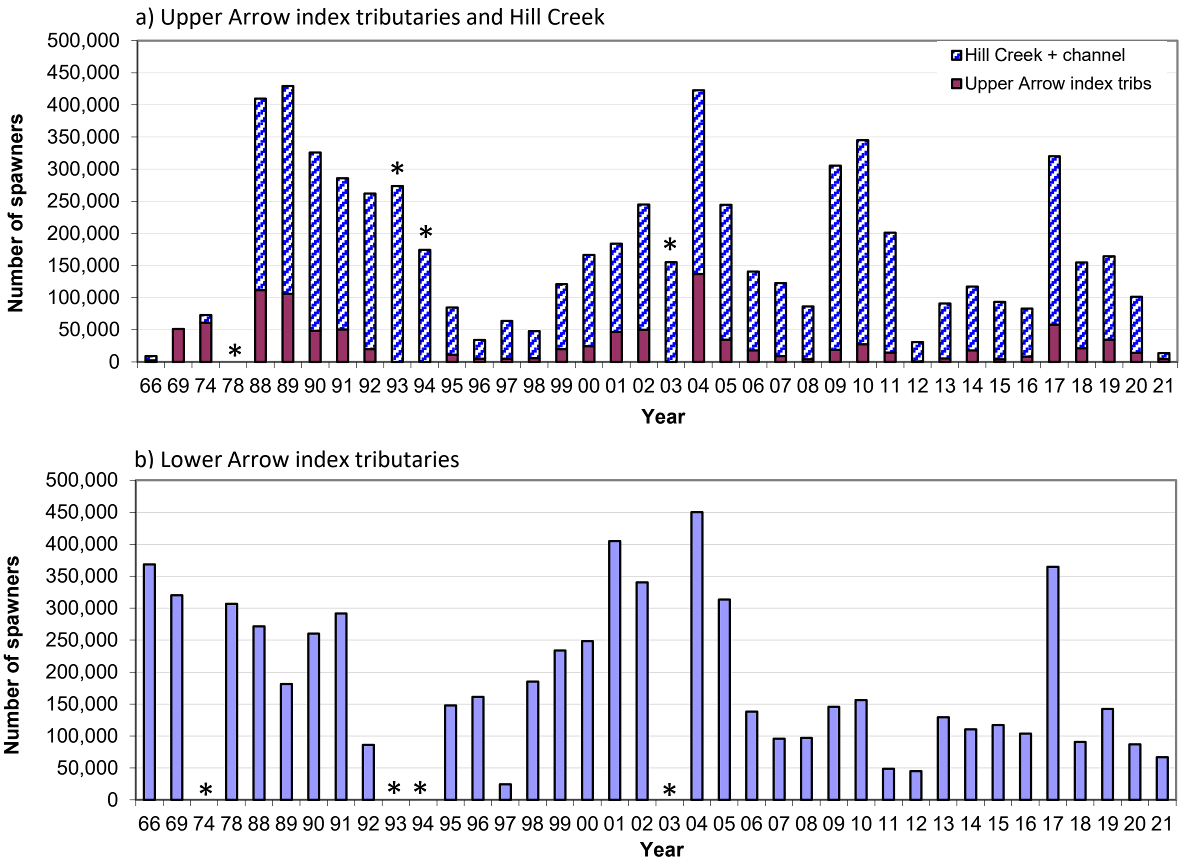

Figure 16. Kokanee Escapement for index tributaries on Arrow Lakes Reservoir for a) Upper Arrow and b) Lower Arrow from 1995-2021. * Indicates years where counts were not conducted or were incomplete.

In-Lake Abundance

The 2021 Kokanee age 0 (fry) population for the combined basins was 5 million (Figure 17). The Upper Arrow fry abundance was 4 million compared to the post-NRP basin average of 4.6 million. The Lower Arrow fry abundance was 1 million compared to the basin average of 2.6 million. The 2021 age 1-3 Kokanee population for the combined basins was 1.2 million (Figure 17). The Upper Arrow age 1-3 abundance was 0.9 million compared to the post-NRP basin average of 1.3 million. The Lower Arrow age 1-3 abundance was 0.3 million compared to the basin average of 0.9 million.

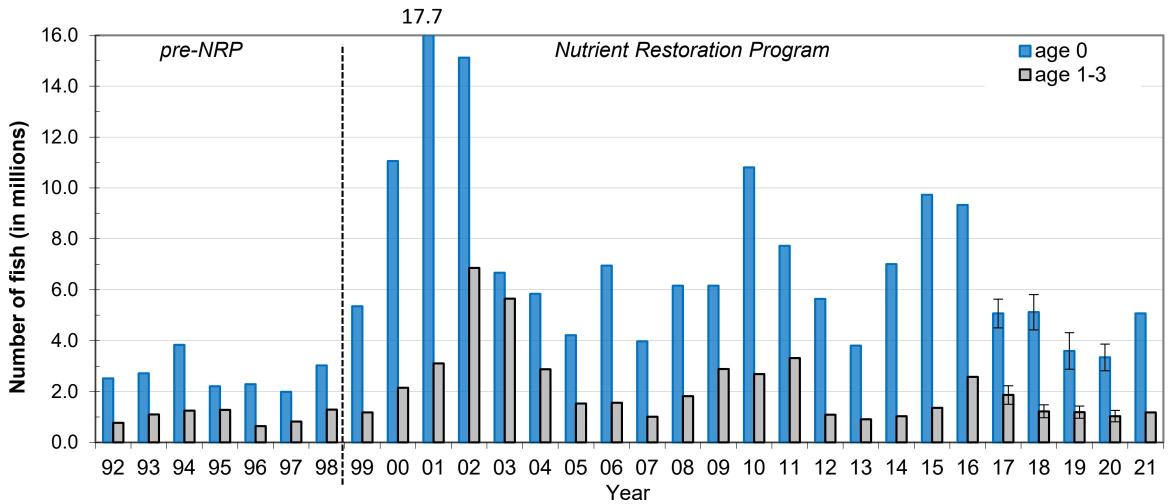

Figure 17. Kokanee abundance from October acoustic surveys in Arrow Reservoir (combined Upper and Lower Arrow basins). A recently completed acoustic time-series re-evaluation has resulted in changes to previously reported estimates, particularly prior to 2008; however, the overall trend remains similar. Confidence intervals on estimates have not yet been re-calculated for the entire timeseries. 2021 data are preliminary.

Survival

Kokanee cohort survival in 2021 was near average for age 0-1 and was above average for age 1-2+ (Figure 18).

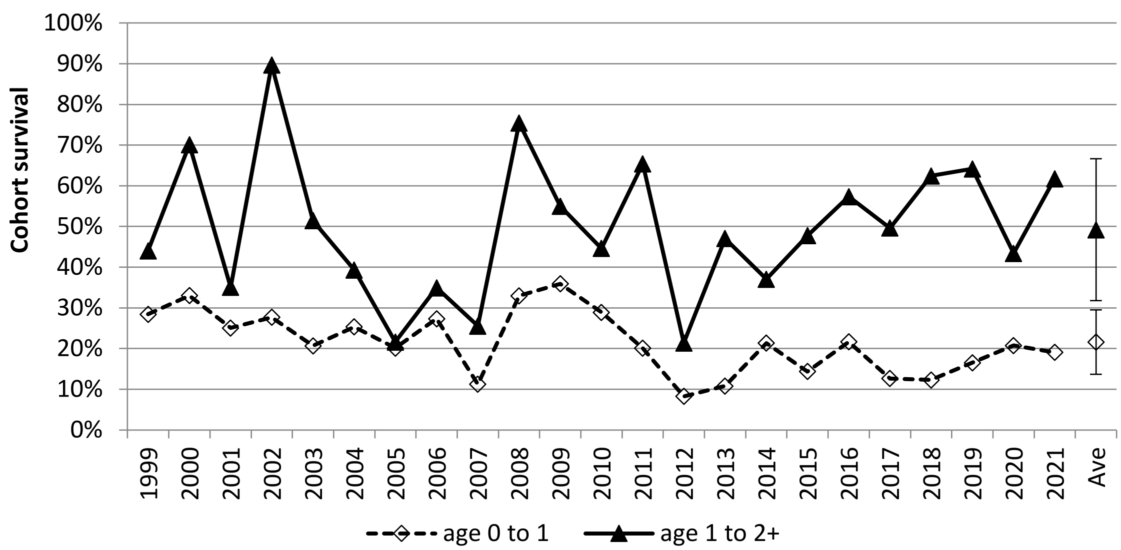

Figure 18. Trends in annual survival for in-lake Kokanee cohorts for Arrow Lakes Reservoir (combined basins) and the post-NRP average and standard deviation. The age 2+ group includes the age 2 and older component estimated in-lake from fall hydroacoustic surveys as well as the estimate of age 2 spawners the same year. The year is labelled by the latter year as each value includes data from two consecutive years. 2021 data are preliminary.

In-Lake and spawner biomass

Kokanee biomass density (combined in-lake and spawners) was 3.3 kg/ha in 2021 (Figure 19). The 2021 total biomass estimate improved only slightly over 2020, however the proportion attributable to in-lake vs. spawner biomass was substantially different; the in-lake Kokanee biomass improved while the spawner biomass declined.

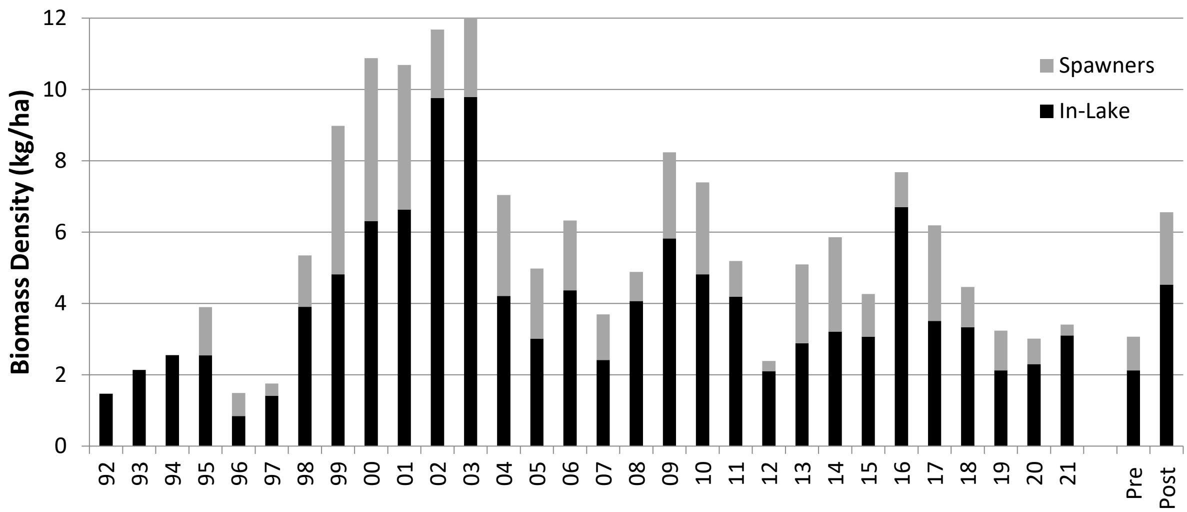

Figure 19. In-lake Kokanee and spawner biomass density estimates for combined basins in Arrow reservoir and pre-NRP (1992-1998) and post-NRP (1999-2020) averages. Data required to estimate spawner biomass from 1992-1994 are incomplete; the pre-NRP spawner biomass average represents 1995-1998. 2021 data are preliminary.

Arrow Creel Survey

The angler creel survey provides important metrics related to the bottom-up effects of the nutrient program on fish populations. A total of 1,070 anglers (including repeat contacts) were interviewed at the three major access locations in the 2021 calendar year. Total fishing effort (95% confidence limits) estimated for Arrow Lakes Reservoir in 2021 was 10,100 (1,700) angler-days, and 50,200 (8,900) rod-hours. This is the second year of decrease from the 2019 effort of 14,000 angler-days. Trends since 1987 show a general decrease prior to the beginning of the nutrient program, a recovery from 2001 to 2011, a second decline from 2011 to 2015, followed by a partial recovery in 2019 and another decline.

Fishing effort in 2021 is statistically the same as the four lowest years on record. A heat dome lasting from late June to early July, followed by forest fire smoke in July and August may have contributed to reduced fishing. Annual expenditures in 2021 based on daily values from a federal angler survey (Fisheries and Oceans Canada, 2019) were $0.55 million for spending wholly attributable to the fishery, or $1.5 million including major purchases partly attributable to the fishery. Residents of BC comprised 94% of the anglers, with non-resident Canadians making up the remainder. About 70% of angling effort was targeting bull trout and/or large rainbow trout, with about 15% of effort targeting Kokanee, or Kokanee and other species. Burbot as usual was the smallest component of the fishery, detected mainly at the Nakusp access but also at the Shelter Bay access in 2021.

Estimated catch of bull trout, rainbow trout, Kokanee, and burbot combined (including released fish) was 9,200 fish in 2021, of which 5,090 were retained for a harvested weight of 4.8 tonnes; this is a slight increase in yield from 2020 but less than that from 2001 - 2011. Bull trout catch was 2,980 of which 1,160 were kept for a weight harvest of 2,760 kg. Catch rate (Catch per unit effort; CPUE) for anglers targeting bull trout was 0.09 fish/rod hour. Bull trout harvest since 2014 has been lower than earlier in the nutrient program (Figure 20). The average size of a harvested bull trout was 59 cm (2.4 kg), and highest recorded weight was 8.3 kg.

Rainbow trout catch was 3,700 fish, of which 1,660 were kept for a weight harvest of 1,320 kg. Rainbow CPUE was 0.08 fish/rod hour, which is among the higher values in the last 15 years. Average size of harvested rainbow trout (41 cm, 0.8 kg) was similar to previous years; the highest recorded weight was 5.2 kg. The number of piscivorous rainbows (≥ 2 kg) in the fishery has been low since 2014 except for 2017 (Figure 21).

Kokanee catch was 2,320 of which 2,070 were kept for a harvest of 320 kg. Kokanee CPUE was 0.31 fish/rod hour, similar to 2020 (0.35) and a substantial decline from 0.83 in 2019. The average fork length of Kokanee increased in 2021 to 24 cm after five years of being less than 21.5 cm (Figure 22). Dense smoke from large wildfires around Octopus Creek and Michaud Creek (between Edgewood and Renata) probably reduced Kokanee fishing in July and August below what might have occurred with the increase in size.

Burbot catch in 2021 was estimated as 200 fish (all kept) for a harvest of 370 kg. Average size of burbot was 55 cm (1.8 kg). Catch rates in the last two years (0.14 and 0.18 fish/rod-hour) are the lowest in the time series starting in 1998.

The condition factor of bull trout is a key metric for looking at their food supply. Relative condition factor (K_n) of bull trout averaged 1.06 in 2021; this is the fourth year for condition remaining between 1.05 and 1.10 (i.e., 5-10% above the pre-nutrient level) (Figure 23). The 2021 average is near the expected value based on phosphorus additions (Figure 24), and slightly above the expected value based on the 2021 Kokanee spawner abundance (Figure 25). Stomach samples collected from bull trout and piscivorous rainbow trout (> 50 cm) will be analyzed in the coming months.

The recreational fishery yield of fish from the reservoir (four species pooled) is positively related to phosphorus additions over the 23 years of the nutrient program (r^2=0.71; Figure 26) and has fluctuated at a lower level since 2012. Consumption rates of piscivores on Kokanee should be estimated using the *in-situ* stomach data to help determine the top-down effects of predators on Kokanee in the reservoir. More detailed results are found in the 2021 angler survey report (Arndt S. , 2022).

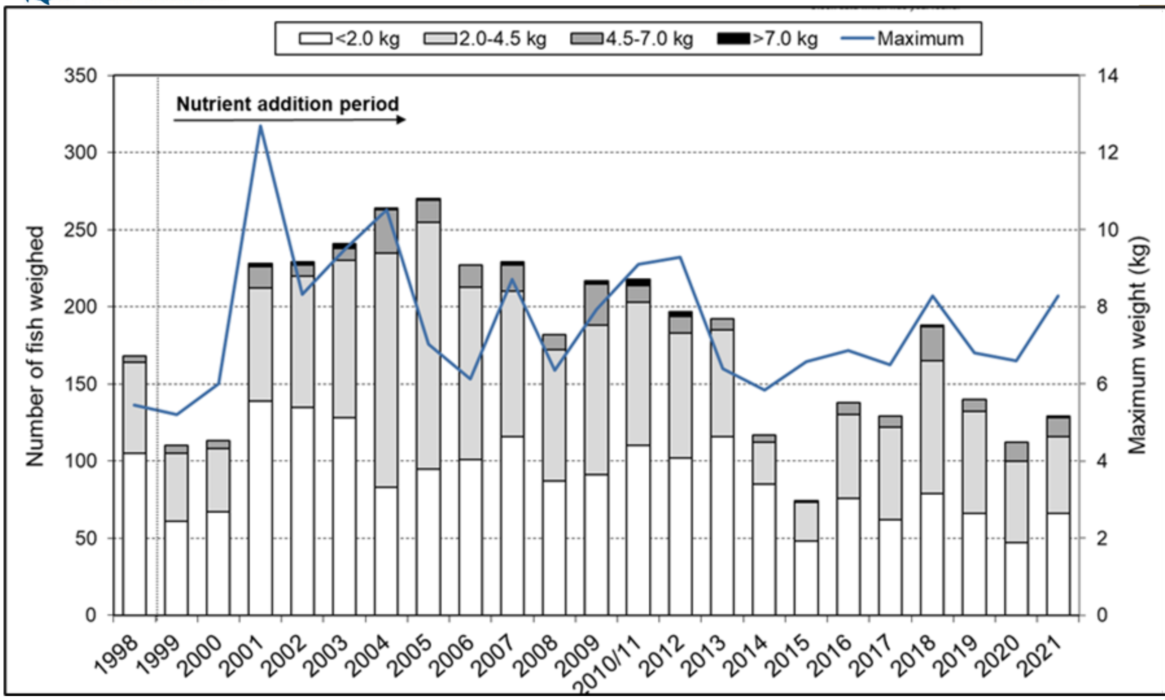

Figure 20. Number of weighed bull trout by size category sampled at three access locations in Arrow Lakes Reservoir from 1998 to 2020 (bars are size categories and blue line is the largest fish weighed in on creel days). [Note: 5 days/month are sampled at 3 locations all year]

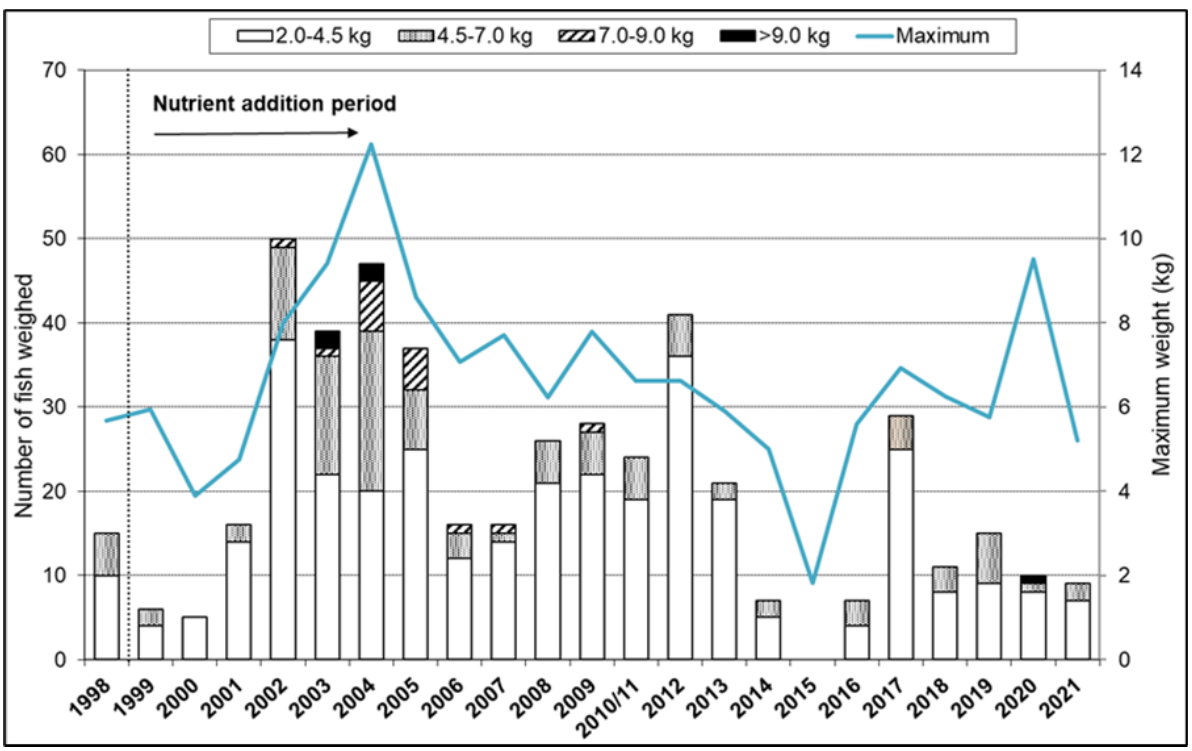

Figure 21. Number of large rainbow trout sampled and maximum size in the Arrow Lakes Reservoir creel survey since 1998.

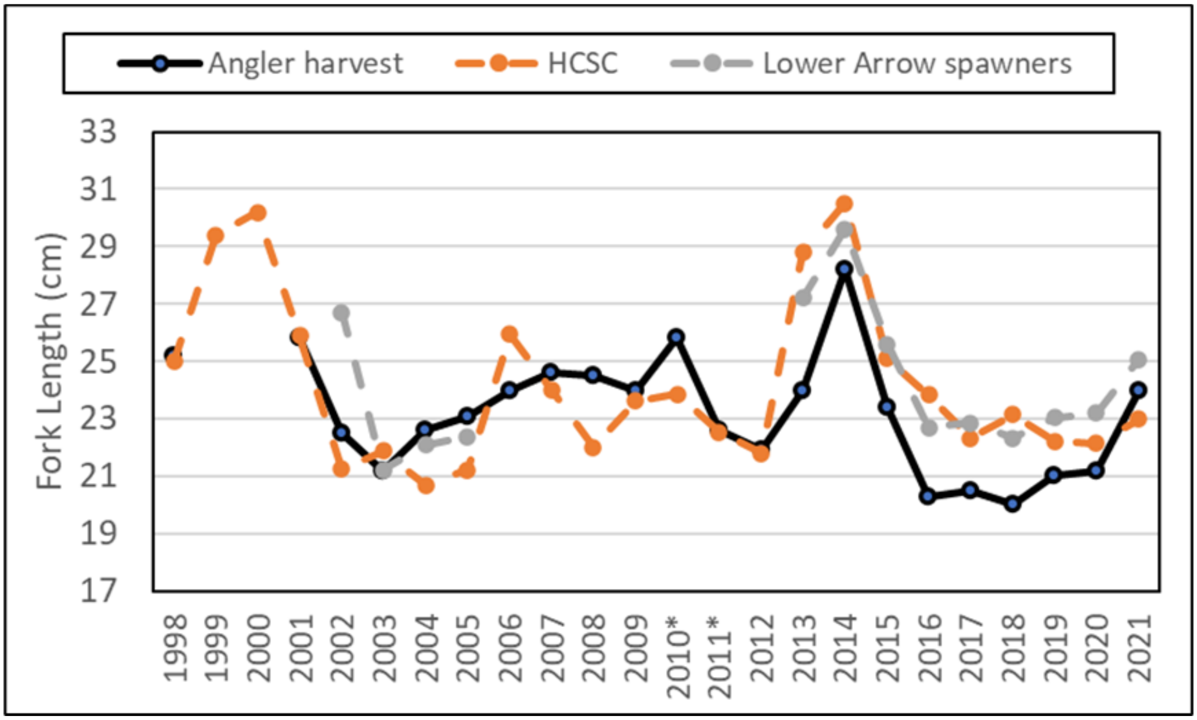

Figure 22. Average fork length of Kokanee harvested in the Arrow Lakes Reservoir fishery, and average length of Kokanee spawners in the fall of the same year from 1998 to 2021.

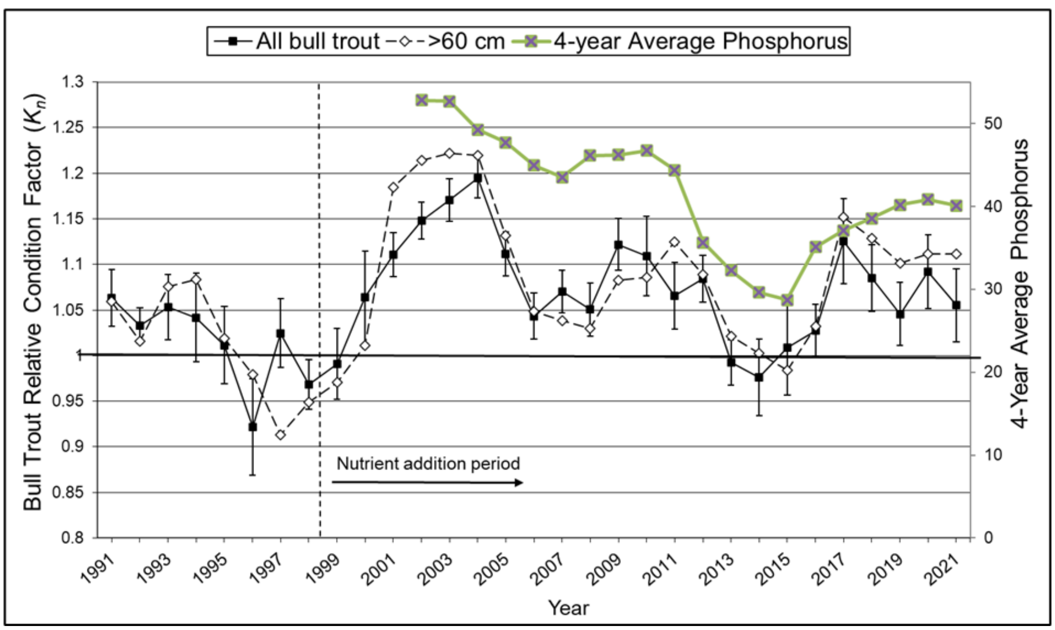

Figure 23. Average condition factor of bull trout sampled in the Arrow Lakes Reservoir creel survey since 1991. Brackets around the average indicate 95% confidence intervals. The line at 1 is the average condition for the available pre-nutrient years. The four-year average of phosphorus additions (starting in 1999) is shown by the green line from 2002.

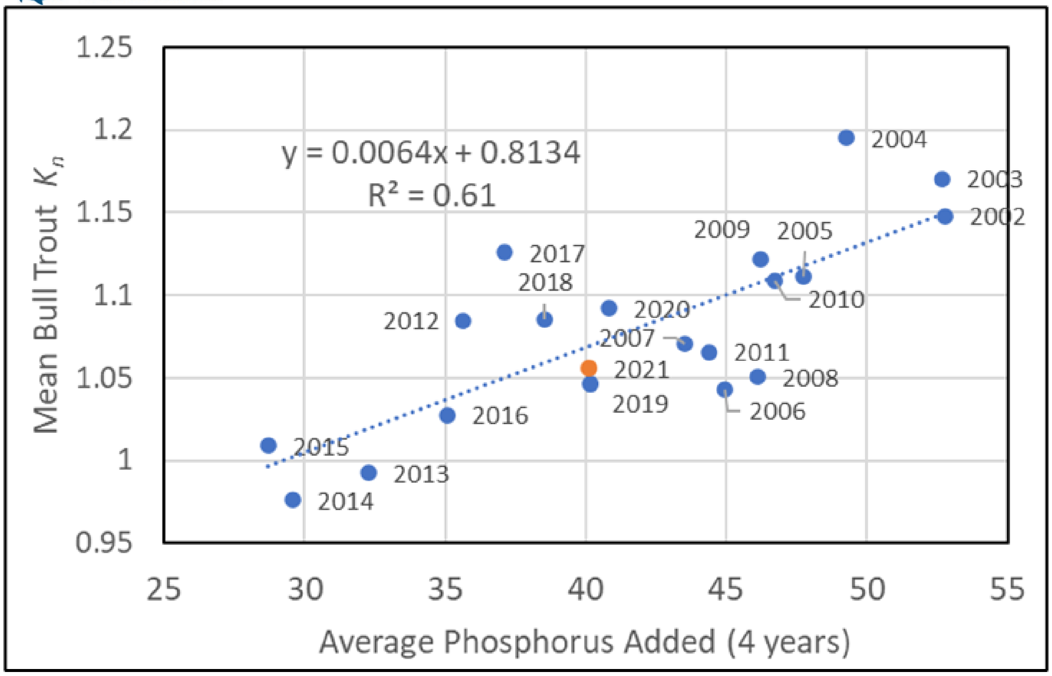

Figure 24. The relationship between amount of fertilizer phosphorus added (averaged over a 4-year period corresponding to the typical Kokanee life cycle) and the condition factor of bull trout in Arrow Lakes Reservoir.

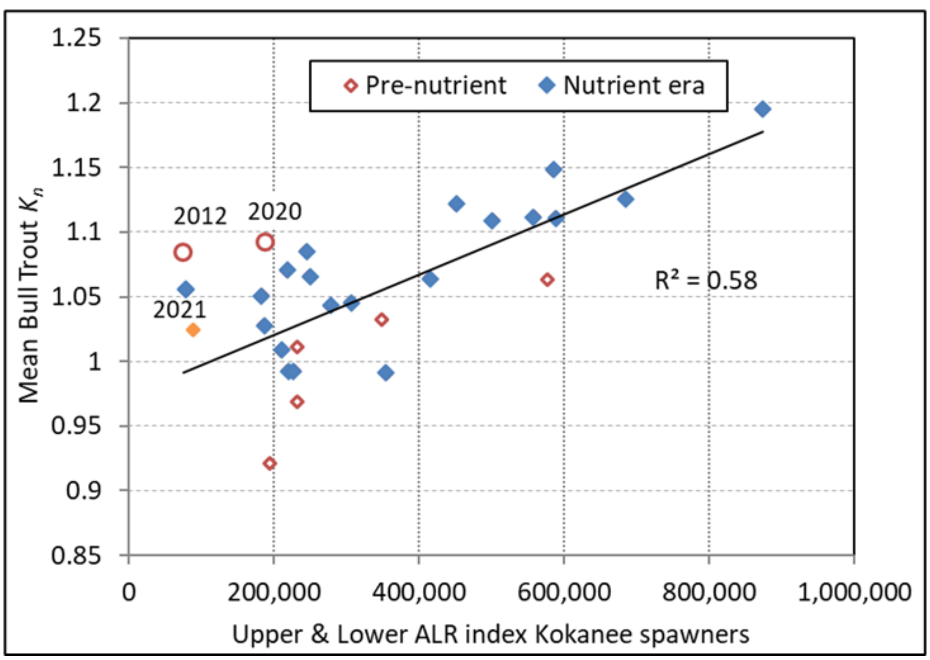

Figure 25. Average condition factor of bull trout compared to the estimate of Kokanee spawner abundance in Arrow Lakes Reservoir. Years 2012 and 2020 were not used for the regression because a large proportion of age-3 Kokanee delayed spawning in 2012 (Arndt, 2014) and smoke delayed spawner counts in 2020.

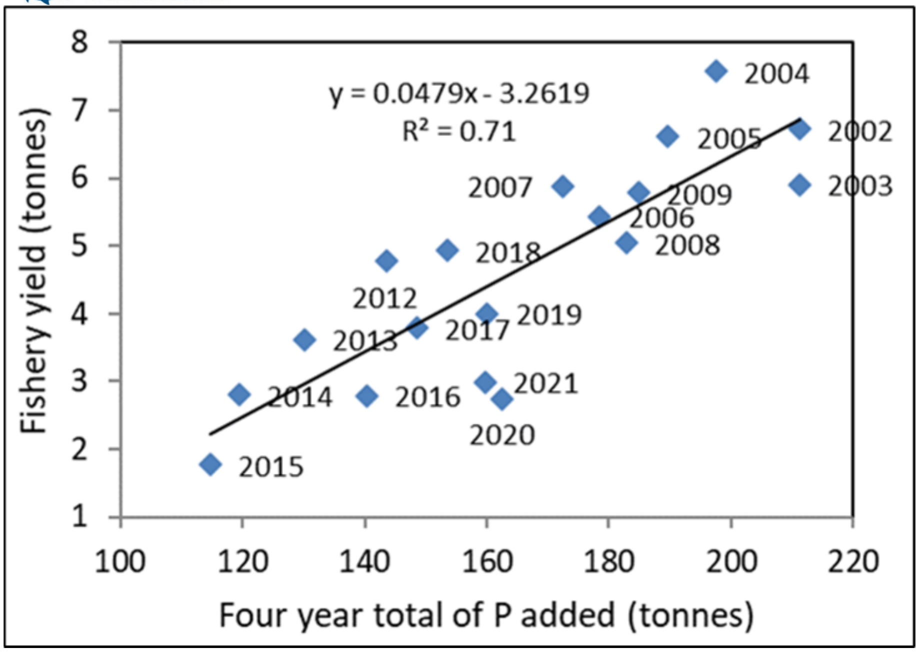

Figure 26. Relationship between the amount of phosphorus added by the nutrient program (4-year cumulative) from 2002-2021 and the fishery yield of bull trout, rainbow trout, Kokanee, and burbot from three primary access locations in Arrow Lakes Reservoir (Shelter Bay, Nakusp, Castlegar). Labels indicate the fourth year of each 4-year period.

Summary and Discussion

The objective of this report is to be a summary activity report of the 2021 (F22) Arrow Lakes Reservoir NRP. The data presented is a subset of the results from the extensive monitoring program. Further details and analysis will be presented in the Ministry of Forests annual report found online (Province of BC, n.d.) upon publication. Below is a discussion of the high-level summary results from the F22 Arrow Lakes Reservoir NRP.

Dissolved phosphorus and nitrogen levels in 2021 were similar to previous years, and indicative of an oligotrophic system. Phytoplankton and zooplankton were above average in 2021, and mysids were below average. Kokanee returns in 2021 were exceptionally low; the reason is not immediately apparent, although it is possible that the cohort expected to spawn at age 3 experienced delayed maturation and will return at age 4 in 2022. A similar phenomenon was observed previously in Arrow following a period of very low *Daphnia* abundance and biomass in 2011 and 2012, which was thought to contribute to the observed shift to age 4 spawners in 2013 (Bassett, Schindler, Sebastian, Weir, & Vidmanic, Arrow Lakes Reservoir Nutrient Restoration Program Year 15 (2013) Report, 2015). The 2020 *Daphnia* outcomes were comparably low to the 2011/2012 outcomes, signaling that the same outcome could occur again. The hydroacoustic data from the fall of 2021 suggests a substantial improvement is likely in spawner numbers in 2022.

Kokanee survival from the egg to fall fry stage is highly relevant to Kokanee abundance and biomass across the lifespan of each cohort. Last year, 2020, marked the fourth consecutive year of low egg to fall fry survival for Arrow Reservoir (Evans, Bassett, Arndt, & Weir, 2021), likely linked to below average winter temperatures. Consecutive years of poor egg to fall fry survival, combined with below average in-lake survival from age 0 to age 1 in previous years resulted in low numbers for all in-lake age classes of Kokanee. This, combined with below average Daphnia outcomes in recent years led to below average Kokanee biomass; an outcome that has persisted into 2021. Though not presented in this report, preliminary analysis suggests egg to fall fry survival has improved in 2021, which combined with average or better in-lake survival and the improved outcomes for *Daphnia* in 2021 should result in improved Kokanee outcomes in 2022. Arrow Lakes Reservoir is a dynamic and complex system with interacting external variables. These variables include productivity (added nutrients), operations (flow through the reservoir), fry output from the spawning channel, mortality events (e.g., die off in 2012 (Bassett, Schindler, Sebastian, Weir, & Vidmanic, 2015)) and weather-related drivers such as air temperature, snowpack, precipitation, and wildfire smoke.

The following list are recommendations for the program moving forward.

- Continue with nutrient additions, 42 MT of phosphorus and 208 MT of nitrogen planned for 2022, similar loading volumes to previous years as a review of the nutrient program is currently underway.
- Continue limnological monitoring.
- Continue exploration of air and water temperature patterns and relationship to zooplankton and Kokanee parameters.

- Develop NRP database.
- Piscivore consumption rates and creel metrics. Review bioenergetics and other estimates of consumption rates of piscivores on Kokanee to determine what the top-down effects are in the reservoir. Review creel metrics in relation to bottom-up effects.

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Appendices

Appendix 1. Personnel on Arrow Lakes Reservoir Nutrient Restoration Programs in 2021.

Project Focus	Personnel - Affiliation
Project co-ordination, management and scientific liaison	Valerie Evans - Resource Management, FLNRORD Marley Bassett - Resource Management, FLNRORD Rob Fox - Resource Management, FLNRORD Irene Manley - Resource Management, FLNRORD
Report compilation	Valerie Evans – Resource Management, FLNRORD Marley Bassett - Resource Management, FLNRORD Tyler Weir - Fish and Aquatic Habitat Branch, FLNRORD Steve Arndt - Resource Management, FLNRORD David Johner - Fish and Aquatic Habitat Branch, FLNRORD Rob Fox - Resource Management, FLNRORD
Report editing and review	Eva Schindler - Resource Management, FLNRORD Marley Bassett – Resource Management, FLNRORD Steve Arndt - Resource Management, FLNRORD Tyler Weir, Resource Management, FLNRORD Mike Hounjet - Columbia Power, Castlegar Crystal Klym – Fish & Wildlife Compensation Program
Fertilizer schedule, loading	Marley Bassett - Resource Management, FLNRORD Valerie Evans – Resource Management, FLNRORD Eva Schindler - Resource Management, FLNRORD Ken Ashley - BC Institute of Technology Rivers Institute
Fertilizer supplier	Nutrien Itafos
Fertilizer application	Crescent Bay Construction - Crescent Bay Construction The Columbia Ferry - Waterbridge ferries
Physical limnology, water chemistry, phytoplankton, zooplankton and mysid sampling	Kootenay Wildlife Services Ltd. Marley Bassett - Resource Management, FLNRORD Rob Fox - Resource Management, FLNRORD Aaron McGregor - Resource Management, FLNRORD Kerry Reed – Reel Adventures
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, FLNRORD David Johner - Fish and Aquatic Habitat Branch, FLNRORD
Kokanee trawling and processing	Tyler Weir - Fish and Aquatic Habitat Branch, FLNRORD David Johner - Fish and Aquatic Habitat Branch, FLNRORD Rob Fox - Resource Management, FLNRORD Kerry Reed – Reel Adventures Autumn Solomon - Okanagan Nation Alliance
Kokanee aerial spawner surveys	Eva Schindler - Resource Management, FLNRORD Valerie Evans- Resource Management, FLNRORD Jessica Spencer - Resource Management, FLNRORD Mark Homis - Highland Helicopters
Kokanee ground spawner surveys	Steve Arndt - Resource Management, FLNRORD Tim Davis - Resource Management, FLNRORD Kersti Vaino - Resource Management, FLNRORD

	Kristen Murphy - Resource Management, FLNRORD Kat McGlynn - Resource Management, FLNRORD Molly Teather – Resource Management, FLNRORD Courtenay Heetebrij - Okanagan Nation Alliance Shelley Hackett – Okanagan Nation Alliance Karen Bray - BC Hydro Beth Manson - BC Hydro
Kokanee analysis and Reporting	Tyler Weir – Fish and Aquatic Habitat Branch, FLNRORD David Johner - Fish and Aquatic Habitat Branch, FLNRORD
Kokanee scale ageing	Morgan Davies - BC Provincial Aging Lab - FFSBC Carol Lidstone - Birkenhead Scale Analyses
Creel surveys	Operations and reporting: Steve Arndt – Resource Management, FLNRORD Shelter Bay: Darlene Riehl - Kingfisher Silviculture Castlegar: Credence New, Helena Garay, Cody Peters, Jacquie Armstrong, Christina Dummer Nakusp: Mark Fjeld, Dominique Nicholas, Dave Tom, Ali Schroeder, Natalie Morrison, Tyler Fortin, Haley Pocaluyko (Nupqu Resource Limited Partnership); Shanon Basil, Torrie Nicholas, Dave Tom, Justin French, Andrew Clarke, Dimitri Basil (Yucwmenlúcwu - Caretakers of the Land); Kat McGlynn (FLNRORD)
Hill Creek Spawning Channel monitoring	Darlene Riehl– Kingfisher Silviculture Ltd. Jessica Spencer – Resource Management, FLNRORD Steve Arndt – Resource Management FLNRORD Valerie Evans – Resource Management, FLNRORD
Regional support	Jeff Burrows - Resource Management, FLNRORD Matt Neufeld - Resource Management, FLNRORD Will Warnock - Resource Management, FLNRORD

Appendix 2. Sampling activities on Arrow Lakes Reservoir in 2021.

Parameter sampled 2021	Sampling frequency	Locations	Sampling technique
Temperature, dissolved oxygen, specific conductance	Monthly: April to October	AR2 AR3, AR7, AR8	SeaBird profiles from surface to 5 m off the bottom. April data is 0-50m only.
Transparency	Monthly: April to October (twice a month in June, July, and August)	AR2, AR3, AR7, AR8 AR4 in June, July, August	Secchi disk
Epilimnion water chemistry Turbidity, pH, TP, TN, NO3, NO2, TIC, TDP, OP, TOC, alkalinity, silica TP, TN, NO3, NO2, TDP, OP	Monthly: April to October Twice monthly in June, July and August	AR2 AR3, AR7, AR8 AR3, AR4, AR8	Integrated sampling tube at 0–20 m Integrated sampling tube at 0–20 m
Total and Dissolved Metals	June and September	AR2 AR3, AR7, AR8	Integrated sampling tube at 0–20 m
Discrete Epilimnion Water Chemistry	Monthly: June to September	AR2 and AR7	Niskin water samples at 2, 5, 10, 15 and 20m

TP, NO3, NO2, TDP, OP, silica			
Hypolimnion Water Chemistry Turbidity, pH, TP, TN, NO3, NO2, TIC, TDP, OP, TOC, alkalinity, silica	Monthly: May to October	AR2 AR3, AR7, AR8	Discrete water sample with Niskin sampler 5m off the bottom
Chlorophyll a (not corrected for phaeophytin)	Monthly: April to October (twice monthly in June, July and August) Monthly: June to September	AR2 AR3, AR7, AR8 AR4 in June, July, August AR2 and AR7	Integrated sampling tube at 0–20 m Discrete samples with Niskin sampler at 2, 5, 10, 15 and 20m
Phytoplankton	Monthly: April to October (twice monthly in June, July and August)	AR2 AR3, AR7, AR8 AR4 in June, July, August	Integrated sampling tube at 0–20 m
Macrozooplankton	Monthly: May to October Monthly: May to October	AR2 AR3, AR7, AR8 AR2 and AR7	Three oblique Clarke-Bumpus net hauls (3-minutes each) from about 40–0 m (150 μm net) 3 vertical Wisconsin net hauls 0-20m
Mysid net sampling	Monthly: May to November	AR2 AR3, AR7, AR8	Two replicate hauls with the mysid net from 5 m above bottom to the surface
Kokanee acoustic sampling	Fall survey	TR 1–18	Standard hydroacoustic methods; 18 transects in Upper and Lower Arrow
Kokanee trawling	Fall trawl series	AR1, AR3, AR7 AR2, AR6, AR8 omitted	Standard trawl series using oblique hauls in Upper and Lower Arrow. Additional directed trawls to increase catch in 2021
Aerial Kokanee spawner counts	September	Arrow tributaries (Bassett, Weir, & Fox, 2020)	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