Columbia River Project Water Use Plan

Kinbasket and Revelstoke Reservoirs Ecological Productivity and Kokanee Population Monitoring

Reference: CLBMON-2, CLBMON-3, and CLBMON-56

Kinbasket and Revelstoke Reservoirs
Ecological Productivity and Kokanee Population Monitoring

2008-2016 (Years 1 to 9) Synthesis Report

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December 2018

Kinbasket and Revelstoke Reservoirs Ecological Productivity and Kokanee Population Monitoring 2008-2016 (Years 1 to 9) Synthesis Report

Kinbasket Reservoir and Mica Dam, May 2013

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December 2018

This is an interim synthesis report for a long term monitoring program and, as such, contains preliminary data. Conclusions are subject to change and any use or citation of this report or the information herein should note this status.

Cover Photo: Kinbasket Reservoir at 723 m, May 2013. Mica Dam and upper Revelstoke Reservoir can be seen. View of the forebay and Main Pool with Canoe Reach to the left, Wood Arm at top, and Columbia Reach to the right off the Main Pool.

Photo Credit: K. Bray

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Executive Summary

The Columbia River Water Use Plan (WUP), approved in 2007, was conducted by BC Hydro to achieve optimal balance among operations and environmental and social values. On Kinbasket and Revelstoke Reservoirs, a lack of ecological data and information resulted in a recommendation to undertake a long-term program of study on reservoir limnology and the productivity of pelagic communities, including continuation of long-term kokanee assessments. The goal of these studies is to provide the information necessary to inform future WUPs on options and decisions for operating Kinbasket and Revelstoke Reservoirs. A 12 year program was initiated in 2008 and includes regular reservoir sampling for physical and chemical parameters, and biological communities, such as phytoplankton, zooplankton, and kokanee.

This second synthesis report for the study covers the first nine years (2008-2016) of effort on the limnological components (CLBMON-3) and includes up to eighteen years of kokanee population monitoring data (nine years from CLBMON-2). Also included are the first four years (2012-2016) of continuous moored data added to meet commitments for the Mica Project Units 5 and 6 Environmental Assessment Certificate (CLBMON 56).

The study period has so far encompassed both unusual activity (dam infrastructure changes) and a wide range of hydrological, meteorological, and operational conditions on Kinbasket and Revelstoke Reservoirs, challenging attempts to distinguish environmental versus operational effects on reservoir productivity. We note, however, several important results to date. Nutrient availability, light conditions, and temperature in the photic zone are considered to exert critical influences on pelagic production. No evident trends in tributary nutrient (nitrogen and phosphorus) inputs were evident over the study years. Reservoir nutrient chemistry and primary production demonstrate that both reservoirs are ultra-oligotrophic (very low in productivity) and limited by phosphorus. Primary production is dominated by smaller phytoplankton (pico- and nano-plankton) as would be expected a low nutrient system. An overall declining trend in phyto- and zooplankton density and biomass was observed over the study period, although with a small period of increase midway. We found no correlation between these primary and secondary trophic levels as might be otherwise expected; however, we have found correlations between zooplankton and kokanee metrics.

The time at which the zooplankton *Daphnia* (preferred food of kokanee) become available for kokanee forage is sensitive to water temperature. Winter conditions are shown to affect both the onset of stratification in spring and water temperature during this time. In Revelstoke Reservoir we have found that operations, particularly outflows from Mica Dam and Generating Station, exert a strong influence on the dynamics of the interflow of Mica water through

Revelstoke Reservoir, and thus nutrient inputs into the photic zone. We will continue to investigate these connections between physical and biological processes and trophic level interactions in these reservoirs as they pertain to the study.

Relative to the long-term dataset, a number of kokanee metrics were noted as declining or low in this second phase of the study, roughly from 2011 to 2016. Kokanee abundance in Kinbasket and Revelstoke Reservoirs has been suppressed since 2011 and the lowest estimates of biomass density (kg/ha) were recorded in the last three to four years of the study period. Age 0 to age 1 survival trends were declining (Kinbasket) or at consistent lows (Revelstoke) since 2011, similar to spawner index trends.

Kokanee productivity is explored with respect to the influence of food supply (zooplankton), flow (inflow/cumulative outflow), pelagic habitat area, and tributary (spawning and incubation) habitat on growth and survival. Relationships between flow, zooplankton, and kokanee metrics are emerging that are compared with other large lake and reservoir data and are providing insight into regional versus local factors affecting reservoir productivity.

This report includes recommendations to continue the regular reservoir and tributary sampling program for physical and biological parameters with annual protocol refinements to establish long term-trends and provide information for addressing the management questions. A final synthesis report will be prepared following analysis of the last year of field data scheduled for 2019.

Status of Management Questions and Hypotheses – CLBMON-3-56-2

Objective	Management Question	Management Hypothesis	Status
CLBMON-3/56			
The objective is to improve our understanding of the ecological productivity of Kinbasket and Revelstoke Reservoirs by obtaining a long-term dataset to describe trophic web mechanisms and dynamics. This information is needed to examine the sustainability of fish populations under the current operating regimes, as well as to allow better predictive capability in exploring potential operational changes.	1. What are the long-terms trends in nutrient availability and how are lower trophic levels affected by these trends? 3. Is pelagic productivity, as measured by primary production, changing significantly over the course of the monitoring period?	H1: There is no change in pelagic productivity in Kinbasket and Revelstoke Reservoirs over the course of the monitoring period.	1. Collection of nutrient data for monitoring long-term trends is underway in both the tributaries and the reservoirs. For nutrients, there is sufficient dissolved inorganic nitrogen (DIN) and, to date, there is no observable trend in DIN over time either in the tributaries or in the reservoir. Phosphorus is low, and there are no discernable trends in phosphorus to date. 3. Primary productivity increased from 2008 to 2014/2015 with a decline noted in 2015/2016 depending on the site. A shift in relative contribution of pico- and nano-plankton has been measured that could have implications for higher trophic levels. H1.The hypothesis cannot be accepted or rejected as the monitoring period is not yet concluded.

Objective	Management Question	Management Hypothesis	Status
	2. What are the interactions between nutrient availability, productivity at lower trophic levels and reservoir operations? 5. Is there a link between reservoir operation and pelagic productivity? What are the best predictive tools for forecasting reservoir productivity? 7. Does the addition of Mica Units 5 and 6 influence pelagic productivity?	H1A: Nutrient availability is not affected by reservoir operations. H1B: Pelagic productivity is not affected by reservoir operations.	2. Phosphorus is shown as limiting over nitrogen for phytoplankton growth. The availability of nutrients in the photic zone is the being assessed. Winter conditions are shown to affect both the onset of stratification in spring and water temperature during this time. In Revelstoke Reservoir we have found that operations, particularly outflows from Mica Dam and Generating Station, exert a strong influence on the dynamics of the interflow of Mica water through Revelstoke Reservoir, and thus nutrient inputs into the photic zone. This management question will be addressed in the final report. 5.This management questions will be addressed in the final report. 7. There is not enough data yet to address this management question. Mica Units 5 and 6 went into service only for the 2015/2016 study years. This management question will be addressed in the final report. H1A.The hypothesis cannot be accepted or rejected as the monitoring period is not yet concluded. H1B.The hypothesis cannot be accepted or rejected as the monitoring period is not yet concluded.
	4. If changes in pelagic productivity are detected, are the changes affecting kokanee populations?	H2: Long-term trends in pelagic productivity have no effect on kokanee populations in Kinbasket Reservoir.	4. This management question is linked with CLBMON-2 management questions and will be addressed in the final report. H2.The hypothesis cannot be accepted or rejected as the monitoring period is not yet concluded.
	6. How do pelagic productivity trends in Kinbasket and Revelstoke reservoirs compare with similar large reservoir/lake systems (e.g., Arrow Reservoir, Kootenay Lake, Okanagan Lake, Williston Reservoir)?		6. Comparisons of Kinbasket and Revelstoke Reservoirs with Arrow Reservoir and Kootenay Lake, in particular, where monitoring data are similar, are being explored. Initial results show some evidence of regional drivers on reservoir production. This management question will be addressed in the final report.

Objective	Management Question	Management Hypothesis	Status
	8. Are there operational changes that could be implemented to improve pelagic productivity in Kinbasket Reservoir?		8. This management question will be addressed in the final report.
CLBMON-2			
The objective is to collect annual time series data as a foundation for further correlation analysis. Results of this monitoring program will be integrated with CLBMON-3 to enable inferences regarding the role of current operating conditions in pelagic productivity and productivity of reservoir kokanee populations.	1. What are the trends in annual distribution, abundance and biological characteristics of kokanee populations in Kinbasket and Revelstoke reservoirs?		1. Annual trends are described in the report. In general, there has been a decline in kokanee abundance, biomass, and survival in both reservoirs since about 2011.

Objective	Management Question	Management Hypothesis	Status
	2. What role does reservoir operation play in the productivity of kokanee populations?	H1: The productivity of kokanee populations is limited by habitat impacts directly related to operation of Kinbasket Reservoir. H1A: Operation of the reservoir reduces kokanee population abundance in Kinbasket Reservoir due to entrainment from the reservoir. H1B: Operation of the reservoir reduces pelagic productivity, which affects abundance and growth of kokanee. H2: Abundance, distribution, and growth of kokanee in Revelstoke Reservoir are limited by impacts directly related to operation of Kinbasket Reservoir (through entrainment).	2. Reservoir operation and kokanee productivity is being evaluated by first assessing operational outcomes, such as seasonal discharge and reservoir elevations, with kokanee metrics. Subsequent analyses will build upon these results and incorporate evaluation of climatic and other regional influences. This management question will be addressed in the final report. H1: The hypothesis cannot be accepted or rejected as the monitoring period is not yet concluded. H1A: While kokanee are known to be entrained from Kinbasket Reservoir, there is no evidence that entrainment is exerting a significant effect on abundance in Kinbasket Reservoir. This hypothesis can be rejected. H1B.The hypothesis cannot be accepted or rejected as the monitoring period is not yet concluded. H2: If operational effects in addition to entrainment are considered then the hypothesis cannot be accepted or rejected as the monitoring period is not yet concluded. If only entrainment is considered then it is the same as H1A.
	3. What are the key habitat factors that contribute to changes in productivity of the Kinbasket Reservoir kokanee population?	H1: The productivity of kokanee populations is limited by habitat impacts directly related to operation of Kinbasket Reservoir.	3. Pelagic habitat area, food availability, and tributary habitat are being assessed as key habitat factors as well as the effects of flow. This management question will be addressed in the final report. H1: The hypothesis cannot be accepted or rejected as the monitoring period is not yet concluded.
	4. Can modifications be made to operation of Kinbasket Reservoir to protect or enhance kokanee populations in Kinbasket or Revelstoke reservoirs?		4. This management question will be addressed in the final report.

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Delivery of such a large program is the result of much collaboration and support.

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Acronyms and Definitions

ASL – Above sea level
BPA – Bonneville Power Authority
GS – Generating Station
CI – confidence interval
CPUE – catch per unit effort
CRT – Columbia River Treaty
DIN - Dissolved inorganic nitrogen, which consists of nitrate, nitrite, and ammonium.
FFSBC – Freshwater Fisheries Society of BC
LTA – long term average
MAF – million acre-feet
MFLNRORD – Ministry of Forests, Lands, Natural Resource Operations and Rural Development
NN – nitrite and nitrate
NTSA – Non-Treaty Storage Agreement
PAR – Photosynthetically Active Radiation
TDP – Total dissolved phosphorus
TP –Total phosphorus
SRP – Soluble reactive phosphorus, also known as ortho-phosphate (PO_4)
USGRCP – U.S. Global Change Research Program (https://www.globalchange.gov/about)
WUP – Water Use Plan

Age 0 – young-of-year kokanee; interchangeable with the term 'fry'
Age 1-3 – the combined in-lake population (or sample) of all kokanee older than age 0
Age 2++ - kokanee age 2 and older; see methods section 2.4.6 - Spawner surveys and alternatives to direct enumeration
Allochthonous – material (e.g. nutrients) imported into an ecosystem
Autochthonous – material originating from within the ecosystem
Biomass- measure of the total weight of organisms (e.g. used for zooplankton, fish)
Biovolume – measure of the total photosynthetic volume of algal cells per volume of water
Epilimnion - surface layer
Fry – young-of-year kokanee; interchangeable with the term 'age 0'
Hypolimnion – deep water
Kokanee – sockeye salmon (*Oncorhynchus nerka*) that live entirely in freshwater
Metalimnion –intermediate water between the epilimnion (surface layer) and hypolimnion (deep water)
Pelagic zone – open water area of a lake or reservoir (or ocean)
Photic zone – the near-surface region where there is enough light for phytoplankton to undergo net growth, taken to be the depth at which light decline to 1% of the surface value.

Primary Production – the rate by which energy is transformed by photosynthesis to carbon biomass

Pool – water in the reservoir, in this context synonymous with reservoir

Operations (reservoir/dam) – manipulation of the storage and release of water by dams and generating stations

Thermocline – the gradient in temperature between the warmer epilimnion (surface layer) to the cooler hypolimnion (deep water) occurring in the metalimnion

Trophic Level – a position in the hierarchy of the food chain that is comprised of organisms sharing the same function and nutritional placement with respect to energy sources. Commonly in this context: primary, secondary, and tertiary levels corresponding to phytoplankton, zooplankton, and planktivirous fish.

Table of Contents

List of Figures

List of Tables

1.0 INTRODUCTION

The Columbia River Water Use Plan (WUP) (BC Hydro 2007a) was accepted by the BC Comptroller of Water Rights in January 2007 following four years of public consultation (BC Hydro 2005). Water Use Plans were developed for each of BC Hydro's facilities to achieve optimal balance between hydropower operations and environmental and social values.

A lack of basic ecological data and information on Kinbasket and Revelstoke Reservoirs impeded informed decisions for any operational changes in the upper Columbia River system. The WUP Consultative Committee acknowledged the importance of understanding reservoir limnology and the influence of current operations on ecosystem processes for planning future water management activities. Therefore, a monitoring program was recommended to provide long-term data on reservoir limnology, the productivity of pelagic communities, and to continue long term monitoring of kokanee populations.

Two key programs ordered by the BC Comptroller of Water Rights and scheduled for implementation over twelve years (2008-2020) are:

- CLBMON-2: Kinbasket and Revelstoke Reservoirs Kokanee Population Monitoring, and
- CLBMON-3: Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring.

In addition, an addendum to CLBMON-3 was added for implementation over eight years (2012-2020) to meet requirements of the Mica Unit 5 and 6 Project Environmental Assessment Certificate commitments:

- CLBMON-56: Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring, Mica Project Units 5 and 6 Addendum

This is the second synthesis report and summarises results from 2008-2016 of these WUP monitoring programs. The study Terms of Reference (TOR) (BC Hydro 2007b) scheduled the second synthesis following the 2015 sampling year; however, 2016 is included here as results were available. The first synthesis report (Bray et al. 2013) compiled findings from the first four years of implementation (2008-2011) of CLBMON-2 and CLBMON-3, before the CLBMON-56 addendum work was initiated. All recommendations for the sampling program made in the first synthesis report were subsequently implemented (Table 1). Annual data reports that include more details around sampling methodology and results can be found at: https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/southern_interior/columbia_river/kinbasket-fish-wildlife.html

Table 1. Summary of the status of recommendations from 2008-2011 Synthesis Report.

	Recommendation	Implementation Status
CLBMON-3		
1.	*The reservoir and tributary monitoring program implemented in 2008 be continued as directed by the Study Team with refinements to the sampling plan made through discussions at annual meetings.*	Complete. Annual Study Team meetings held to refine sampling program.
2.	*Include April and/or November sampling when possible to the sampling plan.*	Complete. April sampling was added to the schedule. November sampling was attempted but it was determined to not be feasible given inclement conditions and limited biological activity.
CLBMON-2		
1.	*Investigate the feasibility of alternate methods for enumerating kokanee spawners in the Columbia River mainstem and determine additional costs.* *Ideally, and if feasible, it is recommended that a system wide spawner survey be conducted in a year when conditions are deemed suitable for viewing.*	Ongoing. Alternatives were discussed. FFSBC installed a fence on the Columbia River near Fairmont in 2016 to collect eggs for Kootenay lake kokanee recovery efforts that provides both numbers and biological data. A system wide survey is desirable although difficult to implement as visibility can be quite variable depending on weather conditions and costs are outside the scope of this project.
2.	*Future adult sampling in Camp and Luxor Creeks be spread evenly over the spawning period to ensure that age structure estimates for spawning kokanee are adequately represented.* *Obtain biological samples from the Columbia River.*	Complete. Sampling occurred over a period of three weeks for Camp Creek, Luxor Creek, and Bush River. Biological samples were obtained from the Columbia River (at Fairmont).
3.	*Explore some alternate methods to capture statistically significant sample sizes of pre-adult kokanee from the reservoir. The effectiveness of overnight gillnet sets in pelagic habitat should be assessed.*	Complete. Overnight pelagic gillnet sets were determined to be the best method for improving sample sizes. Gillnetting is occurring in both Kinbasket and Revelstoke Reservoirs.

Recommendation		Implementation Status
4.	*Investigate further the feasibility of using acoustic surveys to track general size groups of individuals through the population using acoustic size binning.*	Complete. A new empirical relation between acoustic target strength and fish fork length was developed for kokanee allowing for estimating an annual index of abundance for age 1 and age 2/3 kokanee.
5.	*It is recommended that the biomass method used for Alouette Reservoir be applied to Kinbasket acoustic size distributions to develop some 'relative' biomass estimates for 2008-2011. If biomass estimates for 2008-2011 seem reasonable, then it is recommended that some of the earlier data be re-analyzed and compared with recent biomass estimates.*	Complete. A new empirical relation between acoustic target strength and fish size was developed for kokanee providing the basis for generating annual kokanee biomass estimates directly from acoustic data in combination with annual gillnet catch data.
6.	*Install temperature recorders in known spawning streams to determine relative emergence timing based on thermal units from spawning time.*	Ongoing. Temperature loggers have been installed in Camp Creek, Bush River, Dutch Creek, Columbia at Fairmont, and Mica outflow. Also Water Survey of Canada has added temperature monitoring to gauging stations at Columbia at Donald, Beaver River, and Goldstream River after 2015.
7.	*Incorporate results from recent entrainment studies with the next synthesis report.*	Complete/ongoing.

CLBMON-3/56 - The objectives for the Ecological Productivity Monitoring program are to understand reservoir limnology and to determine if changes in pelagic productivity are associated with reservoir operations (BC Hydro 2007b). The sampling program builds upon previous limnological studies of Kinbasket Reservoir by BC Research (1977) and three consecutive years of limnological sampling conducted by BC Hydro from 2003 to 2005 (data on file). The monitoring program was designed to collect data needed to develop a nutrient budget, measure primary productivity, and conduct seasonal monitoring of physical, chemical, and biological (i.e., phytoplankton and zooplankton) parameters. Results of the first phase (2008-2011) and annual reviews of results were used to standardize and fine tune the monitoring program for subsequent years. In order to address uncertainties around the influence of potential changes in operation of these reservoirs on pelagic productivity, the monitoring focuses on reservoir trophic web mechanisms and dynamics, obtaining measurements of aquatic productivity for system modeling, and determining key indicators of change in pelagic production that would affect food availability and thus growth of kokanee.

CLBMON-56 - This work is a commitment under the Mica Unit 5 and 6 Project Environmental Assessment Certificate and focuses on the incremental effect of two additional generating units at Mica Dam. The work focuses on measuring temperature data in both reservoirs at a fine scale through the use of moored arrays. Results from the first four years of this component (2012-2016) are included in this report.

Eight Management Questions (MQs) to be addressed by CLBMON-3/56 over the longer term are:

1. What are the long-term trends in nutrient availability and how are lower trophic levels affected by these trends?
2. What are the interactions between nutrient availability, productivity at lower trophic levels and reservoir operations?
3. Is primary production changing significantly over the monitoring period?
4. If changes in pelagic productivity are detected, are they affecting kokanee populations?
5. Is there a link between reservoir operation and pelagic productivity and what are the best predictive tools for forecasting reservoir productivity?
6. How do pelagic productivity trends in Kinbasket and Revelstoke reservoirs compare with similar large reservoir/lake systems?
7. Does the addition of Mica Units 5 and 6 influence pelagic productivity? (CLBMON-56)
8. Are there operational changes that could be implemented to improve pelagic productivity in Kinbasket Reservoir?

CLBMON-2 - The objectives for Kokanee Population Monitoring are to monitor trends in the biological characteristics, distribution, and abundance of kokanee and to provide information required to evaluate the influence of reservoir operation on kokanee populations in Kinbasket and Revelstoke Reservoirs. Twelve years of kokanee monitoring will be used to verify and compare population trends in abundance and to interpret causes of inter-annual variation (e.g. variation in year class strength as a result of environmental or operational effects). Results of the Ecological Productivity Monitoring will assist in determining whether changes in kokanee population abundance and growth over time are the result of environmental or operational effects. The kokanee monitoring will take advantage of an additional seven consecutive years of standardized kokanee time series data collected from 2001-2007 under BC Hydro's Large River Indexing Program and previously reported by Sebastian (2008a and b) and Sebastian et al. (2010).

Key reservoir management uncertainties encountered during the WUP process were related to how changes in operation would affect kokanee. Interest was focused on kokanee as this species is a key component of the ecosystem, providing an important food source for other fish species and a source of nutrients to the ecosystem. The history of kokanee in these reservoirs is discussed by Sebastian et al. (2010), including stocking[1]. The most important issues to be addressed for kokanee in Kinbasket and Revelstoke Reservoirs were identified as: potential effects of physical dynamics of the reservoir (thermal stratification, water circulation patterns, and water retention time) and resulting impacts on pelagic habitat and productivity.

Four Management Questions to be addressed through CLBMON-2 are:

1. What are the trends in annual distribution, abundance and biological characteristics of kokanee populations in Kinbasket and Revelstoke reservoirs?

2. What role does reservoir operation play in productivity for kokanee?

3. What are the key habitat factors that contribute to changes in productivity of the kokanee?

4. Can modifications be made to operation of dams to protect or enhance kokanee populations?

Results of these monitoring programs will be used to evaluate the role of the current operating regime on pelagic productivity and reservoir kokanee populations. In concert with similar monitoring in Arrow Reservoir and Kootenay Lake, the CLBMON-2 and CLBMON-3 time series data will serve as a useful indicator of productivity in Kinbasket and Revelstoke Reservoirs and will contribute to an assessment of long-term trends for the Columbia River system.

[1] With more complete stocking records now available online, information on stocking in Sebastian et al. (2010) can be updated. It is noted that kokanee were first stocked into the upper Columbia region (Columbia Lake) in 1930 and into Windermere Lake through the early 1940s (see Province of BC Fish Stocking database).

1.1 Study Area

The study area includes Kinbasket and Revelstoke Reservoirs and their associated drainage basins. Kinbasket Reservoir, situated in the Rocky Mountain Trench between Golden and Valemount B.C., is bounded by the Rocky Mountains to the east and the Selkirk and Monashee Mountains to the west. Reservoir filling was initiated in 1973 with completion of Mica Dam and subsequently flooded ~431 km^2 of river and valley bottom habitat from Valemount to Donald (Figure 1). Two small lakes (<3 ha each) were inundated in the Bush Pool area as well as the larger (13 ha) Old Kinbasket Lake that is now a slightly wider and deep section in the Columbia Reach section of the reservoir. The remaining river areas varied from the low gradient and meandering Canoe River to the steep, white water rapids of the Columbia River mainstem. Revelstoke Reservoir lies in a narrow valley between the Selkirk Mountains to the east and Monashee Mountains to the west. Completion of the Revelstoke Dam and Generating Station (GS) in 1983 led to the reservoir filling by spring 1984 and flooding of 116 km^2 of the narrow Columbia River valley.

Both reservoirs are in the Interior Cedar-Hemlock and Engelmann Spruce-Subalpine Fir biogeoclimatic zones with inflows heavily influenced by glacier and snow melt. Forestry is the predominant industrial land use. The communities of Valemount, Golden, and Revelstoke are the main settlements in the area with a small population of workers and transient tourists at Mica Creek.

Morphometrics - Characteristics of Kinbasket and Revelstoke Reservoirs are summarized in Table 2. Kinbasket Reservoir has a surface area of 431 km^3 at normal maximum and a volume of 24,800 million m^3 (Hirst 1991) at normal maximum. The mean and maximum depths are 57 m and 190 m respectively and bulk retention time is about 16 months. The reservoir is approximately 200 km in length at full pool. While the difference between allowable maximum and minimum water level is 47 m (Table 2), the average annual drawdown from 1977-2016 is 25 m, with the greatest annual change in elevation to date of 39 m (2002) and the smallest of 13 m (1977). Over the study period, the average annual elevation change was 27 m, the maximum in 2008 (33.8 m) and the minimum in 2016 (14 m).

Revelstoke Reservoir is less than one third the size of Kinbasket with a maximum surface area of 116 km^3 and mean and maximum depths of 46 m and 120 m, respectively. The reservoir is 130 km long and averages less than 1 km in width. Pool elevation is held relatively constant at a normal maximum elevation of 573 m ASL with an annual fluctuation typically of 1.5 m in spring. Drawdowns of up to 4.5 m are allowed for operational purposes (e.g. extreme weather events) and up to 15 m for dam safety emergencies although the latter has never been used.

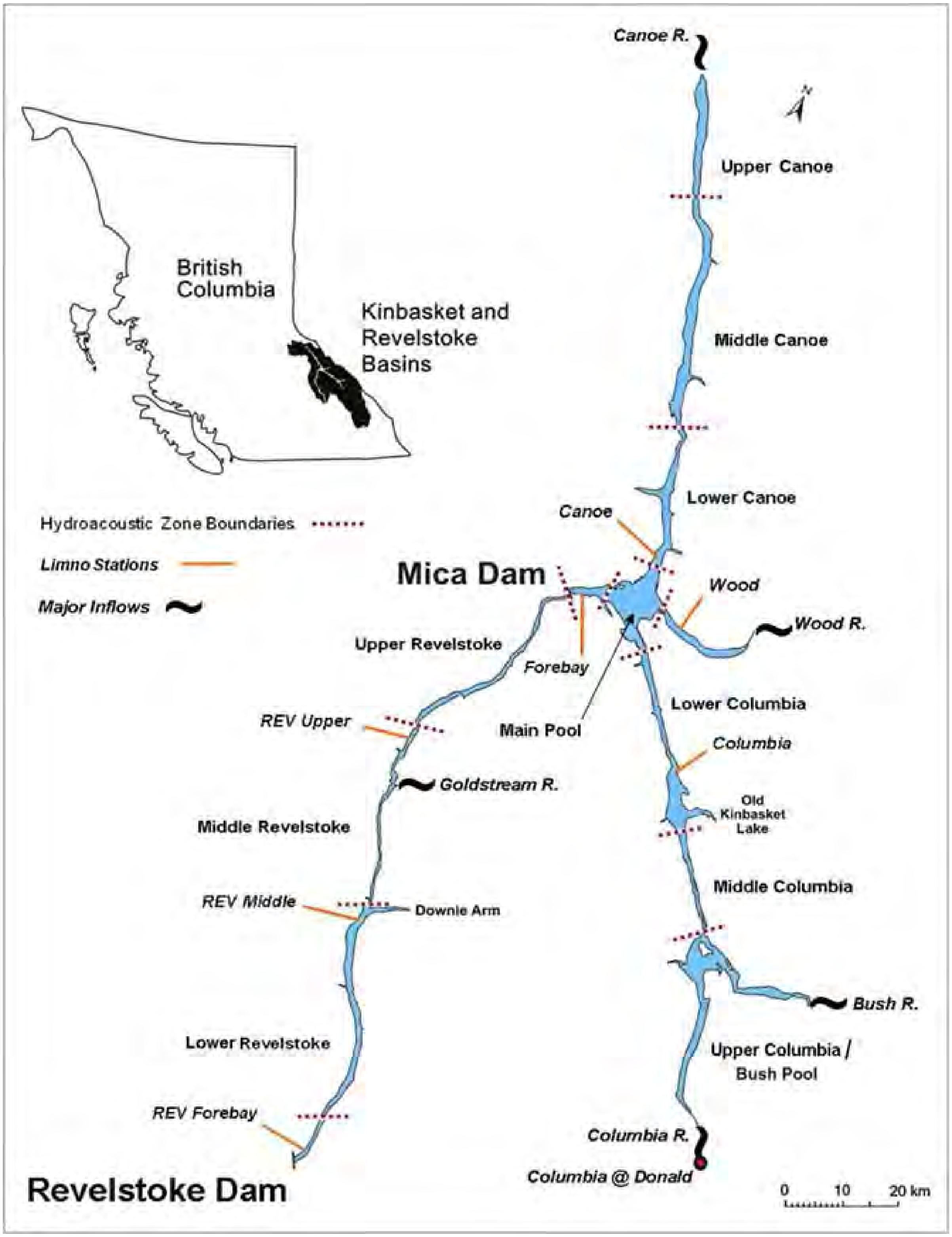

Figure 1. Map of Kinbasket and Revelstoke Reservoirs showing major inflows, location of key limnology sampling stations, and habitat zones for kokanee hydroacoustics.

Table 2. Characteristics of Kinbasket and Revelstoke Reservoirs.

	Max. Depth (m)	Area* (km^2)	Mean Outflow (m^3/s)	Elevation of normal maximum (m ASL)	Elevation of normal minimum (m ASL)	Drawdown Area (km^2)	Outlet Depth** (m)
Kinbasket Mica Dam	~190	431	590	754.4	707.1	220	17-65
Revelstoke Revelstoke Dam	~120	116	750	573.0	571.5	2.4	31-33

* At normal maximum as given by the BC Hydro storage elevation curves (see Pieters and Lawrence 2013a).

** Depth of outlet sill from water surface, from normal minimum to normal maximum.

1.2 Reservoir Operations

For our purposes, operation of Kinbasket and Revelstoke Reservoirs is defined as manipulation of the storage and release of water by the Mica and Revelstoke Dams and Generating Stations. The outcome of operations is manifested in terms of reservoir elevation and discharge (flow), both in terms of magnitude and periodicity (timing).

Operation of dams and reservoirs in the Canadian Upper Columbia River is governed by a hierarchy of international agreements and Federal/Provincial legislation and regulations, and is influenced by variations in climate (weather), flood control rules, electricity demand, facility maintenance, and unpredictable events, such as unplanned outages across the electrical system.

Kinbasket Reservoir has the largest storage volume - more than twice the next largest - of all reservoirs on the Columbia River. The total active storage on Kinbasket Reservoir is 12 million acre-feet (MAF)[2] of which 7 MAF (8.61 km^3) are operated under the Canada-US Columbia River Treaty (CRT) (BC Hydro 2005). The other 5 MAF (6.17 km^3) are operated under a Columbia River Non-Treaty Storage Agreement (NTSA) between BC Hydro and Bonneville Power Administration (BPA), the US entity for CRT. Broadly, the CRT regulates Columbia River discharges at the international border primarily for flood control and secondarily for power generation benefits. Under the NTSA, BC Hydro and BPA co-ordinate the operation of storage additional to treaty storage in Kinbasket and Arrow Reservoirs with benefits to both parties, but without change to any CRT provisions. Revelstoke Dam and Reservoir were not constructed under the CRT; however, its operation is inherently tied to the treaty by virtue of its position between

[2] 1 million acre feet (MAF) = 1.23 km^3. Imperial measure is used here to correspond to Columbia River Treaty values.

Kinbasket and Arrow Reservoirs. The CRT is currently being renegotiated by Canada and the United States.

The original NTSA was negotiated following a dispute over the filling of Revelstoke Reservoir in 1984. After some extensions, that agreement ended in 2004 with both parties fulfilling their obligations to refill their storage accounts by January 2011. This contributed to higher Kinbasket reservoir elevations throughout the first years of the study period compared to the previous decade (cf. Figure 5, Section 3.1 Hydrology). A new NTSA was signed in April 2012 with a termination date of 2024. Annual agreements were negotiated in the interim period between 2004 and 2012. Under the NTSA, both BC Hydro and BPA negotiate weekly operations for water storage or release depending on water year forecasts and both power and non-power benefits (e.g. environmental flow needs, recreation). Use of non-treaty accounts can allow for a deeper draft in Kinbasket to meet winter power demands; however, the ability to draft in Kinbasket is always constrained by elevation limits for flood control in Arrow Reservoir and CRT discharges over the international border (see https://www.bchydro.com/energy-in-bc/operations/our-facilities/columbia/ntsa.html).

Kinbasket and Revelstoke Reservoirs are operated by BC Hydro under provincial water licences that stipulate, among other things, normal minimum/maximum reservoir levels, and any provisions for specific discharges or reservoir elevations outside of operating norms. For Kinbasket Reservoir, application may be made through the Comptroller of Water Rights for additional storage (surcharge) up to 0.3 m above normal maximum (i.e., to 754.68 m) for economic, environmental, or other purposes to assist with managing a risk of high spill volumes at Mica Dam. Reservoir surcharge has been rarely used since the creation of Kinbasket but has been implemented twice in the study period: in 2012 and 2013. In 2012, surcharge was initiated due to record high inflows throughout the Columbia basin and was needed to prevent downstream flooding. In 2013, surcharge was initiated due to operational constraints resulting from construction activities at Mica Dam.

Prior to 2015/2016 and the installation of the fifth and sixth turbines at Mica GS, the total discharge capacity of the turbines was 1,225 m^3/s. The final two units brought the total capacity to the water licence limit of approximately 1,840 m^3/s. There are no specified operational discharge requirements at Mica Dam and Generating Station.

Revelstoke Reservoir has a licensed active storage of 1.5 MAF (1.85 km^3) and an elevation range between 573.02 m and 554.66 m (18 m). The normal operating range is within 1.5 m (i.e., to 571.5 m) to maximize turbine hydraulic head and maintain a small storage buffer for operational flexibility and short-term variations in inflow. Revelstoke Reservoir elevation is kept fairly constant by regulating output at Mica and Revelstoke Dams so that the two facilities are operated in hydraulic balance. Normal surcharge can be up to 573.33 m (0.3 m), maximum up to 574.5 m; however, this can be used only for flood routing purposes. During periods of unusual power demand or to maintain hydraulic balance with Mica GS the reservoir may be drafted by 3 m (to 569.98 m) and, in extreme emergencies (e.g. dam safety), by 15 m (to 557.8 m).

Prior to commissioning the fifth turbine at Revelstoke in December 2010, maximum discharge capacity of the turbines was approximately 1,700 m^3/s and there was no minimum discharge (therefore discharge could be zero). The Columbia Water Use Plan established a continuous minimum discharge of 142 m^3/s for the Columbia River below Revelstoke Dam that was initiated in December 2010 in conjunction with the fifth turbine (although not related). Completion of the fifth unit brought Revelstoke GS maximum turbine discharge capacity to 2,210 m^3/s. Plans for the sixth and final generating unit are being prepared for contingency purposes with an estimated need by 2026 or later. Concurrent with the Environmental Assessment Certificate application for the sixth unit was a water licence application for an additional 85 m^3/s, as the fifth and planned sixth turbines have greater generating capacity and will enable exceedance of the original water licence total of 90,000 cfs (2,548 m^3/s). A sixth unit will increase the total discharge capacity at the Revelstoke Generating Station to 2,633 m^3/s.

1.2.2 A Note on Study Period Conditions

While each year brings its own set of weather and operating conditions related to both planned and unplanned events, it is worth noting that our study period has so far coincided with a period of unusual activity and wide range of conditions with respect to infrastructure, operations, and weather.

From their construction to 2010, Mica and Revelstoke Dams and Generating Stations experienced no major infrastructure changes, operating with the original four turbines installed decades before (1976 and 1984, respectively). Within the first nine years of our study period, however, three additional turbines were installed and began operation: Revelstoke Unit 5 (2011[3]), Mica Unit 5 (2015), and Mica Unit 6 (2016). In addition, there was a major upgrade to the gas insulated switchgear facility at Mica GS (2013). Construction at Mica GS had implications for both Kinbasket and Revelstoke Reservoir operations, particularly in 2013, and the new turbines have changed operations by virtue of providing increased capacity. Coinciding

[3] Actual in service dates of Units at Revelstoke and Mica were in December the year prior. For this study, however, the year in parenthesis indicates the first study year affected.

with Revelstoke Unit 5 was implementation of a continuous minimum flow (ordered at 142 m3/s). Initially these minimum discharges were delivered at ~163 m^3/s; however, in June 2013, minimum discharges increased to ~283 m^3/s for turbine reliability. Only during small spill events is minimum discharge provided at less than this (~170 m^3/s).

Climate and operational scenarios were also highly variable during the study period and included many previously rare events. Inflows ranged from almost record highs (2012) to almost record lows (2015). The first large spill events in over 20 years occurred at Revelstoke and Mica (2012), as well as reservoir surcharges at Kinbasket (2012, 2013), periods of lower than normal elevation (i.e., below 571.5 m) at Revelstoke (2013), and initiation of heretofore unknown spring spilling events at Revelstoke due to lack of electricity demand and to maintain the new minimum flow (2012, 2014, 2016). The third driest year in the United States and the strongest El Niño year on record (2015) triggered higher than normal and previously unseen CRT outflows from Kinbasket Reservoir with resulting high flows through Revelstoke and Arrow Reservoirs through the growing season (April to September). The smallest annual elevation change for Kinbasket Reservoir (14 m) since 1977 also occurred in 2015 and left Bush Pool inundated over the winter for only the second time. In addition to these operational and climatic anomalies, kokanee in Kinbasket Reservoir were affected by a unique and large scale die-off in spring 2016 (likely disease related). Going forward, Kinbasket kokanee may also be influenced by egg takes (the first in the fall of 2016) from spawners at the Columbia River near Fairmont in support of Kootenay Lake kokanee recovery efforts.

All this is to illustrate the wide range of conditions experienced during the first nine years of our study. While useful for demonstrating extremes, this variability injects both opportunity and challenges for data interpretation and confounds our ability to distinguish operational versus environmental influences on these reservoir ecosystems. With climate change effects having an increasing and destabilizing presence on the region's ecology (USGCRP 2018) and with concomitant impacts to flood control and energy demands (operations), it is increasingly difficult to develop prescriptive operations for maintaining maximum reservoir productivity based on historical trend data as anticipated in the study TORs. We anticipate, rather, providing predictions of most likely reservoir ecological productivity outcomes based on a suite of operational and environmental conditions.

2.0 METHODS

2.1 Hydrology

Flow and water level records were provided by BC Hydro and Water Survey Canada. The local flow to each reservoir was computed from a water balance as described in Pieters and Lawrence (2018a). Daily average values are shown unless noted otherwise.

2.2 Tributary chemistry and temperature

Two types of tributary sampling were undertaken over the study period: (1) occasional surveys of many tributaries to assess variations across the drainage; and (2) frequent sampling of a set of reference tributaries to assess seasonal variations and long-term trends. Surveys were undertaken across both reservoirs on 25 June and 5 August 2008, 7-8 July 2009 and 6 May 2013 to capture a range of seasonal flows (for further detail see Pieters et al. 2016a). Tributary surveys sampled approximately 2/3 of the total inflow to Kinbasket and 9/10 of the inflow to Revelstoke Reservoir.

Sampling of reference tributaries began in 2009 and reference tributaries were generally sampled monthly from March to December except twice monthly during freshet from April to June; for sampling details see Pieters et al. (2018b). The reference tributaries are: Columbia River at Donald, Kinbasket (Mica) outflow, Goldstream River, and Revelstoke outflow. Beaver River was added in 2013 to complement samples collected by Parks Canada and analysed by Environment Canada. Downie Creek was added in 2016 because of its importance to the lower Revelstoke Reservoir. From 2008 to 2012, water samples were analysed by the Cultus Lake Salmon Research Laboratory, Department of Fisheries and Oceans, Cultus Lake, British Columbia. From 2013 to 2016, samples were analysed by Maxxam Analytics Inc., Burnaby, British Columbia. Details of sample locations, water quality parameters, and laboratory methods are given in Pieters and Lawrence (2018b).

2.3 Reservoir Limnology

2.3.1 Reservoir Sampling Stations

Reservoir pelagic sampling was scheduled once a month from April/May to October at four stations in Kinbasket Reservoir (KIN Forebay, KIN Canoe, KIN Wood, and KIN Columbia) and three stations in Revelstoke Reservoir (REV Upper, REV Middle, and REV Forebay) from 2008-2016 (Figure 1). Sampling was conducted for physical properties (depth profiles), water chemistry, phytoplankton, picoplankton, and zooplankton.

The study began in July 2008 with the first full seasonal sampling conducted in 2009. In 2013, April sampling was added to the regular schedule to improve data for early season conditions. Some monthly data are incomplete or missing when sampling was curtailed due to logistical (e.g. field conditions) or mechanical (e.g. equipment failure) issues. Kinbasket Reservoir has presented a greater challenge for sampling due to debris, fluctuating water levels, and more dangerous conditions; therefore, the dataset for this reservoir is less complete than for Revelstoke Reservoir. Details on station coordinates and sampling schedules are in annual reports available at:
https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/southern_interior/columbia_river/kinbasket-fish-wildlife.html.

2.3.2 CTD

Profiles of water properties were collected with a CTD (conductivity-temperature-depth) profiler at each station and at the middle of the main pool in Kinbasket. A Sea-Bird Electronics SBE 19plus V2 profiler was used, with the following additional sensors:

- Turner SCUFA II fluorometer and optical back scatter (OBS) sensor,
- Biospherical QSP-2300L (4 pi) photosynthetically active radiation (PAR) sensor,
- Sea-Bird SBE 43 dissolved oxygen sensor, and
- WETlabs CStar transmissometer (red, with 25 cm path).

The profiler collects data at 4 Hz and, when lowered at approximately 0.3 m/s, collects data every 0.1 m. For further detail see Pieters and Lawrence (2018c).

2.3.3 Moored Temperature Recorders

Beginning in 2012, temperature data were collected at fixed sites in Kinbasket and Revelstoke Reservoirs as part of the CLBMON-56 Addendum #1 to CLBMON-3 (BC Hydro 2007b). Data were collected from two base locations: the forebay of Revelstoke Reservoir and the forebay of Kinbasket Reservoir. Each mooring consisted of two parts: a line with instruments hung from the log boom at the dam to collect temperature near the surface, and a subsurface line approximately 1 km from the dam to collect temperature from depth. Instrument lines have also been moored at other locations such as at the middle and upper sampling stations in Revelstoke Reservoir, and at the location of the Old Kinbasket Lake on the Columbia Arm of Kinbasket Reservoir (Figure 1).

All instruments were internally recording and were recovered, uploaded, serviced, and re-installed annually. Onset Hobo U22 temperature recorders (accuracy 0.2 °C) were generally spaced every 2 m, with higher resolution Seabird SBE56 or RBR Solo-T recorders (accuracy 0.002 °C) every 20 m. Also used were autonomous vertical profilers tethered in Revelstoke Reservoir that collected a temperature, conductivity, and turbidity profile once a day. For further detail see Pieters and Lawrence (2016b, 2018d).

2.3.4 Water Chemistry

Five litre Niskin bottles were lowered by cable in series to collect discrete depth samples at 2, 5, 10, 15, 20, 60 and 5 m off bottom (where possible) for all years. Intermediate depth samples between 25 to 80 m were collected in various years to determine the most appropriate metalimnion depths to sample. A plastic tube with inside diameter of 2.54 cm was used to obtain a 0-20 m integrated depth sample at each station.

Discrete depth samples were analysed for nitrite+nitrate (NO_2+NO_3 or NN), total phosphorus (TP), total dissolved phosphorus (TDP), soluble reactive phosphorus (SRP), alkalinity, conductivity, pH, and turbidity. Integrated tube samples were analysed for soluble reactive silica. Secchi disk readings were taken without a viewing tube at each site using a standard 20 cm Secchi disk. Further details on sample preparation, analytical methods, and laboratory detection limits are available in annual data reports.

From 2008-2012, samples were analysed at the DFO Cultus Lake laboratory; however, beginning in 2013 samples were sent to Maxxam Analytics Laboratory (Burnaby) as the DFO lab was no longer able to process samples. Detection limits changed between laboratories, particularly for phosphorus fractions, and some analytical differences resulted in changes to the results for phosphorus, alkalinity, and soluble reactive silica. Phosphorus data continue to be under review; however, silica and alkalinity data have been reconciled (see Results).

2.3.5 Primary Production

Sampling methods and analytical procedures used are presented in detail in Harris and Sarchuk (2018). Primary productivity, chlorophyll *a*, and alkalinity were measured once a month from June to September on Kinbasket Reservoir at the Forebay station, and on Revelstoke Reservoir at the Forebay station and Middle station. Exceptions are 2002 (Kinbasket August only), 2008 (all sites July to September only), and 2011 (Kinbasket June to August only). Data presented here from 2002 and 2008 were obtained by methods described in Stockner and Korman (2002) and TG Ecologic LLC (2009), respectively.

2.3.6 Phytoplankton and Picoplankton

Discrete samples were typically collected monthly from April through October at the four Kinbasket Reservoir and three Revelstoke Reservoir sites at depths of 2, 5, 10, 15, and 25 m and preserved in the field in acid Lugol's iodine preservative for identification and enumeration by Advanced Eco-Solutions Inc. in Newman Lake, WA.

Two depth strata, the epilimnion and hypolimnion, were assessed by creating composites of discrete samples. The mean of the taxa densities from samples collected at 2, 5, and 10 m were used to calculate epilimnetic density and biovolume while samples from 15 and 25 m were used to calculate the hypolimnetic density and biovolume. In 2008 and 2009, samples taken at various depths were composited in the field and then identified and enumerated in the laboratory. A change in methodology in 2010 through 2016 whereby samples were not composited in the field is compatible with the previous sampling methodology. However, the taxa richness could be higher in the composited samples from 2010 to 2016 since counting multiple samples and then compositing them after identification and enumeration will result in an increase in the fraction of the sample counted compared with counting a single field composited sample.

Phytoplankton samples were gently shaken for 60 seconds and poured into 25 mL settling chambers and allowed to settle for a minimum of 3 hrs prior to quantitative enumeration using the Utermohl Method (Utermohl 1958). Counts were done using a plankton microscope. All cells within a random transect of 3.5 mm in length were counted at high power (900X magnification) that permitted a semi-quantitative enumeration of minute (<2 µ) autotrophic pico-cyanobacteria cells (1.0-2.0 µ) [Class Cyanophyceae], and of small, delicate auto-, mixo-, and hetero-trophic nano-flagellates (2.0-20.0 µ) [Classes Chrysophyceae and Cryptophyceae]. Comments on the relative density of ciliates in each sample were also noted on count sheets. Where feasible, from 250-300 cells were enumerated in each sample to assure counting consistency and statistical accuracy (Lund et al. 1958). The compendium of Canter-Lund and Lund (1995) was used as a taxonomic reference. The primary taxonomist was Nichole Manley of Advanced Eco-Solutions Inc...

2.3.7 Zooplankton

Samples were collected monthly at each of the seven reservoir sites with a vertically hauled 153 µm mesh Wisconsin net having a 0.2 m throat diameter. Each haul was to 30 m and duplicate samples were taken at each site. Collected zooplankton samples were rinsed from the dolphin bucket and preserved in 70% ethanol. Zooplankton samples were analyzed for species density, biomass, and fecundity. Enumeration protocols for zooplankton are described in Vidmanic

(2013). Zooplankton species were identified with reference to taxonomic keys (Sandercock and Scudder 1996, Pennak 1989, Wilson 1959, Brooks 1959). Similar sampling was conducted in Revelstoke Reservoir in 2003 and Kinbasket Reservoir in 2003 to 2005 although the Revelstoke Upper and Kinbasket Columbia Reach station locations in the previous work were slightly different from our current locations. Data from this period are included as appropriate.

2.4 Kokanee

2.4.1 Habitat

Estimates of pelagic habitat area for kokanee at maximum and minimum annual pool elevations and for summer survey periods were derived following methods in Appendix 5 of Sebastian et al. (2010). To conform with the limnology sampling, two additional habitat zones were identified near the forebay areas of Revelstoke and Mica Dams and two of the original habitat zones in Kinbasket (Lower Columbia and Old Kinbasket Lake) have been combined into a single zone referred to as the Lower Columbia (Bray et al. 2013). In Kinbasket Reservoir, the Main Pool is located upstream of the Forebay and represents a junction of three upstream reaches, Canoe, Wood, and Columbia. Habitat zones for both Kinbasket and Revelstoke are described in (Table 3).

Table 3. Kinbasket and Revelstoke Reservoirs showing habitat zones based on kokanee distribution and limnology sampling stations.

Zone	Description	Hydroacoustic Transects	Limno Sampling
Kinbasket Reservoir			
Forebay	Mica Dam to Main Pool outlet	9-11	Yes
Main Pool	East of Sprague point	12-16, 20	
Lower Canoe	Main Pool to Narrows	5-8	Yes
Middle Canoe	Narrows to 40 m contour	1-4	
Upper Canoe	40 m contour to Valemount	NOT SURVEYED	
Wood Arm	Main Pool to Wood River	17-19	Yes
Lower Columbia	Main Pool to Old Kinbasket L. inlet	21-27	Yes
Middle Columbia	Old Kinbasket Lake to Bush Pool	28-30	
Upper Columbia/Bush Pool	Bush Pool to Upper Columbia R	31-39[a]	
Revelstoke Reservoir			
Forebay	Revelstoke Dam to Martha Cr	1-3	Yes
Lower	Martha Cr. to Downie Narrows	4-12	Yes
Middle	Downie Narrows to Nicholls Cr	13-20	Yes
Upper	Nicholls Cr to Mica Camp	NOT SURVEYED	

a) an additional 9 transects were done in 2015 to examine kokanee use of Bush Pool (Zone 9)

Note that assessment of Bush Pool was continued in 2016 with 6 of the 9 transects surveyed.

2.4.2. Hydroacoustic Surveys

Kokanee hydroacoustic surveys were conducted at night within 5 days of the new moon from mid-July to mid-August 2008-2016. Surveys consisted of 30 transects in Kinbasket Reservoir and 20 transects in Revelstoke Reservoir following the survey design in Sebastian et al (2010). An additional 9 transects were done in 2015 to assess kokanee use in Bush Pool as outlined in Sebastian and Weir (2016). Six of the nine new transects in Bush Pool were repeated in 2016. Due to adverse sampling conditions (e.g., high winds and dense debris fields) not all transects could be accessed all years. Detailed descriptions of equipment and specifications used in data collection and in post field data processing and analyses can be found in data reports by Sebastian et al. (2010) and Johner and Weir (2012). A new method for setting the lower acoustic thresholds was developed in 2013 (Sebastian and Weir 2014) following extremely high noise levels in Revelstoke Reservoir acoustic data in 2012. This method has since been applied to all 120 kHz data (2009-2016) to standardize and improve the separation of low end noise (i.e., non-fish targets) from small kokanee fry. Examples of target size distributions for high and low noise surveys are compared in Sebastian and Weir (2016). Acoustic data prior to 2009 were collected using a lower frequency of 70 kHz; this lower resolution did not detect low end noise to the point of being problematic for developing kokanee fry estimates.

2.4.3 Trawl Sampling

Trawl sampling was conducted in Kinbasket Reservoir concurrent with the acoustic surveys during the 2008-2016 study period, and typically consisted of 1-2 trawls in the Main Pool or Forebay and 1-3 trawls in Wood Arm as weather, debris, and other sampling logistics allowed. Methods and equipment are described in Bray et al. (2013). Additional trawling of relatively shallow habitat in Bush Pool was conducted for the first time in 2015. A smaller 2.5 x 2.5 m experimental trawl net was deployed to minimize the risk of entanglement on the bottom of these uncharted waters. A single trawl was done starting at a depth of 5-7.5 m and gradually dropping to ~10-12.5 m over a 45 minute duration. The purpose was to determine if kokanee was the main species viewed on the echo sounder in Bush Pool. Due to poor catch efficiency, trawling was discontinued in Revelstoke Reservoir following 2012 and when initial gillnet surveys proved to be more successful at capturing age 1-3 kokanee (see next section).

2.4.4 Gillnet Sampling

The feasibility of using gillnets to capture age 1-3 kokanee at very low densities was tested with 4 sets in Revelstoke Reservoir in 2012. Gillnet sampling has been continued annually in Revelstoke Reservoir concurrent with acoustic surveys, and was expanded to include Kinbasket Reservoir starting in 2013. Details of set locations, net specifications and methods of deployment, and results are available in annual data reports starting with the Year 5 (2012) report by Sebastian and Weir (2013). A modification was made to Resources Information Standards Committee (RIC) standard nets starting in 2015 when an additional panel of 32 mm stretched mesh size was added to each net to target fish of approximately 150 mm, the size of an age 1 kokanee (see Appendix 8 in Sebastian and Weir (2016) for RIC net modifications). Gillnet surveys were extended to include Bush Pool in 2015 and 2016 to determine species composition and collect biological information, including length, weight, stage of maturity, and aging structures.

2.4.5 Biomass Estimation

A method to generate kokanee biomass estimates directly from acoustic data was developed following a recommendation from the first synthesis report (Bray et al. 2013). Biomass estimates presented in this report have not been previously reported. The biomass estimation method outlined in the Sonar5 Manual (Balk et al. 2015) has been calibrated specifically for assessing kokanee with a downward-looking transducer using acoustic and fish capture data from Kinbasket and Revelstoke Reservoirs. We compared seven years of acoustic size distributions on Kinbasket Reservoir (2009-2015) with cumulative fork length distributions for kokanee from combined trawl and gillnet catches over the same time period (n=1292 kokanee). Six features identified on both acoustic and fish size distributions were used to develop the following empirical relation between acoustic target strength and fish fork length for kokanee:

(1) $TS = 23.909 \log FL - 68.216$ $R^2 = .992$ $n = 6$ (Appendix 7.1)

where TS is echo target strength (dB) and FL is fork length (cm).

This equation was then applied to estimate kokanee fork length equivalents for each 1 decibel size interval over the full range of kokanee sizes. The following empirical relations between fork length and weight were developed from combined trawl and gillnet catches of kokanee:

(2) Kinbasket: $WT = 0.0073 * FL^{3.134}$ $R^2 = 0.997$ $n = 1199$ (Appendix 7.2)

and

(3) Revelstoke: $WT = 0.0096 * FL^{3.075}$ $R^2 = 0.991$ $n = 361$ (Appendix 7.2)

where WT is weight (g) and FL is fork length (cm).

Relations (2) and (3) were applied to convert fork length estimates to mean weight estimates for Kinbasket and Revelstoke Reservoirs, respectively, by 1 dB size intervals (Appendix 7.3). For each survey, the fish abundance by 1 dB size interval was converted to biomass by multiplying by its corresponding mean weight. Biomass estimates by 1 dB size increments were then summed over the full range of kokanee sizes to estimate the total kokanee biomass. The biomass density ($kg \cdot ha^{-1}$) for each survey was calculated by dividing the total biomass (kg) by the total area (ha) of pelagic habitat surveyed.

The above two relations were also used to calculate average weight for acoustic size increments of 3 dB by averaging the weights of three one dB size increments. These weights were then applied to older single beam abundance estimates by 3 dB size increments to calculate a biomass equivalent. Side by side correlations comparing age 0 density to age 0 biomass and then comparing age 1-3 density to age 1-3 biomass, however, confirm observations by Rudstrom et al. (1999) that deconvolution procedures used by HADAS software (i.e. modified Craig and Forbes 1969) for estimating fish size distributions from single beam data tends to underestimate fish size compared with split beam estimates. Our data show that for a given density, the biomass of age 0 was similar while the biomass of age 1-3 fish was well below the biomass estimated by newer split beam technology (Appendix 7.4). To address the problem we developed a custom target strength to fork length (TS:FL) relation for single beam data (lower curve in Appendix 7.1) which corrected for fish size and brought the density to biomass correlations for age 1-3 kokanee in line with split beam correlations (Appendix 7.4). The new TS:FL equation was developed using Kinbasket data and was tested and validated using acoustic data from Revelstoke Reservoir (Appendix 7.4). Upper and Lower Arrow Reservoir data provided further validation that the single beam calibration brought age 1-3 biomass into line with more recent split beam estimates.

2.4.6 Spawner surveys and alternatives to direct enumeration

Aerial survey methods described by Johner and Weir (2012) have been subject to considerable variability from stream to stream and year to year depending on water clarity, weather, flow stage, and peak spawning time. As a result of continuing difficulties in direct enumeration, an alternate method has been developed to provide an index of basin wide spawner abundance for Kinbasket and Revelstoke Reservoirs based on the abundance index of age 2 and older kokanee from acoustic surveys. A cumulative length frequency distribution for all fish captured by gillnet was used to determine where the length cut-off occurred between age 1 and 2 kokanee (Appendix 7.5). This length was converted to a decibel equivalent using the TS:FL relation (equation 1 above) enabling an acoustic abundance estimate of age 2 and older fish (collectively called 2++ fish hereafter). Due to the imprecise nature of acoustic data, the 2++

abundance is considered as an index of abundance rather than an actual estimate, as are all other estimates derived from such methods. The proportion of age 2 and older fish in the gillnet samples that were maturing (expected to spawn later the same year) was then applied to estimate the proportion of all age 2++ fish that could potentially spawn for each year. Because we had gillnet samples from only 5 years in Revelstoke and 4 years in Kinbasket, the average percent maturing value was applied to years with no gillnet data. The index estimates do not incorporate any mortality between the summer survey and fall spawning time, a period of 6 to 8 weeks.

A length to fecundity relation reported by McGurk (2000) was applied to female spawner length data to estimate fecundity for each fish and provided an estimate of average fecundity for each reservoir and year. Assuming a 1:1 sex ratio, the reservoir spawner index and average fecundity were used to predict potential annual egg deposition. The resulting potential egg deposition values were divided by the following year fry abundance to produce an index of egg to fry survival.

2.4.7 Biological sampling of spawners

Following recommendations from the first synthesis report, effort directed at biological sampling was increased. Biological sampling of spawners by angling continued on Camp Creek. Dip-net sampling continued on Luxor and Standard Creeks and was extended to include Bush River starting in 2013 and the Upper Columbia River in 2014-2015. Both angling and dip-netting were used to capture fish on Upper Columbia in 2014 and angling was used in 2015. Furthermore, following a recommendation from the phase 1 synthesis, an effort was made to conduct multiple sampling trips spread across the spawning period to ensure annual age structure and size at age estimates adequately represent all stages of the run. This was moderately successful, but was sometimes limited by heavy rain events resulting in an inability to observe or capture fish on multiple dates some years. Sex and fork length were recorded and otoliths collected the same day of capture. Spawner ages were determined from otolith interpretations following protocols in Casselman (1990). The intent of increased biological sampling in phase 2 was to improve our understanding of spawner size, age at maturity, and age composition among different spawning populations around the reservoir.

2.4.8 Age 0 to 1 survival

The approach described above to partition age 2++ from age 1 fish was also employed to develop an index of age 1 kokanee abundance. We assume that the abundance of fish that fall between the age 0 to 1 size cut-off and the age 1 to 2++ size cut-off described above provides an index of age 1 abundance. Dividing this abundance by the previous year fry abundance provided an index of age 0-1 survival for kokanee.

2.4.9 Kootenay Lake and Arrow Reservoir data

Where applicable in the discussion section, data from nearby Arrow Reservoir and Kootenay Lake are presented for comparison to Kinbasket and Revelstoke Reservoirs and to assist with addressing CLBMON-3 Management Question 3-6. Long-term datasets exist from these two nearby waterbodies that were collected and managed by the Province of BC through partnerships and funding from BC Hydro and the Fish and Wildlife Compensation Program, the Kootenay Tribe of Idaho, and the Columbia Power Corporation. Zooplankton and kokanee data are on file with MFLNRORD (Nelson & Victoria BC), and have also been reported in annual data reports, the most recent being Basset et al. (2018a) for Arrow, and Basset et al. (2018b) for Kootenay Lake. Hydroacoustic data collection and analysis methods were nearly identical among all four systems; however, the Kootenay and Arrow surveys occur in September and October respectively, compared to the Kinbasket and Revelstoke surveys which occur between mid-July and mid-August. All available data for each system from 2001-16 are presented, which aligns with the extent of the kokanee time series for Kinbasket and Revelstoke. Due to an unprecedented collapse of the main kokanee population in Kootenay Lake (Basset et al. 2016), kokanee data from Kootenay Lake are separated into discrete periods labelled 'pre-collapse' (2001-2012) and 'post-collapse' (2013-2016).

3.0 RESULTS

3.1 Hydrology

The Columbia River is the major tributary to Kinbasket Reservoir, accounting for 30% of the inflow (Pieters and Lawrence 2018a). In addition, tributaries along the Upper Columbia Reach of the reservoir also contribute significantly to the total inflow (29%) and, together with the Columbia River, provide 59% of the inflow to Kinbasket Reservoir at the outlet of Bush Pool (Figure 1). The Middle and Lower Columbia Reaches together contribute a further 15%. In contrast, the contribution from tributaries to the northern part of Kinbasket Reservoir – Canoe Reach – is only 18%, of which the Canoe River, entering at the north end, contributes only 3%. Wood Arm, entering the main pool from the east contributes the balance (7%).

The water level in Kinbasket Reservoir is drawn down in winter for hydroelectric generation (Figure 2a). Inflow to Kinbasket Reservoir has a natural hydrograph with a large freshet peak of snowmelt in spring that tails off gradually through summer (Figure 2b). From May to July, the water level rises as freshet inflow is stored to provide flood control downstream; during this time the outflow from Kinbasket Reservoir is low (Figure 2b). Once Kinbasket Reservoir has almost filled, the tail of the freshet is released, with increasing outflow from Kinbasket Reservoir in July and August.

Revelstoke Reservoir is operated run-of-the-river, a type of hydroelectric generation where inflow is immediately balanced by outflow, and as a result there is little change in water level (Figure 2c). The outflow from Kinbasket Reservoir provides the majority (71%) of the annual inflow to Revelstoke Reservoir. However, from May to July when Kinbasket Reservoir is filling and outflow from Kinbasket is low, the inflow to Revelstoke Reservoir is dominated by local inflows (Figure 2d).

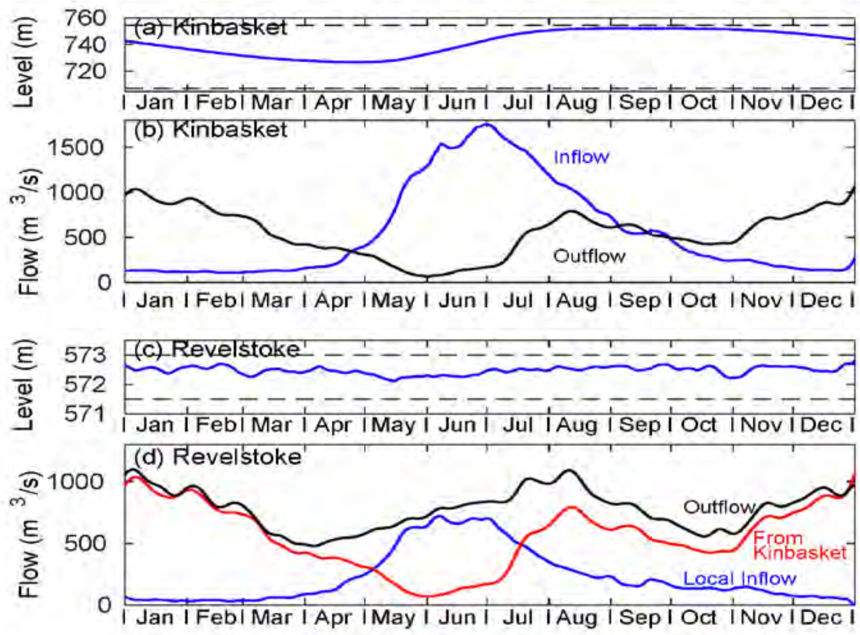

Figure 2. (a) Average water level for Kinbasket Reservoir, (b) average inflow and outflow for Kinbasket Reservoir, (c) average water level for Revelstoke Reservoir, and (d) average local inflow, inflow from Kinbasket Reservoir, and outflow for Revelstoke Reservoir. All data were averaged for 2008-2016.

Year to year variation in the natural inflow during the study period is illustrated using selected years for Columbia River at Donald (Figure 3). Other gauged tributaries (Beaver and Goldstream Rivers), as well as the computed local inflow to both Kinbasket and Revelstoke Reservoirs, were similar (Pieters and Lawrence 2018a). The natural inflow was close to average in 2014, significantly above average in late June and July 2012 due to heavy rain, and below average in 2009 (Figure 3).

To compare the inflow from year to year, the flow of the Columbia River at Donald is shown averaged over the productive period, April through October, in Figure 4. A wide variety of natural inflows were observed during the study period, including those that were both significantly high (2012) and low (2009, 2010, 2015).

The water level in Kinbasket Reservoir is shown in Figure 5a. While the difference between the normal minimum (707.41 m ASL) and the normal maximum (754.38 m ASL) is 47 m, drawdown in any given year averages 25 m. The area of the reservoir changes significantly; the area of the reservoir at minimum water level ranged from 240 to 320 km^3 (Figure 5a, right scale), which is 55-75% of the area at maximum water level later in the year.

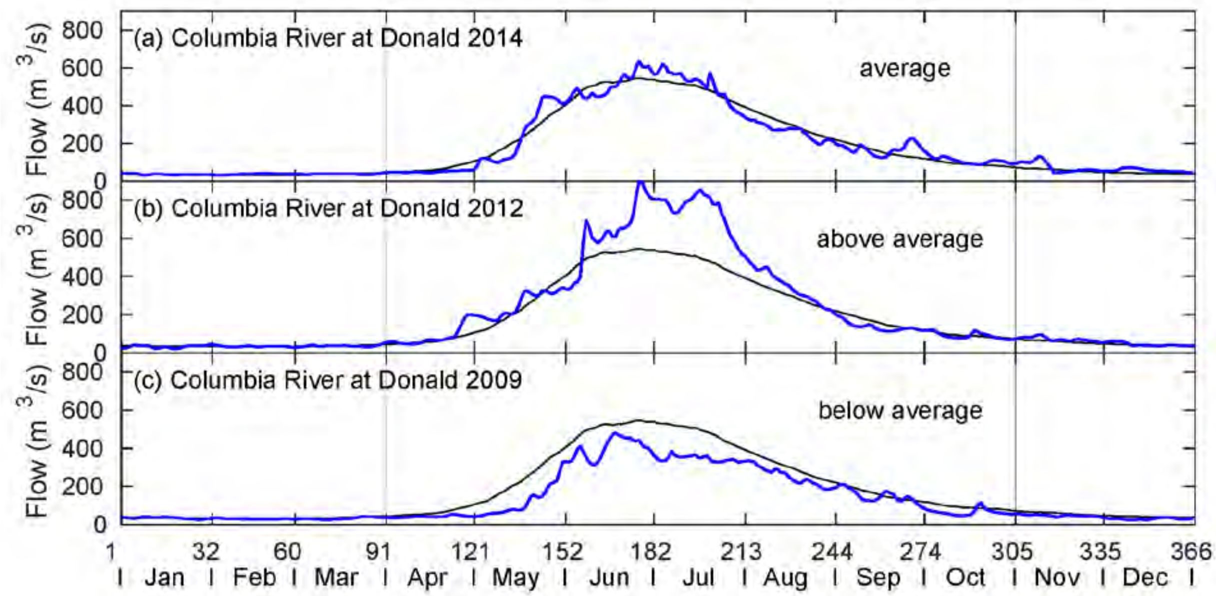

Figure 3. Columbia River at Donald, selected years. The black line is the daily average, 1945-2016. The vertical lines mark April to October.

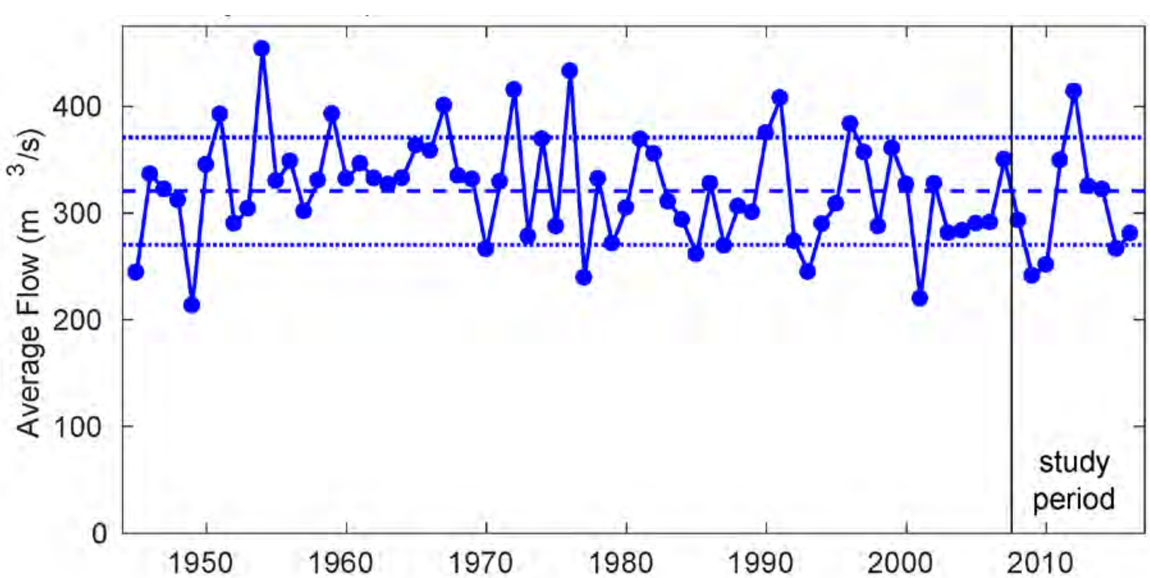

Figure 4. Average flow of the Columbia River at Donald through the productive season, April-October, 1945-2016. The dash line marks the average and the dotted lines mark ±1 standard deviation.

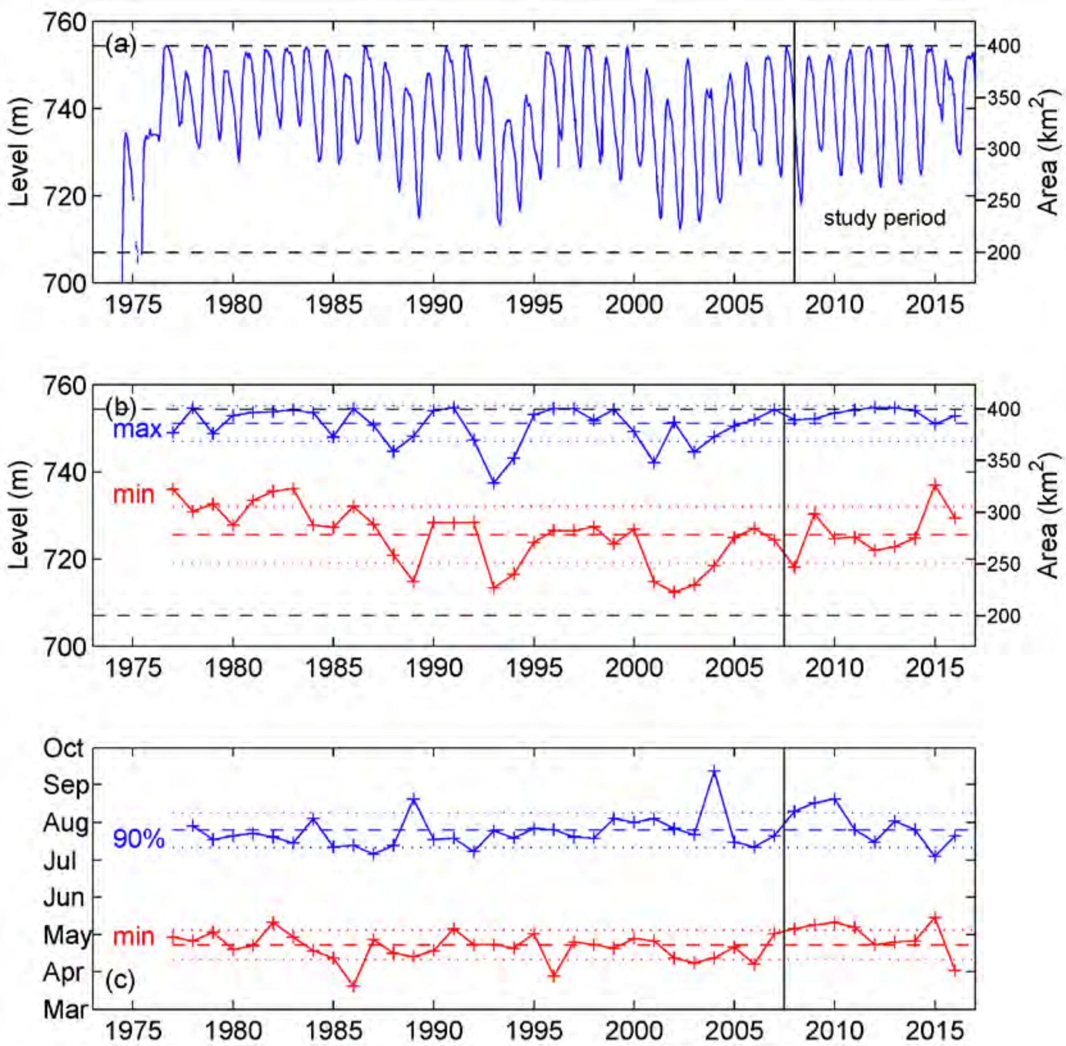

Figure 5. (a) Water level in Kinbasket Reservoir, 1973-2016. (b) Minimum (red) and maximum (blue) water level for 1977-2016. (c) Date of minimum (red), and 90% maximum (blue) water level for 1977-2016. The time to 90% full is shown as the time to the maximum water level can occur later in some years. Black dash lines mark normal minimum and maximum water level. Red and blue dash lines mark the average, and dotted lines mark ±1 standard deviation.

There are periods of time when the water level is relatively low throughout the year (e.g. 1992-1994) and other periods when the water level is relatively high (e.g. during the study period 2008-2016). The minimum and maximum water levels are shown in Figure 5b, along with the corresponding dates in Figure 5c. During the first 4 years of the study period, the minimum water level occurred significantly later than average, in early May (Figure 5c).

The outflow from Kinbasket Reservoir is shown for selected years in Figure 6. Of particular note is the very low outflow during late May to early July, as Kinbasket Reservoir was filling. In 2014 the outflow from Kinbasket Reservoir was close to average (Figure 6a). In 2012, the outflow was far above average beginning in mid-July. This flow pattern resulted from mid-June to late-July rainstorms noted earlier (Figure 3b), as well as the decision to lower water levels on Kootenay Lake to reduce flooding before releasing water from Kinbasket Reservoir. Outflow in 2015 was also high during the productive season, but showing a different pattern with above average outflow from April to September (Figure 6c). In contrast, 2009 illustrates outflow that was below average (Figure 6d).

Outflow from Revelstoke Reservoir for each of the study years was relatively steady on a seasonal time scale. However, there were significant variations in the flow within a day and from weekday to weekend. An example of the flow is shown in Figure 7**:** each day the flow increased rapidly around 6 AM and then decreased rapidly around midnight. The flow can decline slightly mid-day (e.g. Tue and Wed), and, in this example, flow on the weekend is reduced from that during weekdays**.** Revelstoke Dam and GS is used for peaking capacity which means generation is used to meet hourly energy demands, and therefore, it can cycle rapidly to meet Provincial power needs. Of note is a required minimum outflow of 142 m^3/s from Revelstoke Reservoir that began officially on 20 December 2010 in conjunction with the start of the fifth turbine operation (see Section 1.2.2).

The deviation from the seasonal mean air temperature measured at Revelstoke Airport is shown in Figure 8. For example, in 2011 the average spring and summer air temperatures were notably below average. Characteristics of each study year are summarized in Table 4.

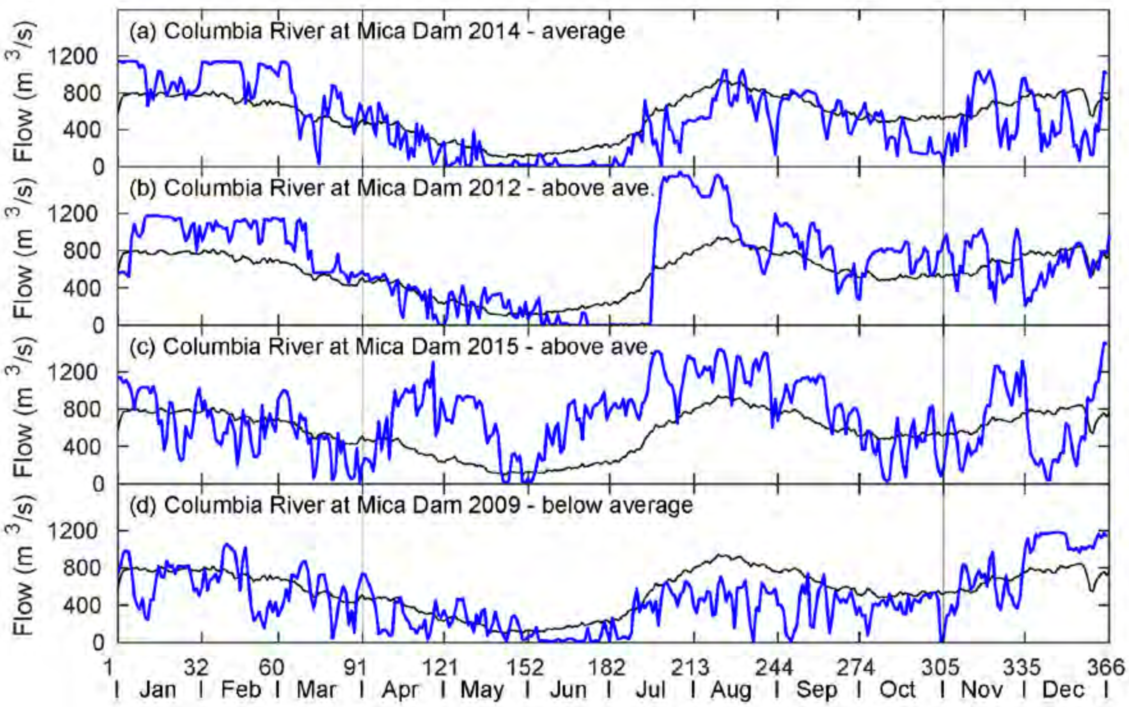

Figure 6. Daily average outflow from Kinbasket Reservoir, selected years. Black line gives average, 1976-2016. The vertical lines mark April to October.

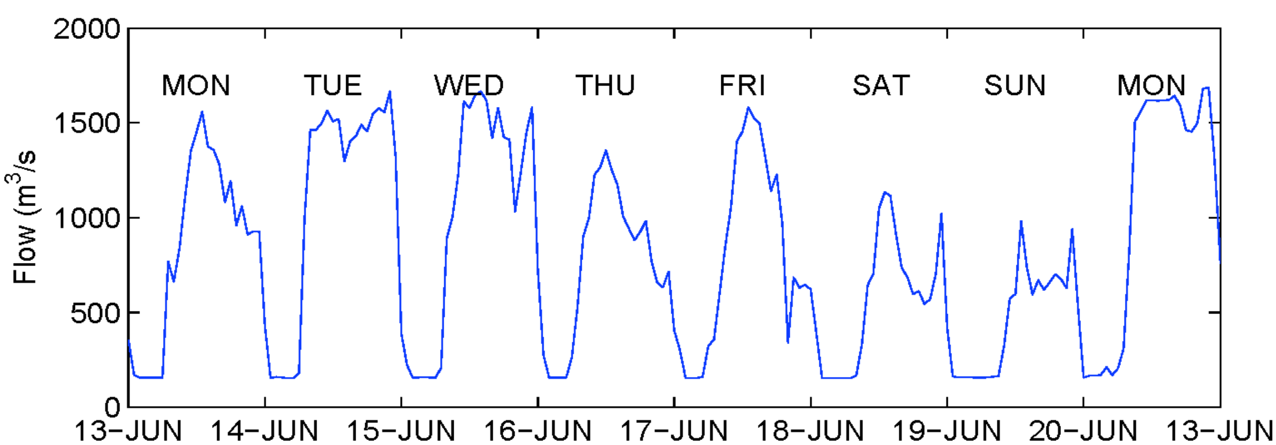

Figure 7. Hourly outflow from Revelstoke Reservoir over 8 days, 13-21 Jun 2011.

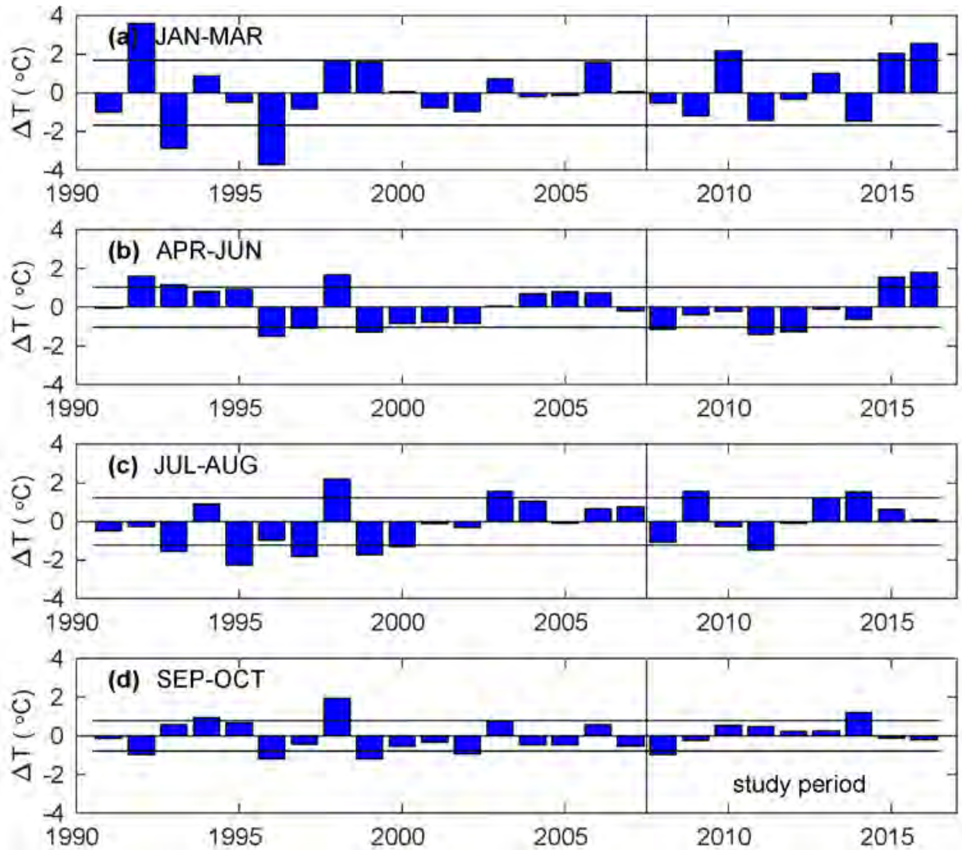

Figure 8. Deviation of the air temperature at Revelstoke Airport from the seasonal mean, 1991-2016. Horizontal black lines show the mean and the mean ±1 standard deviation.

Table 4. Summary of meteorological and hydrological conditions during study years.

2008	Strong La Niña (Jan-Mar 2008)
	Columbia Region Snow Basin Index (April 1st), 104%
	Flow slightly below average, delayed and sharp onset of freshet in mid-May
	Cool mid-March to mid-May
2009	Weak La Niña (Aug 2007 - Feb 2008)
	Columbia Region Snow Basin Index (April 1st), 78%
	Flow generally below average
2010	Strong El Niño (Jan-Mar 2010)
	Columbia Region Snow Basin Index (April 1st), 84%
	Flow generally below average
2011	Strong La Niña (Jul 2010 - Apr 2011)
	Columbia Region Snow Basin Index (April 1st), 101%
	Flow average
	Colder than average from April to July
2012	Weak El Niño (Apr 2012)
	Columbia Region Snow Basin Index (April 1st), 125%
	Local flow above average in late June and early July
2013	Weak La Niña (Jun - Aug 2013)
	Columbia Region Snow Basin Index (April 1st), 103%
	Flow average
2014	El Niño (Apr - Aug 2014)
	Upper Columbia Region Snow Basin Index (April 1st), 123%
	Flow average
2015	Strong El Niño (Mar - Dec 2015)
	Upper Columbia Region Snow Basin Index (April 1st), 86%
	Flow below average (after early and high freshet mid-May to mid-June)
	High inflow event during late September
	High outflow from Kinbasket Reservoir, April to September
2016	Strong El Niño (Mar 2015 - May 2016)
	Upper Columbia Region Snow Basin Index (April 1st), 99%
	Flow average (mid-Apr to mid-May slightly above average; mid-Jun to end Jul, slightly below average)
	Mica outflow average

3.2 Tributary nutrients

Tributary chemistry results from the two surveys are summarised in Table 5. Tributaries to both Kinbasket and Revelstoke Reservoirs are generally low in nutrients. Soluble reactive phosphorus (SRP) was very low, close to the detection limit of 0.5 to 1.0 µg/L. Total dissolved phosphorus (TDP) was also low, with a median of 2.8 and 3.5 µg/L, for the tributaries of Kinbasket and Revelstoke Reservoirs, respectively. Total phosphorus (TP) was highly variable, reflecting the glacial origin of many of the tributaries, and is likely of inorganic origin having low biological availability. For glacial inflows, such as those to Kinbasket and Revelstoke Reservoirs, TDP is preferred over TP as a measure of available phosphorus (Pieters et al. 2003).

Nitrate[4] is the dominant form of nitrogen in the tributaries. Nitrate values varied between tributaries with a median of 91 and 102 µg/L for tributaries to Kinbasket and Revelstoke Reservoirs, respectively. However, data from the reference tributaries show that nitrate changes significantly with time of year. For example, data from Beaver River for 2009-2016 are shown in Figure 9. Nitrate increased from winter levels of below 200 µg/L to over 300 µg/L during the start of freshet, and then declined rapidly to summer values of approximately 50 µg/L. Nitrate concentrations gradually increased through fall, returning to winter levels in December. A similar pattern was observed in the other reference tributaries with natural flows (Pieters and Lawrence 2018a), in the tributaries to the Arrow Reservoir (Pieters et al. 2003), and in other systems (e.g. Pellerin et al. 2012).

The flow weighted average concentration of TDP is shown for the reference tributaries in Figure 10. Only one sample was collected from the reference tributaries in 2008, insufficient to calculate a volume weighted average, and this year is excluded. For 2009-2016, the most noticeable feature is the shift in the data due to the change in laboratory. The Maxxam laboratory used from 2013-2016 resulted in more readings at or below detection (2 µg/L). This shift is obscured by one or two higher readings which occurred in 2013 (see Figure 10 caption). The source of the shift in laboratory readings is not known and is currently under investigation.

Table 5. Summary of tributary chemistry, surveys 2008, 2009 and 2013.

Station/ Parameter	*Units*	*KIN Median*	*KIN Min*	*KIN Max*	*REV Median*	*REV Min*	*REV Max*
NO_2+NO_3 (NN)	µg/L	91	18	929	102	1.6	882
TP	µg/L	15	2.7	115	7.2	2.5	49
TDP	µg/L	2.8	1.5	11	3.5	0.2	18
SRP	µg/L	1.9	0.7	5.4	2.1	0.9	5.7
NN:TDP (w/w)		25	4.2	465	22	0.42	310
Conductivity	µS/cm	81	24	296	38	10	149
Alkalinity	mg$CaCO_3$/L	60	7.5	181	27	4	115
pH	pH units	7.7	6.6	8.4	7.3	6.3	8.0
Turbidity	NTU	13	0.4	1830	2.2	0.14	68

[4] The laboratory method (NN) measures both nitrate, NO_3, and nitrite, NO_2, but nitrite is low in systems with high levels of dissolved oxygen such as Kinbasket and Revelstoke Reservoirs.

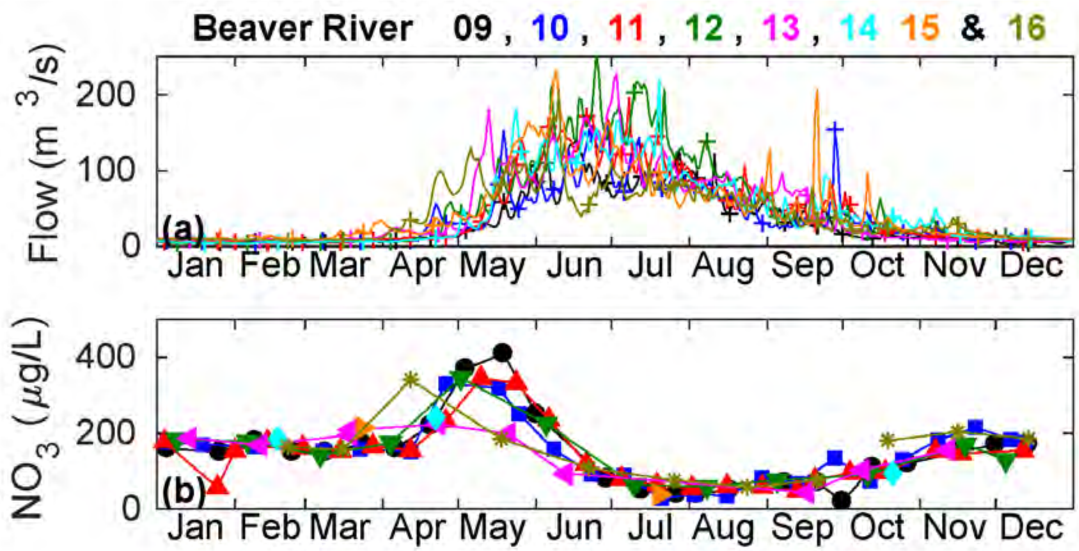

Figure 9. (a) Flow and (b) nitrate concentrations for Beaver River, 2009-2016. Note the increase in nitrate at the start of freshet, followed by lower values in summer.

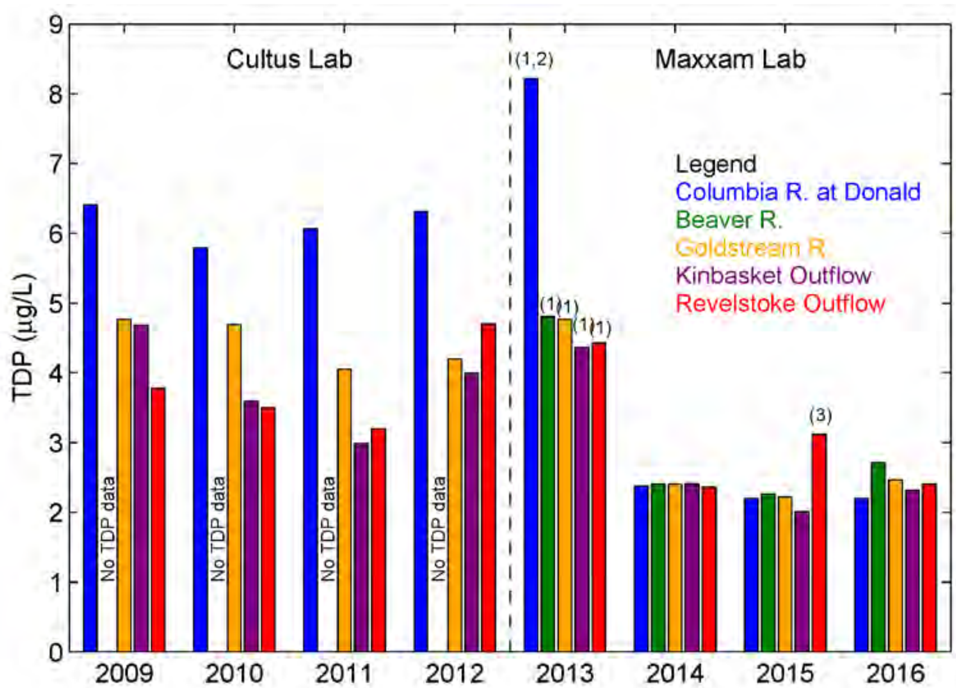

Figure 10. Estimated volume weighted concentration of TDP from reference tributaries, for April to October, 2009-2016. The dash line marks the change in laboratory at the start of 2013. Note (1): all samples of 6-7 August 2013 had high TDP of 7.5-15.3 μg/L, and this was the primary reason the 2013 means were higher than in 2014-2016. Note (2): the additional height of the mean for the Columbia at Donald resulted from a single value of 46 μg/L on 10 September 2013. Note (3): high average resulted from a single value of 29.3 μg/L on 8 April 2015.

The flow weighted average concentration of nitrate (NO_3) is shown for the reference tributaries in Figure 11. The nitrate data are consistent between the laboratories and there are no significant trends across time. Of the natural flow, the average nitrate concentration in the Columbia River at Donald is lowest and that in the Goldstream River is highest. Sampling of the reference tributaries will be continued to assess long term trends.

The N:P ratio for the reference tributaries remains well above 10 (by weight), suggesting phosphorus limitation. The exception is the Columbia River at Donald, where the N:P ratio can occasionally be less than 10 in the summer.

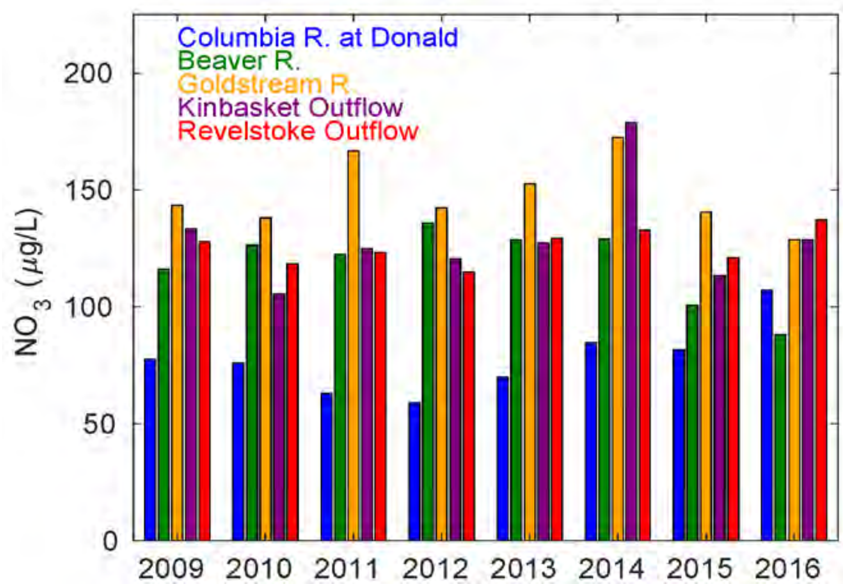

Figure 11. Estimated volume weighted concentration of NO_3 from reference tributaries, 2009-2016.

3.3 Reservoir Light and Temperature

The depth of the 1% light level defines the photic zone; the monthly averages are shown in Figure 12 for Kinbasket and Revelstoke Reservoirs. In spring the photic zone was over 20 m in depth, becoming shallower in June with an average depth of 16 m in Kinbasket and 12 m in Revelstoke, and then gradually increasing in depth again through summer and fall. These deep photic zone depths are consistent with oligotrophic conditions in both reservoirs.

The multi-year average of the photic zone depth was consistently 4 m deeper in Kinbasket Reservoir than in Revelstoke Reservoir in all months. In each reservoir the Forebay station had the deepest mean monthly photic zone; the Forebay stations receive the least amount of glacial input and have had greater time for particles to settle. In contrast, the photic zone depths are shallower at stations highly influenced by turbid tributaries, such as Wood Arm in Kinbasket Reservoir and the Middle station near

Downie Arm in Revelstoke Reservoir (Figure 1). The photic zone depth can be slightly shallower in September or October in years with high precipitation events (Figure 12).

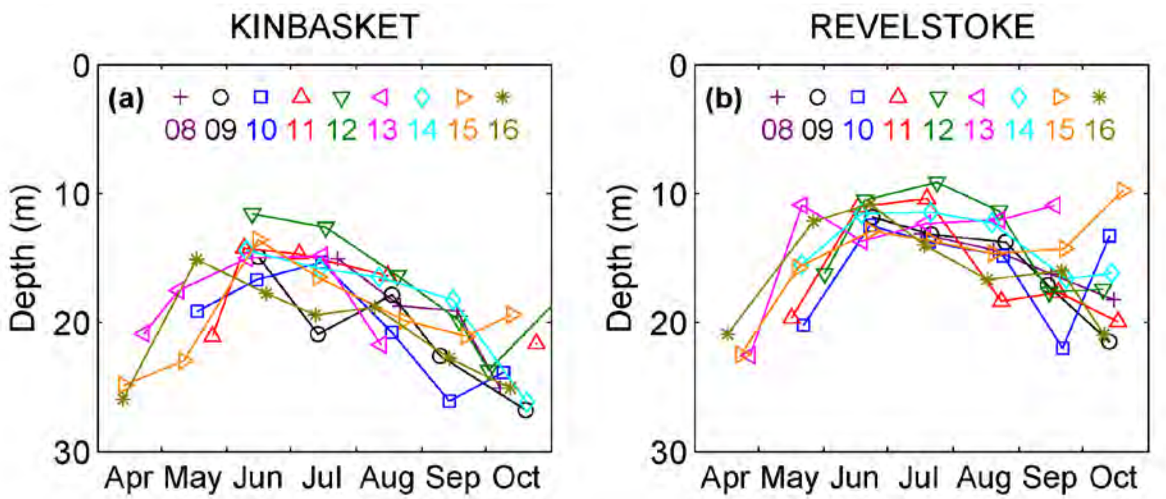

Figure 12. Depth of the 1% light level, 2008-2016, (a) averaged over the 5 main stations in Kinbasket Reservoir, and (b) averaged over the 3 main stations in Revelstoke Reservoir.

An example of temperature and conductivity gradients along Kinbasket Reservoir is shown for 15-16 September 2008 in Figure 13. The reservoir was thermally stratified with warmer water near the surface capping cooler denser water at depth. At this time the temperature stratification was relatively uniform across the reservoir (Figure 13a). However, the conductivity provides a tracer which shows lower conductivity inflow in Canoe Reach in contrast with the higher conductivity inflow to the Columbia Reach (Figure 13b).

An example of the temperature and conductivity along Revelstoke Reservoir is given for 8-9 September 2008 in Figure 14. The temperature shows three layers, a warmer surface layer, a layer of intermediate temperature (10°C) from 15 to 60 m, and a cold (5 °C) deep layer below 60 m (Figure 14a). The conductivity was lower in the top 60 m as a result of fresh tributary inflow during snowmelt and higher below 60 m, indicating water remaining from winter (Figure 14b). However, at the time of these observations there was high inflow from Kinbasket Reservoir; this inflow was cool and has a conductivity intermediate to that in Revelstoke. This Kinbasket water formed an interflow (110-120 µS/cm, yellow to orange) in Revelstoke Reservoir, centered on the outlet depth at 28 m. In effect, at the time of the profiler survey the inflow from Kinbasket Reservoir short circuited below the photic zone to the Revelstoke outlet. This would suggest that the nutrients in the flow from Kinbasket were not available for biological production; however, data described below suggests that some of this water can occasionally be moved into the photic zone by internal waves.

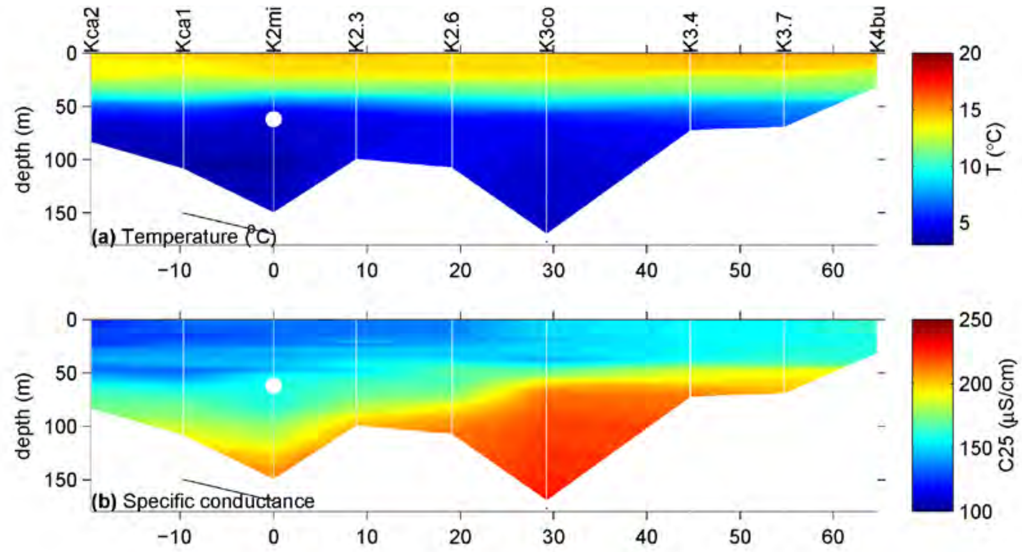

Figure 13. (a) Temperature and (b) conductivity in Kinbasket Reservoir, 15-17 September 2008. The outlet is marked at 62 m with a circle. White lines mark the location of the CTD casts. The contour is taken along the length of Canoe and Columbia Reaches, where Kca1 is the Canoe sampling station, K2mi is in the main pool, K3co is the Columbia sampling station in Old Kinbasket Lake, and k4bu is in Bush Pool (Figure 1, see Pieters and Lawrence 2018c for detail).

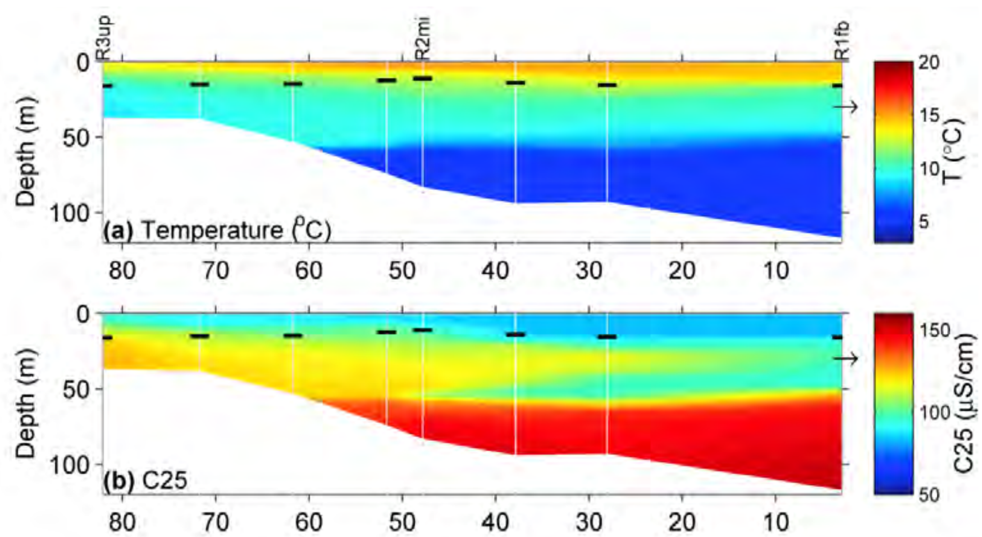

Figure 14. (a) Temperature and (b) conductivity (C25) in Revelstoke Reservoir, 8-9 September 2008. The inflow from Kinbasket Reservoir, which has slightly elevated conductivity, forms an interflow between 15 and 60 m depth which exits through the outlet marked by an arrow at 28 m on the right. White lines mark the location of the CTD casts. Black bars mark the depth of the photic zone.

Thermal stratification of the reservoir has important biological consequences. Stratification provides both increased temperature as well as a stable near surface layer in which phytoplankton can grow, in marked contrast to fall and spring turnover when the water is cold and phytoplankton are mixed throughout the water column, with the result that they spend much of their time in the dark. Thermal stratification also plays an important role in zooplankton and kokanee feeding and predator/prey interactions.

Temperature data from the moorings in the Revelstoke forebay are shown in Figure 15. Each year the reservoir stratifies in spring, with warmer surface water over cooler water at depth. The maximum stratification occurs in July and August and as the reservoir cools in fall the surface layer mixes deeper. Because of the large volume of water in the reservoir, fall turnover (complete mixing) does not occur until December. The entire reservoir continues to cool through January and early February often cooling below the temperature of maximum density, T_{MD}. Water that is colder than T_{MD} is less dense and can form what is known as 'reverse' stratification which is particularly noticeable in January to March 2017 (Figure 15). In March and April the reservoir begins to warm and summer stratification begins soon after the reservoir warms above $T_{MD.}$

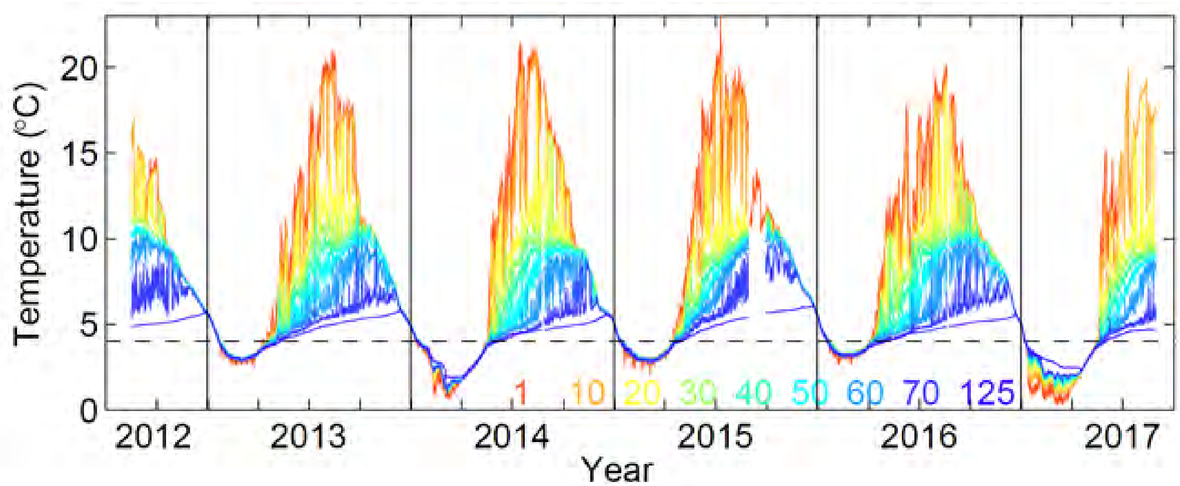

Figure 15. Temperature at selected depths at Revelstoke Forebay, 2012-2017. The dash line marks 4 °C, the temperature of maximum density. Depth is indicated by colour gradient.

Observed are both milder winters, when the reservoir did not cool much below T_{MD} (e.g. 2015-2016), and colder winters, when the surface cooled toward 0 °C and reverse stratification formed (e.g. 2016-2017, Figure 15). The result of a colder winter is to significantly delay the onset of summer stratification. For example, following a mild winter, stratification began on 13 April 2016, while after a cold winter stratification began over a month later on 18 May 2014 (Table 6). Delayed onset of stratification resulted in colder mean spring temperature (Apr-Jun, Table 6). This will likely delay the onset of phytoplankton and zooplankton production. Zooplankton requires both adequate phytoplankton forage and warmer water temperature for growth to reach gestation.

In contrast to average spring temperature (Apr-Jun) which showed significant variation between years, the average summer (Jul-Aug) and fall (Sep-Oct) temperature was relatively uniform between years (Table 6). The temperature in Kinbasket Reservoir followed a similar pattern to that in Revelstoke Reservoir.

Table 6. Onset of stratification and seasonally average water temperature (0-40 m), Revelstoke Forebay, 2012-2017.

Year	Onset of stratification	Apr-Jun	Jul-Aug	Sep-Oct
2012	-	-	-	10.8
2013	1 May	6.8	12.9	11.6
2014	18 May	4.8	12.6	11.0
2015	26 Apr	7.6	12.6	10.7
2016	13 Apr	7.5	12.5	11.1
2017*	19 May	5.2	-	-
Average	*3 May*	*6.4*	*12.7*	*11.1*
Deviation		*1.3*	*0.2*	*0.3*

* Data from early 2017 are shown here to illustrate the contrast between warm and cold winters.

An autonomous profiler also collected daily temperature and salinity profiles at the Revelstoke Forebay (Figure 16). As described earlier, upstream Kinbasket Reservoir provided little inflow from May to July, while local tributaries provided high inflow of low salinity snowmelt (Figure 2d). From these data we can see clearly how from May to July this low salinity input gave rise to a fresh surface layer that deepened over time to 60 m as shown for Revelstoke Forebay in Figure 16b. The upper part of this fresh layer stratified thermally, giving rise to a shallow epilimnion (Figure 16a).

After July, outflow of colder and more saline water from Kinbasket Reservoir increased. As has been discussed, the Kinbasket inflow forms an interflow from the upper end of Revelstoke Reservoir to the outlet at Revelstoke Dam. The interflow can be seen in the autonomous profiler data from Revelstoke Forebay in early August (higher salinity water [red] from 20 to 40 m depth, Figure 16b). The profiler data indicate there are significant internal motions on the interface between the interflow and the surface layer within a period of a week to ten days. From late-August to mid-October, these motions brought water from the interflow into the photic zone for significant periods of time. This suggests that some of the nutrients in the interflow may be available for photosynthesis in the photic zone. The potential contribution to aquatic productivity is being assessed for the final synthesis report.

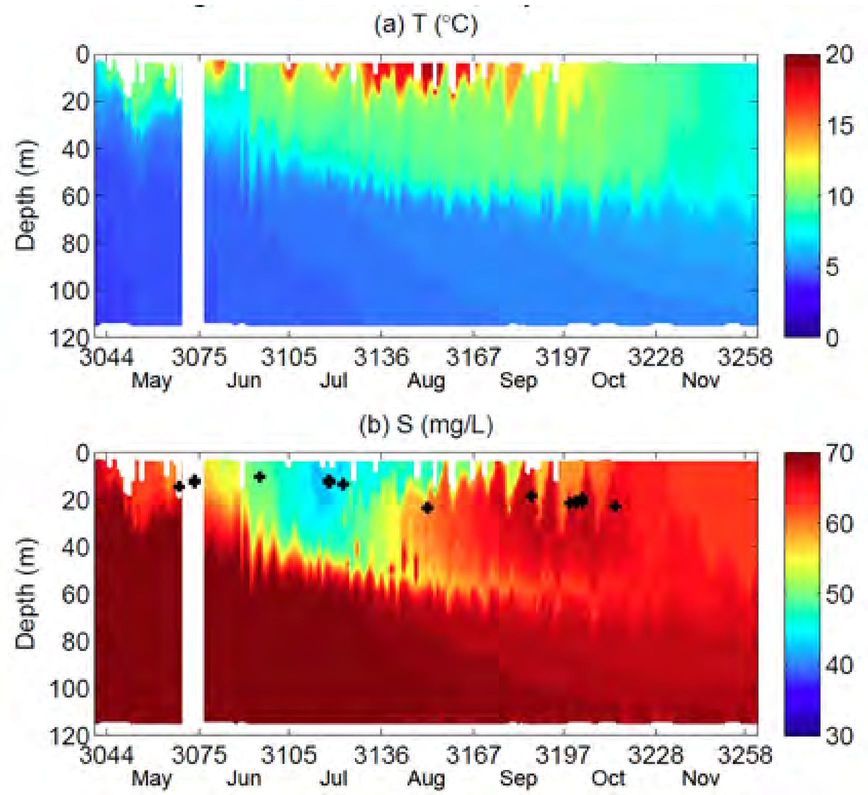

Figure 16. Contours of (a) temperature and (b) salinity from daily profiles collected using an autonomous profiler at Revelstoke Forebay, May to November 2016. (b) The '+' marks the 1% light level determined from Seabird profiles.

3.4 Reservoir Water Chemistry

Mean annual values for reservoir water chemistry are summarised in Table 7. Both reservoirs are considered ultra-oligotrophic with severe nutrient limitation according to Wetzel's (2001) classification of epilimnetic phosphorus levels.

Mean dissolved inorganic nitrogen (DIN), composed primary of nitrate (NO_3), is slightly lower in Kinbasket (108 µg/L) than Revelstoke Reservoir (124 µg/L). Where stations are more influenced by tributary inflows, nitrate concentrations have a more pronounced peak in May and June (e.g. KIN Columbia Reach and REV Middle). Total phosphorus (TP, $\bar{x} \cong 2.6$ µg/L) can be variable given the glacial inputs to the both reservoirs and is, however, generally low in reservoir samples.

Total dissolved phosphorus (TDP) is most often at or below the detection limit of 2 µg/L. Lab results can be highly variable, often with TDP values in excess of TP, due to a combination of extremely low levels of phosphorus that can easily be compromised by contamination, aliquot variability, or lab error.

Soluble reactive phosphorus (SRP) values are low with a mean of 1.3 and 1.4 µg/L in Kinbasket and Revelstoke, respectively, and normally close to detection (1 µg/L) (Figure 17). The laboratory change in 2013 resulted in marked changes for phosphorus fractions, and efforts are underway to resolve this issue. TP/TDP values shown from 2008-2012 may be higher than actual and should be interpreted with caution. Nitrate results, however, are considered to be comparable between labs. There is no significant long-term change in nitrate values in either reservoir, nor in phosphorus fractions by laboratory.

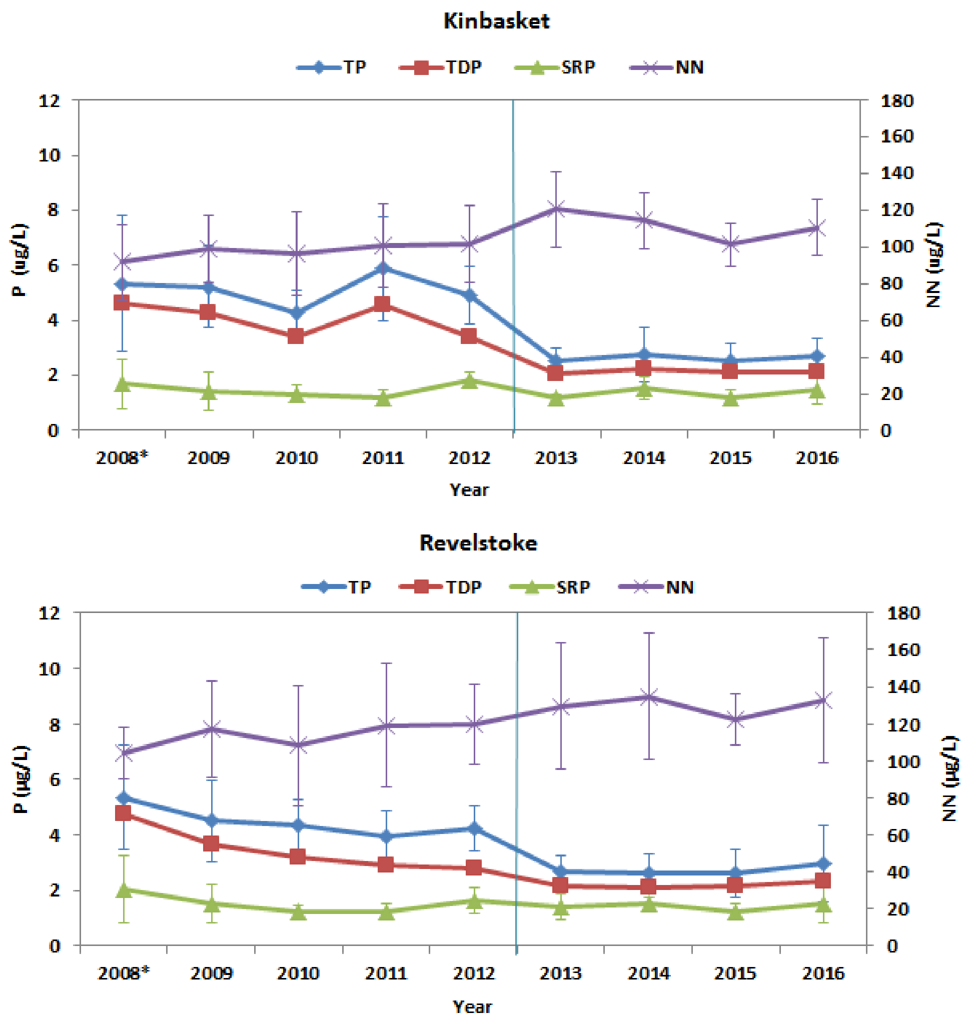

Figure 17. Average annual NN, TP, TDP, and SRP in Kinbasket and Revelstoke Reservoirs, 2008-2016. Error bars for are ±1 standard deviation and are not included for TDP (to keep the graph readable). Vertical blue line indicates when laboratory change occurred starting 2013. *Note that the 2008 average is based on a partial year.

Both Kinbasket and Revelstoke Reservoirs are slightly alkaline. Silica, an important element for diatoms, was consistently above the level considered limiting for growth, 0.5 mg/L (Table 7). Turbidity is normally higher in Revelstoke Reservoir than in Kinbasket, especially at Revelstoke Middle station which is influenced by Downie Creek and other large glacial tributary inputs (e.g. Goldstream River). The exception, however, is Wood Arm in Kinbasket Reservoir which can have very high turbidity depending on time of year. The highly turbid glacial input of the Wood River at first mixes through the embayment and then plunges as surface water warms and is then observed only in deep samples.

Table 7. Summary of reservoir chemistry and lower trophic level parameters, 2008-2016.

Station/ Parameter	Units	KIN Forebay	KIN Canoe	KIN Wood	KIN Columbia	REV Forebay	REV Middle	REV Upper	KIN Mean	REV Mean
NO_2+NO_3 (NN)	µg/L	106	109	106	110	123	123	128	108	124
TP*	µg/L	2.4	2.8	2.8	2.7	2.5	3.2	2.4	2.6	2.7
TDP*	µg/L	2.1	2.2	2.1	2.2	2.2	2.3	2.1	2.1	2.2
SRP*	µg/L	1.3	1.4	1.4	1.5	1.4	1.4	1.5	1.4	1.4
Conductivity	µS/cm	140	133	135	163	111	108	105	143	108
Alkalinity	mg $CaCO_3$/L	66	63	65	79	52	52	49	68	51
Silica	mg/L	1.3	1.3	1.3	1.3	1.5	1.5	1.6	1.3	1.5
Turbidity	NTU	0.39	0.51	1.23	0.70	0.57	0.98	1.04	0.68	0.84
pH		8.0	7.9	8.0	8.1	7.8	7.8	7.8	8.0	7.8
Secchi Depth	m	7.6	6.4	6.5	6.0	6.9	6.0	4.7	6.6	5.9
Primary Production	mg C/m^2/ day	93.4	-	-	-	79.1	58.8	-	93.4	70.0
Phytoplankton	0-10m									
Density	#/L	1612	1539	1568	1448	1763	1455	1182	1542	1472
Biovolume	µg/L	0.16	0.15	0.17	0.16	0.13	0.13	0.12	0.16	0.13
Zooplankton	0-30m									
Density	#/L	11.06	9.52	9.37	8.93	5.68	7.17	3.28	9.43	5.73
Biomass	µg/L	32.92	30.30	29.14	28.08	22.49	31.82	11.53	29.39	23.68
***Daphnia* spp.**										
Density	#/L	0.98	0.92	0.81	0.86	0.50	0.79	0.37	0.87	0.55
Biomass	µg/L	14.37	15.53	14.24	13.58	11.68	16.38	7.27	14.15	11.78

N.B. Mean values are based on available months, stations, and depths sampled. Not all months and stations were sampled each year.
*Detection limits and results for phosphorus fractions can differ substantially between laboratories. Mean value shown is all data combined for SRP, mean is shown for 2013-2016 for TDP and TP. See text for more detail.

3.5 Primary Production

The optical properties of lakes and reservoirs are important regulatory parameters in the physiology and behavior of aquatic organisms (Wetzel 2001). Solar radiation is important in driving productivity of aquatic ecosystems. Photosynthetically active radiation (PAR), defined as radiation in the 400-700 nm waveband, varied from year to year and site to site throughout the study period (N.B. only Jun to Sep months and three sites for primary production measures). Values rarely exceeded 1000 $\mu mol/m^2/s$ with the highest readings reaching 1615 $\mu mol/m^2/s$ in July 2015 at the Kinbasket station, 1776 $\mu mol/m^2/s$ in June 2016 at Revelstoke Middle, and 1356 $\mu mol\ m^2/s$ in June 2015 at Revelstoke Forebay (Appendix 7.10). The photic zone was typically between 0 and 20 m and on occasion the 1% light level dropped below 20 m (cf. Figure 12). These maximum 1% light depths were typically reached at the end of the season in September. Annual average photic zone depth measured during primary production sampling from 2009-2016 was 18.5 m at Kinbasket, 15.7 m at Revelstoke Forebay, and 12.8 m at Revelstoke Middle.

The attenuation coefficient is a measure of water transparency and depends largely on the concentration and composition of suspended and dissolved matter. A high attenuation coefficient is indicative of low transparency caused by high concentration of colloidal matter and a low attenuation coefficient indicates high transparency caused by low turbidity. In Kinbasket and Revelstoke, the attenuation coefficient has shown consistent seasonal variation during the whole study period (2002 to 2016). Early in the growing season the attenuation coefficient is consistently high, between 0.3-0.4 cm^{-1} (or 60-70% transmission m^{-1}) whereas as the growing season progresses, the attenuation coefficient decreased to between 0.2-0.3 cm^{-1} (or 70-80% transmission m^{-1} (Figure 18). On average water transparency has been higher in Kinbasket followed by Revelstoke Forebay while transparency has generally been the lowest at Revelstoke Middle. In 2010, the same general optical trend was observed but the attenuation coefficients measured in July and August 2010 were slightly higher in Kinbasket than in Revelstoke Forebay. On average between 2002 to 2016, the attenuation coefficient in Kinbasket was 0.28 cm^{-1} (72% transmission m^{-1}) and at Revelstoke Forebay and Revelstoke Middle, 0.32 cm^{-1} (68% transmission m^{-1}) and 0.37 cm^{-1} (63% transmission m^{-1}) respectively.

Secchi depths varied seasonally as expected for a temperate reservoir with shallower Secchi depths recorded in June and the deepest depths recorded in September for Kinbasket and Revelstoke Middle with a few exceptions (Figure 19). Secchi depth for Revelstoke Forebay was more variable and changed year to year (Figure 19). On average, the Secchi depth was deeper for Kinbasket than both Revelstoke sites (Revelstoke Middle and Revelstoke Forebay); average Secchi depths were 6.8 m, 5.6 m, and 6.6 m in Kinbasket, Revelstoke Middle, and Revelstoke Forebay, respectively. Some exceptions to this general pattern were noted, for example mean Secchi depths were shallowest in 2011 in Kinbasket and in 2012 in Revelstoke Middle relative to the other study years indicating reduced water transparency either due to high algal biomass or particulate matter in the reservoir.

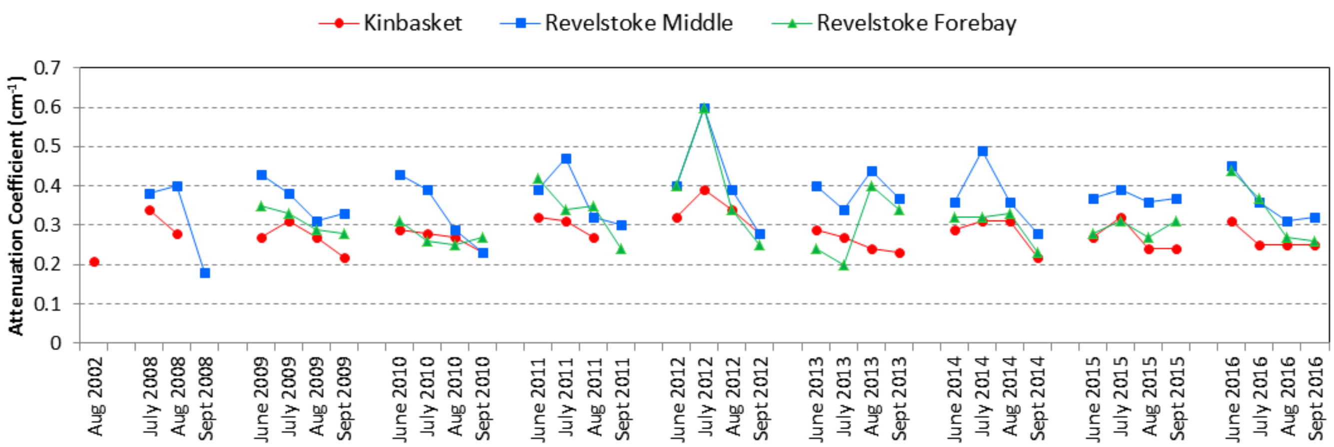

Figure 18. Attenuation coefficients (cm^{-1}) in Kinbasket, Revelstoke Middle and Revelstoke Forebay from 2002-2016. Attenuation coefficients were calculated from Secchi disk depths in 2002 and 2008 and from the vertical profiles of photosynthetically available radiation in 2009-2016.

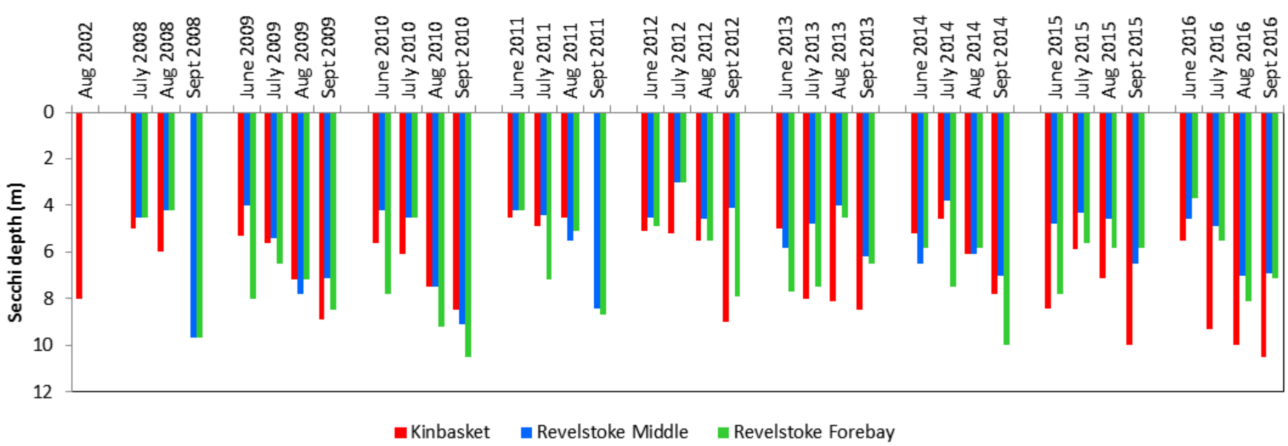

Figure 19. Monthly Secchi depth from 2002, 2008-2016 at the Kinbasket, Revelstoke Middle, and Revelstoke Forebay.

3.5.1 Chlorophyll

Chlorophyll *a* (Chl *a*) is a photosynthetic pigment found in all autotrophic phytoplankton. It is frequently measured as an indicator of phytoplankton biomass and when size fractionated can provide insights on the size structure of the phytoplankton community. The three commonly studied fractions include: picoplankton (0.2-2 µm), nanoplankton (2.0-20 µm) and microplankton (>20 µm). The size structure of the phytoplankton community plays an important role in the structure and efficiency of the food web, and in functional relationships in the ecosystem. The size structure can also provide some insight into the nutrient dynamics of aquatic ecosystems. Small cells often dominate in oligotrophic waters as their large surface area to volume ratio supports efficient uptake of nutrients. On the other hand, large cells often dominate in nutrient rich eutrophic conditions due to the uptake kinetics and the large storage vacuoles of microplankton.

Chlorophyll *a* concentrations in Kinbasket and Revelstoke Reservoirs have been remarkably stable and low over the study period (2009-2016; note no chlorophyll samples were collected in 2002 or 2008) with discrete concentrations ranging from less than 1 µg/L to slightly higher than 2 µg/L (Figure 20). Generally, the lowest concentrations were measured at Revelstoke Middle. Chlorophyll concentrations rarely approach 3.0 µg/L with the exception of in 2011 and 2013 (Kinbasket in August only). In 2011, there appears to have been a small bloom in spring at all sites. On average, 2009-2016 chlorophyll concentrations were higher in Kinbasket at 1.43 µg/L compared to 1.01 µg/L at Revelstoke Middle and Revelstoke Forebay, but all measurements are indicative of oligotrophic conditions (Wetzel 2001).

Depth integrated chlorophyll biomass has been consistently low, rarely exceeding 20 mg Chl *a*/m^2 in Revelstoke Reservoir and rarely exceeding 30 mg Chl *a*/m^2 in Kinbasket (Figure 21). For Revelstoke Forebay, seasonal variability was high from 2009 to 2012, then from 2013-2016 the biomass became more stable and there was very little seasonal or inter-annual variability (Figure 21). During all study years the annual average chlorophyll *a* biomass was highest at Kinbasket, generally greater than 20 mg/m^2 in all years, whereas at Revelstoke Middle and Revelstoke Forebay the biomass was typically between 10-20 mg/m^2 (Figure 22). No apparent trend was noted for Revelstoke Reservoir, in some years Revelstoke Forebay biomass was higher and in other years Revelstoke Middle biomass was higher (Figure 22). The 2009-2016 depth integrated averages were 25.1, 14.5, and 15.8 mg/m^2 for Kinbasket, Revelstoke Middle, and Revelstoke Forebay, respectively.

On average, the size distribution of the chlorophyll biomass has also been remarkably stable over the study period (2009-2016) where picoplankton (0.2-2.0 µm) and nanoplankton (2.0-20.0 µm) have accounted for 87% of the total biomass, while microplankton (cells >20 µm in size), have accounted for just 13% of the total biomass (Figure 23). In all years (2009-2016), the phytoplankton community in both Kinbasket and Revelstoke (Middle and Forebay) were dominated by picoplankton (average of 42%, 48% and 48%, respectively) followed by nanoplankton (average of 44%, 41%, and 39%, respectively) and then by microplankton (average of 14%, 11%, and 13%, respectively). This size distribution of the phytoplankton assemblage is typically seen in oligotrophic lakes and reservoirs where assemblages of small algae are common (Wetzel 2001).

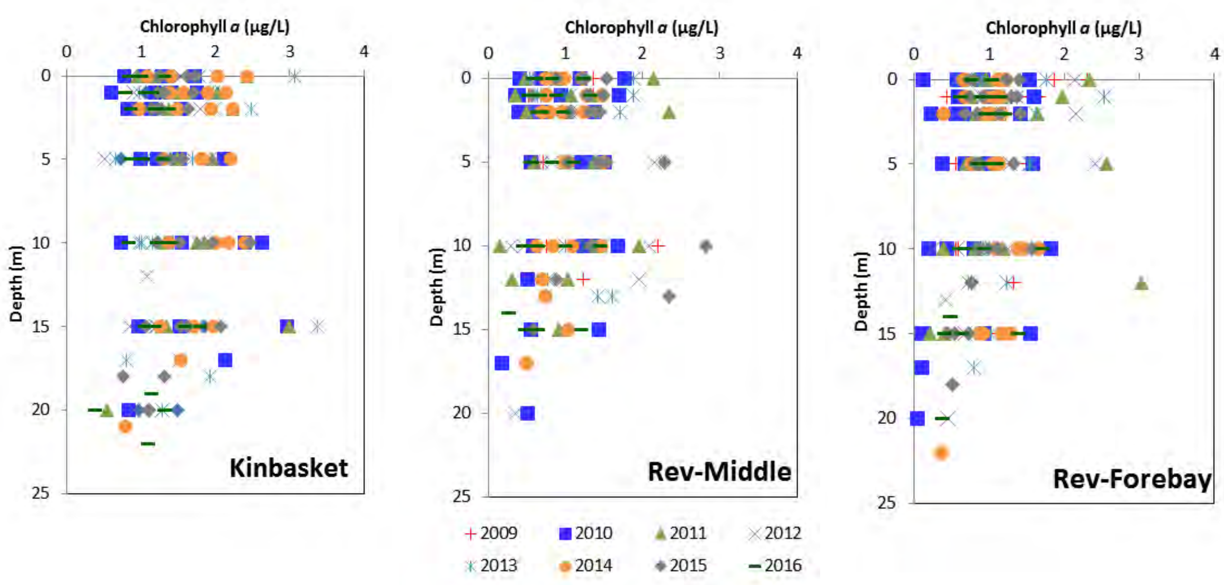

Figure 20. Vertical profiles of chlorophyll *a* (µg/L) for 0.2 µm filter in Kinbasket, Revelstoke Middle, and Revelstoke Forebay in 2009-2016. Data are not available for 2002 and 2008.

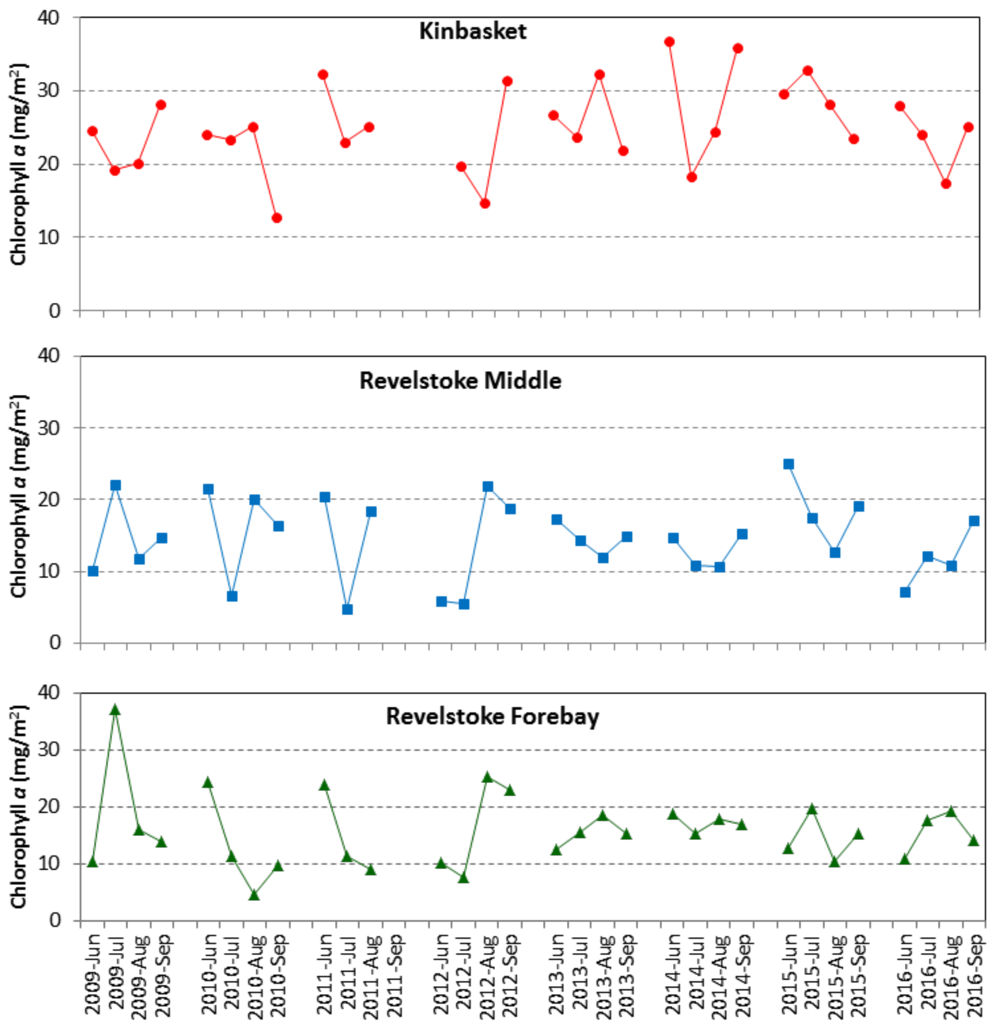

Figure 21. Monthly depth integrated (1-100% surface PAR) chlorophyll (mg Chl *a*/m^2) biomass in Kinbasket, Revelstoke Middle, and Revelstoke Forebay in 2009-2016. Data were not collected in 2002 and 2008.

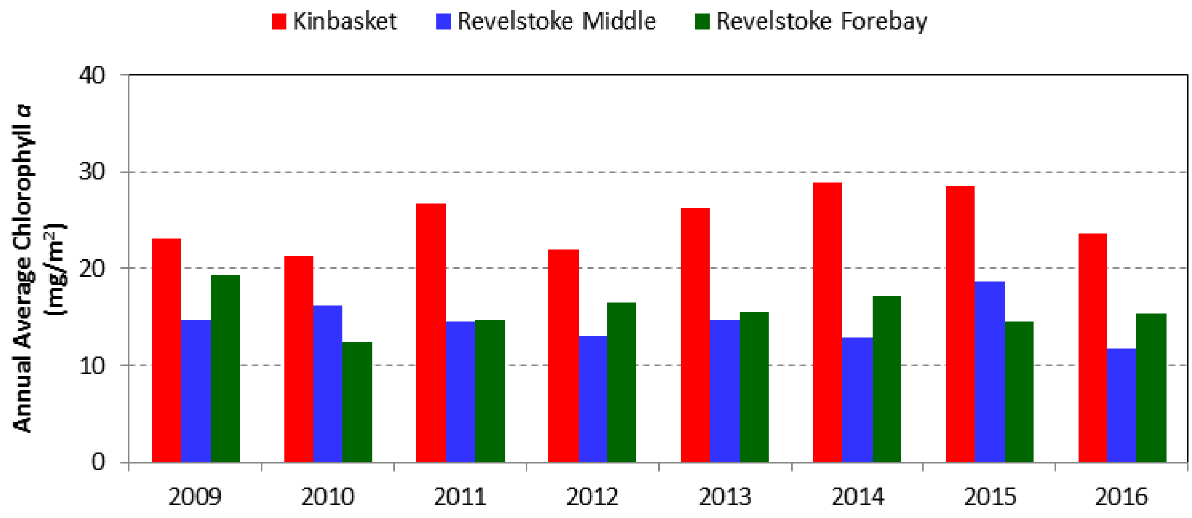

Figure 22. Annual average depth integrated chlorophyll *a* (mg/m^2) in Kinbasket, Revelstoke Middle, and Revelstoke Forebay in 2009-2016. Data were not collected in 2002 and 2008.

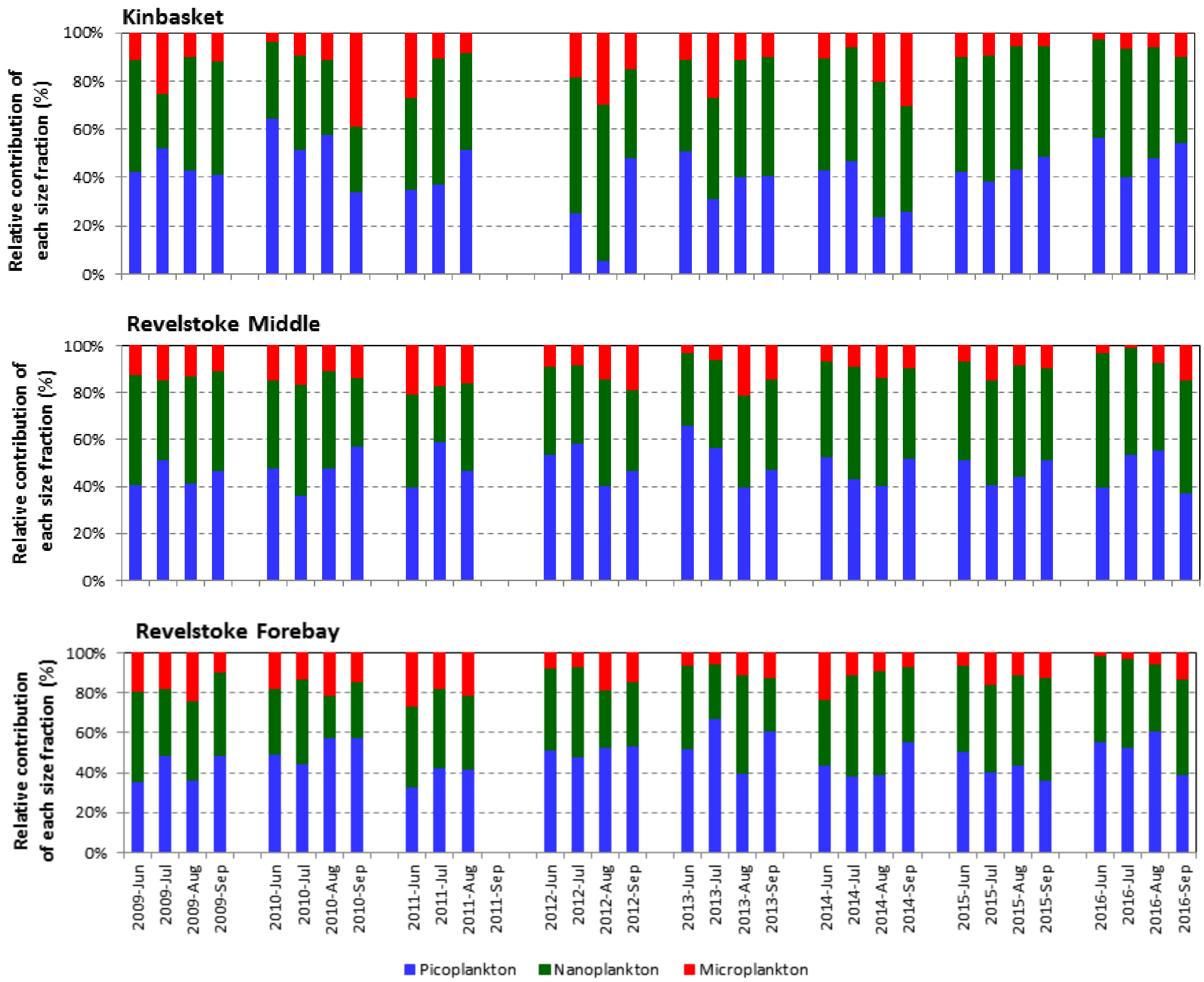

Figure 23. Monthly relative contribution of picoplankton (0.2-2 µm), nanoplankton (2.0-20 µm) and microplankton (>20 µm) to depth integrated chlorophyll in Kinbasket, Revelstoke Middle, and Revelstoke Forebay in 2009-2016.

3.5.2 Primary productivity

In Kinbasket Reservoir, monthly primary productivity rates were typically under 150 mg $C/m^2/d$, with some exceptions, particularly in June and July in 2015 where rates were approaching 200 mg $C/m^2/d$ (Figure 24). In Revelstoke Reservoir, monthly primary productivity rates were generally lower, usually under 100 mg $C/m^2/d$, with some exceptions measured in 2014 at both Revelstoke stations (Figure 24). The highest monthly rates were measured in Kinbasket Reservoir in September 2014 at 262.1 mg $C/m^2/d$ (this is excluding Revelstoke Forebay September 2015 as it was uncharacteristically high for this site at 361.7 mg $C/m^2/d$, calculations were checked but caution should be exercised), while the lowest primary productivity of 8.4 mg $C/m^2/d$ was measured in Revelstoke Middle in August 2008 (Figure 24). Primary productivity of phytoplankton in reservoirs can vary seasonally as shown in Kinbasket Reservoir while in Revelstoke Reservoir the productivity was less variable, especially for Revelstoke Middle. Seasonal average primary productivity was higher in Kinbasket (93.4 mg $C/m^2/d$) than in Revelstoke (69 mg $C/m^2/d$). The 2008-2016 annual primary productivity averages were 93.4, 58.8, and 79.1 mg $C/m^2/d$ for Kinbasket, Revelstoke Middle, and Revelstoke Forebay, respectively.

In general, from 2008 to 2016, primary productivity increased annually at Kinbasket and Revelstoke Forebay stations until 2016 when productivity decreased. A similar trend of increasing productivity was noted at Revelstoke Middle but the decline in productivity was first observed in 2015 (Figure 25). Primary productivity is often used for trophic classification determination based on the assumption that littoral and allochthonous sources are small relative to pelagic sources (Wetzel 2001). The low primary productivity rates measured in Kinbasket and Revelstoke Reservoirs are further indications of oligotrophic conditions.

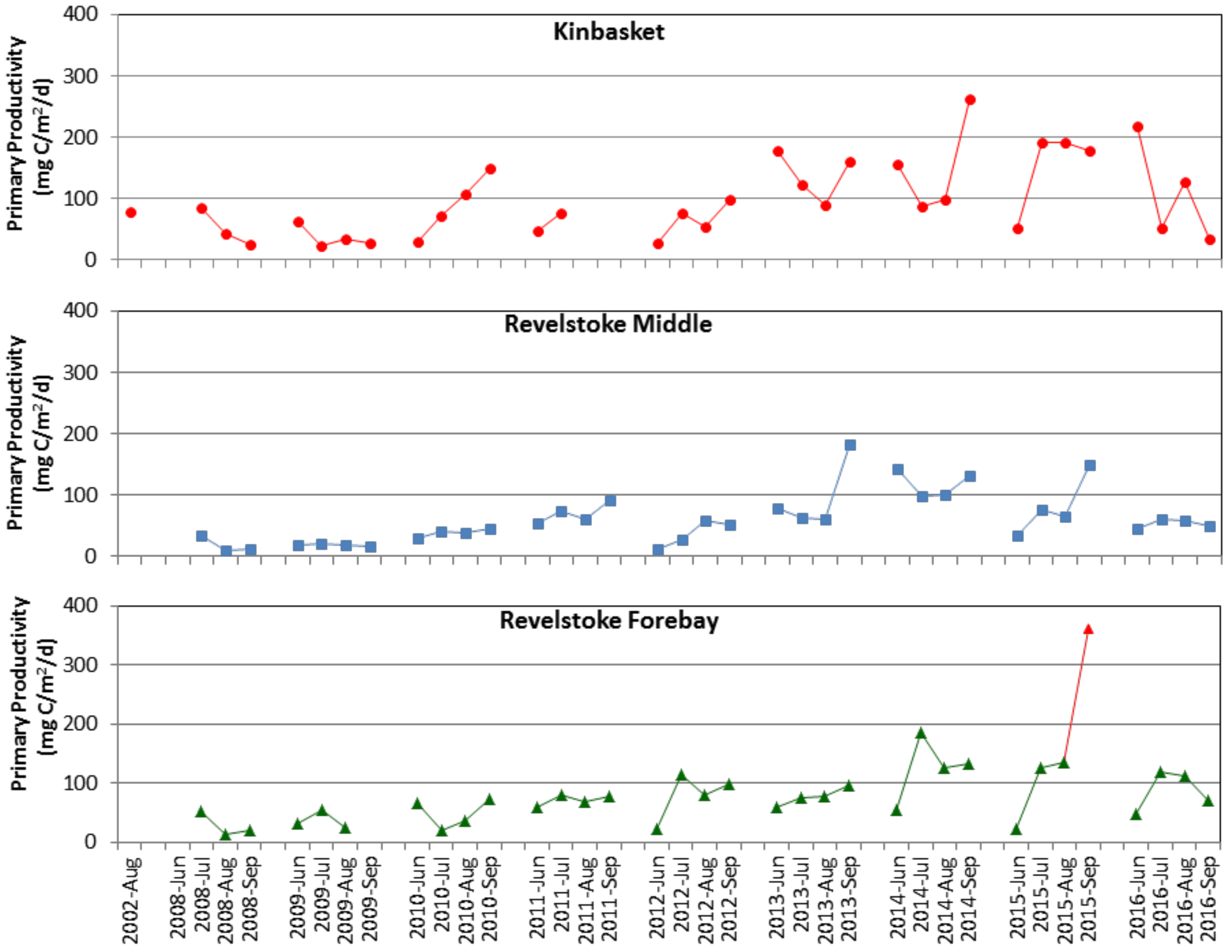

Figure 24. Monthly depth integrated (1-100% surface PAR) primary productivity (mg C/m^2/d) in Kinbasket and Revelstoke Middle and Revelstoke Forebay in 2002-2016. Note Revelstoke Forebay September 2015 is highlighted in red as uncharacteristically high and should be used cautiously.

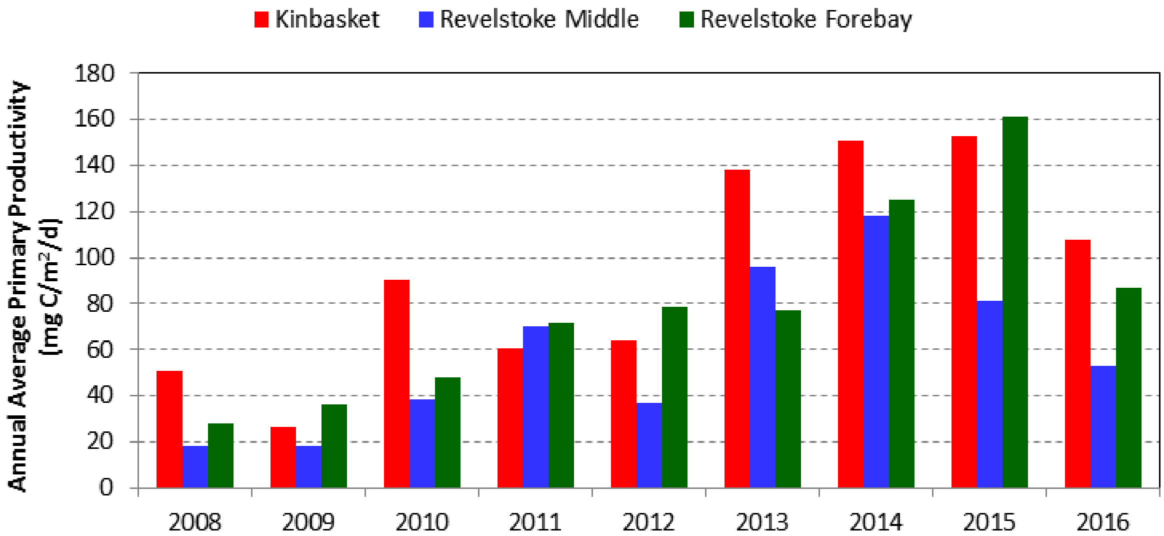

Figure 25. Annual average depth integrated primary productivity (mg C/m^2/d) in Kinbasket, Revelstoke Middle and Revelstoke Forebay in 2008-2016.

In all study years, picoplankton (0.2-2.0 µm) and nanoplankton (2.0-20.0 µm) productivity accounted for between 60-97% of productivity, while microplankton (2.0-20.0 µm) contributed the least (3-40%) (Figure 26). Size fractionation of primary productivity revealed some changes over the eight study years. The relative contribution of picoplankton and nanoplankton increased from 2009-2016 at all three stations while microplankton productivity decreased (Figure 26). In both Kinbasket and Revelstoke Reservoirs, total picoplankton and nanoplankton accounted for ~70% of the total productivity in 2009 and in 2016 picoplankton and nanoplankton productivity increased to ~90%. This shift in the size structure is due to changes in both picoplankton and nanoplankton production. Picoplankton accounted for <20% of total production at the start of the study period, but their relative contribution increased annually from 2009 to a high of 46% in 2012 and has remained at ~40% since 2013 (Figure 26). Nanoplankton, the phytoplankton fraction preferred by herbivorous zooplankton, accounted for greater than 50% of the production in both Kinbasket and Revelstoke at the start of the study period, but from 2009-2012 nanoplankton production declined and, on average, now accounts for 42% and 40% of the production in Kinbasket and Revelstoke, respectively. Microplankton have generally been the least productive fraction accounting for less than 30% of the total production with a few notable exceptions in earlier years (Figure 26). Food chains dominated by picoplankton tend to be less efficient at transferring carbon up the food chain to higher trophic levels and the decrease in nanoplankton productivity and increase in picoplankton productivity may suggest impacts to upper trophic level productivity.

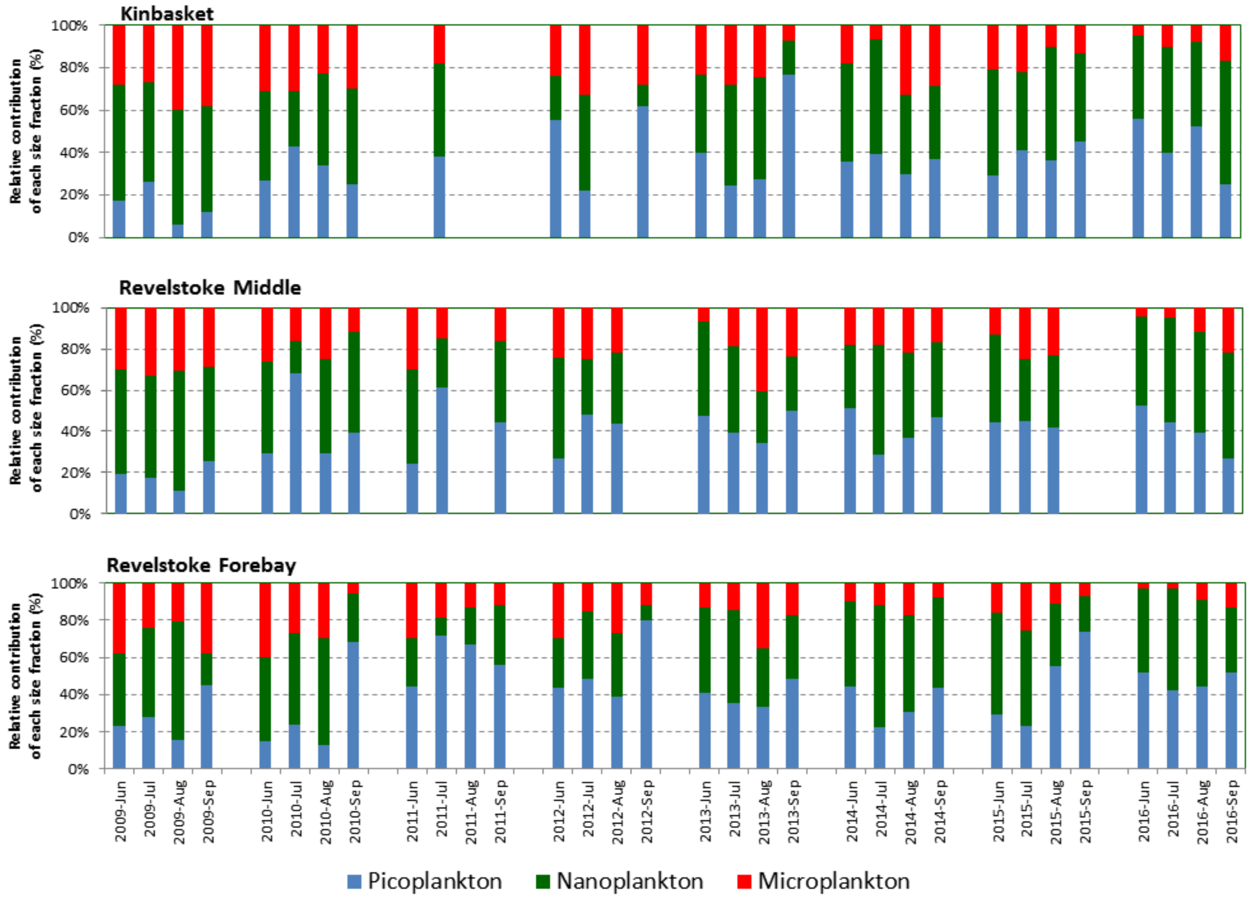

Figure 26. Monthly relative contribution of picoplankton (0.2-2 µm), nanoplankton (2.0-20 µm), and microplankton (>20 µm) to primary productivity in Kinbasket, Revelstoke Middle and Revelstoke Forebay in 2009-2016. Fractionation was not undertaken in 2002 or 2008.

3.6 Phytoplankton

3.6.1. Taxa Composition

From 2008 to 2016, 168 unique phytoplankton taxa were identified in Kinbasket Reservoir and 164 taxa were identified in Revelstoke Reservoir. The majority of these taxa are grouped into the major taxonomic groups of greens and flagellates, with the remaining taxa consisting of diatoms, blue-greens and dinoflagellates. The most common taxa was *Synechococcus* sp. Over 30 taxa were observed only once in the nine years and 1,969 distinct phytoplankton samples.

3.6.2 Density and Biomass

From 2008-2016, seasonal average epilimnetic (0-10 m) phytoplankton density was 1,542 cells/mL in Kinbasket Reservoir and 1,472 cells/mL in Revelstoke Reservoir (Table 7). Both reservoirs show a clear seasonal pattern of low densities in the spring and late fall with higher densities in the late spring and summer (Figure 27 and Figure 28). A statistical analysis indicated that average density and biomass was significantly different between months (Kruskal-Wallis Test) in Kinbasket ($p<0.001$) and marginally significant in Revelstoke ($p=0.054$). In both reservoirs phytoplankton density and biovolume was significantly different in May when compared to the other months. September and October were also found to be significantly different from the June through August samples.

Phytoplankton data collected prior to this study (2003-2005 in Kinbasket and 2003 in Revelstoke) had similar collection and analysis methodology; however, these data were not included in the statistical analysis due to the lack of monthly data for those years. However, for both Kinbasket and Revelstoke, the average annual cell densities and biovolumes for those pre-study years were greater than the majority of the study years (Figure 29).

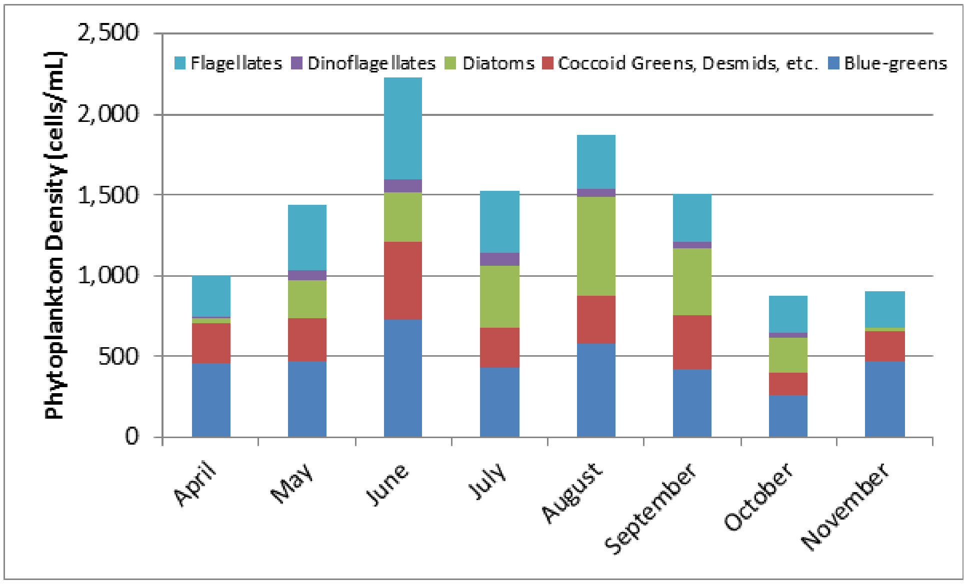

Figure 27. Monthly average phytoplankton density for Kinbasket over the study period, 2008-2016.

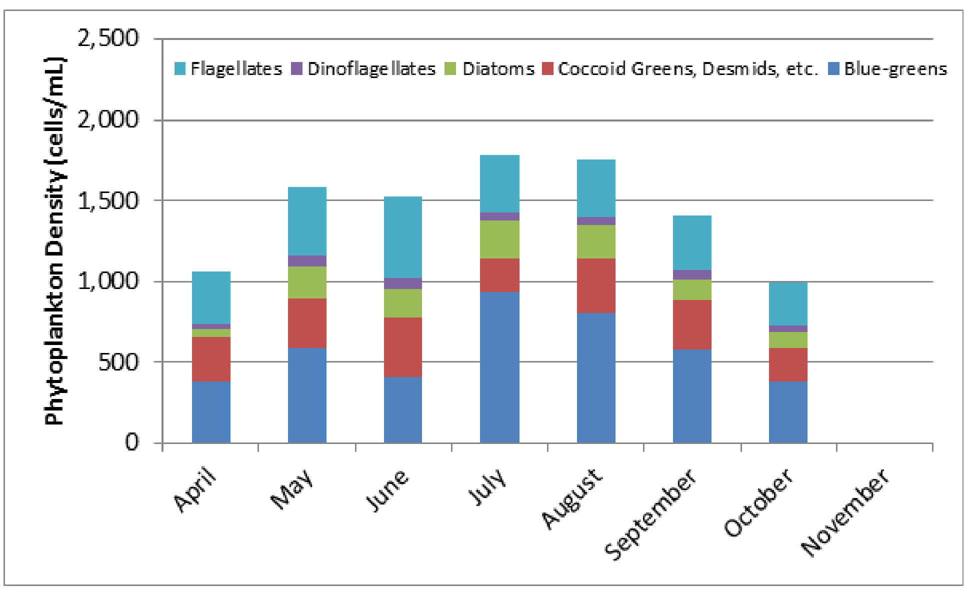

Figure 28. Monthly average phytoplankton density for Revelstoke over the study period, 2008-2016.

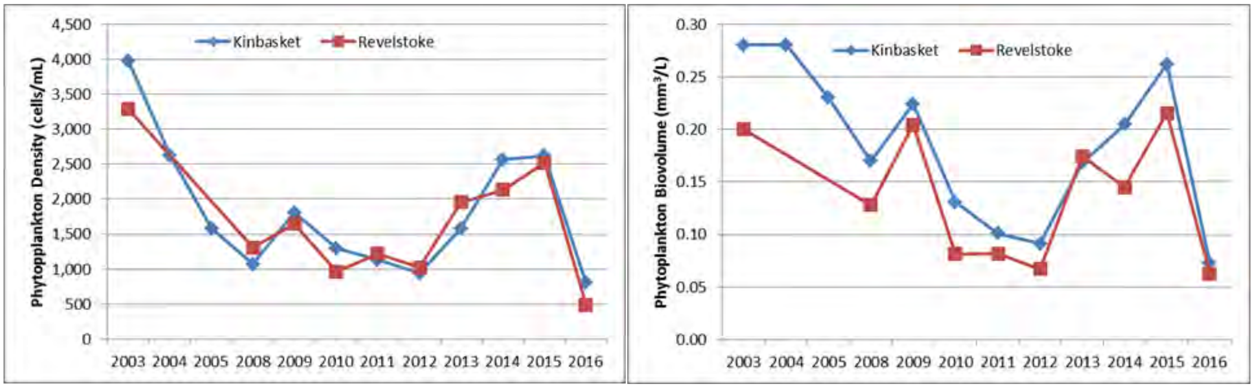

Figure 29. Yearly average total phytoplankton density (left) and biovolume (right) in Kinbasket Reservoir and Revelstoke Reservoir, 2003-2005, 2008-2016.

Yearly average phytoplankton density and biovolume varied considerably between years (Figure 29). There was a significant difference in density and biovolume between years in both Kinbasket and Revelstoke Reservoirs (Kruskal-Wallis Test, $p<0.001$). In Kinbasket, the average phytoplankton density falls into three groups that are not significantly different from the others within the group, but are significantly different from those outside the group. The statistical grouping results are: (1) 2008, 2011, 2012; (2) 2009 and 2010; and (3) 2013 to 2016. Membership to a particular group does not mean they are similar, just not significantly different. One of the driving factors in determining group membership is monthly variability. The annual mean between years may be quite different but they can be in the same statistical group due to greater similarity in the variation pattern. In Revelstoke Reservoir, phytoplankton density and biovolume from 2008 was significantly different from all other years except for 2012 and 2014. The other years in the study were not significantly different from any other year. We will be examining these groupings and additional analyses in the context of all datasets in the final study years.

Kinbasket and Revelstoke phytoplankton density and biovolume are tightly correlated when we look at yearly average values (Figure 30 and Figure 31). This could indicate that they are either responding to similar environmental and trophic level interactions, or that the phytoplankton community in Revelstoke is dependent upon the water it receives from Kinbasket Reservoir.

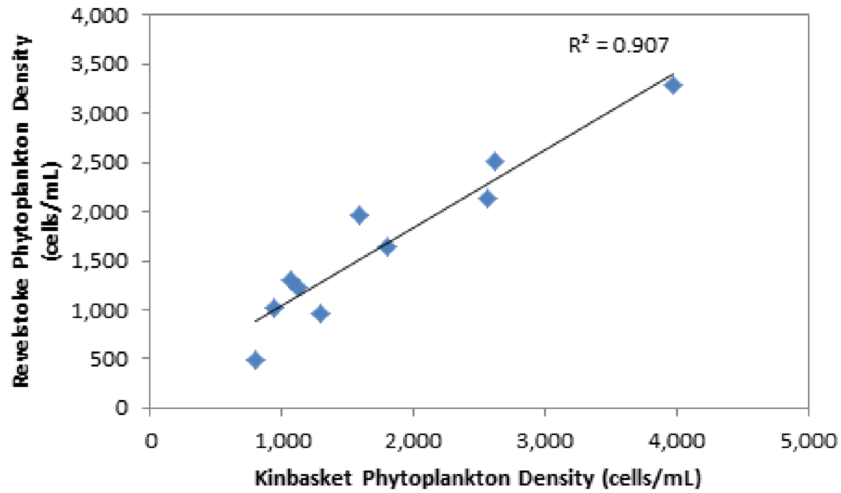

Figure 30. Correlation between Kinbasket and Revelstoke Reservoir yearly average phytoplankton density for 2003, 2008-2016.

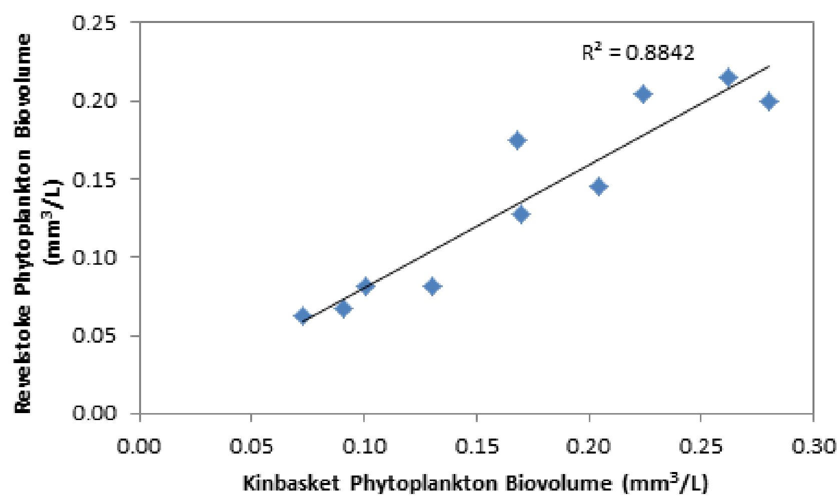

Figure 31. Correlation between Kinbasket and Revelstoke Reservoir yearly average phytoplankton biovolume for 2003, 2008-2016.

The phytoplankton community variation was not consistent between locations within the reservoirs over the course of the study. In Kinbasket Reservoir, the Canoe and Columbia sampling locations had greater between year variability than the Forebay and Wood locations (Figure 32). In Revelstoke Reservoir, the Upper station had considerably lower inter-annual variability than the Middle or Forebay stations (Figure 33).

Another noticeable change during the study has been the community composition by year. The increase in total phytoplankton density observed in 2012-2015 can be accounted for by an increase in two major taxonomic groups (blue-greens and greens) in both reservoirs. An examination of changes in biotic and abiotic conditions is underway to ascertain the cause of the density increase in these two groups.

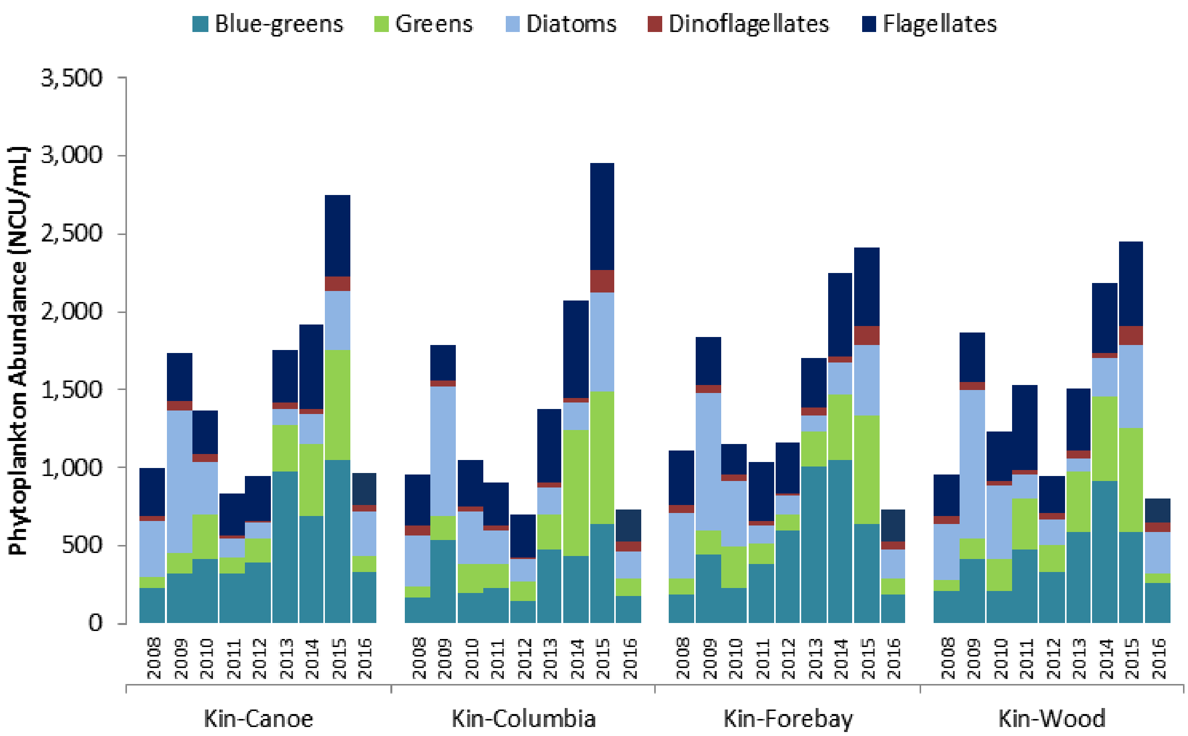

Figure 32. Seasonal average phytoplankton density by group and station in Kinbasket Reservoir over the study period, 2008-2016.

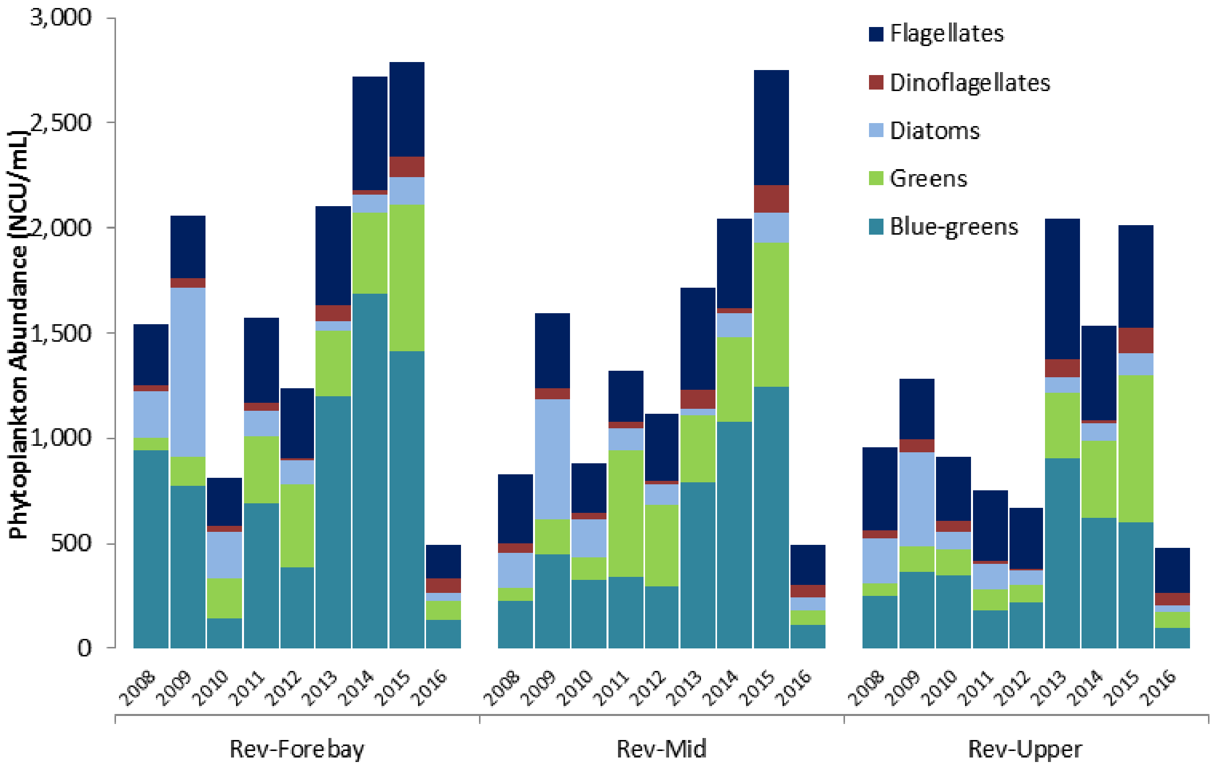

Figure 33. Seasonal average phytoplankton density by group and station in Revelstoke Reservoir over the study period, 2008-2016.

3.7 Zooplankton

3.7.1. Species Composition

From 2008 to 2016, eleven species of Cladocera were present in Kinbasket Reservoir and fifteen species in Revelstoke Reservoir. Of these, six cladocerans were found in each reservoir every year, four of which were common to both reservoirs: *Daphnia galeata mendotae* (Birge), *Daphnia rosea* (Sars), *Bosmina longirostris* (O.F.M.), and *Leptodora kindtii* (Focke). In Kinbasket Reservoir, *Daphnia schoedleri* (Sars) and *Scapholeberis rammneri* (O.F.M.) were also found in each year while in Revelstoke Reservoir *Daphnia pulex* (Leydig) and *Holopedium gibberum* (Zaddach) were common to each year. Other species were observed sporadically. *Daphnia schoedleri* occurred only in Kinbasket and *Daphnia pulex* occurred only in Revelstoke*,* while *H. gibberum*, common in Revelstoke Reservoir, was detected only sporadically in Kinbasket Reservoir. *Daphnia* were not identified to species for density counts.

Two calanoid copepod species common to both reservoirs were present in samples throughout the sampling period: *Leptodiaptomus sicilis* (Forbes) and *Epischura nevadensis* (Lillj.) while *Leptodiaptomus ashlandi* (Marsh) was infrequent and *Aglaodiaptomus leptopus* (Forbes) identified only rarely in Kinbasket Reservoir. The cyclopoid copepod, *Diacyclops bicuspidatus thomasi* (Forbes), was commonly found in both reservoirs throughout the study period.

In both reservoirs, density was dominated by copepods throughout the season, tending to peak in in July. Early season biomass was also dominated by copepods until about July/August when the larger bodied cladocerans, especially *Daphnia*, became dominant (Figure 34).

While Kinbasket Reservoir had greater total zooplankton density and biomass, the proportion of seasonal zooplankton composition is usually similar between reservoirs. Copepods made up 57-89% of the total zooplankton density in Kinbasket Reservoir and 66-80% in Revelstoke Reservoir, while *Daphnia* contributed 1-24% in Kinbasket and 4-15% in Revelstoke Reservoir (Figure 34). Even though monthly densities of *Daphnia* and other cladocerans were similar between reservoirs, the proportion of biomass contributed by cladocerans tended to be higher in Revelstoke Reservoir, particularly early in the season: 40% at the lowest compared to a low of 20% in Kinbasket Reservoir. There was a larger proportion of other cladocerans, such as *Bosmina longirostris* (O.F.M.), and *Leptodora kindtii* (Focke), from April to July in Revelstoke Reservoir compared to Kinbasket. By August and through to October, *Daphnia* contributed up to 70-80% of the biomass in both reservoirs (Figure 34). The presence of the large-bodied *Daphnia pulex* (Leydig) in Revelstoke likely contributes to overall biomass being higher relative to density when compared with Kinbasket.

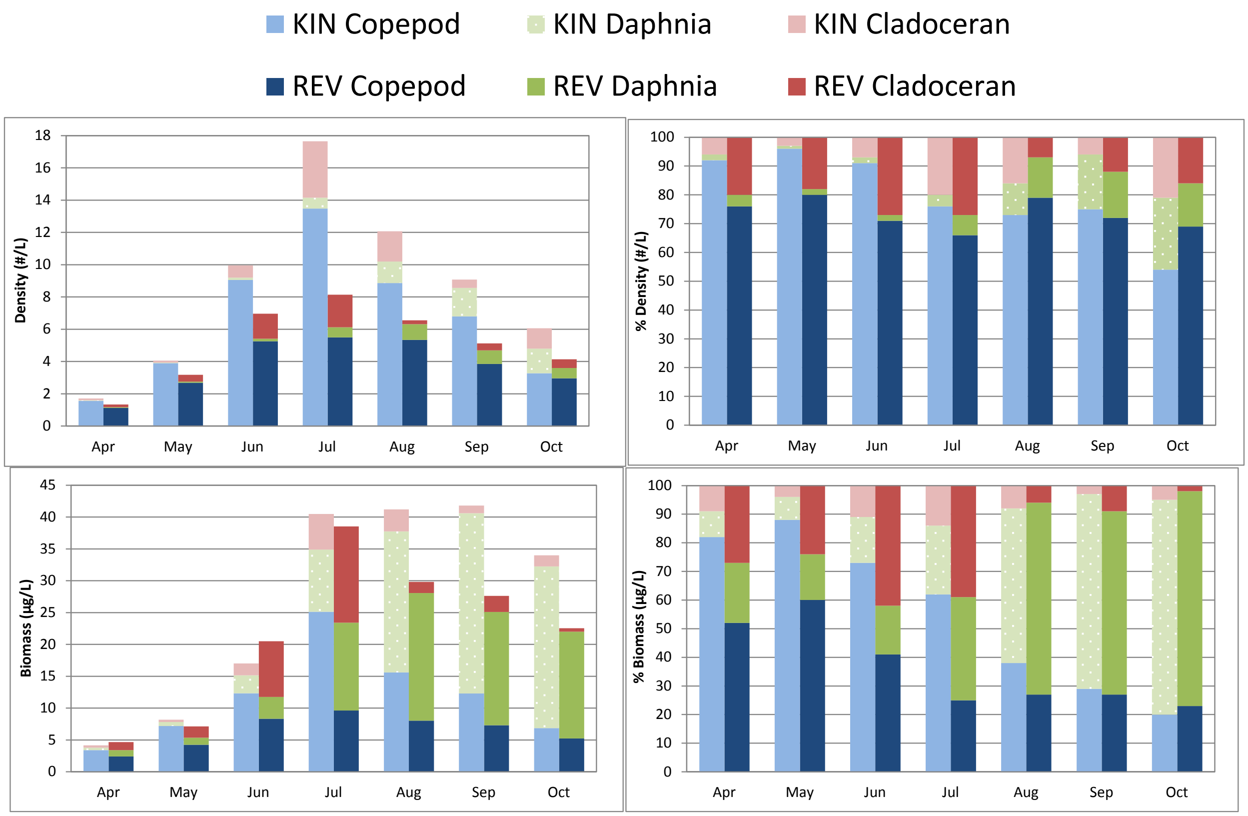

Figure 34. Monthly average zooplankton density and biomass (left) and monthly zooplankton density and biomass percent frequency composition (right) over the study period, 2008-2016. Kinbasket Reservoir data are left side bars and Revelstoke Reservoir data are right side bars.

3.5.2 Density and Biomass

Seasonal average May to October zooplankton density over the study period was 9.43 ind/L in Kinbasket Reservoir and 5.73 ind/L in Revelstoke Reservoir, and seasonal average zooplankton biomass was 29.39 µg/L and 23.68 µg/L, respectively (Table 7). Including the 2003-05 data has the effect of elevating the long-term averages slightly (Figure 35).

As April sampling was introduced in 2013, those monthly data are not included in the long-term average. Since 2011, and with the exception of 2013, average seasonal densities have been below the long-term average. The same general trend occurs for biomass although biomass increased in 2016 above the mean, particularly in Revelstoke (Figure 35). Trends in zooplankton density and biomass as well as implications for upper and lower trophic levels will be explored in future years.

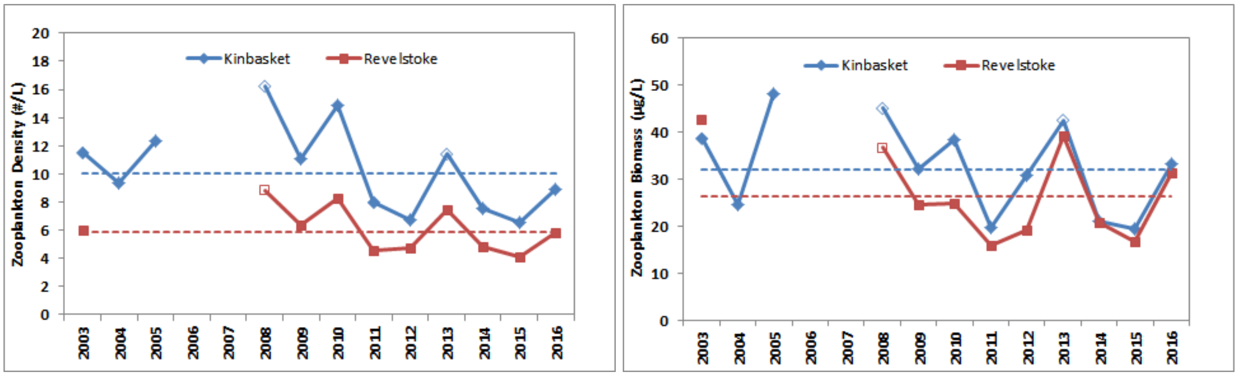

Figure 35. Long term seasonal average (May-Oct) total zooplankton density (left) and biomass (right). Dashed lines are mean values over years sampled. Open points indicate two months are missing from the data set which results in a higher value than would occur with full data.

Density and biomass of zooplankton can be quite variable across reservoir stations and seasons. Zooplankton are not uniformly distributed but outliers between stations have only occasionally been seen in the data. Kinbasket stations are generally similar with Columbia Reach having the lowest average total zooplankton density and biomass and the Forebay station the highest (Table 7). In Revelstoke Reservoir, the Upper station has the lowest values of all likely owing to its shallow and riverine characteristics. The Middle station has, on average, higher density and biomass than the Forebay station, both for total zooplankton and *Daphnia* spp., with values approaching those in Kinbasket Reservoir (Table 7).

As a preferred food, the availability of *Daphnia* prey is important for kokanee growth and survival. Scheuerell et al. (2005) found that juvenile sockeye (*O. nerka)* in Lake Washington switched to exclusive consumption of *Daphnia* at a density of 0.4 ind/L, preying on copepods when *Daphnia* became scarce. In Kinbasket and Revelstoke Reservoirs, this threshold *Daphnia* density was first reached in July for four of the nine years, in August for four years, and in some years (e.g. 2008 Kinbasket, 2011 Revelstoke) not until September (Figure 36). Of note is the early presence of *Daphnia* (and other Cladocerans) in Revelstoke Reservoir in 2016 when early spring air temperatures were unusually warm (cf. Figure 8) and stratification was particularly early (Table 6). The same increase was not seen in Kinbasket zooplankton data although air temperatures did not reach the same spring highs in that area [based on air temperature data from the Water Survey of Canada gauging station “Kinbasket Lake Below Garrett Creek” (08NB017)].

Spring (Apr-Jun) and summer (Jul-Aug) zooplankton density and summer biomass are more strongly correlated between reservoirs, likely a result of copepod density and *Daphnia* biomass (Figure 37). As with phytoplankton, this could indicate a similarity of environmental conditions, but the different species composition of each reservoir could indicate that Kinbasket is not a significant contributor to the Revelstoke zooplankton community.

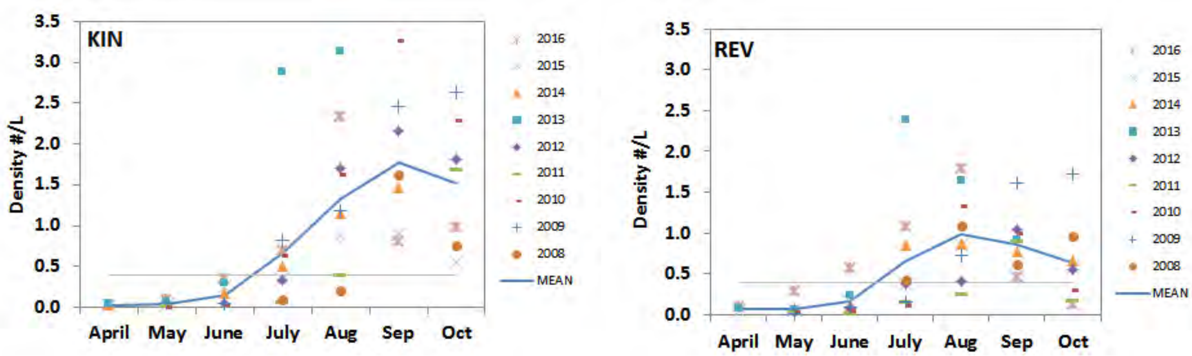

Figure 36. Seasonal *Daphnia* spp. density in Kinbasket and Revelstoke Reservoirs, 2008-2016. Grey line indicates 0.4 #/L.

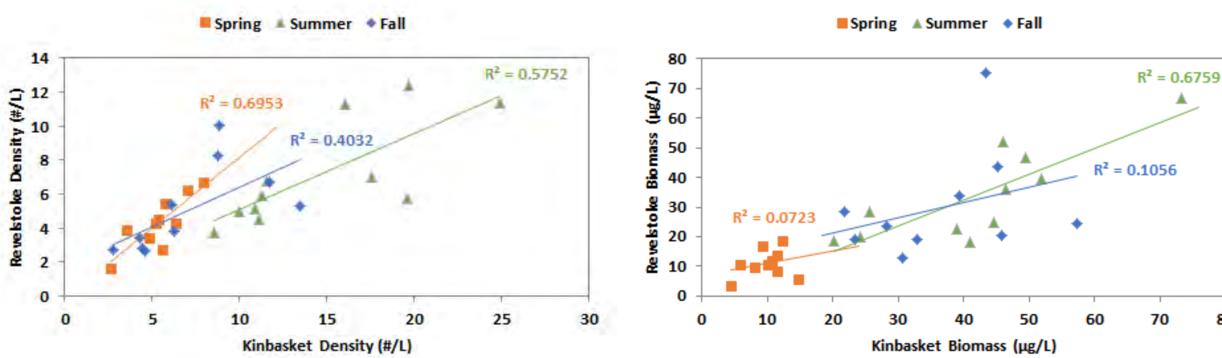

Figure 37. Correlations of seasonal total zooplankton density (#/L) and biomass (µg/L) between Kinbasket and Revelstoke Reservoirs, 2003, 2008-2016.

3.8 Kokanee

CLBMON-2 monitoring was designed to take advantage of seven years (2001-2007) of hydroacoustic and trawl survey data collected previously under BC Hydro's "Large Rivers Indexing Program". This WUP study continued the monitoring and our approach has been to use the entire dataset in this synthesis to establish "average conditions" for the various indicators of kokanee status. A range of ± one standard deviation of the mean was considered "normal" and values outside that range were considered either higher or lower than average and are of special interest in identifying and understanding the key factors affecting kokanee production. Where applicable, the kokanee population statistics for Kinbasket and Revelstoke have been compared to other large lakes and reservoirs with long term datasets.

3.8.1 Kokanee Habitat

Kokanee prefer pelagic or deep water habitat defined as areas at least 20 m deep (Pennak 1989). Pelagic habitat in Kinbasket Reservoir changed substantially with annual and seasonal changes in reservoir level. As the reservoir filled from June through late summer the main reservoir pelagic area increased by an average of 54 km^2 (30%) and a further 69 km^2 (39%) as additional low gradient areas at either end of the main reservoir became flooded to a depth of 20 m or greater. These additional habitats described as Upper Canoe and Upper Columbia (Bush Pool) Zones in Figure 1 and Table 3 have previously been considered marginal for kokanee production since they have to be re-colonized with age 1-3 kokanee every summer as they re-fill and their shallow depths may inhibit predator avoidance. The annual increase in total pelagic area ranged considerably from 89 km^2 in 2001 (57% increase from minimum to maximum) to 156 km^2 in 2002 (108% increase). From 2008-2016, average minimum reservoir level was 7 m higher and average maximum pool level was ~4 m higher than during the seven years prior to the study (2001-2007).

Reservoir elevations during summer hydroacoustic surveys were very similar to maximum level estimates for most years. Exceptions were in 2004, 2008, and 2010 when the reservoir continued to fill after summer sampling was completed. Estimates of pelagic habitat area available to kokanee at annual minimum and maximum pool elevations in Kinbasket Reservoir from 2000-2016 are presented in Appendix 7.6.

3.8.2 Acoustic Surveys

Longitudinal distribution of kokanee - As indicated in Section 2.4, Kinbasket Reservoir was divided into 9 habitat zones of which seven were sampled consistently across both phases of the study period. The Upper Columbia/Bush Pool zone was previously assumed to be marginal habitat based on a preliminary investigation (Sebastian et al. 2010), and therefore, was not included in standard acoustic surveys. In 2015, a second attempt was made to evaluate this habitat in conjunction with pelagic gillnetting, required to validate species composition for targets oriented near bottom in the relatively shallow habitat. Kokanee were observed using the Bush Pool habitat at densities similar to other zones in 2015. Sampling of Bush Pool was then added to the annual monitoring and was conducted again in 2016. Density distribution data for the Upper Columbia/Bush Pool are not presented here but can be found in the annual data reports (Sebastian and Weir 2016, 2017), and will be incorporated in future reporting. Based on limited shallow habitat, the Upper Canoe zone is unlikely to support significant numbers of kokanee and therefore has been omitted from surveys.

Density distributions for the nine study years (2008-2016) are compared with the 16 year average for the seven zones in Kinbasket Reservoir and three zones in Revelstoke Reservoir (Figure 38). In phase 1 (2008-2011), a relatively high abundance year for kokanee occurred in 2008, when fry densities were above one S.D. of the 16 year mean in four of seven zones (Figure 38a). The same year, age 1-3 densities were higher than average in two zones; Lower Canoe and the Main Pool (Figure 38b). A second noteworthy year was 2011, when fry densities were below 1 S.D. from average in three of seven zones of Kinbasket, and age 1-3 densities were below 1 S.D. in two of seven zones.

During phase 2 (2012-16), fry densities in Kinbasket (Figure 38a) were within 1 S.D. of the mean for most years and stations with several exceptions. The 2012 fry densities were above average in the Middle Canoe zone but below average in both Columbia Arm zones. Fry densities in 2013 were near average in all zones except the Middle Columbia where they were >2 S.D. above the zone mean. Fry densities in 2015 were also near average in six of seven zones, however the exception was Wood Arm where fry densities were very high at >2 S.D. above the mean. Fry densities in 2016 were near or lower than 1 S.D. below the mean in all stations with the exception of the Lower Columbia zone, and were the lowest observed in both study period phases in both Canoe zones and in Wood Arm. Comprehensive escapement counts would be required to fully understand this spatial variability; however, the difficulties around achieving this are acknowledged in Section 2.4.6.

Revelstoke fry densities (Figure 38a) were generally low across the five years of Phase 2, near or lower than 1 S.D. below the mean for all stations and years; with the exceptions of average densities in 2012 in the Middle zone, and higher than average densities in the Forebay zone in 2015. A steep density gradient is apparent in Revelstoke in 2015, with very low fry densities in the Middle zone that increased nearly 5-fold by the Lower zone and nearly 10-fold by the Forebay zone. A similar but less dramatic density gradient was also apparent in 2011.

Age 1-3 kokanee density distributions are illustrated for both Kinbasket and Revelstoke in Figure 38b. Kinbasket densities from 2012-16 were generally within 1 S.D. of the zone means with the exceptions of 2012 and 2016. Zone densities were below average at the Forebay, Wood Arm and Middle Columbia, in 2012, and all zones in 2016 were below average and were the lowest in the study period.

Revelstoke age 1-3 densities were low for all zones each year of Phase 2, near or lower than 1 S.D below the mean (Figure 38b). Age 1-3 kokanee remained below 15 fish/ha in all zones each year and reached as low as 2 fish/ha in the Forebay zone in 2013 and in the Middle zone in 2015.

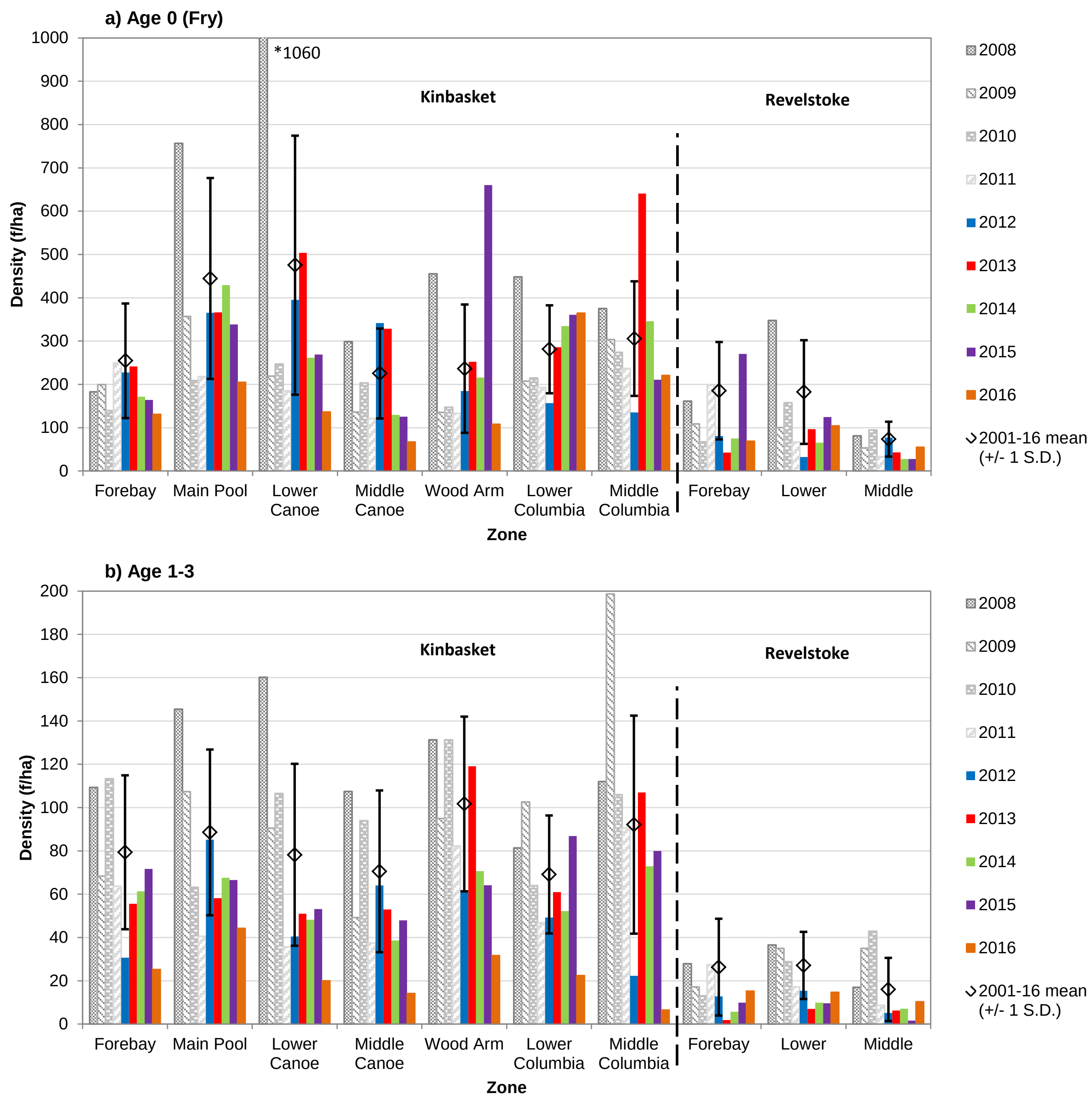

Figure 38. Longitudinal density distribution (fish/ha) of a) age 0 (fry) and b) age 1-3 kokanee in Kinbasket and Revelstoke Reservoir during 2008-2016 compared with the 16 year average. The error bars on the 16 year average represent ±1 standard deviation.

Trends in kokanee abundance - Kinbasket Reservoir fry abundance ranged from 3.2 to 15.1 million and averaged 6.6 million with 95% C.I. of 5.3 to 8.0 million on the 18 year average (Figure 39a). A significant difference between the individual years and the long-term average occurred in 6 of 18 years. Fry estimates were above average in 2007 and 2008 and below average in 1993, 1994, 2010, and 2011. The 2007 fry year was highly unusual with an abundance estimate of 15 million, 3 standard deviations above the long-term average. Fry abundance estimates over the 2008-2016 study were average in 6 of the 9 years, above average in 2008 and below average in 2010 and 2011.

The age 1-3 fish abundance ranged from 0.6 to 2.7 million and averaged 1.7 million with 95% C.I. of 1.5 to 2.0 million on the 18 year average (Figure 39b). Age 1-3 abundance was significantly higher than average in 2001, 2008 and 2009, and lower than average in 2011, 2012, 2014 and 2016. The highest abundance of age 1-3 fish occurred in 2008 following the highest fry abundance on record. The age 1-3 population declined after 2008 to well below average in 2011. Four of six years since 2011 were significantly below average, with only 2013 and 2015 near average. The most notable outlier was 2016 when abundance was estimated at only 0.6 million, approximately two standard deviations below the 18 year average. A large-scale kokanee die-off was reported in Kinbasket Reservoir in late May 2016 prior to the summer sampling, and is presumably linked to the dramatic decline in age 1-3 kokanee abundance that year (Sebastian and Weir 2017).

Revelstoke Reservoir fry abundance estimates ranged from 0.28 to 1.66 million and averaged 0.83 million with 95% C.I. of 0.62 to 1.04 million on the 18 year average (Figure 40a). Individual annual fry estimates were significantly above average in 2003 and 2008 and below average in 1993-94, 2012-2014, and 2016. Fry abundances during the 2008-2016 study were above average one year, average for four years, and below average for four of the last five consecutive years.

The age 1-3 kokanee abundance ranged from 0.04 to 0.36 million and averaged 0.17 million with 95% C.I. of 0.13 to 0.22 million on the 18 year average (Figure 40b). Age 1-3 abundance was significantly higher than average in 2003, 2005, and 2006, and lower than average in 2001 and 2012-2016. Similar to Kinbasket, age 1-3 kokanee numbers in Revelstoke have been generally suppressed since 2011.

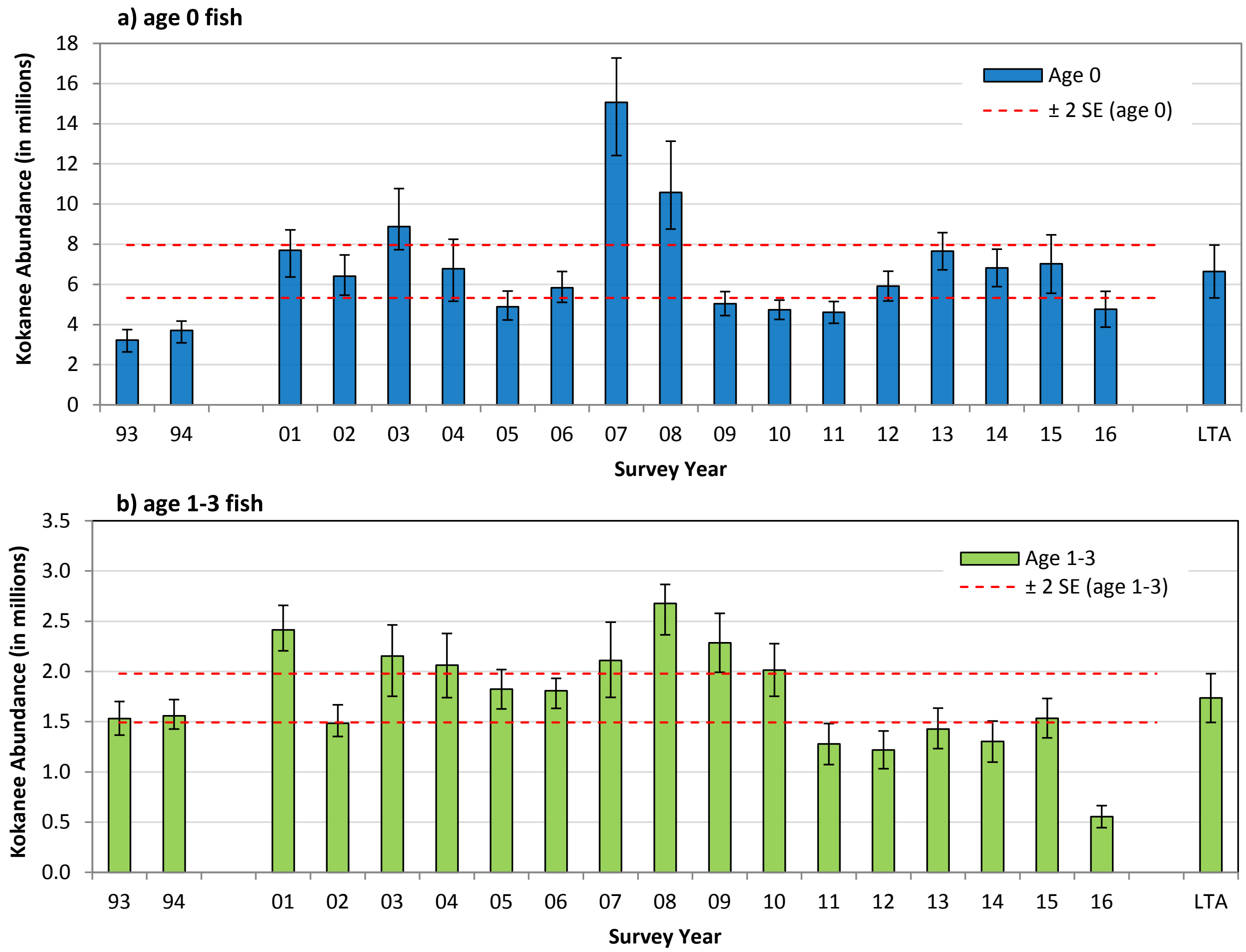

Figure 39. Trends in abundance for a) age 0 (fry) and b) age 1-3 kokanee in Kinbasket Reservoir based on summer time hydroacoustic surveys during 1993-94 and 2001-2016. Error bars denote 95% confidence limits on annual maximum likelihood estimates and red dotted lines indicate ± 2 standard errors of the long term (18 year) average.

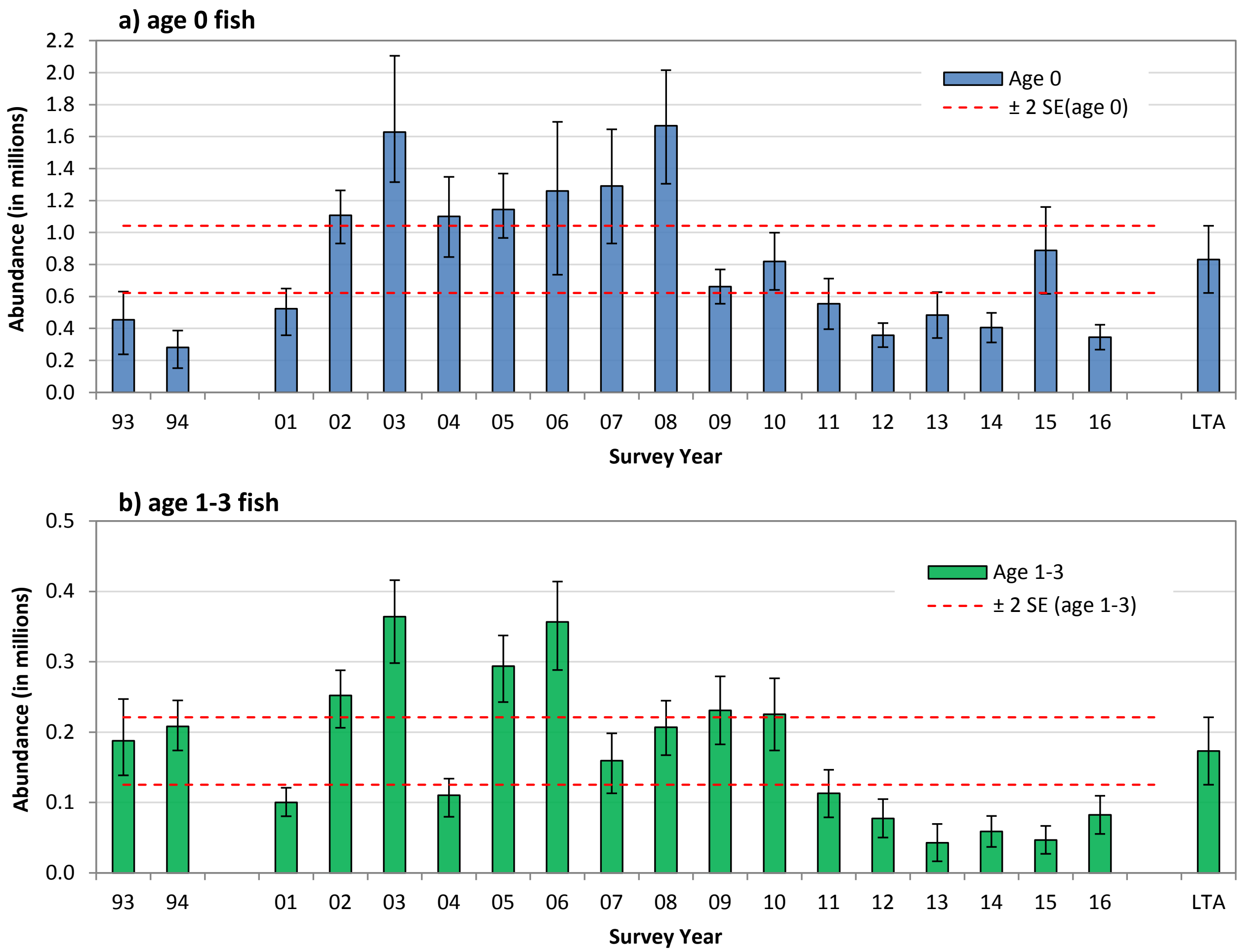

Figure 40. Trends in abundance for a) age 0 (fry) and b) age 1-3 kokanee in Revelstoke Reservoir based on summer time hydroacoustic surveys during 1993-94 and 2001-2016. Error bars denote 95% confidence limits on annual maximum likelihood estimates and red dotted lines indicate ± 2 standard errors of the long term (18 year) average.

3.8.3 Trawl and Gillnet Sampling

Over five years and 14 trawls, 503 kokanee and 6 sculpins were captured on Kinbasket Reservoir. The kokanee catch consisted of 68% fry, 21% age 1, 9% age 2 and 1% age 3 kokanee (Table 8). Trawling in Revelstoke Reservoir was discontinued in 2013 due to very low catches of age 1-3 kokanee (0.3 fish per hour).

Gillnet sampling, which began in 2012 in Revelstoke and 2013 in Kinbasket, has provided size at age information as well as the proportion of fish that would spawn the same year. Since 2012, a 327 age 1-3 kokanee have been captured in 16 gillnet sets in Revelstoke Reservoir (Table 9). An average of 84% (76-95%) age 2 and older fish in Revelstoke were maturing and expected to spawn later the same year while 100% of age 1 fish were immature. Kokanee catch rates were slightly higher in Kinbasket Reservoir with 308 age 1-3 kokanee captured in 13 gillnet sets. An average of 87% (80-100%) were mature age 2 and older fish in the gillnet catches for Kinbasket over the four years surveyed. Note that the largest fish are most vulnerable to the gillnets so would be over-represented in the catch. As such, the percent mature estimate is likely an over-representation of the true proportion given that on average the mature fish are the oldest and largest. Similarly, regardless of maturity, the oldest age classes are assumed to be over-represented as well given their larger size. This is particularly evident in Revelstoke where age 2 and older fish are exceptionally large relative to age 1 fish, resulting in a cumulative age structure where age 2 fish greatly outnumber age 1 fish.

The modification on RIC nets to include an additional small mesh panel starting in 2015 appears to have increased the catch of age 1 kokanee substantively in both reservoirs. The proportion of age 1 (to total kokanee) increased from 9% to 29% in Revelstoke and from 36% to 60% in Kinbasket Reservoir, however these numbers are qualified by the fact they were collected from different years where proportions of age 1 fish in the population may have been different.

Table 8. Summary of effort and catch for trawl surveys on Kinbasket and Revelstoke during 2012-2016.

Reservoir	Year	No. of Trawls	Trawl Location[1]	Duration (minutes)	Number of kokanee					Cottus spp.	% Kokanee
					age 0	age 1	age 2	age 3	*Tot KO*		
Rev	2012	3	3,4,5	60,60,60	25	0	1	0	*26*	0	100%
	2013		trawling discontinued								
Kin	2012	2	8,15	60,60	134	1	1	0	*136*	0	100%
	2013	3	16,18,19	40,60,60	52	30	14	1	*97*	2	98%
	2014	3	17,17,18	45,60,30	84	18	8	0	*110*	0	100%
	2015	3	11,17,31	60,60,45	29	30	7	0	*66*	1	99%
	2016	3	14,17,17	60,60,30	45	27	17	5	*94*	3	97%
Rev	**Total**	**3**		**180**	**25**	**0**	**1**	**0**	**26**	**0**	**100%**
Kin	**Total**	**14**		**730**	**344**	**106**	**47**	**6**	**503**	**6**	**99%**

1. Trawl locations in Kinbasket by acoustic transect#: 8 Lower Canoe, 11 Forebay, 14-16 Main Pool, 17-19 Wood Arm and 31 Bush Pool (note: Bush Pool trawl net was non-standard 2.5x2.5m experimental net) Revelstoke: #3 Forebay, 4 and 5 Lower Basin near Martha Creek

Table 9. Catch statistics for gillnet sampling of Revelstoke and Kinbasket Reservoirs, 2012-2016.

	Gillnet sets	Location (tansect #)	Effort (ha.hrs)	KO Catch (no.)	Other Spp. (no.)	Number of kokanee by age					mat.[b] (%)
						Age 1	Age 2	Age 3	Age 4	mature	
Revelstoke											
2012	4	5,5,14,16	5.7	20	2	4	5	11	0	14	88%
2013	4	5,6,11,12	5.1	74	6	1	46	25	2	56	77%
2014	4	5,6,14,14	4.27	63	3	9	36	13	5	41	76%
2015	2[a]	11,12	3.67	57	6	31	21	5	0	22	85%
2016	2[a]	11,12	2.7	113	4	18	79	16	0	90	95%
Total	*16*		*21.39*	*327*	*21*	*63*	*187*	*70*	*7*	*223*	*84%*
Kinbasket											
2013	2	11,17	2.04	41	1	10	27	4		26	84%
2014	4	17,17,23,24	4.67	87	13	36	37	13	1	43	84%
2015	5[a]	11,17,17,32,32	6.87	160	16	100	58	2	0	48	80%
2016	2[a]	11,32	2.94	20	6	8	8	4	0	12	100%
Total	*13*		*16.52*	*308*	*36*	*154*	*130*	*23*	*1*	*129*	*87%*

a) indicates modified RIC (1997) standard gillnets with 7th panel were used starting in 2015

b) indicates the percentage of age 2 and older fish that were maturing to spawn the same year

3.8.4 Kokanee length at age

Kokanee growth in BC large lakes is typically monitored through trends in trawl length at age for all age groups in the lake. However, the trawl sample sizes were often too low in Kinbasket to show reliable year to year trends in kokanee length at age for age 1 and 2 kokanee (Sebastian et al. 2010; Johner and Weir 2012), and trawl catches of age 1-3 kokanee in Revelstoke were only sporadic and discontinued in after 2012. Gillnet sampling increased sample sizes substantially, allowing for evaluation of length at age. As such, to demonstrate kokanee length at age trends we have combined trawl and gillnet data as far back as gillnet data exist for each system.

Average kokanee length at age by year from gillnet and trawl captured fish is illustrated in Figure 41 for both Kinbasket and Revelstoke Reservoirs. Kinbasket mean age 1 kokanee length was smallest in 2014 at 138 mm, and this cohort translated to the smallest age 2 kokanee in 2015 at 204 mm. While the mean length of age 3 was small and similar to age 2 length in 2015, the sample size was very small at n=2 (note that small sample sizes are identified by hollow data points in Figure 41; arbitrarily set at n <10).

Average kokanee length at age in Revelstoke illustrated in Figure 41 indicates a dramatic increase in length at age after 2012, particularly for age 2 and 3 kokanee, although the sample sizes were very low from 2012-2014 for age 1. The mean length of age 2 kokanee in Revelstoke in 2012 was 233 mm, which was similar to the mean lengths of age 2 kokanee (219 mm) in Kinbasket averaged for all 4 years. After 2012, the mean length of age 2 kokanee ranged from 274-295 mm, and the mean length of age 3 ranged from 320 mm to 340 mm.

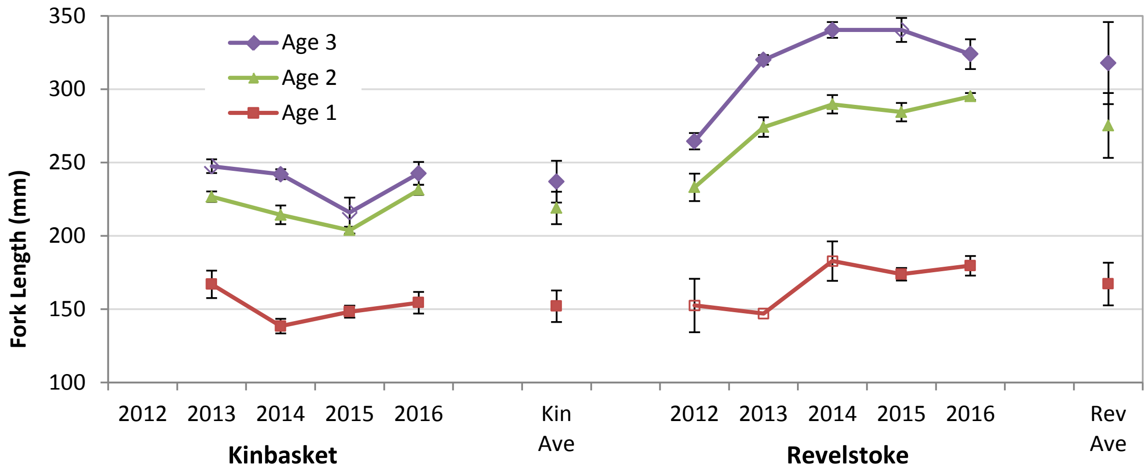

Figure 41. Kokanee mean length at age in Kinbasket (left) and Revelstoke (right) reservoirs based on combined gillnet and trawl catches during 2012-2016. Error bars denote ± 2 standard errors of the mean. Hollow data points indicate small sample size (n <10).

Trends in mean spawner fork length for all ages combined are presented in Figure 42 for Kinbasket tributaries including Bush, Luxor, and Camp Creeks, and for Revelstoke spawners sampled from Standard Creek. Revelstoke spawners were larger than Kinbasket spawners each sampled year, consistent with the larger size observed from in-lake sampling illustrated in Figure 41. Revelstoke spawners ranged from 265-303 mm between 2007 and 2012 before increasing in length to range from 309-341 mm between 2013 and 2016.

Camp Creek is a tributary to the north end of Kinbasket and spawners there were consistently larger than in Luxor Creek or Bush River, both tributaries to the southern end of the reservoir. Camp Creek was often dominated by age 3 spawners (Appendix 7.7), which could be partially behind the larger mean length at age compared to southern tributaries where age 2 spawners were usually dominant (Appendix 7.7). However, while data are somewhat sparse, comparison of mean length at age demonstrated that Camp Creek spawners were generally larger at both age 2 and age 3 (not shown) so the difference is not solely attributable to age structure. Regardless of the differences in mean size, Camp Creek size data show a similar trend to Luxor Creek (not shown; n=9, R^2=0.88) and given that we have a longer time series for Camp Creek it will be used as a proxy for spawner size trends for the entire reservoir.

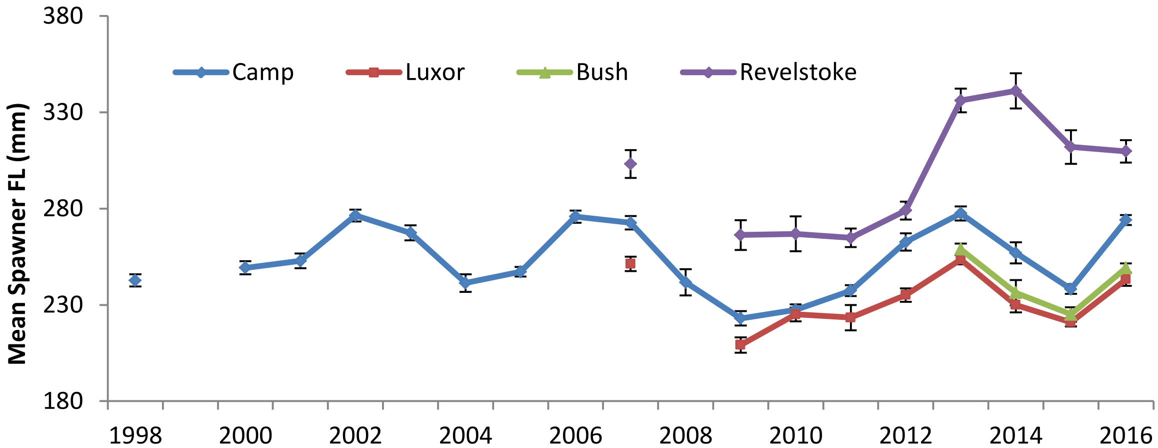

Figure 42. Trends in mean spawner fork length ± 2 S.E. for Kinbasket Reservoir tributaries (Bush River, Luxor and Camp Creeks), and for Revelstoke Reservoir (Standard Creek).

3.8.5 Trends in kokanee biomass

From 2001-2016, kokanee biomass in Kinbasket Reservoir ranged from 37,700 to 164,900 kg ($\bar{x}$ = 106,000 kg) and in Revelstoke Reservoir biomass ranged from 3,100 to 34,800 kg ($\bar{x}$ =16,500 kg). Kinbasket Reservoir made up 76% of the pelagic habitat (not including zones 1 and 9) and supported an average of 86% of the kokanee biomass in the two reservoirs. Biomass estimates in kg were converted to biomass density (kg/ha) to enable comparisons between reservoirs. Biomass density in Kinbasket ranged from 1.7-7.4 kg/ha ($\bar{x}$ = 4.3 kg/ha) and from 0.4-4.6 kg/ha in Revelstoke ($\bar{x}$ = 2.1 kg/ha) (Figure 43). Biomass density declined to less than 1 S.D. from the mean in Kinbasket in 2014 and remained similarly low through 2016. Biomass density also declined dramatically in Revelstoke Reservoir in recent years, with the four lowest estimates on record occurring from 2013 to 2016.

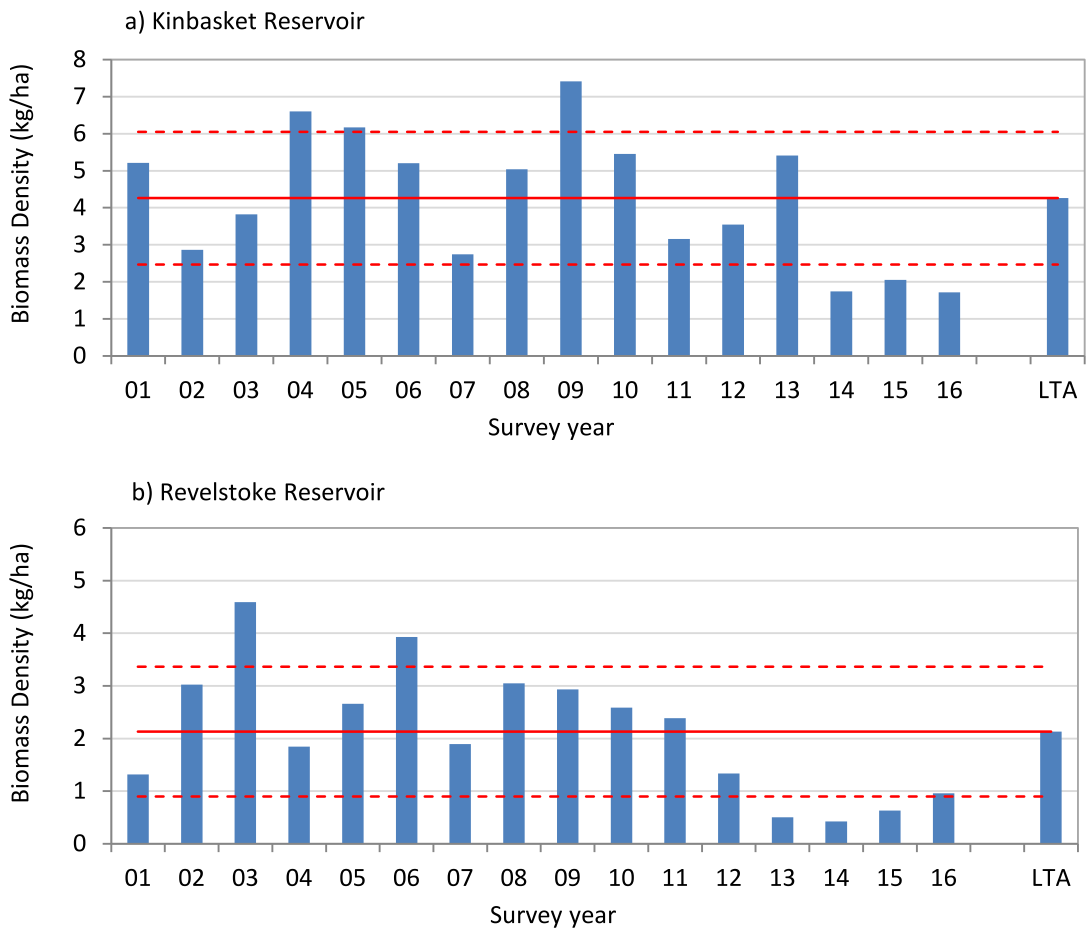

Figure 43. Trends in biomass density (kg/ha) for a) Kinbasket and b) Revelstoke reservoirs based on acoustic abundance and size distributions during 2001-2016. The solid red line indicates the 16 year average and dotted lines indicate ± 1 standard deviation.

3.8.6 Spawner abundance and egg deposition

With a limited number of index spawner counts and highly variable observation conditions, annual index count data were not meaningful for tracking spawner abundance for either Kinbasket or Revelstoke Reservoirs. Therefore, we developed an alternative index of spawner abundance derived from the summer acoustic and gillnet survey data. These index estimates do not incorporate any mortality between the summer survey and fall spawning time, a period of 6-8 weeks.

Spawner index estimates over the last eight years in Kinbasket Reservoir ranged from 127,000 to 650,000 ($\bar{x}$ = 305,000) (Figure 44**,** Appendix 7.8). Estimates of female spawner size and predicted fecundity suggest an average basin wide egg deposition of ~62 million with a range of 26-111 million eggs. By comparison, spawner index estimates for Revelstoke Reservoir averaged ~31,000 and ranged from 5,000 to 69,000. These estimates, combined with predicted fecundity estimates where spawner size data are available (2007, 2009-2016), suggest an average potential basin wide egg deposition of 6.6 million for Revelstoke Reservoir with a range of 2.5-11.1 million eggs.

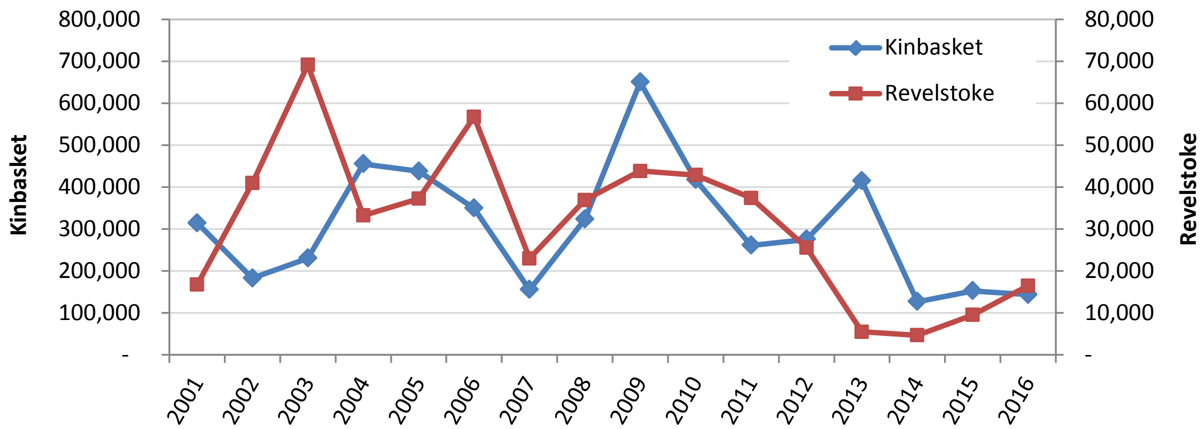

Figure 44. Kokanee spawner index trends for Kinbasket and Revelstoke Reservoirs. Index estimates are derived from summer acoustic and gillnet data.

3.8.7 Trends in Kokanee Survival

Indices of kokanee survival between age classes were developed to compare reservoirs and to gain insight into drivers of kokanee survival and productivity. Egg to fry survival estimates were similar in Kinbasket and Revelstoke Reservoirs: Kinbasket survival estimates averaged 13% (5-27%) and Revelstoke estimates averaged 12% (4-36%) (Appendix 7.8). Index estimates are available only for 2007 and 2009-2016 for Revelstoke due to limited data required to estimate annual fecundity.

An index of survival over the first winter can provide valuable insight into factors controlling kokanee population dynamics. Figure 45 depticts survival index trends from fry to age 1 for both Kinbasket and Revelstoke. Survival to age 1 was slightly better in Kinbasket most years and averaged 18% compared to 14% in Revelstoke (Appendix 7.9). Kinbasket kokanee survival to age 1 peaked in 2010 and then generally declined to a record low of 5% in 2016. Revelstoke kokanee survival to age 1 was variable up to 2010 after which it declined and remained consistently low (7-10%) through to 2016.

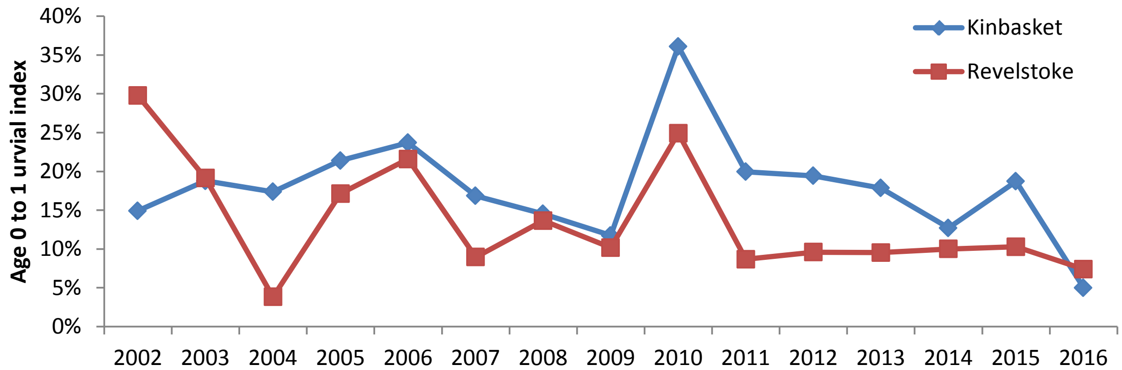

Figure 45. Trends in age 0 to 1 survival indices for Kinbasket and Revelstoke reservoirs. Estimates are labeled as the later year (e.g. survival from 2002 age 0 to 2003 age 1 is labeled as 2003).

4.0 Discussion

Discussion for CLBMON-3/56 and CLBMON-2 is focused on results to date and progress toward answering the management questions (MQ). Both programs continue until 2019/2020. This second synthesis report addresses data collected to 2016 (Years 1 to 9) and provides preliminary insight into the function of these reservoirs. The discussion also describes how the larger question of reservoir operations and their influence on pelagic production and kokanee populations will be addressed.

Our monitoring program has made a significant contribution to the scientific information available for Kinbasket and Revelstoke; in fact this monitoring program represents the longest and most comprehensive time series available to date for Kinbasket and Revelstoke. Despite this long-term data set, the time series represents a snapshot in time in the context of the four year life cycle of kokanee salmon and the wide range of infrastructure changes, operational changes, and extremely variable meteorological and hydrological conditions observed during our study years. It is necessary to continue to collect data to support our understanding of the complex ecosystem relationships in Kinbasket and Revelstoke in the context of multiple complicating drivers.

This long-term study of Kinbasket and Revelstoke Reservoirs also adds significantly to the data available for understanding other British Columbia lakes and reservoirs. Similarly, lessons learned from studies on other large reservoir/lake systems may further our understanding of the pelagic community structure in Kinbasket and Revelstoke Reservoirs. By expanding our spatial lens to include other large reservoirs we can gain insight into the relative importance of regional vs. large scale environmental factors (e.g. climate) that are shaping the structure and function of the aquatic community.

4.1 CLBMON-3/56 Ecological Productivity Management Questions

MQ 3-1. What are the long-terms trends in nutrient availability and how are lower trophic levels affected by these trends?

There are two sources of nutrients for pelagic productivity: allochthonous nutrients that originate from outside the reservoir and are transported into the reservoir by tributary inflow, and autochthonous nutrients that originate within the reservoir, for example, from decomposition of organic matter at the bottom. New reservoirs often undergo a ‘boom and bust’ cycle, where, shortly after impoundment, nutrient availability is high due to flooding of soils and decomposition of organic matter (Stockner et al. 2005). As a result, pelagic productivity is initially high, but then decreases as this source of nutrients declines. In order to assess the long-term trends in nutrient availability we will examine both nutrients transported by inflows and nutrient concentrations in the reservoir.

Data are being collected from five reference tributaries to address the question of long-term trends in nutrient input. For the first nutrient, phosphorus, concentrations to date were low, with soluble reactive phosphorus (SRP) and total dissolved phosphorus (TDP) close to the detection limit, similar to results in other ultra-oligotrophic systems. The results were affected by a change in laboratory in 2013. An inter-comparison, with phosphorus samples sent to four laboratories, has just been completed (September 2018), and the data will be analyzed to better characterize variability in measurements at low phosphorus levels.

The second nutrient, nitrogen, is found primarily as nitrate (NO_3) and has annual volume weighted concentrations in the tributaries ranging from 60 to 170 µg/L N. Nitrogen concentrations appear to be unaffected by the change in laboratory.

Data have also been collected from seven stations in Kinbasket and Revelstoke Reservoirs. These data also show low SRP and TDP concentrations that were close to the detection limit, and were affected by the change in laboratory in 2013. In contrast, nitrate remains high, averaging 108 µg/L N in Kinbasket Reservoir and 224 µg/L N in Revelstoke Reservoir.

From the data to date (2008-2016), we conclude the following about Kinbasket and Revelstoke Reservoirs:

- they are oligotrophic systems;
- they are phosphorus limited (N:P > 10 by weight);
- given the proximity of phosphorus concentrations to the detection limit and given the slight shift in concentrations due to the change in laboratory in 2013, there are no major trends observable over the study period in the mean annual phosphorus concentrations; and,
- there are no evident trends over the study period in the mean annual nitrogen concentrations.

We intend to continue collection of data from the reference tributaries and reservoirs.

MQ 3-2. What are the interactions between nutrient availability, productivity at lower trophic levels and reservoir operations?

Understanding the physical and chemical environment of these systems can provide important information regarding the productivity of primary and secondary producers. These abiotic factors can be correlated with both primary and secondary productivity but in many cases the biological community is impacted by inter- and intra- trophic level interactions. Due to these additional causative agents it is critical to study the trophic structure of these systems.

Phytoplankton productivity is largely controlled by light, temperature and nutrients. Specifically, production in freshwater ecosystems is primarily controlled by the availability of phosphorus and in some cases nitrogen. In Kinbasket and Revelstoke, sampling for reservoir and tributary water chemistry has generally occurred monthly from May to October at four stations in Kinbasket Reservoir and three stations in Revelstoke Reservoir with some exceptions due to logistical challenges.

The reservoir water chemistry from 2008-2016 clearly show SRP concentrations in the tributaries and the reservoir are low and values are close to the analytical detection limit of 1 µg/L. In contrast, the mean dissolved inorganic nitrogen (predominately nitrate) concentration is >100 µg/L at all stations in Kinbasket and Revelstoke Reservoir. Several lines of evidence suggest that phosphorus is the most critical nutrient controlling productivity:

- Concentrations of dissolved inorganic nitrogen are well above 20 µg/L, the threshold considered limiting to phytoplankton growth (Wetzel 2001);
- Mean SRP concentrations of 1.4 µg/L in both Kinbasket and Revelstoke Reservoirs are extremely low and are near the analytical detection limits; and
- The N:P ratio for the reference tributaries remains well above 10 (by weight), suggesting phosphorus limitation.

These results have clearly shown that phytoplankton productivity is not limited by the availability of dissolved nitrogen over the study period and suggest that phytoplankton productivity is controlled by the availability of dissolved phosphorus in Kinbasket and Revelstoke Reservoir.

Our study has shown that the instantaneous concentration of phosphorus is low but another factor to consider in understanding the effect of nutrients on primary productivity is the importance of the rates of loading and the physical dynamics of these allochthonous nutrients in the water column. The principle drivers of nutrients to primary production is whether these nutrients enter the photic zone, the time of year they enter the photic zone, as well as the amount of time these nutrients spend in the photic zone.

One key observation from our study was recording numerous examples of interflow of Kinbasket outflow in Revelstoke Reservoir (Figure 14). Water discharged from Kinbasket Reservoir was transported directly to the outlet of Revelstoke Reservoir, bypassing the photic zone. In effect, water from Kinbasket Reservoir was short circuited below the photic zone through much of the summer. The interflow dissipated in the fall due to water cooling which allowed Kinbasket water to enter into the photic zone of Revelstoke, and thereby allowing biological uptake of potential nutrients in the Kinbasket source water by the phytoplankton community. The availability of these nutrients in October when biological productivity is winding down, however, is much less valuable than they would have been in June or July, when strong phytoplankton growth occurs. This short circuiting of the nutrients from Kinbasket during the warmer months could result in a cascade of reduced productivity in all trophic levels of Revelstoke Reservoir.

The timing of the inflows from the watershed was highly variable during the time frame of our study. For example, in 2012, the flow from Kinbasket was at or below average through mid-July, when the flow rose to very high levels to the end of August (Figure 3b). Changes in inflow characteristics can have a profound impact on the productivity of these systems given that the phytoplankton community can rapidly respond to pulse sources of nutrients due to extremely high uptake rates. These uptake dynamics allow the phytoplankton community to respond positively to a changing environment. Phytoplankton are also able to assimilate phosphorus in excess of their actual needs and store phosphorus for future use when external concentrations of phosphorus are low (known as luxury consumption); this allows the phytoplankton community to maximize growth in environments where phosphorus is dynamic. Inflow characteristics will be further explored in future study years to assist our understanding of pelagic productivity in a highly variable environment.

Not only are the large changes in inflow rate important, but the fate of these large inflows within the reservoir is also important. Information from the autonomous profilers has detailed, for example, the fate of the interflow in Revelstoke Reservoir and the possibility that the interflow can extend into the photic zone (Figure 16). There are models, some developed in the past few years, which can be used to estimate whether tributary inflow enters the photic zone (e.g. Pieters and Lawrence 2012). We plan to both use the observations, and apply the models to Kinbasket and Revelstoke Reservoirs to estimate the transport of inflows to the photic zone and estimate the time that inflows will remain in the photic zone, and therefore, make nutrients available for biological production.

As we have discussed, data analysis of the nutrient and water transport through the system shows an interflow layer from Kinbasket short circuiting through Revelstoke. We note, however, that this appears to be in contradiction to the similarities in our observations of phytoplankton densities between the two reservoirs. A highly significant correlation exists between Kinbasket and

Revelstoke phytoplankton density and biovolume (Figure 30 and Figure 31). This relationship is also true for zooplankton density and to a lesser degree zooplankton biomass (Figure 37).

There are a several potential reasons why phytoplankton and zooplankton metrics are highly correlated between these systems. One hypothesis is that similar environmental conditions result in similar phytoplankton and zooplankton densities in reservoirs that are in close geographical proximity to each other. Another hypothesis is that the primary and secondary producers in Revelstoke Reservoir are dictated by the populations in Kinbasket Reservoir (e.g. by transport downstream). Alternatively, it could be some combination of the two.

Although there is a correlation of the same trophic level between the two reservoirs (e.g. Figure 30 and Figure 31), there is no correlation apparent between the phytoplankton community (first trophic level) and zooplankton community (second trophic level) within each reservoir (Figure 46). Certain zooplankton metrics do correlate with certain kokanee metrics (third trophic level, discussed below); however, kokanee densities generally do not correlate well with either zooplankton or phytoplankton densities. These relationships suggest that the second and third trophic levels (zooplankton and kokanee) may be more tightly linked to each other than they are to the first trophic level (phytoplankton), although impacts of grazing on each trophic level are unaccounted for, and may obscure these relationships to varying degrees.

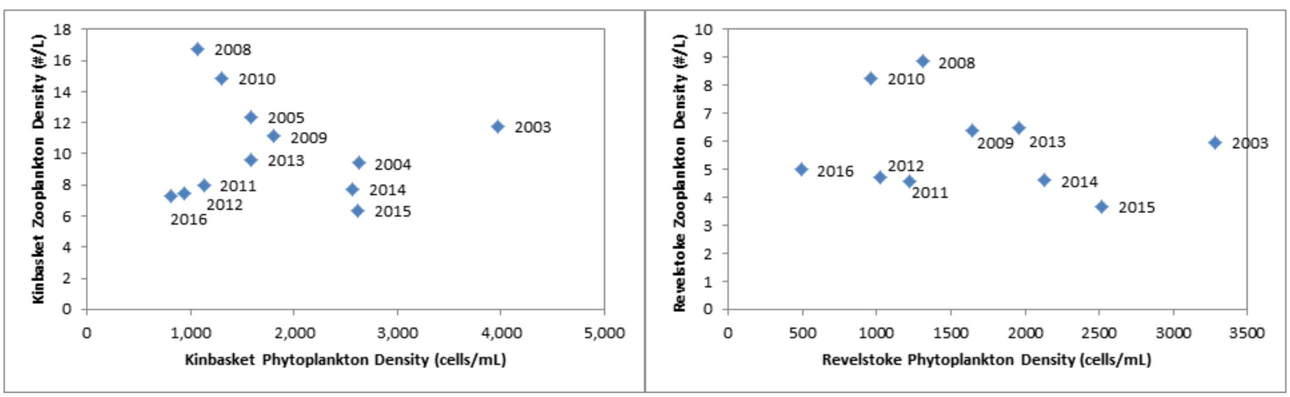

Figure 46. Correlations of phytoplankton density to seasonal average zooplankton density in Kinbasket and Revelstoke Reservoirs, 2003-05, 2008-16.

A possible explanation for these correlations is that there are regional environmental or operational conditions that are important drivers of zooplankton and kokanee densities, which are different than the key drivers of the primary producers. One approach to determine if it is an environmental factor that is resulting in similar conditions between these reservoirs is to examine another waterbody in close proximity to Kinbasket and Revelstoke that would likely be experiencing similar environmental conditions. Arrow Reservoir has a similar phytoplankton, zooplankton, and kokanee data set to the Revelstoke and Kinbasket projects; therefore, it should be possible to compare Arrow to the two project reservoirs. It should be noted that Arrow Reservoir is under a nutrient supplementation program which may complicate comparisons between the systems.

A plot of annual average zooplankton density between the three systems shows a good correlation between Kinbasket and Arrow zooplankton densities as well as Revelstoke and Arrow Reservoirs zooplankton densities (Figure 47). It should be noted that although the general trend between the systems are similar there is a significant difference in the mean zooplankton densities with Arrow, a fertilized reservoir, which has a much higher 2009-2016 average zooplankton density of 17 ind/L, compared to Kinbasket with 9 ind/L, and Revelstoke with 6 ind/L.

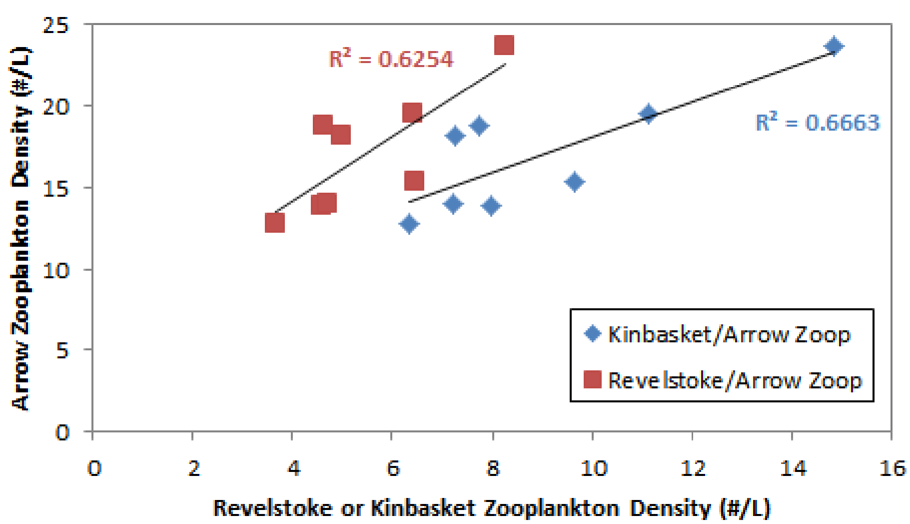

Figure 47. Annual average zooplankton density of Arrow Reservoir plotted against annual average zooplankton densities of Kinbasket and Revelstoke Reservoirs from 2009-2016.

While there is a statistically significant correlation in both zooplankton metrics between the three reservoirs, when Arrow, Kinbasket, and Revelstoke phytoplankton densities are plotted against each other there is no discernable relationship between phytoplankton in Arrow, and phytoplankton in Revelstoke and Kinbasket Reservoirs (Figure 48). These differing relationships suggest that the phytoplankton production may be more tightly correlated with local conditions and that secondary and tertiary production may be influence by more regional level conditions.

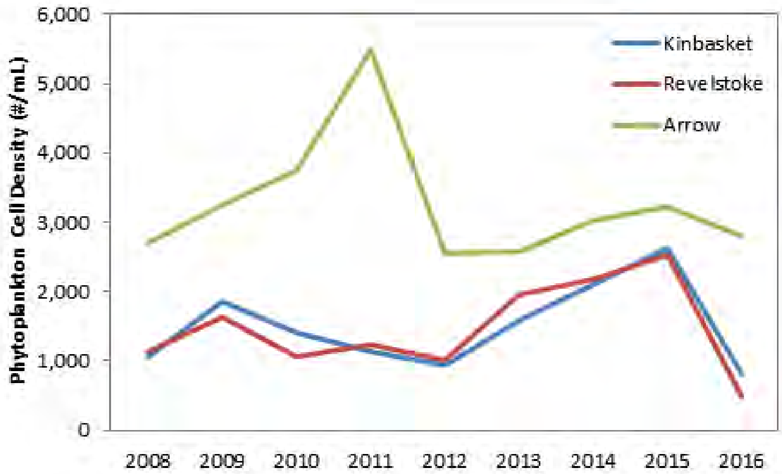

Figure 48. Annual mean phytoplankton densities for Arrow, Revelstoke, and Kinbasket Reservoirs, 2008-2016.

In the upcoming years of data collection and analysis on Kinbasket and Revelstoke Reservoir special attention will be paid to connectivity of lower trophic level production between Kinbasket and Revelstoke Reservoirs as well as factors that may be influencing the upper trophic levels. Understanding the dichotomy of the findings from the water transport data with the primary producer data as it relates in inter-reservoir effects will need to be examined in more detail.

The data collected so far have not been sufficient for a determination of the environmental or operational factors that are affecting the lower trophic level dynamics. Continued data collection and analysis will result in increased statistical power in our analysis and should allow a more complete understanding of how nutrients, environmental conditions, and operations impact the productivity of the lower trophic levels.

MQ 3-3 Is pelagic productivity, as measured by primary production, changing significantly over the course of the monitoring period?

For this study pelagic productivity is defined as that of the primary and secondary trophic levels. The primary trophic level in our study is represented by phytoplankton and we will also examine the secondary trophic level as represented by zooplankton. For our analysis of the primary trophic level, we will examine primary productivity, size fractionated primary productivity and phytoplankton taxonomy data (densities and biomass) and for secondary trophic level (zooplankton), we will examine zooplankton taxonomy data (densities and biomass).

A number of changes have been measured in Kinbasket and Revelstoke Reservoirs across the study period. In summary:

- Primary productivity generally increased annually from 2008-2015 in Kinbasket and Revelstoke Forebays and from 2008-2014 at Revelstoke Middle (Figure 25);
- In Kinbasket Reservoir the relative contribution of each size class to primary productivity has changed. Nanoplankton were the most productive size class except for in 2013 and 2014 when small sized picoplankton accounted for the greatest production. Picoplankton and nanoplankton contributed equally to primary productivity over the study period at Revelstoke Middle. At Revelstoke Forebay, picoplankton were the most productive fraction in three years, nanoplankton were the most productive fraction in three years, and for the remaining two years production was equal for these two size classes. At all stations, microplankton were the least productive fraction and over the study period the relative contribution of microplankton has declined;
- Phytoplankton densities and biomass in both reservoirs have declined from 2009-2012, increased from 2013-2015 and then declined again in 2016 (Figure 29);
- Zooplankton density has declined in Kinbasket and Revelstoke over the study period and zooplankton biomass has generally declined with the exception of 2013 and 2016 (Figure 35);

As shown in section 3-2, our study has found no correlation between the phytoplankton community (first trophic level) and the zooplankton community (second trophic level) within each reservoir, at least in evaluating standing crop estimates. Bottom up regulation suggests that phytoplankton growth will translate to resources (food) for herbivorous zooplankton and consumers of zooplankton (Wetzel 2001). It is well established in the literature that organic carbon resources always influence productivity at all trophic levels; however, at first glance it does not appear that increased production at lower trophic levels in Kinbasket and Revelstoke translated to secondary production, i.e., into more zooplankton biomass. We have noted a prevalence and increasing contribution of small picoplankton in Kinbasket from 2008-2015 which will lead to less efficient transfer of carbon up the food chain and potentially fewer resources for secondary production. However, from 2013-2015, nanoplankton densities increased, which should translate into edible resources for zooplankton, but we did not see a positive response in the zooplankton community during this time period.

We have also shown that phytoplankton densities are unrelated to kokanee densities, again suggesting the simplistic view of energy flow up the food chain was impacted by other factors. One theory is that enhanced primary production is translating into increased zooplankton productivity; however, our measurements are not capturing this growth because kokanee grazing pressure is cropping biomass to low levels. This is commonly termed a top-down effect, where predation by invertebrates or fish will influence the zooplankton community structure and density. This concept of cascading negative trophic interactions is not supported by our data given that kokanee grazing pressure would have broadly declined over the study period concurrent with the general decline in kokanee abundance and biomass mentioned above. In addition, evidence provided in Discussion section Management Question 2-3 (Figure 50 and Figure 51) suggests that Revelstoke zooplankton may be near a state of release from grazing given the extremely low kokanee densities in Revelstoke Reservoir in recent years, similar to Kootenay Lake kokanee/zooplankton relationships after the collapse of the kokanee population at that lake. Alternatively, the uncoupling of lower trophic levels can be explained by losses of zooplankton biomass from physical processes such as advection/entrainment.

At present we do not have a complete understanding of trophic interactions of the lower trophic levels and we acknowledge that ecosystems are complex and dynamic, and it is likely that there are a number of drivers: bottom up control, top down control, and advective losses, that are likely operating in concert on productivity in these reservoirs. We acknowledge that measurements of plankton standing crop may be limiting our understanding of plankton community dynamics and we are investigating methods of calculating zooplankton production for future analyses. Our understanding of the physical, chemical, and biological limnology of Kinbasket and Revelstoke has advanced due to the availability of this extremely valuable long-term data set. We will continue to develop and refine our emerging perspective of trophic interactions in these large complex reservoirs to guide our understanding of how reservoir operations may influence ecosystem productivity.

MQ 3-4 If changes in pelagic productivity are detected, are the changes affecting kokanee populations?

It stands to reason that changes in lower trophic levels should affect upper trophic levels given that upper trophic levels derive energy and nutrients required for growth and reproduction from lower trophic levels. However, a number of mediating factors can impact the flow of energy up the food chain and the accumulation of biomass at any given component of the food web. For instance, the primary trophic level, specifically primary production, is more likely driven by climatic variables such as temperature, light and local variability in nutrient inputs and phytoplankton are also influenced by sinking and grazing by zooplankton. The extent of grazing pressure on the phytoplankton community is dependent on zooplankton community structure and abundance. In turn, kokanee populations can be impacted by a number of factors including, but not limited to, disease (e.g. the Kinbasket kokanee die off in May 2016), recruitment failure, top-down grazing by piscivores, harvest, and export/entrainment of fry. While it is relatively easy to describe the food web and quantify abundances of individuals at different trophic levels, understanding the interactions and drivers of each component is more complicated, although ultimately more informative.

Concurrent with changes in pelagic productivity as summarized in management question 3-3, the following changes to kokanee populations were detected in our monitoring studies:

- In Kinbasket Reservoir, kokanee fry abundance remained mostly stable and near the long-term average, while age 1-3 abundance declined from a peak in 2008 and then were generally below average from 2011-2016 (Figure 39). Kokanee biomass (Figure 43) and spawner abundance (Figure 44) were generally above average in 2008-2010, then poor from 2011-2016 (with the exception of 2013). Age 0-1 survival in Kinbasket generally declined from 2010-2016 (Figure 45);
- In Revelstoke Reservoir, the kokanee fry population was more variable and was generally below the long term average over most of the study period. Age 1-3 kokanee declined in recent years similar to Kinbasket, although in Revelstoke the decline was much more substantial (Figure 40). Age 0-1 survival has remained low and stable since 2011 (Figure 45), while kokanee biomass and spawner numbers declined through 2011 and 2012, and reached very low levels by 2013, where they remained through 2016 (Figure 43, Figure 44).

Additional details and discussion on kokanee and reservoir pelagic production is provided in Section 4.2 below in Management Questions related to CLBMON-2.

MQ 3-5 Is there a link between reservoir operation and pelagic productivity? What are the best predictive tools for forecasting reservoir productivity?

There are many physical, chemical and biological parameters that must be quantified in order to develop a mechanistic understanding of how (and if) physical forcing i.e., reservoir operations, impacts pelagic productivity. Prior to this program few data were available on trophic status of Kinbasket and Revelstoke Reservoirs and even less information was available for the factors controlling productivity in the reservoirs.

With mooring data available beginning in 2012 (CLBMON-56), we have observed, for example, how changes in outflow from Kinbasket Reservoir can dramatically alter the interflow through Revelstoke Reservoir. The next step is to determine whether this has an effect on nutrient supply to the photic zone during summer. Another example of a physical linkage is the delay in the onset of summer temperature stratification following a cold winter (Table 6). The physical linkages will be examined using both the observations (e.g. the onset of summer stratification and the timing of the interflow), and models developed to estimate whether tributary inflow enters the photic zone (Pieters and Lawrence 2012).

From these linkages between reservoir operation and the physical limnology we have also begun to explore linkages between both the physical limnology and lower trophic levels, as well as between the trophic levels (e.g. between phytoplankton, zooplankton, kokanee). Our coordinated monitoring approach is continuing and additional years of monitoring will lead to a greater understanding of how the ultra-oligotrophic ecosystem functions in Kinbasket and Revelstoke. We continue making progress towards a clearer understanding of reservoir dynamics and linkages among physical, biological, and chemical processes that will help refine tools for forecasting reservoir productivity.

MQ 3-6 How do pelagic productivity trends in Kinbasket and Revelstoke reservoirs compare with similar large reservoir/lake systems (e.g., Arrow Reservoir, Kootenay Lake, Okanagan Lake, Williston Reservoir)?

This study benefits from the collection of limnological and kokanee data on Kinbasket and Revelstoke Reservoirs in a consistent manner that allows for a comprehensive comparison of the two reservoirs. The monitoring protocols were established so that our data will be comparable with datasets for Kootenay Lake and particularly Arrow Reservoir, reservoirs with multi-year monitoring programs of multiple trophic levels intended to assess the effects of large scale multi-year nutrient restoration programs. Unfortunately, similar studies over the same time frame are limited for many lakes and reservoirs in British Columbia due to the high cost of monitoring programs, competing priorities, and/or limited personnel.

Arrow Reservoir is located downstream of Revelstoke Reservoir and the reservoirs share some similar hydrological properties, such as a short water residence time. To date, a preliminary comparison of some components of plankton communities (phytoplankton and zooplankton) of Arrow Reservoir with Kinbasket and Revelstoke Reservoirs has been conducted as has a comparison of hydroacoustic data on the three systems. Preliminary analyses show that, in general, *Daphnia* density and biomass metrics were strong in 2013 and 2016 across all three reservoirs, while in 2011 *Daphnia* density and biomass in all three reservoirs was poor. By comparing data from multiple systems, we can gain insight into the relative importance of large-scale environmental factors driving production across the three reservoirs and more localised effects, such as how reservoir operations may impact the pelagic community. These inter-reservoir comparisons are currently underway (see next sections) and will be more fully explored in the final synthesis (post 2019/2020). We also include an examination of Kootenay Lake data as those data provide additional opportunities for insights into pelagic community dynamics. For instance, recent changes in the trophic dynamics in Kootenay Lake, specifically the collapse of the kokanee population and the large response of the zooplankton community due to relaxation of grazing pressure, suggest the kokanee population in Kootenay Lake is uncoupled with zooplankton production. This is similar to the preliminary relationships seen in Revelstoke Reservoir and will be further examined in the final years of this study.

Comparisons with other reservoirs in BC can include Willison Reservoir, located in the northeast of BC, however the last comprehensive monitoring program on Williston Reservoir was completed nearly 20 years ago and the study was for a relatively short duration: only 2 years (1999-2000). The paucity of monitoring studies on Williston Reservoir prevents a comparison with recent Kinbasket and Revelstoke data, however some value can be gained by comparison of the available data. It must be noted that comparison of the two studies may be further complicated by differing climatic conditions; the Williston study was completed exclusively during a La Nina event while this current study includes various ENSO events of differing magnitudes. All three systems share similar characteristics such as: low SRP (often at detection limits), sufficient nitrate-nitrite concentrations for phytoplankton growth, low rates of primary production indicative of oligotrophic status, similar size distribution of carbon production where pico- and nanoplankton account for the greatest carbon production (~80%) and the least productive fraction were large microplankton (cells> 20 µm). Many differences between the reservoirs were also noted, particularly the predominance of light limitation of primary productivity in Willison Reservoir due to the prevalence of high turbidity from high erosion of unstable shorelines (example of a localised factor affecting productivity). In addition, the limited data available for Williston Reservoir suggest there are nearly double the zooplankton densities in Kinbasket relative to Williston (10 ind/l vs 6 ind/l), and higher zooplankton biomass in Kinbasket Reservoir compared to Williston (31 µg/L vs 24 µg/L). These comparisons with Williston Reservoir offer some understanding for Kinbasket and Revelstoke; however, further relationships will not be examined due to the limited data available.

In the remaining years of the study, analysis and comparison of data from Kinbasket and Revelstoke Reservoirs with other similar BC lakes and reservoirs will continue to further our understanding of environmental and operational controls of pelagic productivity.

MQ 3-7 Does the addition of Mica Units 5 and 6 influence pelagic productivity?

This management question stems from CLBMON-56, the addendum resulting from the Mica 5/6 Environmental Assessment (EA) commitments. Work on this component began in 2012 with the testing and deployment of moored temperature arrays and profilers and will continue to 2019/2020.

The final two turbines at Mica Generating Station, Units 5 and 6, were constructed in tandem starting in 2012 and concluding with in service dates of mid-December 2014 for Unit 5 and mid-December 2015 for Unit 6. In conjunction with the installation of these two turbines, the Gas Insulated Switchgear (GIS) facility at Mica Generating Station was upgraded in 2013, work that resulted in unusual operating conditions.

For this report there are only two years of operation available for Unit 5 (2015 and 2016) and only one monitoring year of operation for Unit 6 (2016), therefore this question will be addressed in the final synthesis report. We anticipate that we will not be able to distinguish an operational effect of Units 1-5 versus Unit 1-6 as there is only one year in between their in-service dates.

The Mica Unit 5/6 Environmental Assessment (BC Hydro 2009) discussed the duration of flows with each new unit and predicted similar net flow, however with greater time at higher flow and less time at lower flow overall. Water quality is expected to remain unchanged.

To date the temperature moorings have focused on Revelstoke Reservoir and Kinbasket Forebay as installation was more secure/logistically feasible and as it was thought that Revelstoke Reservoir would be more influenced by the additional units than Kinbasket Reservoir. Additional moorings have been deployed in the Main Pool and the Middle Columbia Reach (Old Kinbasket Lake) during summer 2017 and 2018.

As discussed, the data will be examined to determine the effect of reservoir operations on stratification characteristics that are important to biological function, such as: the date of onset of stratification (Table 6), water temperature in spring and summer (important to the emergence of *Daphnia*), the effect of internal waves on water masses in the photic zone, and the transport of water from tributary inflows into the epilimnion. In summary, we will examine the linkages between reservoir operation and the physical processes in the reservoir, and the linkages between these physical processes and pelagic productivity.

MQ 3-8 Are there operational changes that could be implemented to improve pelagic productivity in Kinbasket Reservoir?

This management question will be addressed in the final synthesis report. The monitoring program will continue to document the current status of these reservoirs at a number of trophic levels, from primary productivity to kokanee. We are continuing to explore relationships between trophic levels and links to hydrological processes to further investigate key influences on pelagic communities, including a better understanding of environmental and operational influences and an improved capability to assess and predict pelagic productivity. With climate change effects predicted to have an increasing and destabilizing presence on the region's ecology (USGCRP 2018) and with concomitant impacts to flood control and energy demands (operations), it becomes increasingly difficult to develop prescriptive operations for maintaining maximum reservoir productivity as anticipated in the study TORs. We anticipate rather providing predictions of likely reservoir ecological productivity outcomes based on a suite of operational/environmental conditions.

The Study Team is working together closely and continues to collaborate by conference calls and annual meetings to review findings, discuss progress to date, and refine work plans to address data gaps in the final years of the monitoring program.

4.2 CLBMON-2 Kokanee Population Assessment Management Questions

MQ 2-1 What are the trends in annual distribution, abundance and biological characteristics of kokanee populations in Kinbasket and Revelstoke Reservoirs?

For comparing trends in distribution and abundance, kokanee have been partitioned into two groups based on their different acoustic size: age 0 (fry) and combined age 1-3. Characteristics of the fry population may relate to a recruitment and/or an environmental change in the current year while the age 1-3 group may also represent conditions over a longer period including the winter/spring low-water habitat conditions. In addition to kokanee distribution and abundance, other biological characteristics examined were trends in survival, recruitment, age and size.

Annual distribution

In Bray et al. (2013), we suggested that for Kinbasket Reservoir passive drift of fry in reservoir currents was likely the primary mechanism affecting fry distribution, given a lack of supporting evidence for other possible influences, including proximity to spawning sites or elevated local productivity. The addition of 5 more years of data (2012-16) does not provide any new insight. However, comparison of mean zone densities across phase 1, 2 and 2001-07 illustrates a declining density trend for the Lower Canoe and Main Pool zones; by phase 2, the zone densities were similar across all 7 zones, with the Forebay and Middle Canoe zones only slightly lower. The declining density trend for the Lower Canoe and Main Pool zones relative to other zones could be related to changes in the relative contribution of fry from spawning tributaries over time, however lacking reliable annual system wide tributary spawner estimates, it is not possible to evaluate this potential influence on fry distribution.

Unlike fry, on average there was no tendency for age 1-3 kokanee accumulations in the Main Pool or Lower Canoe zones in Kinbasket, suggesting their typical distribution was determined by different factors than for fry. It is expected that food availability is a primary driver of the distribution of age 1-3 kokanee, and the relatively stable zooplankton density and biomass values across all stations for Kinbasket (Table 7) supports this theory.

In Revelstoke Reservoir, the average zone fry densities were highest in the Forebay and Lower Revelstoke zones, which averaged ~185 fry/ha. The Middle Revelstoke zone is narrow and riverine (with relatively higher currents) and had consistently lower densities than the other two zones at ~70 fry/ha. This distribution is expected given the Downie Creek is the main fry recruitment area that enters the Lower zone.

A steep density gradient was apparent for Revelstoke fry in 2015, with very low densities in the Middle zone that increased nearly 5-fold by the Lower zone and nearly 10-fold by the Forebay zone. The unusual fry distribution in 2015 corresponded with exceptionally high water flow throughout the productive season during that year (Figure 6), which likely caused increased advective drift of fry in reservoir currents towards the forebay. This density distribution was not apparent in 2015 for the age 1-3 kokanee, which are expected to be less directly affected by advective drift in reservoir current. Bassett et al. (2018a) observed an unusually high proportion of large kokanee fry in the October trawl sampling in Upper Arrow Reservoir in 2015 and identified that they potentially originated from Revelstoke Reservoir based on an assumption of increased entrainment related to the exceptionally high flows throughout the 2015 growing season, and also supported by the density gradient observed in our summer acoustic survey of Revelstoke that year. The potential to evaluate this empirically by genetic analysis of the archived 2015 Arrow Reservoir trawl samples is being evaluated and, if it is possible to confidently assign fry proportions to each reservoir in 2015 and other years, it will add greatly to our understanding of entrainment of fry out of Revelstoke.

The age 1-3 kokanee distribution in Revelstoke was similar to the fry distribution with higher densities in the Forebay and Lower zones compared to the Middle zone. On average, the kokanee density distribution by zone corresponded with mean zooplankton density and biomass estimates, which were both higher at the Forebay and Middle limnology stations compared to the Upper limnology station[5] (Table 7). This suggests the age 1-3 kokanee distribution was determined by food availability in Revelstoke as well as Kinbasket.

Trends in abundance

During phase 2, fry abundance was near the long-term average for Kinbasket, while the age 1-3 kokanee population entered a period of reduced abundance beginning in 2011. Most notably, the age 1-3 abundance in 2016 was >2 S.D. below the long-term average and the lowest on record. The abnormally low abundance of age 1-3 kokanee in 2016 is likely linked to a large- scale mortality event that occurred in Kinbasket between mid-May and early-June (prior to the acoustic survey). Due to this abnormal mortality event, the 2016 age 1-3 and related or derived data points require qualification or omission from analysis against other variables. Further details are provided by Sebastian and Weir (2017).

Revelstoke fry abundance has remained at a reduced level since 2009 relative to the seven years prior, and four out of the five years in phase 2 were significantly below average. Similar to Kinbasket, age 1-3 kokanee in Revelstoke entered a period of reduced abundance in 2011 that persisted throughout phase 2, although the decline was more severe in Revelstoke. No observations of dead or dying kokanee were reported from Revelstoke Reservoir in 2016 as they were in Kinbasket, although lower densities in Revelstoke could have reduced the likelihood of incidental observation of floating dead fish. Age 1-3 abundance increased in 2016 over 2015 in Revelstoke in contrast to the dramatic decline in Kinbasket, suggesting that if the mortality event occurred concurrently in Revelstoke, the population impact was not apparent as it was in Kinbasket.

Trends in kokanee survival

Figure 49 illustrates trends in kokanee survival from age 0 to age 1 for Kinbasket, Revelstoke, and Arrow Reservoirs, each standardized to illustrate deviation from their respective series mean to facilitate comparison between systems. Kokanee survival in all three systems track remarkably well in certain years, despite known or assumed differences in key factors such as entrainment rate, predator community and density, kokanee density, spawning habitat quality/quantity (including enhanced spawning channel habitat in Arrow), presence of *Mysis diluviana* (Arrow), and lake fertilization (Arrow). Despite these differences, all three systems share generalized characteristics related to geography and climate as well as water quality and

[5] The Revelstoke Upper limnology station is within the Middle Revelstoke hydroacoustic zone, and the Revelstoke Middle limnology station is within the Lower Revelstoke hydroacoustic zone (Figure 1).

zooplankton communities. In light of this, it is likely that years with similarly good or poor survival among all three populations were a result of the influence of common factors such as seasonal weather patterns, or possibly common operational circumstances/outcomes that affect kokanee survival.

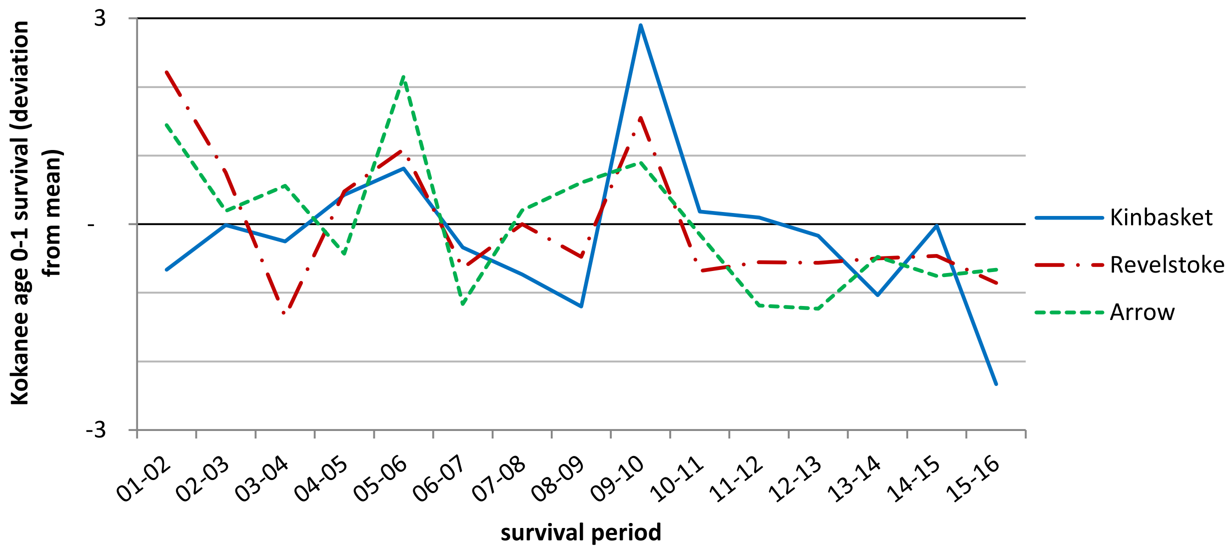

Figure 49. Trends in kokanee survival from age 0 to age 1 for Kinbasket, Revelstoke, and Arrow Reservoirs, each standardized to illustrate deviation from their respective series mean. Survival was estimated as differences between acoustic surveys conducted annually near the beginning of August for Kinbasket and Revelstoke, and in October for Arrow. Note that the 2015-2016 point for Kinbasket and the 2011-2012 point for Arrow were both likely influenced by abnormal and large-scale mortality events in May of those years in each system.

Two periods where survival was commonly high were 2005-06 and 2009-10. While periods with commonly poor survival among all three are less apparent, all three systems demonstrated reduced survival on average since ~2011. It is notable that Revelstoke and Arrow survival trends track more closely together than either does to Kinbasket. Considering only Arrow and Revelstoke trends, another common high survival year was 2001-02, and common low years become more apparent and include 2006-07 and all years since ~2011. Factors that could influence these respective survival trends are discussed further under subsequent management questions below.

Spawner size, age at maturity, and fry recruitment

The size of kokanee spawners can be an important factor in determining annual egg deposition and the recruitment of fry the following year. This was tested for Kinbasket Reservoir where there was a good relationship (R^2 = 0.79) between spawner length in Camp Creek (where the long term mean size trend is considered representative of all Kinbasket spawners) and the acoustic estimate of fry density the following summer (Figure 50). There was no relationship between relative abundance of spawners in Camp Creek and fry density in the reservoir; however, Camp Creek has historically represented a small fraction of total Kinbasket spawners.

Spawners measured for length and fecundity over three decades at Arrow Reservoir and Kootenay Lake demonstrate the reliable relationship between spawner length and fecundity (Bassett et al. 2016a,b). However, in 2013, spawner measurements in both those systems demonstrated that fecundity fell well below the predicted value for their sizes (Bassett et al. 2016a,b). As such, it was noteworthy that the data point for the Camp Creek 2013 spawner fork length fell well below the regression line in Figure 50**,** suggesting that fecundity was also abnormally low for spawner size in Kinbasket Reservoir that year. Bassett et al. (2016a,b) identified that this outcome occurred during a year of very rapid growth immediately following a period of declining spawner sizes in both Kootenay and Arrow. Accordingly, it is likely that observation of this phenomenon, now in three separate waterbodies including Kinbasket, was a result of dramatically different productivity (kokanee growth) conditions between 2012 and 2013 in each system (2013 far exceeded 2012). As such, we omitted the 2013 spawner data point from the regression as an outlier and note that this observation lends strength to the concept discussed in the previous section that broad regional productivity drivers can have significant common impacts across multiple systems. The data point for 2013 spawners in Revelstoke was also omitted from the regression in Figure 50 for consistency; however, there was no effect on the relationship either way.

Figure 50 also illustrates that the Revelstoke fry population is not related to spawner size/fecundity for those years where data are available (2007, 2009-16), indicating a potential difference between Revelstoke and Kinbasket Reservoirs with respect to this component of kokanee productivity.

Camp Creek spawners generally matured as a mix of age 2 and age 3, but were often dominated by age 3 spawners, with a mean age at maturity of 51% age 3 over 18 years of sampling (Appendix 7.7). The annual proportion of age 3 fish was positively correlated with spawner size (and therefore fecundity), and accordingly it appears that age at maturity played a role in the following year fry recruitment. The shift in Camp Creek age at maturity to age 2 for three consecutive years from 2009-11 was unprecedented in the time series and has not been observed to the same extent in other large lakes in BC where the dominant age at maturity is age 3 (MFLNRORD data on file). In other systems such as Arrow and Kootenay, shifts to a larger proportion of younger age at maturity occurred during periods of exceptional growing conditions, such as the onset of fertilization.

In Luxor Creek, a tributary to the upper Columbia River near Brisco, spawners return primarily at age 2, with only 13% age 3 mean age at maturity over nine years of sampling (Appendix 7.7). It is unusual and noteworthy that kokanee rearing in a common waterbody would differ in dominant age at maturity among tributaries. Due to the large size of Kinbasket Reservoir and the distance between Luxor Creek to the south and Camp Creek to the north, it is possible that these two stocks reared in different parts of the reservoir with different productivity and/or at substantially different densities for at least part of their lives. This observation hints at the complexity of the physical and biological processes driving the productivity of Kinbasket Reservoir and suggests that limitations in the spatial (and possibly temporal) scale of monitoring data could present increased challenges in identifying drivers of kokanee productivity for the reservoir as a whole.

The observation of differing age at maturity among tributaries was partially behind the recommendation to sample different reaches of the reservoir using pelagic gillnets to evaluate differences in size at age (if any) in phase 1 reporting. As such, gillnet and trawl sampling were conducted annually in combinations of the Middle Columbia, Wood Arm, Main Pool, and Bush Pool (Upper Columbia) zones with results indicating significant differences in size at age between zones some years and not others (Sebastian and Weir 2015, 2016, 2017). Overall, no clear pattern has emerged for size differences in any given age class or habitat zone; however, continued sampling across multiple zones may provide further insight.

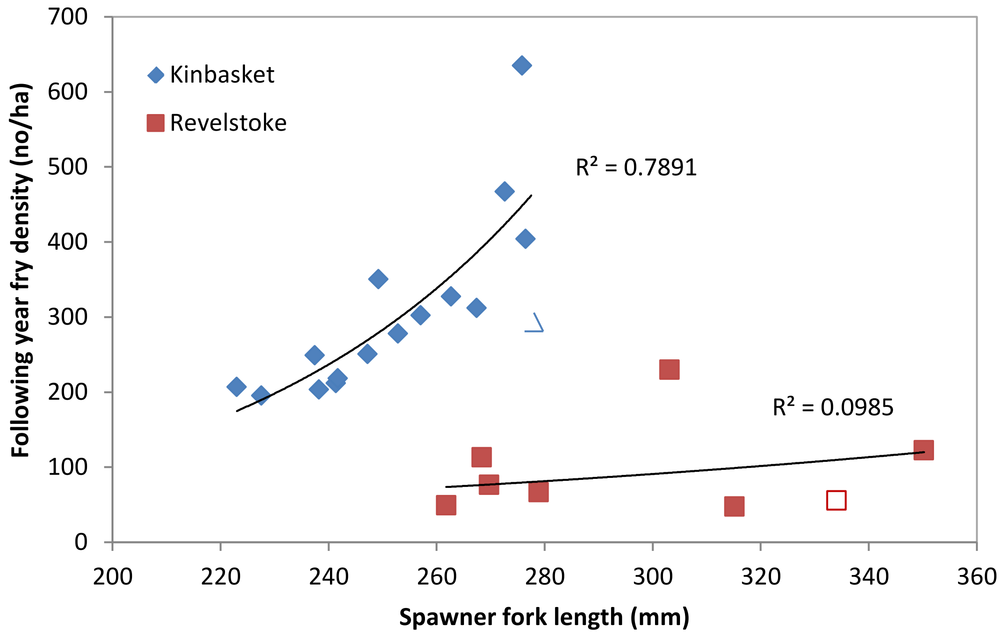

Figure 50. Plot of following year fry density and spawner length in Camp Creek for Kinbasket (2000-2016) and Standard Creek for Revelstoke (2007, 2009-16). The data points for the 2013 spawners were omitted as outliers (hollow points) due to observation of unusual spawner size/fecundity relationships in Kootenay and Arrow the same year (Bassett et al. 2016).

MQ 2-2 What role does reservoir operation play in productivity for kokanee?

In order to evaluate the role of reservoir operation in productivity for kokanee, the elements of the question require definition, as 'reservoir operation' and 'productivity for kokanee' can be interpreted and represented in various ways. The kokanee datasets for Kinbasket and Revelstoke are not sufficiently robust to produce reliable annual kokanee production estimates (defined as the rate of generation of biomass over a given time frame) for evaluation against reservoir operations. In place of direct estimates of kokanee production, we consider standing crop biomass a viable proxy under the assumption that top down pressures on kokanee (harvest and predation), which would influence annual standing crop biomass estimates, are relatively stable and are not driving annual variability in kokanee metrics. Kokanee size and density data are incorporated to estimate standing crop biomass, but as independent metrics they are also relevant. As such, standing crop kokanee biomass and kokanee size and abundance/density are all considered high level measures of kokanee productivity.

Survival between age classes is also an informative variable that directly affects kokanee abundance, size, age structure, and biomass, and allows for evaluation against variables representing reservoir operations. Fry production is another metric that represents a component of population productivity, and by extension factors that influence fry production, such as spawner numbers and size/fecundity, impact productivity. Accordingly, we define kokanee productivity broadly as standing crop biomass and population abundance/density and will evaluate impacts to productivity through metrics including kokanee fry production, size, age-structure, and survival. Primary and secondary trophic level productivity also have implications for kokanee productivity and population dynamics; accordingly, they are also considered indirect measures of kokanee productivity with respect to reservoir operations.

As identified under section 1.2 above, the outcomes of reservoir operations are manifested in changes in reservoir elevation and discharge (flow), both in terms of magnitude and periodicity. At a broad scale, the operation of Mica and Revelstoke dams shifts the hydrograph, reducing downstream spring freshet flows by storing water to mitigate flood risk and increasing flows in winter (and increasingly summer due to heat events) to meet power production. At a finer scale, large diurnal manipulations also occur, increasing flows during the daytime when power is needed and reducing flows at night when power demands are low. Our approach to evaluating reservoir operation as it relates to kokanee (and/or pelagic productivity in general) is to identify, broadly at first, which operational outcomes (seasonal discharge/flow and reservoir elevation conditions) are linked to increased or decreased productivity.

The role of reservoir operation as it relates to kokanee productivity cannot be categorically defined after year nine (2016). Our initial approach to answer this management question involves evaluating two dimensional relationships between adjacent trophic levels in order to develop a mechanistic understanding of the ecosystem processes. Variables representing each trophic level have also been evaluated against metrics representing reservoir operations to define where and how operations might interact with ecosystem processes. In addition, the role of climatic drivers is understood to be important, potentially confounding, and challenging to represent empirically. As such, climatic influences will be evaluated as drivers where empirical data allow, or as potential contributors to observed outcomes through processes of logical inference and weight of evidence. Initial investigations into the relationships between trophic levels and reservoir operations are presented and discussed below under management question 2-3.

MQ 2-3 What are the key habitat factors that contribute to changes in productivity of the kokanee?

The focus of analysis to date has been to explore relationships within and between adjacent trophic levels in an effort to understand what linkages are apparent and how weather/climate and operations interact with kokanee and lower trophic levels. Here we present several notable correlations observed to date. Where applicable, data are presented from nearby Arrow Reservoir and Kootenay Lake to allow greater insight into each relationship. Note that due to an unprecedented collapse of the main lake kokanee population in Kootenay Lake (Basset et al. 2016), kokanee data from Kootenay Lake are separated into two periods labelled 'pre-collapse' (2001-2012) and 'post-collapse' (2013-2016).

Zooplankton data presented below are seasonal averages for months where data are consistent within each system. For Kinbasket, the zooplankton seasonal averages presented below include June-August, for Revelstoke they include May-September, and for Arrow they include April-October.

Effects of food supply on kokanee growth and survival

The primary period of kokanee growth each year occurs during the summer and fall months, when *Daphnia* are present and available to kokanee. However, copepods are abundant and present throughout the year and they usually peak in abundance earlier in the productive season than *Daphnia*. In addition, copepods are known to be consumed when the preferred *Daphnia* are not available and they can sustain kokanee growth and survival, at a minimum for kokanee fry (Clarke and Bennett 2002). As such, copepods are also considered important for kokanee growth and survival.

To evaluate the relationship between *Daphnia* and kokanee productivity in Kinbasket and Revelstoke, kokanee biomass density (kg/ha) is plotted against the two-year average *Daphnia* biomass density (µg/L) in Figure 51. *Daphnia* biomass is represented by the two-year average given that kokanee biomass is largely driven by the older age classes which have been consuming *Daphnia* and accruing biomass over at least two seasons. Figure 51 illustrates that weak positive correlations exist for Kinbasket (panel a) and Kootenay Lake (panel d) prior to the collapse of the kokanee population to historic record lows, no correlation is apparent for Arrow (panel c) and negative correlations exist for Revelstoke (panel b) and Kootenay Lake post-collapse (panel d). While the weak positive relationships do not demonstrate a strong link between *Daphnia* biomass and kokanee biomass, we note that the data presented in Figure 51 are standing crop estimates where the effects of grazing are not accounted for and could be significant. However, the observation of extremely high zooplankton biomass values for post-collapse Kootenay Lake demonstrates the outcome of a release from grazing pressure on the zooplankton population. As such, the primary observation of interest in Figure 51 is the similarity between Revelstoke Reservoir and Kootenay Lake post-collapse in comparison to all other systems (including pre-collapse Kootenay Lake). Post-collapse Kootenay Lake is a system operating well under capacity for kokanee production and where kokanee/*Daphnia* dynamics are functioning outside of the normal range considering the outcome observed in Figure 51 (panel d). With respect to Revelstoke, the apparent similarity of the relationship to post-collapse Kootenay Lake may be spurious; however, it does suggest the possibility that the Revelstoke kokanee population is limited by one or more factors such that the kokanee/*Daphnia* dynamics are also functioning outside of the normal range observed in other systems. While kokanee predators are not monitored in Revelstoke Reservoir, there is no anecdotal or other information suggesting that there was a predator imbalance, or that harvest or disease were limiting the kokanee population. The remaining habitat factors that could be limiting kokanee abundance, therefore, are high entrainment rates and/or limitations on juvenile production (i.e., limited spawning habitat). Spawning habitat is discussed below, although the trend in kokanee age 0-1 survival discussed above indicates that in-lake survival has been poor in Revelstoke, leaving entrainment as the primary factor limiting kokanee abundance/survival.

To further explore the relationship between *Daphnia* and kokanee productivity, two-year average *Daphnia* biomass values (µg/L) are plotted against kokanee spawner size (fork length in mm) (Figure 52). Although the strength of the relationships vary, all four systems demonstrate a positive correlation, suggesting that changes in *Daphnia* biomass affect spawner size, which in turn affect fecundity and following year fry production. As noted above, zooplankton data presented are standing crop estimates and the relationships in Figure 52 would be affected by variable and unquantified grazing impacts. *Daphnia* biomass estimates for Kootenay Lake post-collapse (panel d) would not be likewise affected given that Kootenay Lake *Daphnia* appear to be functionally released from grazing during that period. The relationship in the post-collapse era is exceptionally strong (R^2 0.96), which could be explained as the outcome when *Daphnia* are released from grazing. The relationship between kokanee and *Daphnia* is also very similar between Revelstoke and post-collapse Kootenay Lake (Figure 52**).**

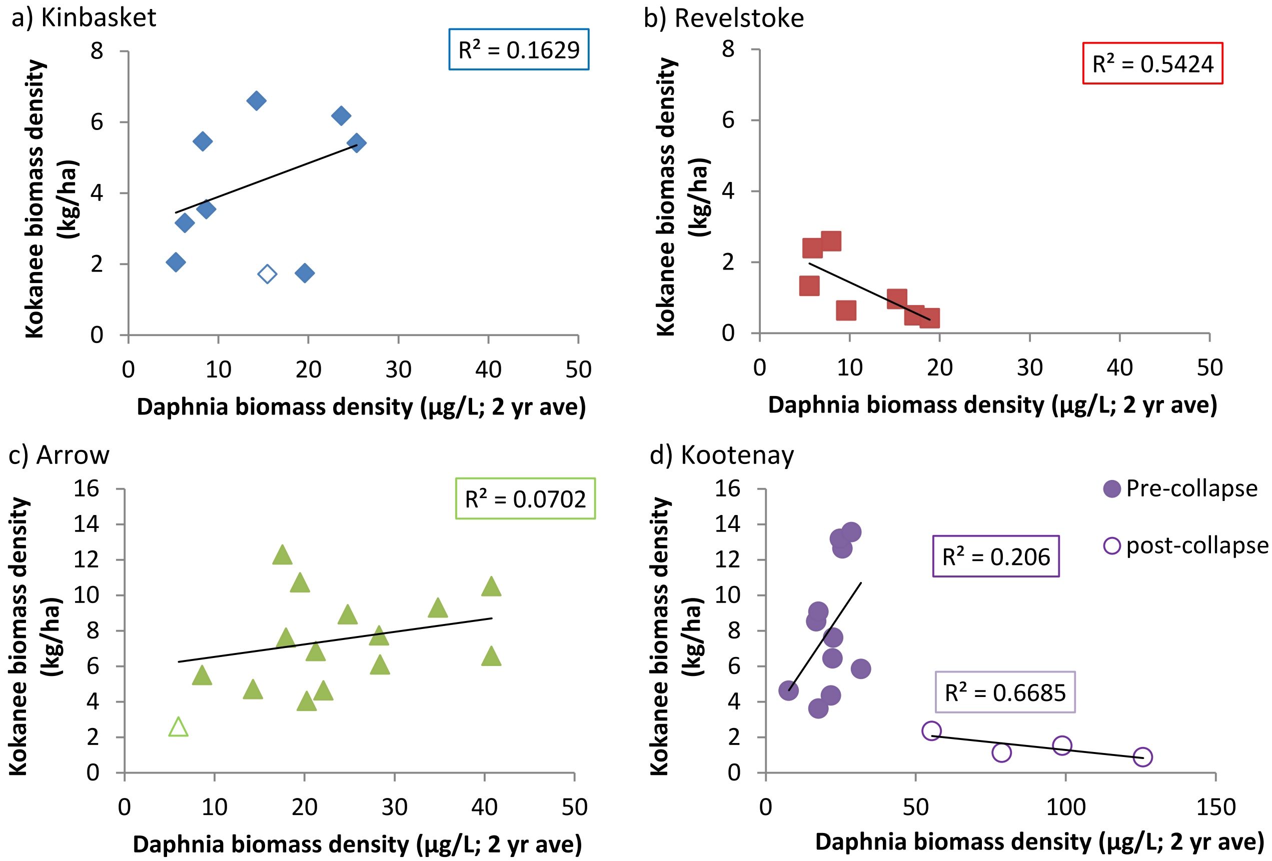

Figure 51. Relationship between the two-year average daphnia biomass density (µg/L) and the kokanee biomass density (kg/ha) for a) Kinbasket Reservoir, b) Revelstoke Reservoir, c) Arrow Reservoir, and d) Kootenay Lake. All available data for each system between 2001-2016 are presented. Kokanee data for Kinbasket in 2016 and Arrow 2012 were omitted due to large-scale spring mortality events and are presented as hollow points in panel a and c. Kootenay Lake kokanee are separated into discrete periods due to an unprecedented collapse of the main lake kokanee population (see Basset et al. 2016); pre-collapse includes data from 2001-2012 and post collapse includes data from 2013-16.

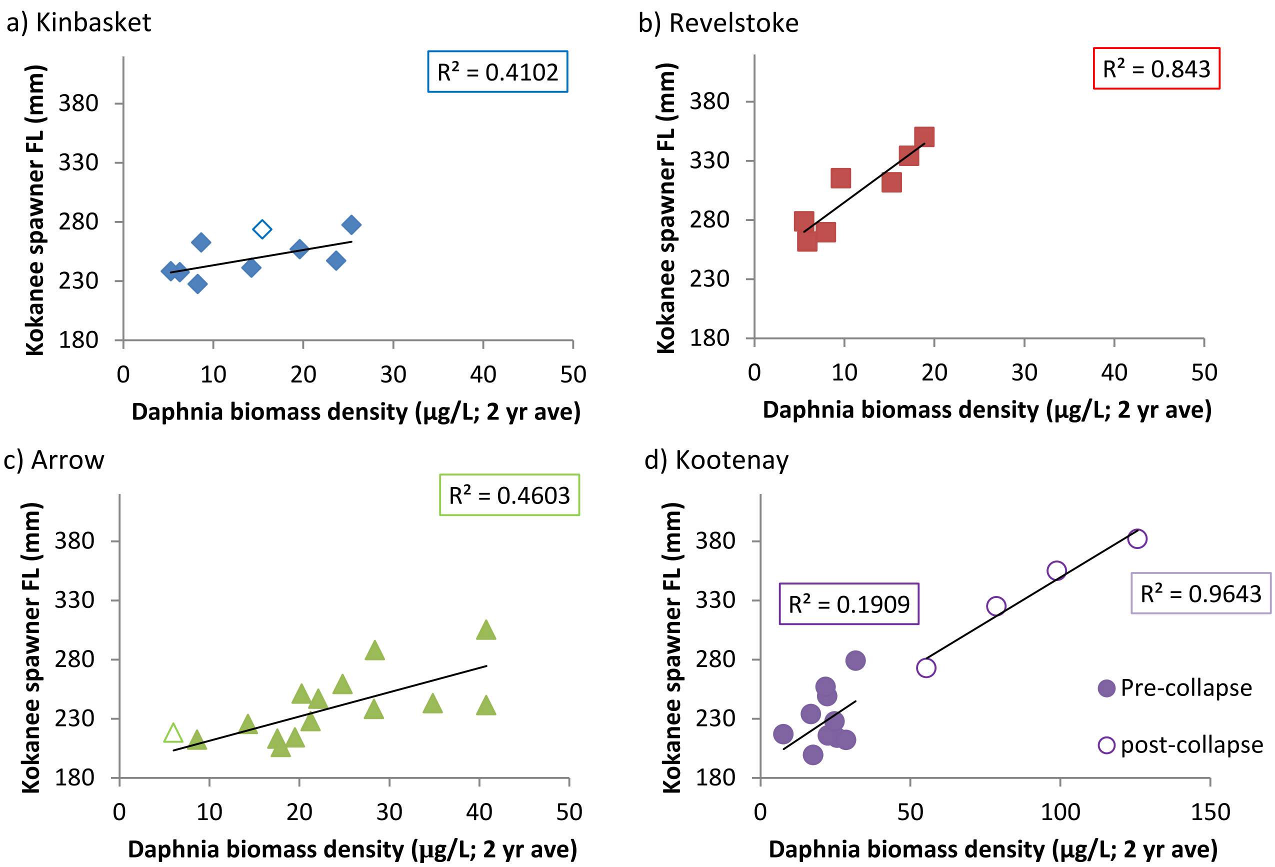

Figure 52. Relationship between the two-year average daphnia biomass density (µg/L) and the kokanee spawner fork length (mm) for a) Kinbasket Reservoir, b) Revelstoke Reservoir, c) Arrow Reservoir, and d) Kootenay Lake. All available data for each system from 2001-16 are presented. Kokanee data for Kinbasket in 2016 and Arrow 2012 were omitted due to large-scale spring mortality events, and are presented as hollow points in panels a and c. Kootenay Lake kokanee are separated into discrete periods due to an unprecedented collapse of the main lake kokanee population (see Basset et al. 2016a); pre-collapse includes data from 2001-2012 and post-collapse includes data from 2013-16.

Correlations between copepod density and kokanee biomass density and age 0-1 survival for Kinbasket, Revelstoke, and Arrow Reservoirs are illustrated in Figure 53. The copepod data presented are single season averages as opposed to the two-year averages evaluated in Figures 52 and 53 for *Daphnia*. Both single season data and two-year average data were evaluated for copepods with very similar outcomes in the correlations.

There was no relationship apparent between copepod seasonal average density and kokanee biomass density for Revelstoke, and only moderate positive relationships for Kinbasket and Arrow Reservoirs (R^2=0.41, 0.28 respectively; Figure 53a). While Figure 53a does not provide conclusive evidence that copepod density correlates with kokanee biomass in Kinbasket and Arrow, when data from all three reservoirs are combined (Figure 53b), a stronger positive correlation exists between copepod seasonal average density and kokanee biomass density (R^2= 0.67). The evidence for increasing kokanee biomass with increasing copepod density in the combined plot in panel b may be a function of differing productivity in general among reservoirs. Grazing effects are also not considered.

To further evaluate the relationship between copepods and kokanee productivity, copepod seasonal average density is plotted against kokanee age 0-1 survival in Figure 53c, which demonstrates moderate positive correlations for Revelstoke and Kinbasket (R^2~0.4); however, both are leveraged by a single high point. Similar to the outcome observed in panel b, when all data are combined across the three systems (Figure 53d), we observe a moderate positive relationship where kokanee survival increases with increasing copepod seasonal average density. Taken as a whole, Figure 53 suggests that factors that influence copepod productivity are also likely to affect kokanee productivity, directly or indirectly.

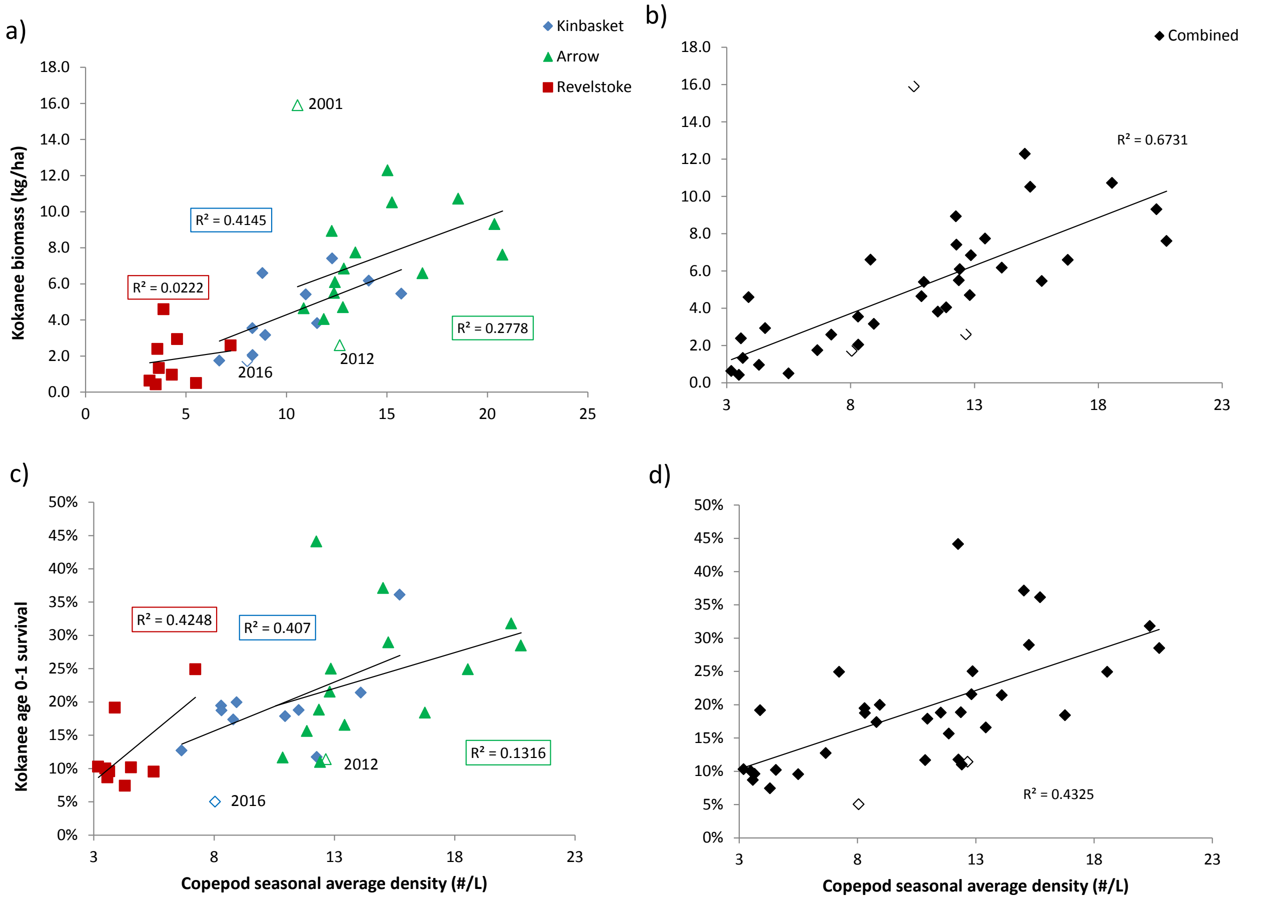

Figure 53. Relationships between copepod seasonal average density (#/L) and a) kokanee biomass density (kg/ha) for each of Kinbasket, Revelstoke and Arrow Reservoirs, b) kokanee biomass density in all three reservoirs combined, c) kokanee age 0-1 survival for each of Kinbasket, Revelstoke and Arrow Reservoirs, and d) kokanee age 0-1 survival in all three reservoirs combined. All available data for each system from 2001-16 are presented. Kokanee data for Kinbasket in 2016 and Arrow 2012 were omitted from correlations due to large-scale spring mortality events. The data point for Arrow 2001 kokanee biomass was omitted because it was in proximity to the onset of Arrow Reservoir nutrient restoration, a period not considered to be representative of typical post-fertilization conditions.

Effects of flow

We will use an annual metric that represents cumulative flow over the course of an entire year to evaluate the influence of reservoir operations on kokanee and/or lower trophic level productivity. This metric considers that kokanee biomass estimates represent biomass accrued over a relatively long time period and that kokanee survival estimates are derived by data spanning two calendar years.

Figure 54 illustrates the annual cumulative outflow values for each of Kinbasket, Revelstoke, and Arrow Reservoirs, representing an August 1st to July 31st time frame (labelled August to August). The three highest outflow points occurred in 2011/12, 2012/13, and 2014/15, which correspond with years of below average kokanee abundance, density, biomass, and survival. Conversely, cumulative outflow was below average from 2008-09 to 2010-11, a time frame that corresponded with generally average or better outcomes for kokanee metrics. The two-year moving average is also shown in Figure 54 in acknowledgment that ecosystem processes that occur in any given year are linked to the adjacent years.

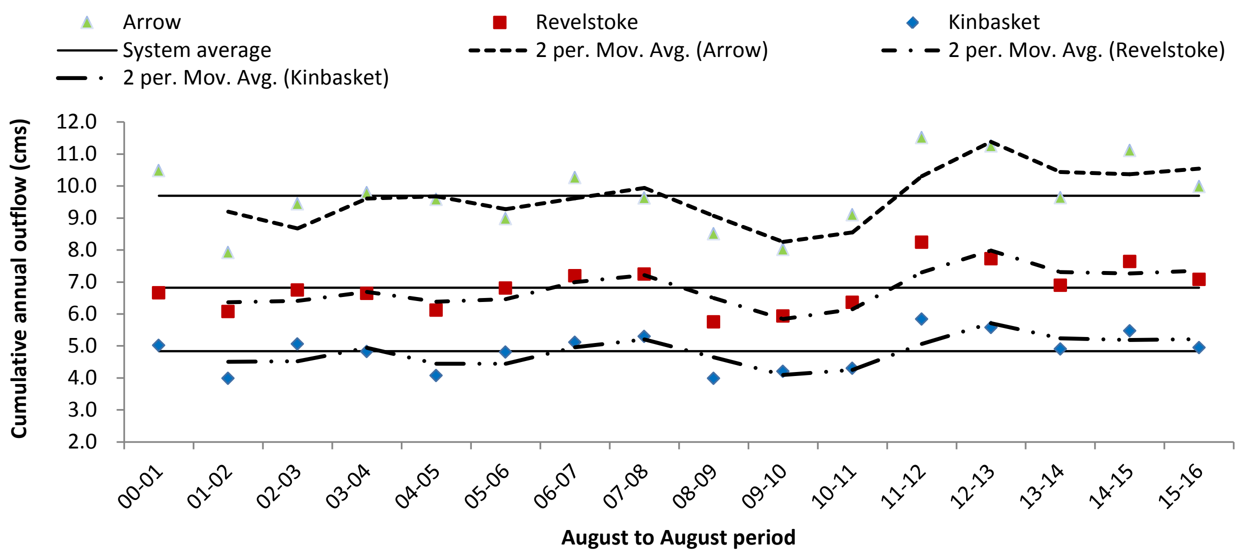

Figure 54. Cumulative outflow from August 1st to July 31st the following year for Kinbasket Reservoir (Mica Dam), Revelstoke Reservoir (Revelstoke Dam), and Arrow Reservoir (Hugh Keenleyside Dam) in millions of cubic metres per second.

Correlations between cumulative outflow and selected kokanee, copepods, and *Daphnia* data are shown in Figure 55. Negative correlations exist between cumulative outflow and kokanee productivity as represented by biomass density and age 0-1 survival for Kinbasket, Revelstoke, and Arrow Reservoir, with the fit increasing in strength moving downstream among reservoirs, namely with increasing outflow (Figure 55**,** panels a and b). Cumulative reservoir outflow is also negatively correlated with copepod density, although the model fit is relatively weak for each system (Figure 55**,** panel c). There was no relationship apparent between reservoir outflow and *Daphnia* density for any of the three reservoirs, although we expect that cumulative outflow from August to August may not be the most appropriate variant of the flow metric to evaluate against *Daphnia* metrics. *Daphnia* are not present in pelagic sampling until mid-summer and are expected to be highly influenced by factors that occur within, or in closer proximity to, the productive season, as opposed to factors such as flow or entrainment that occur over the winter and prior to the productive season. We expect that copepods, which are present throughout the year and peak in abundance earlier in the productive season, are exposed to flow conditions over a longer time frame leading up to the productive season sampling. Figure 55 suggests that increasing outflow appears to negatively affect kokanee and copepods, regardless of the overall productivity of the waterbody.

Inflow and habitat area

In Bray et al. (2013), we identified that a weak negative correlation existed between inflows (measured at Columbia River at Donald) and kokanee age 1-3 abundance in Kinbasket. Expanding the analysis to include phase 2 data (2012-2016) resulted in a similar outcome with only a minor improvement in the fit (R^2=0.3 versus 0.2 in phase 1). Also similar to phase 1, no relationships were found between kokanee abundance and inflow data for other periods of the year. The weak negative relationship between summer pool elevation and kokanee age 1-3 abundance observed during phase 1 (R^2=0.2) also remained essentially the same. Unless greater contrast in summer pool elevation is observed during the remainder of the study period, it is unlikely that further insight can be drawn from that relationship. It is possible that if changes in densities of age 1-3 fish are related to changes in pool level, it could be at least in part a result of fish moving from the main basins into the shallower basins such as Bush Pool and habitat zone 1 under higher pool elevations. We have made some progress in assessing fish abundance in Bush Pool; however, two years of data were insufficient to determine the extent to which fish are redistributing into shallow habitats as they fill to depths suitable for rearing during the summer. We will continue to monitor and assess kokanee in Bush Pool.

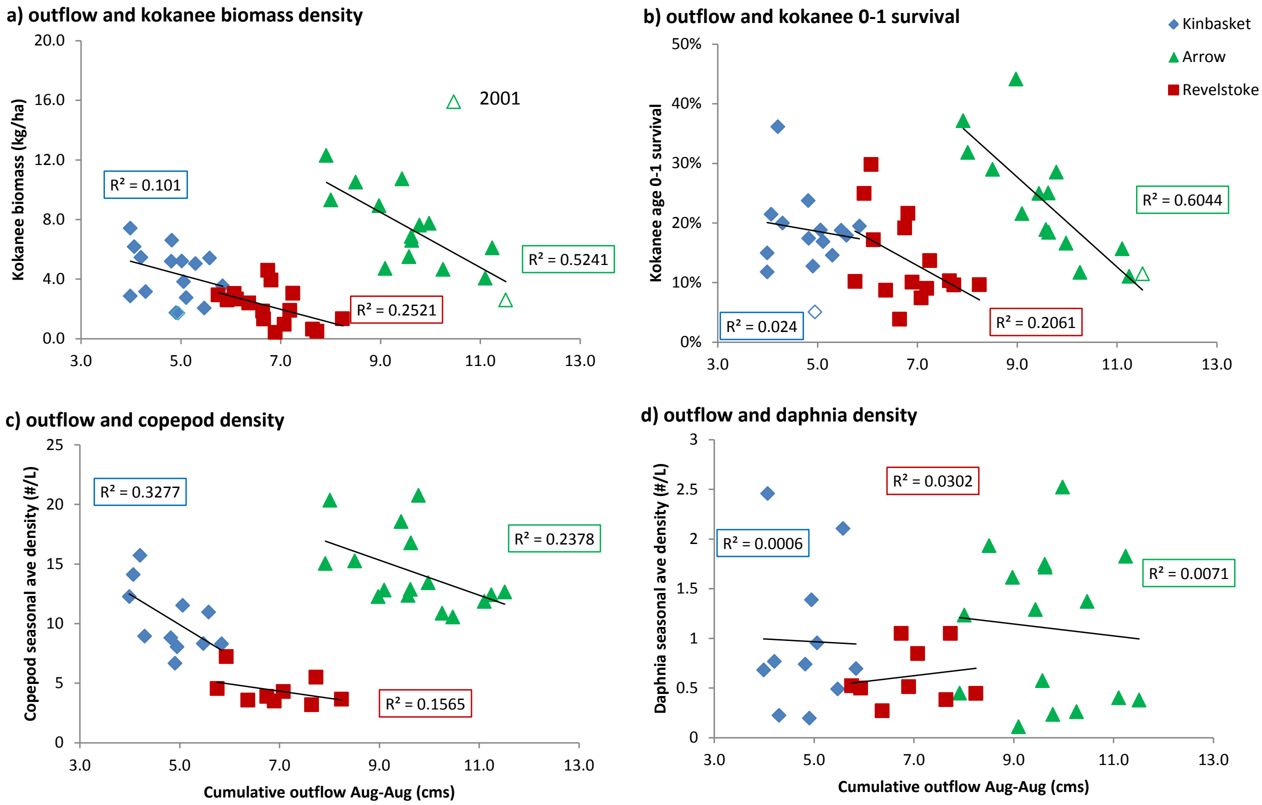

Figure 55. Relationships between annual cumulative outflow (millions of m^3/s) and a) kokanee biomass density (kg/ha), b) kokanee age 0-1 survival, c) copepod seasonal average density (#/L), and d) daphnia seasonal average density (#/L). Cumulative outflow is the sum of daily outflow values between August 1st to July 31st the following year for Kinbasket Reservoir (Mica Dam), Revelstoke Reservoir (Revelstoke Dam) and Arrow Reservoir (Hugh Keenleyside Dam). All available data from 2001 to 2016 are presented. Kokanee data for Kinbasket in 2016 and Arrow 2012 were omitted due to large-scale spring mortality events, and are presented as hollow points in panels a and b. The data point for Arrow 2001 kokanee biomass was omitted because it was in proximity to the onset of Arrow Reservoir nutrient restoration, a period considered not representative of typical post-fertilization conditions.

Spawning habitat quality/quantity

The newly developed indices of spawner abundance and egg-to-fry survival provide an opportunity to evaluate fry production trends and make inferences about spawning habitat characteristics. There was no apparent relationship between spawner abundance and fry density in the following year in either Kinbasket or Revelstoke (not shown); however, correlations between the egg-to-fry survival and both spawner size and spawner abundance are informative (Figure 53). In Kinbasket Reservoir there was a moderate positive correlation (R^2=0.42) between spawner size and egg-to-fry survival (Figure 56a). This observation, in conjunction with the strong positive correlation (R^2=0.78) between spawner size and the following year fry density in Kinbasket (Figure 50), indicates that there is a significant advantage in being a spawner at the large end of the size range (i.e. 250-275 mm range) to ensure improved fry recruitment to Kinbasket Reservoir.

For Kinbasket Reservoir, the strong negative correlation between spawner abundance and egg-to-fry survival (R^2=0.82, Figure 56b) is evident for many kokanee populations, and is indicative of a self-regulating population where egg-to-fry survival typically declines at higher spawner densities. The mechanism is likely that the best quality spawning habitat is limited and fully utilized by only part of the spawning run and late arriving fish either spawn over top of others in good habitat (superimposition) or move to lower quality habitats. In either event, egg-to-fry survival declines with increased numbers of spawners and can limit overall fry production.

In Revelstoke, where spawners have been relatively large compared to Kinbasket during the study period, there was an even stronger correlation between spawner size and egg-to-fry survival (R^2=0.80) further indicating an advantage to fish at the large end of the spawner size range (e.g. 300+mm in Revelstoke; Figure 56c). Where there is overlap in spawner size between the two systems, the egg-to-fry survival is considerably lower in Revelstoke tributaries, suggesting that spawning habitats are more limiting in area or quality compared to Kinbasket. This is consistent with observations that spawning habitat in Revelstoke tributaries appears to be limited to streams lacking extensive stable side channels that mean fish are more reliant on using mainstem channels with larger substrates and higher flow. The large spawner size in Revelstoke can be considered an advantage in these conditions. By comparison, there are a number of streams in Kinbasket with low gradient sections, extensive side channels, and more suitably sized gravel substrates.

In Revelstoke, kokanee population densities may now be so low that even with very large fecund spawners fry recruitment is limited, and egg-to-fry survival compensation may not be sufficient for recovery unless recent declines in age 0 to age 1 survival improve.

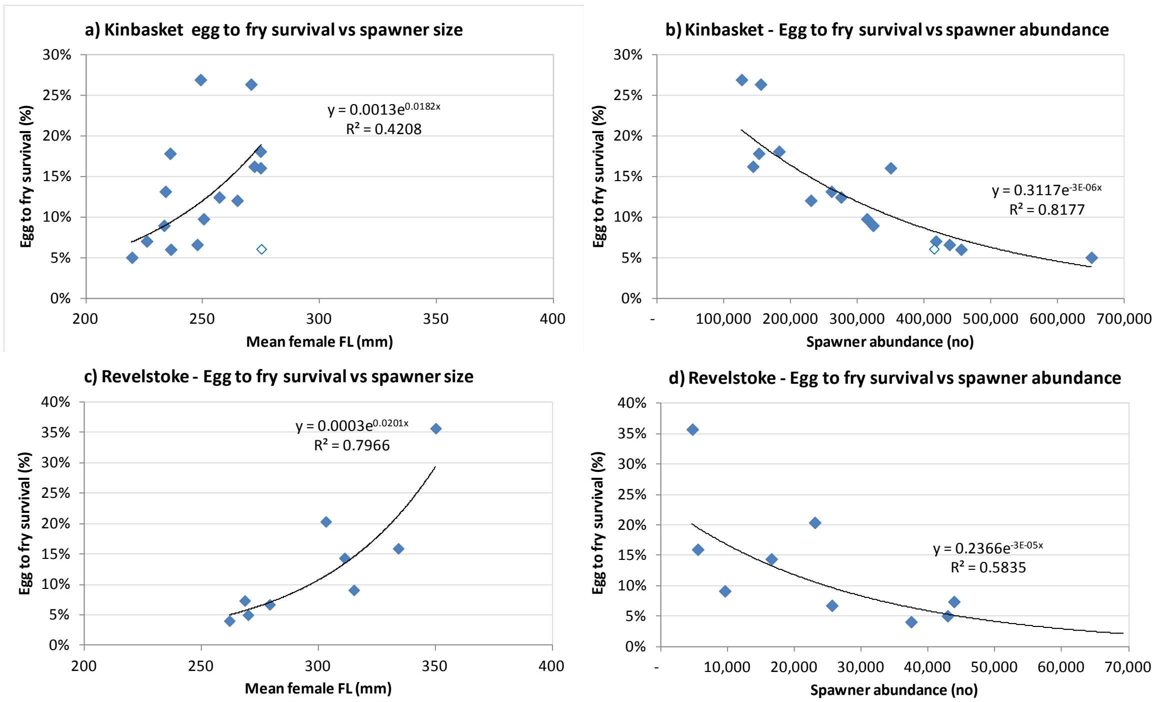

Figure 56. Correlations between egg-to-fry survival and mean female fork length of spawners in a) Kinbasket and c) Revelstoke are shown on the left side panels. Correlations between egg-to-fry survival and spawner abundance are shown on the right side panels for b) Kinbasket and d) Revelstoke. The hollow point in panels a and b for Kinbasket denotes an outlier in 2013 where it is believed that fecundity did not keep up to rapid increase in spawner size following a period of slow growth (see discussion surrounding Figure 50 above).

MQ 2-4 Can modifications be made to operation of dams to protect or enhance kokanee populations?

As with management question 3-8 that deals with potential operational modifications, this management question will be addressed in the final synthesis report. Addressing this question requires furthering our understanding of the role of reservoir operations on kokanee productivity and the key habitat factors that contribute to changes in kokanee productivity (Management Questions 2-2 and 2-3). Data collected to date are providing valuable insight and continuation of the time series alongside further evaluation of trophic level interactions will allow for a better understanding of the key drivers that are influencing kokanee populations over time and what options may be available to benefit kokanee.

5.0 Recommendations

The Study Team has met each spring to discuss results available and make alterations to the upcoming field year sampling plan based on collective learnings. This collaborative approach has proven very successful for implementing a complex, multi-disciplinary, cross-agency project.

In addition to furthering the analysis of results as described throughout this report, the following items are recommended:

1. Continue regular reservoir and tributary sampling program for physical and biological parameters with annual protocol refinements to establish long term trends.
2. Add total nitrogen to tributary and reservoir water chemistry analyses.
3. Continue spawner counts, collection of biological data on spawners, and pelagic gillnetting in addition to trawling,
4. Continue tributary temperature monitoring, calculate swim-up, and incorporate into analysis.
5. Further develop acoustic size distributions to track cohorts and estimate kokanee survival.
6. Explore potential to analyse genetics of the annual fall Arrow Reservoir trawl fry catch, with the intent of assigning kokanee fry to Revelstoke origin to better inform entrainment rates and annual variability.

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7.0 APPENDICES

Appendix 7.1 Echo target strength (TS) to Fork Length (FL) relation for Kinbasket Kokanee used to estimate biomass from density

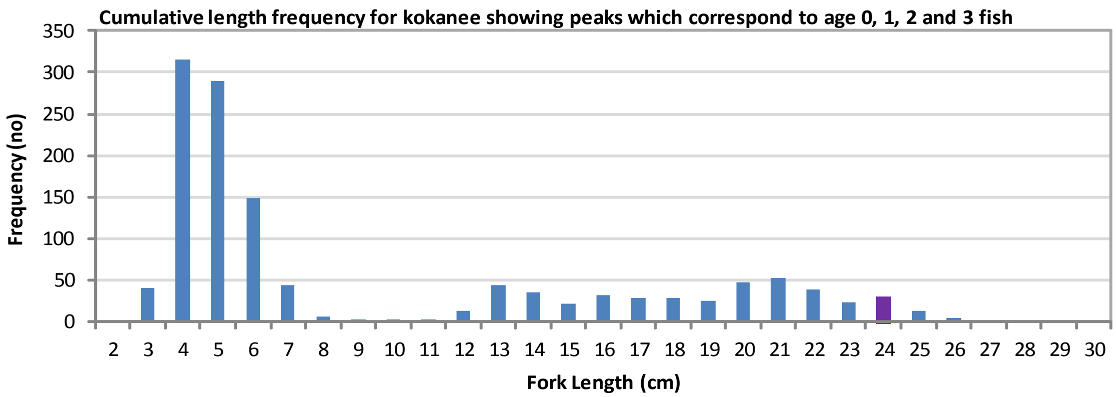
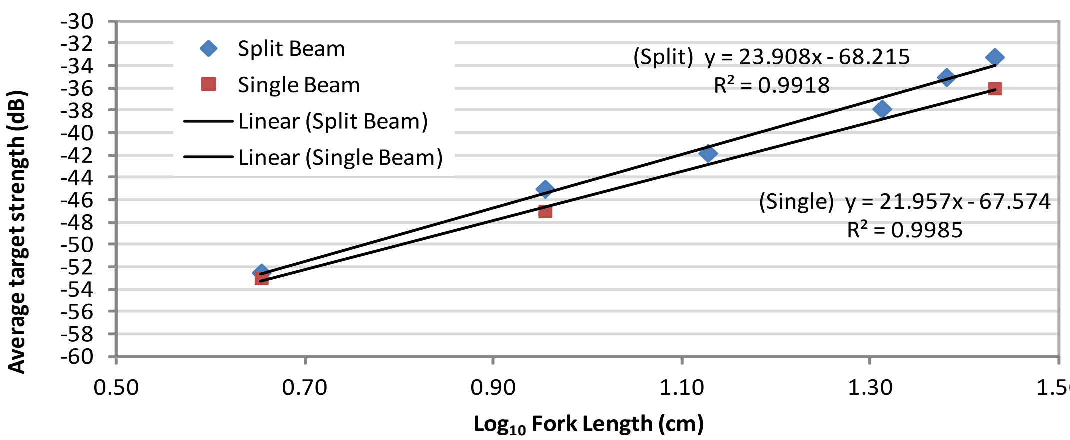


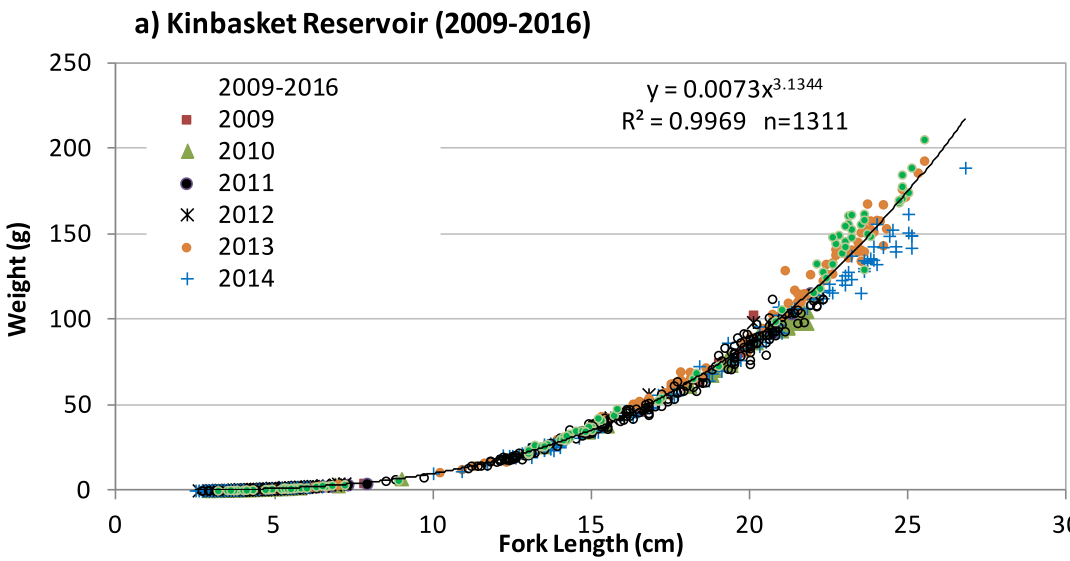
Table shows data used for Kokanee TS:FL regressions for split beam (SONAR5) and single beam (HADAS) data

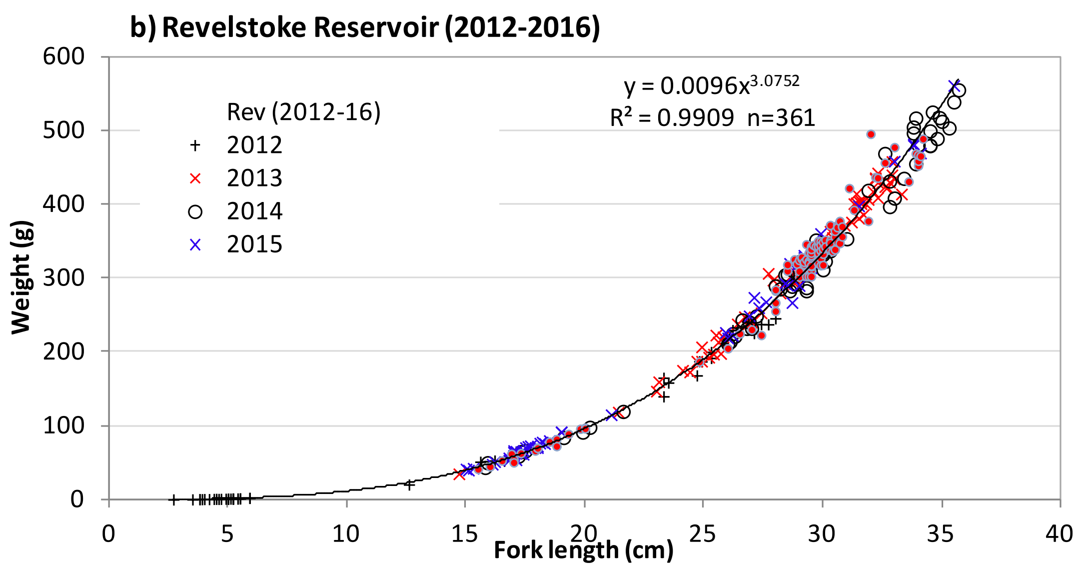
Reference	peak FL (cm)	scaled peak FL[1] (cm)	$Log_{10}(FL^1)$	Split Beam TS (dB)[2]	Single Beam TS (dB)[3]
age 0 (fry)	4	4.5	0.6532	-52.5	-53
cut-off	9	9	0.9542	-45.0	-47
age 1	13	13.4	1.1271	-41.8	
age 2	21	20.5	1.3118	-37.8	
age 3[4]	24	24	1.3802	-35.0	
largest KO	27	27	1.4314	-33.2	-36

1) based on a weighted average of two highest peaks
2) represents average of TS values from split beam 2009-2014 (note 2015 TS data not used due to early sampling date)
3) best estimate for single beam to correct for bias in fish size to bring biomass in line with split beam estimates
4) also contains 95% of all age 1-3+ so used as upper inflection and may indicate 3 peak



Appendix 7.2 Empirical length weight relations for Kokanee in a) Kinbasket and b) Revelstoke Reservoirs based on combined gillnet and trawl catches up to and including 2016

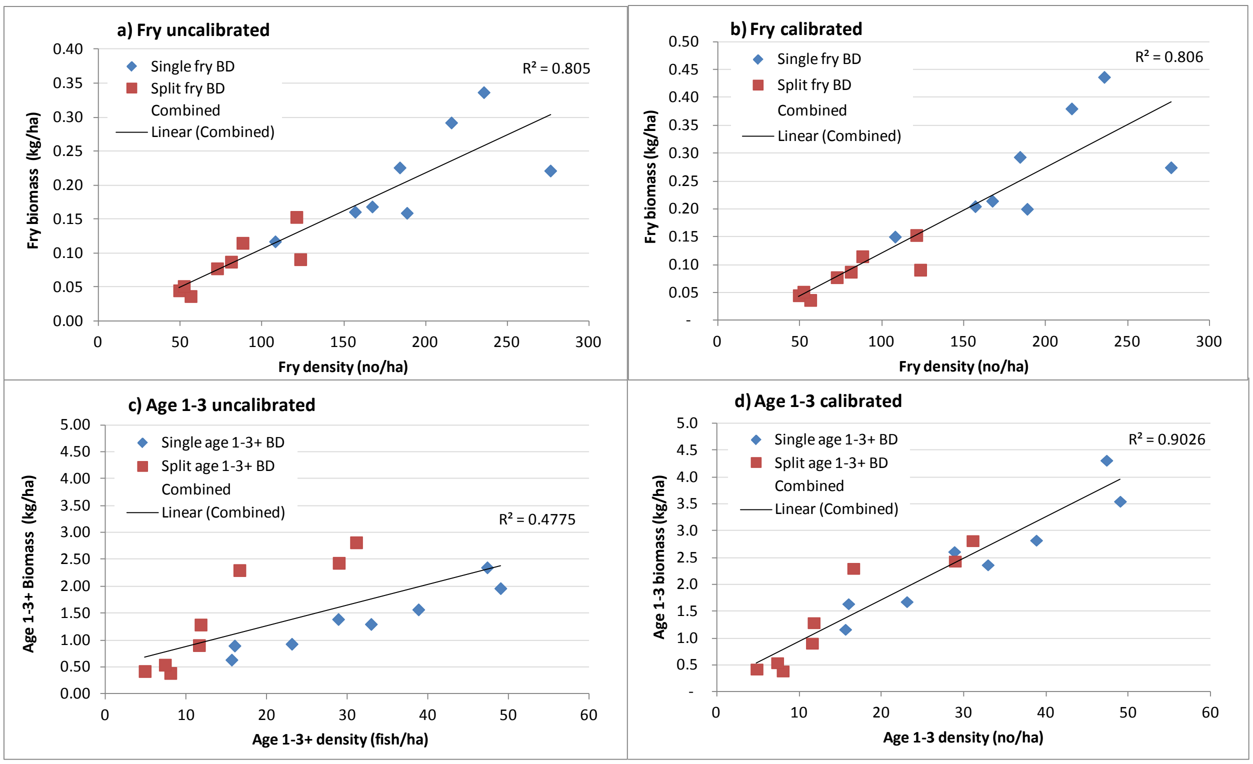




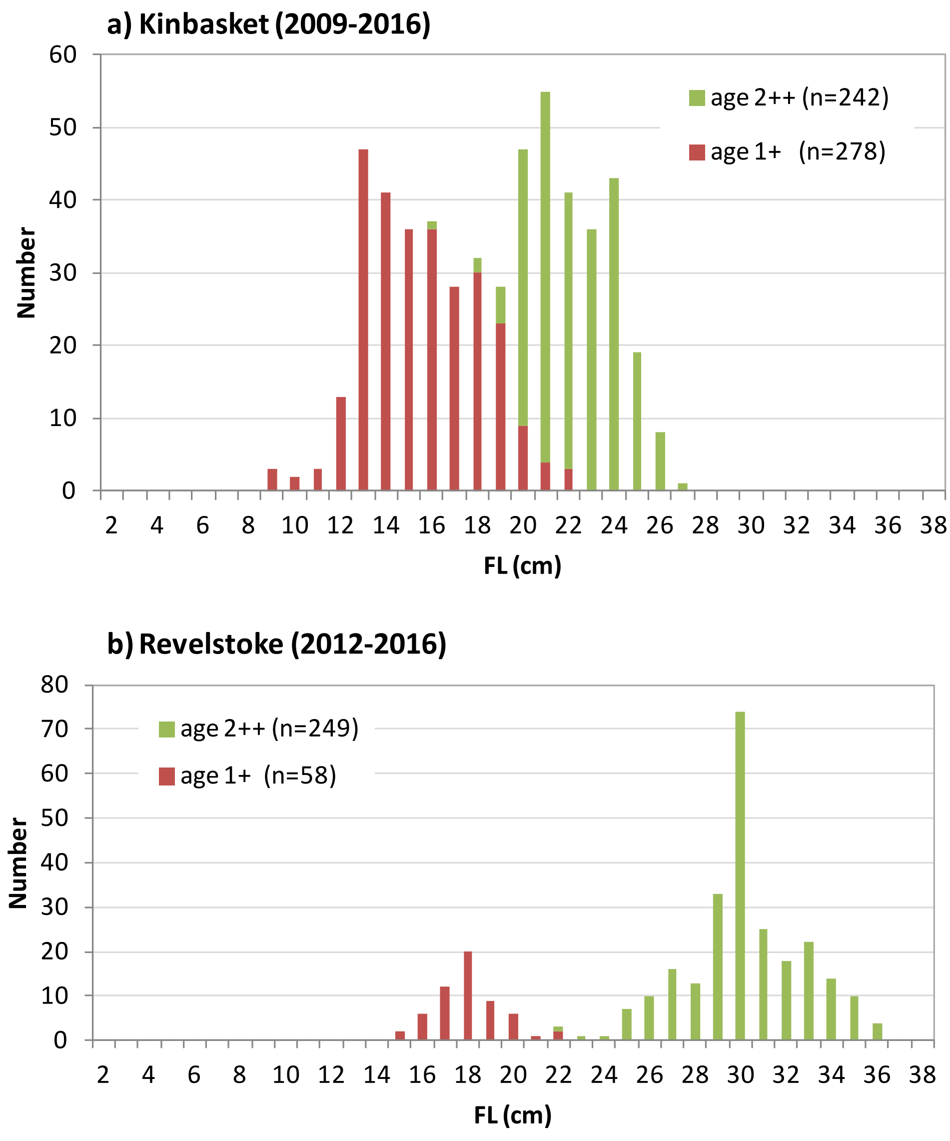
Appendix 7.3 Calculation of fork length and mean weight by 1 decibel size increment for Kokanee in Kinbasket and Revelstoke Reservoirs (used in biomass calculations)

TS:FL coefficients		**FL:WT coefficients P and Q**		
			Kinbasket	Revelstoke
A=	**23.909**	**P=**	0.0073	0.0096
B=	**-68.216**	**Q=**	3.1344	3.0752
TS	**FL (cm)**		**Kinbasket** Weight (g)	**Revelstoke** Weight (g)
-62	1.8		0.05	0.06
-61	2.0		0.06	0.08
-60	2.2		0.09	0.11
-59	2.4		0.12	0.15
-58	2.7		0.16	0.20
-57	2.9		0.22	0.27
-56	3.2		0.29	0.36
-55	3.6		0.39	0.48
-54	3.9		0.53	0.65
-53	4.3		0.72	0.87
-52	4.8		0.98	1.17
-51	5.2		1.32	1.57
-50	5.8		1.78	2.11
-49	6.4		2.41	2.84
-48	7.0		3.26	3.82
-47	7.7		4.41	5.14
-46	8.5		5.97	6.91
-45	9.4		8.07	9.30
-44	10.3		10.91	12.50
-43	11.3		14.76	16.81
-42	12.5		19.96	22.60
-41	13.8		26.99	30.40
-40	15.1		36.51	40.87
-39	16.7		49.37	54.96
-38	18.4		66.77	73.91
-37	20.2		90.29	99.38
-36	22.3		122.11	133.64
-35	24.5		165.14	179.70
-34	27.0		223.33	241.64
-33	29.7		302.02	324.93
-32	32.7		408.45	436.93
-31	36.0		552.37	587.53
-30	39.7		747.01	790.05
-29	43.7		1010.24	1062.36
-28	48.1		1366.23	1428.55
-27	53.0		1847.65	1920.95
-26	58.3		2498.72	2583.07

Appendix 7.4 Plots comparing corrected and uncorrected relation of density to biomass in Revelstoke Reservoir used to validate the calibration between single and split beam echosounder data developed from Kinbasket Reservoir acoustics.



Appendix 7.5 Cumulative length frequency distributions from combined trawl and gillnet catches in Kinbasket (2009-16) and Revelstoke (2012-16) Reservoirs showing the size cut-off between age 1+ and older (age 2++) Kokanee that was applied to partition acoustic data. Note the lower cut-off for age 2++ fish was ~20 cm (-37dB) in Kinbasket and ~23cm (-36dB) in Revelstoke Reservoir.



Appendix 7.6 Estimates of pelagic habitat area available to kokanee at annual minimum and maximum pool elevations in Kinbasket Reservoir, 2000-2015. Minimum and maximum values denoted by blue and red font respectively.

	Minimum pool elevation and habitat area			Maximum pool elevation and habitat area for kokanee					
Year	Low pool elevation (m)	Relative elev. [1] (m)	Pelagic habitat area [2] (km^2)	High pool elevation (m)	Relative elev. [1] (m)	Increase in main pelagic area [3] (km^2)	Increased marginal pelagic area [4] (km^2)	Total Increased pelagic area (km^2)	Total pelagic area (km^2)
2001	715	-39	156	742	-12	64	25	89	245
2002	712	-42	145	751	-3	88	68	156	301
2003	714	-40	152	744	-10	70	35	105	257
2004	718	-36	167	748	-6	60	55	115	282
2005	725	-29	186	750	-4	45	64	109	295
2006	727	-27	190	752	-2	44	73	117	307
2007	724	-30	183	754	0	54	83	137	320
2008	717	-37	163	752	-2	71	73	144	307
2009	730	-24	197	752	-2	37	73	110	307
2010	725	-29	185	753	-1	50	78	128	313
2011	725	-29	185	754	0	52	83	135	320
2012	722	-32	178	754	0	59	83	142	320
2013	723	-31	181	754	0	56	83	139	320
2014	725	-29	185	754	0	52	83	135	320
2015	737	-17	212	751	-3	20	69	89	301
2016	729	-25	195	753	-1	40	78	118	313
16yr ave	723	-31	179	751	-3	54	69	123	302
Pre Ave[5]	719	-35	168	749	-5	61	58	118	287
SP Ave[6]	*726*	*-28*	*187*	*753*	*-1*	*49*	*78*	*127*	*313*

1. Refers to elevation in m from the full pool elevation of 754 m
2. Pelagic habitat refers to habitat with depth of 20 m or greater
3. Refers to habitat zones 1-8; the steep sided main reservoir
4. Refers to the shallow zone 1 (near Valemount) and zone 9 (Bush Pool) where pelagic habitat was considered marginal for kokanee as depth is greater than 20m but <35 m.
5. Refers to average of 2001-2007 survey years (pre-study period)
6. Italicized averages are for the recent study period years 2008-2016

Appendix 7.7 Spawner size at age, age proportions and theoretical fecundity for Kinbasket Reservoir tributaries Camp, Luxor, Bush and Upper Columbia River.

Year	Mean Length at age (mm)			Sample size (no.)			% age 3+	Mean Female	Theoretical
	age 2+	age 3+	age 4+	age 2+	age 3+	age 4+	spawners	Length (mm)	Fecundity[1]
Camp Creek[2]									
1998	238	264		62	15		19%	242	377
2000	244	267		47	13		22%	249	411
2001	242	264		30	30		50%	250	416
2002	265	278		7	53		88%	275	536
2003	250	277		21	39		65%	265	487
2004	235	257		43	17		28%	236	356
2005	242	253	260	32	27	1	46%	248	402
2006	226	277		1	59		98%	275	536
2007		273			60		100%	271	516
2008	223	253		11	19		63%	233	347
2009	223			30			0%	220	289
2010	228			60			0%	226	313
2011	237	244		28	2		7%	234	344
2012	247	265		4	26		87%	257	446
2013	264	283		15	34		69%	275	540
2014	238	266		19	41		68%	249	411
2015	237	241		40	17		30%	236	350
2016	271	275	271	10	27	1	73%	272	523
Mean	242	264	260	460	479	1	51%	251	422
S.D.	14	12					32%	18	83
Luxor Creek[2]									
2007	249	268		27	4		13%	249	410
2009	209			30			0%	203	233
2010	224	244		29	1		3%	222	295
2011	223			10			0%	224	303
2012	233	247		24	17		41%	233	342
2013	252	264		41	13		24%	254	430
2014	231	256		36	3		8%	226	310
2015	221			33			0%	222	297
2016	243	255		46	3		6%	247	397
Mean	232	256		276	41		13%	231	335
S.D.	14	9						16	65
Bush River[2]									
2013	259			34	0		0%	259	455
2014	234	244		16	27		63%	229	324
2015	224	233		19	14		42%	225	311
2016	248	255		51	5		9%	243	382
Mean	241	239		120	46		28%	239	368
S.D.	15	8						15	66
Upper Columbia									
2014	234			45			0%	237	356
2015	226	225		14	2		13%	230	325
2016	261			39			0%	261	464
Mean	240	225		98	2		2%	243	382
S.D.	18							16	73

1. Fecundity was derived from female length based on an empirical relation by McGurk (2000)
2. Camp represent Kinbasket north end while Luxor and Bush represent south end populations
3. Red indicates years with large spawner size and blue indicates small spawner size defined as beyond ± 1 S.D. of the mean

Appendix 7.7 continued. Spawner size at age, age proportions and theoretical fecundity for Standard Creek, tributary to Revelstoke Reservoir.

Year	Mean Length at age (mm)			Sample size (no.)			% age 3+	Mean Female	Theoretical
	age 2+	age 3+	age 4+	age 2+	age 3+	age 4+	spawners	Length (mm)	Fecundity[1]
Standard Creek[3]									
2007	292	329		22	10		31%	303	710
2009	263	306		14	1		7%	268	505
2010	264	293		9	1		10%	270	511
2011	260	277		14	6		30%	262	469
2012	265	280		1	14		93%	279	559
2013	332	340		5	5		50%	334	922
2014	330	375		16	24		60%	350	1060
2015	303	333		18	9		33%	315	791
2016	307	342		14	1		7%	311	761
Mean	291	319		113	71		39%	299	699
S.D.	29	33						31	205

1. Fecundity was derived from female length based on an empirical relation by McGurk (2000)

2. Standard Creek, tributary to Downie Creek represents Revelstoke Reservoir spawners.

3. Red indicates years with large spawner size and blue indicates small spawner size defined as beyond ± 1 S.D. of the mean.

Appendix 7.8 Indices of spawner abundance, potential egg deposition and egg-to-fry survival for Kinbasket and Revelstoke Reservoirs based on acoustic abundance and size.

	Abundance of age 2++	% maturing	Spawner Index	Female FL (mm)	Fecundity[2]	Potential Eggs[3]	Following year Fry[3]	Suggested E-F survival
Kinbasket								
2001	378,576	83%	314,218	250	416	65.42	6.409	10%
2002	220,173	83%	182,744	275	536	49.02	8.883	18%
2003	277,523	83%	230,344	265	487	56.11	6.774	12%
2004	548,485	83%	455,243	236	356	81.00	4.887	6%
2005	527,416	83%	437,755	248	402	87.96	5.827	7%
2006	421,333	83%	349,706	275	536	93.67	15.068	16%
2007	187,068	83%	155,266	271	516	40.04	10.573	26%
2008	389,768	83%	323,507	233	347	56.12	5.040	9%
2009	783,507	83%	650,311	220	289	93.84	4.733	5%
2010	502,993	83%	417,484	226	313	65.32	4.608	7%
2011	314,660	83%	261,167	234	344	44.88	5.915	13%
2012	331,898	83%	275,476	257	446	61.43	7.663	12%
2013	501,983	83%	414,682	275	540	111.96	6.818	6%
2014	149,035	85%	126,679	249	411	26.03	7.021	27%
2015	212,704	72%	152,385	236	350	26.67	4.766	18%
2016	158,019	91%	143,654	272	523	37.57	6.111	16%
		83%	305,664	251	426	62.31		13%
Revelstoke								
2001	19,777	85%	16,748				1.108	
2002	48,369	85%	40,961				1.628	
2003	81,657	85%	69,151				1.100	
2004	39,236	85%	33,227				1.145	
2005	43,972	85%	37,237				1.260	
2006	67,022	85%	56,757				1.291	
2007	27,175	85%	23,013	303	710	8.17	1.667	20%
2008	43,579	85%	36,905				0.661	
2009	51,781	85%	43,851	268	505	11.08	0.820	7%
2010	50,642	85%	42,886	270	511	10.96	0.554	5%
2011	44,200	85%	37,431	262	469	8.77	0.358	4%
2012	28,987	88%	25,577	279	559	7.15	0.484	7%
2013	6,579	84%	5,499	334	922	2.53	0.405	16%
2014	6,059	77%	4,687	350	1060	2.48	0.888	36%
2015	11,289	85%	9,552	315	791	3.78	0.346	9%
2016	17,666	93%	16,512	311	761	6.28	0.905	14%
		85%	31,250	299	697	6.63		12%

1. Mean fork length of females for Camp Creek was used as an indices for Kinbasket Reservoir

2. Fecundity estimated using empirical relation in McGurk (2000)

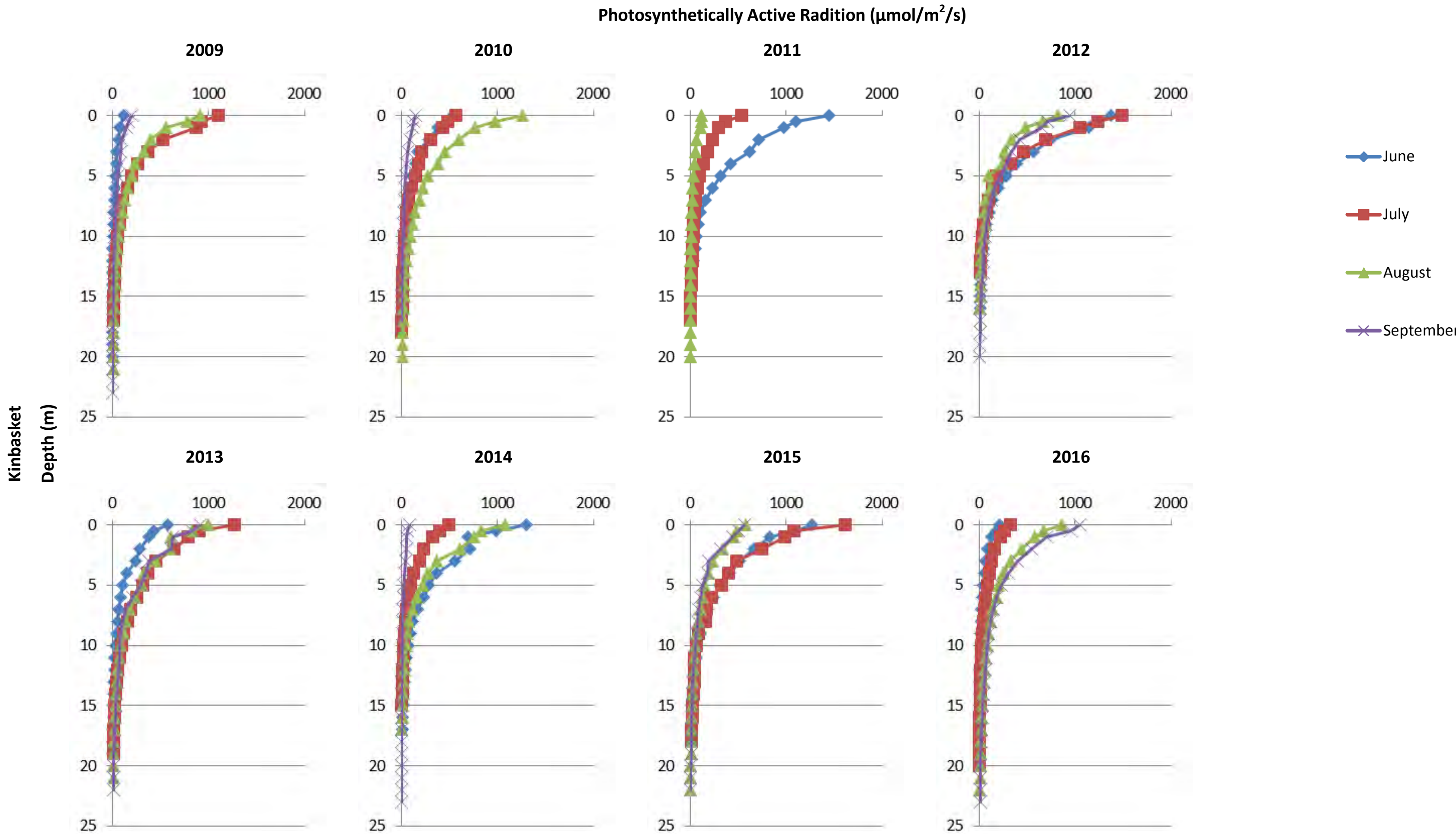
3. Potential egg deposition and following year fry are in millions

Appendix 7.9 Indices of age specific abundance based on acoustic size using cumulative trawl and gillnet data to determine best cut-off points between age 1 and age 2 fish. Indices of annual survival for age 0 - 1 and age 1 - age 2++ are also presented.

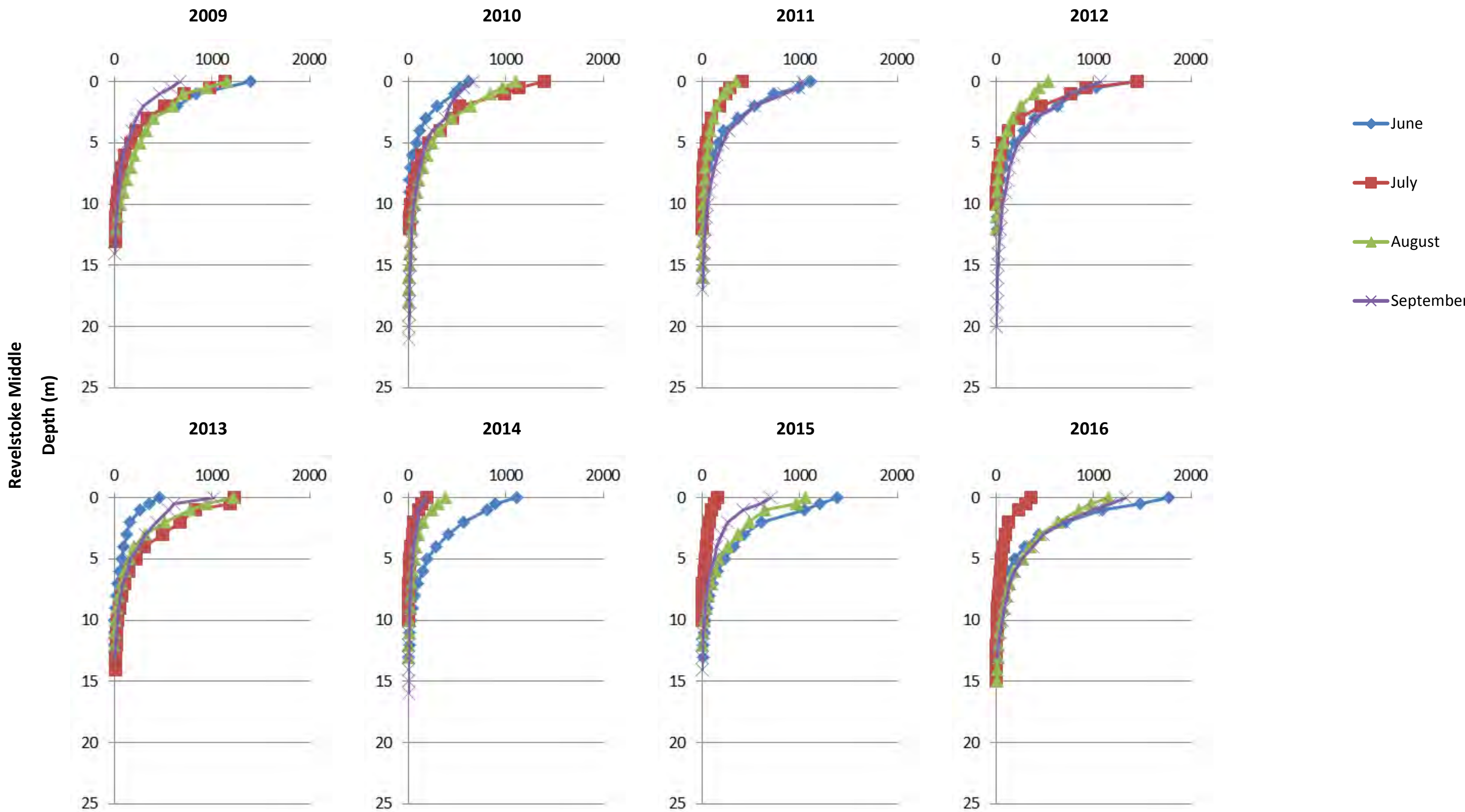
	Acoustic abundance estimates[1]			Index of	Index of
	Age 0+[2]	Age 1+[3]	Age 2++[3]	Age 0-1 survival	Age 1-2+ survival
Kinbasket					
2001	8,622,140	1,909,837	378,576		
2002	8,211,240	1,287,158	220,173	15%	12%
2003	9,759,767	1,541,560	277,523	19%	22%
2004	6,352,629	1,695,294	548,485	17%	36%
2005	5,614,416	1,359,215	527,416	21%	31%
2006	8,171,704	1,330,374	421,333	24%	31%
2007	14,506,091	1,376,439	187,068	17%	14%
2008	11,678,689	2,106,827	389,768	15%	28%
2009	4,756,431	1,370,620	783,507	12%	37%
2010	4,815,341	1,717,239	502,993	36%	37%
2011	4,282,746	960,808	314,660	20%	18%
2012	6,069,389	832,414	331,898	19%	35%
2013	8,626,582	940,711	501,983	15%	60%
2014	6,136,548	1,097,009	149,035	13%	16%
2015	6,420,751	1,149,144	212,704	19%	19%
2016	4,559,457	321,695	158,019	5%	14%
	7,411,495	1,312,272	369,071	18%	27%
Revelstoke					
2001	782,696	93,370	19,777		
2002	1,366,780	232,936	48,369	30%	52%
2003	2,002,965	261,530	81,657	19%	35%
2004	1,136,979	76,625	39,236	4%	15%
2005	1,334,952	194,693	43,972	17%	57%
2006	1,563,583	288,157	67,022	22%	34%
2007	1,212,781	140,120	27,175	9%	9%
2008	1,707,543	165,576	43,579	14%	31%
2009	638,399	173,537	51,781	10%	31%
2010	877,158	159,078	50,642	25%	29%
2011	587,537	76,069	44,200	9%	28%
2012	357,843	56,366	28,987	10%	38%
2013	519,881	34,153	6,579	10%	12%
2014	408,106	52,038	6,059	10%	18%
2015	894,323	41,941	11,289	10%	22%
2016	378,010	66,211	17,666	7%	42%
	985,596	132,025	36,749	14%	30%

1. based on abundance by acoustic size using 1 dB bins. Note these estimates are similar but not exactly the same as Maximum Likelihood Estimates (MLEs) for total abundance with bounds
2. The visual cut-off was used for separating age 0 and age 1 kokanee
3. The cut-off to separate age 1 and age 2 kokanee was based on cumulative trawl and gillnet catches suggesting a size of around 200mm in Kinbasket equating to -37dB for 120kHz data and -39dB for 70kHz single beam data. The Revelstoke cut-off was approximately 220mm equating to -36db for 120kHz data and -38dB for 70kHz single beam data.

Appendix 7.10 Photosynthetically active radiation (PAR) (µmol/m²/s) profiles at the Kinbasket, Revelstoke Middle, and Revelstoke Forebay from 2009-2016.



Appendix 7.10 continued Photosynthetically active radiation (PAR) ($\mu mol/m^2/s$) profiles at the Kinbasket, Revelstoke Middle, and Revelstoke Forebay from 2009-2016.



Appendix 7.10 continued Photosynthetically active radiation (PAR) (µmol/m²/s) profiles at the Kinbasket, Revelstoke Middle, and Revelstoke Forebay from 2009-2016.