Columbia River Project Water Use Plan

Kinbasket and Revelstoke Reservoirs Ecological Productivity and Kokanee Population Monitoring

Reference: CLBMON-2 and CLBMON-3

Kinbasket and Revelstoke Reservoirs Ecological Productivity and Kokanee Population Monitoring

2008-2011 Synthesis Report

Bray, K.[1], D. Sebastian[2], T. Weir[3], R. Pieters[4], S. Harris[5], D. Brandt[6], L. Vidmanic[7]

[1]BC Hydro, Revelstoke, B.C.
[2]Ministry of Forests, Lands and Natural Resource Operations/British Columbia Conservation Foundation, Victoria, B.C.
[3]Ministry of Forests, Lands and Natural Resource Operations, Victoria, B.C.
[4]University of British Columbia, Vancouver, B.C.
[5]Ministry of Environment, Vancouver, B.C.
[6]Advanced EcoSolutions, Newman Lake, Washington
[7]Limno Lab, Vancouver, B.C.

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Executive Summary

The Columbia River Water Use Plan (WUP), approved in 2004, 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. The goal of these studies is to provide the information necessary to inform future WUPs on operational decisions. 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 synthesis report covers the first four years (2008-2011) of effort on the limnological components and includes up to 10 years of kokanee population monitoring data.

With the limited four year set of limnological data it is difficult to assess long term trends or changes over time. The sample period was characterised by generally high full pool levels in Kinbasket Reservoir and cooler spring seasons. No trend in tributary nutrient inputs is evident to date although reservoir pelagic phosphorous values showed a general decline over the sample period. Nutrient chemistry and primary production demonstrate that both Kinbasket and Revelstoke Reservoirs are low in productivity and are classified as ultra-oligotrophic. Some key differences were noted between Kinbasket and Revelstoke Reservoirs. Primary productivity and phytoplankton monitoring have shown increasing abundance of small phytoplankton resulting in decreasing biomass in Kinbasket Reservoir, whereas Revelstoke Reservoir showed no appreciable trend. In turn, the zooplankton community, while showing some inter-annual variation, has also shown decreasing abundance and biomass in both reservoirs. Relative to 11 consecutive years of acoustic and trawl information kokanee were in a downward cycle over the four year study period. Age at maturity appears to be a key factor influencing kokanee size and annual recruitment levels in Kinbasket Reservoir, although it is not currently known which factors trigger maturation. Differences were apparent between Kinbasket, Revelstoke and other kokanee populations that may be indicative of flow and/or operational impacts, and require further study.

The report includes recommendations to continue regular reservoir and tributary sampling program for physical and biological parameters with annual protocol refinements to establish long term trends, and to attempt conducting sampling in shoulder months (April and Nov) as possible. Recommendations for kokanee population monitoring centre around improving spawner counts, collecting more biological data on spawners, increasing sample sizes for age 1-3 fish in both reservoirs using pelagic gillnetting, further developing acoustic size distributions to track cohorts and estimate kokanee biomass directly, and determining fry emergence times by installing temperature recorders in key spawning streams.

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1.0 INTRODUCTION

The Columbia River Water Use Plan (WUP) (BC Hydro 2007a) was concluded in 2004 following four years of public consultation (BC Hydro 2005) and accepted by the BC Comptroller of Water Rights in January of 2007. Water Use Plans were developed for each of BC Hydro's facilities to achieve optimal balance among 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 and the productivity of pelagic communities.

Two key programs ordered by the BC Comptroller of Water Rights and scheduled for implementation over twelve years (2008-2019) are:

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

The monitoring programs are being implemented in a phased approach with three consecutive four year cycles over a twelve year period. This report summarizes results of the first phase (2008-2011) of these WUP Monitoring Programs. Recommendations are made for adjustments and improvements to the two monitoring programs over the next two phases.

CLBMON-3 - The objectives for the Ecological Productivity Monitoring program (CLBMON-3) are to understand reservoir limnology and to determine if changes in pelagic productivity are associated with reservoir operations (BC Hydro 2007a). The sampling program will take advantage of previous limnological studies of Kinbasket Reservoir by BC Research (1977) and three consecutive years of limnological sampling conducted by BC Hydro during 2003-05 (data on file). The first of three phases has focussed on collecting data needed to develop a nutrient budget, measuring primary productivity, and conducting seasonal monitoring of physical, chemical and biological (i.e., phytoplankton and zooplankton) parameters. Results of the first phase are used to standardize and fine tune the monitoring program for the next two phases. When more data are available, a model will be developed to examine the factors that are most important in determining pelagic production in Kinbasket and Revelstoke Reservoirs. In order to address uncertainties around the influence of potential changes in operation of these reservoirs on pelagic productivity, the monitoring will focus 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. Seven management questions to be addressed by CLBMON-3 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. Are there operational changes that could be implemented to improve pelagic productivity in Kinbasket Reservoir?

CLBMON-2 - The objectives for Kokanee Population Monitoring (CLBMON-2) are to monitor trends in the biological characteristics, distribution, and abundance of kokanee and to provide information required to link the influence of reservoir operation to population levels. Twelve years of 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 natural (environmental) or operational (e.g. changes in water level, entrainment, etc.) effects. The kokanee monitoring project will take advantage of an additional seven consecutive years of standardized kokanee time series data collected during 2001-2007 under BC Hydro's Large River Indexing Program and previously reported by Sebastian (2008a and b) and Sebastian et al. (2010). Key management uncertainties encountered during the WUP process were related to how changes in operation would affect kokanee. Concerns focused on kokanee as this species is a key driver of the ecosystem providing an important food source for other sportfish species and a source of nutrients to the ecosystem. The history of kokanee in these reservoirs including kokanee stocking (1982-85) is discussed in detail by Sebastian et al. (2010). The most important issues to be addressed for kokanee in Kinbasket

Reservoir were identified as: potential effects of annual water level fluctuations on the 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 over the 12 year period 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 which affects productivity of reservoir kokanee populations. In concert with similar monitoring in Arrow Lakes Reservoir, 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.

CLBMON-56 - There is an additional component initiated in 2012 entitled 'CLBMON-56: Addendum #1 to CLBMON-3 Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring Program - Mica Project Units 5 and 6 Addendum'. This work is part of the Mica Unit 5 and 6 Environmental Assessment commitments, and focuses on the incremental effect of two additional generating units at Mica Dam on pelagic production and kokanee populations. The work will focus on measuring temperature data in both reservoirs at a fine scale through the use of moored arrays. Results from this component will be integrated with those of CLBMON-2 and CLBMON-3 for 2012 onward.

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 BC, is bounded by the Rocky Mountains to the east and the Columbia Mountains to the west. The reservoir was formed in 1973 with completion of Mica Dam and subsequent flooding of approximately 431 km^2 of river and valley bottom habitat along the Columbia, Canoe, Wood, and Bush Rivers, including some small lakes (Figure 1).

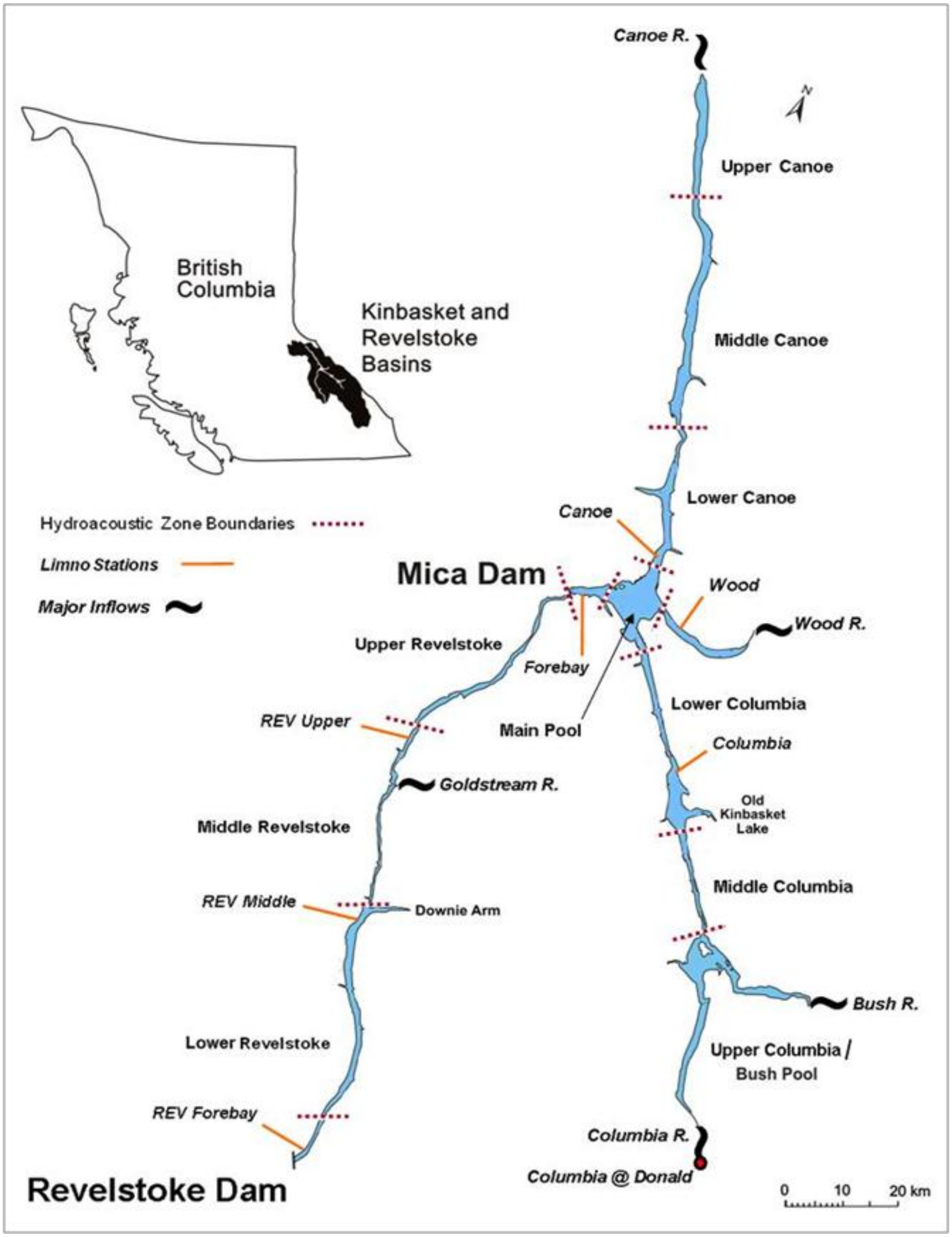


Figure 1. Map of Kinbasket and Revelstoke reservoirs showing major inflows, location of key limnology sampling stations, and habitat zones for kokanee hydroacoustics.

The combined inflows pass through Mica Dam and enter Revelstoke Reservoir. Revelstoke Reservoir, bounded by the Selkirk Mountains to the east and the Monashee Mountains to the west, extends from the base of Mica Dam, 130 km south to Revelstoke Dam located 5 km upstream of Revelstoke BC. The reservoir was formed in 1984 with completion of Revelstoke Dam and subsequent flooding of 116 km^2 of the narrow Columbia River valley.

Morphometrics - The characteristics of Kinbasket and Revelstoke Reservoirs are summarized in Table 1. Kinbasket Reservoir has a surface area of 43,100 ha at normal maximum and volume of 24,800 million m^3 (Hirst 1991) at normal maximum. The mean and maximum depths are 57 m and 170 m respectively and bulk retention time is about 16 months. The reservoir is ~216 km in length at full pool (Bray 2012). While the difference between maximum and minimum water level is 47 m (Table 1), the average drawdown is 25 m, with an average reduction in surface area of 30%.

Revelstoke Reservoir is less than one third the size of Kinbasket with a maximum surface area of 11,600 ha and mean and maximum depths of 46 and 120 m respectively. It is 130 km long and averages less than 1 km in width. Pool elevation is held relatively constant at ~572 m above sea level with an annual fluctuation typically less than 2 m. The bulk retention time is about three months.

Table 1. Characteristics of the reservoirs.

	Max. Depth (m)	Area* (km^2)	Mean Outflow (m^3/s)	Elevation of normal maximum (m ASL)	Drawdown (m)	Drawdown Area (km^2)	Outlet Depth** (m)
Kinbasket R. Mica Dam	~190	431	590	754.4	47	220	17-65
Revelstoke R. Revelstoke Dam	~120	116	750	573.0	1.5	2.4	27-29

* At normal maximum as given by the BC Hydro storage elevation curves (see Pieters and Lawrence 2013a).
** Depth of outlet from water surface, from normal minimum to normal maximum.

Reservoir Operations – Kinbasket Reservoir has the largest storage volume - more than twice the next largest - of all reservoirs on the Columbia River. The total storage on Kinbasket Reservoir is 12 million acre-feet (MAF)[1] of which 7 MAF are operated under the Columbia River Treaty (BC Hydro 2007). The other 5 MAF are operated under a Columbia River Non-Treaty

[1] 1 million acre feet (MAF) = 1.2 km^3.

Storage Agreement (NTSA) with Bonneville Power Administration (BPA). Under this agreement, BC Hydro and BPA co-ordinate the operation of storage additional to Treaty storage in Kinbasket and Arrow Lakes reservoirs and share the use of mainstem Columbia River power generation facilities in Canada and the United States, with benefits to both parties. Under the NTSA, both BC Hydro and BPA may request daily changes in the scheduled discharges from Arrow Lakes Reservoir. For the period 2008-2011 no NTSA was in place, the original agreement terminated in 2004 and both parties fulfilled their obligation to refill the storage accounts by January 2011. This contributed to higher reservoir elevations throughout the study period. A new NTSA was signed in April 2012.

Application may be made for additional storage up to 0.3 m above normal maximum through the Comptroller of Water Rights for economic, environmental or other purposes if there is a high probability of spill. The total discharge capacity of the four turbines at Mica Dam is 1265 m3/s. Two additional units scheduled for completion by 2015 will bring the total capacity to approximately 1840 m^3/s.

Revelstoke Reservoir has licensed storage of 1.5 MAF and an operating range of between 573.02 m and 554.54 m although the reservoir is normally kept within 1.5 m of the maximum elevation throughout the year to maximize the turbine hydraulic head and maintain a small storage buffer for operational flexibility and short-term variations in inflow. Revelstoke water level is maintained fairly constant by regulating output at Mica and Revelstoke Dams so that the two facilities are operated in hydraulic balance. A continuous minimum flow of 142 m^3/s was established for the middle Columbia River below Revelstoke Dam in Dec 2010 together with initiation of the fifth turbine operation. The completion of the fifth unit brought Revelstoke Dam discharge capacity to 2124 m^3/s; there is room for one remaining generating unit.

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 (2013a). Daily average values are shown unless noted otherwise.

2.2 Tributary chemistry and temperature

Two types of tributary samples have been collected over the study period: (1) sampling of reference tributaries in June 2008 and May to November 2009-2011, and (2) surveys of many tributaries at the same time. Surveys were undertaken across both reservoirs in 2008 and 2009 (Pieters et al. 2011) and are planned in future years to capture a range of seasonal flows.

Four reference tributaries – Columbia River at Donald, Kinbasket outflow, Goldstream River, and Revelstoke outflow – were sampled in June 2008, and then twice monthly in May and June, and once a month from July to October in 2009-2011. Water samples were collected in a bucket and then transferred into sample bottles. Temperature was measured with a handheld thermometer. Filtration was done later the same day. Water samples were either frozen or kept on ice and shipped within 48 hours to the Department of Fisheries and Oceans, Cultus Lake Salmon Research Laboratory, 4222 Columbia Valley Highway Cultus Lake, British Columbia. Details of sample locations, water quality parameters and laboratory methods are given in Pieters and Lawrence (2013b). Samples from the fifth reference tributary - Beaver River - were collected by Parks Canada and analyzed by Environment Canada.

The first survey was conducted in 2008, with 12 tributaries sampled on June 24 and 21 sampled on August 5. The second survey was conducted in 2009, during which 37 tributaries (the 33 tributaries of 2008 plus an additional 5) were surveyed on July 7-8. These surveys sampled approximately 2/3 of the total inflow to Kinbasket, and 9/10 of the inflow to Revelstoke Reservoir. Samples were collected as described above for the reference tributaries; for details see Pieters and Lawrence (2011).

2.3 Reservoir Limnology

2.3.1 Reservoir Sampling Stations

Regularly scheduled sampling occurred once a month from May to October at four stations in Kinbasket Reservoir and three stations in Revelstoke Reservoir (Figure 1). Sampling began in July 2008; Kinbasket sampling was not conducted in June and September 2011 due to high water levels and the presence of large amounts of woody debris that prevented boat access. Samples were collected for physical properties, water chemistry, phytoplankton, picoplankton, and zooplankton as described below.

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 (2013c).

2.3.3 Water Chemistry

Five litre Niskin bottles were lowered by cable in series to collect discrete depth samples at 2, 5, 10, 15, 20, and 60 m. An additional sample at 5 m above bottom was collected at all stations except for Revelstoke Upper (~40 m max depth) and sometimes Kinbasket Wood when max. depth is <65 m depth. In 2011, 35 m and 45 m depth samples were added to provide more data from the metalimnion. Samples were field filtered for TDP and SRP and kept cold or frozen before shipping to the Cultus Lake Laboratory for analyses. Samples were analysed for nitrite+nitrate (NO_2+NO_3), total phosphorus (TP), total dissolved phosphorus (TDP), soluble reactive phosphorus (SRP), alkalinity, conductivity, pH, turbidity, and TP turbidity. A 20 m tube with inside diameter of 2.54 cm was used to obtain a 0-20 m integrated depth sample for analysis of silica (Si) and chlorophyll *a* at each station. A summary of sample preparation, analytical methods, and laboratory detection limits is contained in Pieters and Lawrence (2013b). The ratio of NO_2+NO_3 to TDP (weight:weight) was calculated to evaluate nutrient limitation in lieu of DIN:TDP with a minimum target ratio of 7.5:1 (Ashley and Stockner 2003). In this case, NO_2+NO_3 is considered an adequate replacement for dissolved inorganic nitrogen as both NO_2 and NH_4 are in low concentrations, the latter found to be consistently below detection limits in 2003-2005 sampling (BC Hydro, data on file). Secchi disk readings were taken without a viewing tube at each site using a standard 20 cm Secchi disk. The disk was lowered on the shady side of the boat (no sunglasses were worn) to a depth where it could no longer be seen and then raised to where it became visible; the two depths were averaged to arrive at the final reading.

2.3.4 Phytoplankton and Picoplankton

Discrete depth samples were taken at depths of 2, 5, 10, 15, and 25 m and preserved with Lugol's for identification and enumeration. Two depth strata, epilimnetic and hypolimnetic, were assessed by calculating the mean of the densities and biovolume of taxa from samples collected at 2, 5, and 10 m and 15 and 25 m, respectively. In 2008 and 2009 composite sample were prepared in the field by combining equal volumes from each depth stratum, whereas in 2010 and 2011 all discrete depth samples were analyzed separately and the data combined to determine epilimnetic and hypolimnetic composites. The change in methodology in 2010 and 2011 is compatible with the previous years' sampling methodology; however, the taxa richness could be higher in the composited samples from 2010 and 2011 due to the increased taxonomic effort.

Additionally, at each station an aliquot of composited water was taken for bacterial and pico-cyanobacterial enumeration. Bacteria samples were preserved with three drops of 25% glutaraldehyde and placed in a brown polyethylene bottle. Bacterial and pico-cyanobacterial densities from composite water samples from both the epilimnion (0-10 m) and hypolimnion (15-25 m) were collected. Enumeration protocols for phytoplankton and picoplankton are described in Brandt (2013). The compendium of Canter-Lund and Lund (1995) was used as a taxonomic reference.

2.3.5 Zooplankton

Samples were collected with a vertically hauled 153 µm mesh Wisconsin net with a 0.2 m throat diameter. The depth of each haul was 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).

2.4 Primary Production

Primary productivity was measured once a month from June-September on Kinbasket Reservoir at the Forebay station and on Revelstoke Reservoir at the Forebay station and Middle station. Water samples for chlorophyll and primary production were collected between 8:00 and 9:00 am using Niskin bottles. Samples were collected from the surface to the 1% light depth as determined with a Licor LI-185A quantum sensor and meter. Two light and one dark 300 ml acid-cleaned BOD bottles were rinsed three times with lake water before filling. Disposable latex gloves were used for all sampling to avoid contamination. Care was taken to eliminate contact with latex since latex is toxic to phytoplankton (Price et al. 1986). The samples were maintained under low light conditions during all manipulations until the start of the incubation. Samples were inoculated with 0.185 MBq (5 µCi) of $NaH^{14}CO_3$ New England Nuclear (NEC-086H). The BOD bottles were attached to acrylic plates and were suspended in situ for 3-4 h, generally between 9 am and 2 pm. Alkalinity samples were collected from the surface and the deepest sample depth in 125 ml polycarbonate bottles. At the end of the incubation period, the BOD incubation bottles were stored in a dark box until the incubations were terminated by filtration. One hundred ml from each BOD bottle was filtered through each of a 0.2, 2 and 20 µm 47-mm polycarbonate filter using <100 mm Hg vacuum differential (Joint and Pomroy, 1983). Each filter was placed in a 7-ml scintillation vial and stored in the dark until processing at the UBC lab. In 2008, the 20 µm filter was replaced with a 10 µm filter due to difficulty in obtaining 20 µm filters. This change in methodology prevents the direct comparison of the current study with the data collected in 2008 due to lack of a clear separation of nanoplankton and microplankton. Results from the 2011 study are comparable to those collected in 2010, 2009 (Harris 2010) and 2002 (Stockner and Korman 2002).

In the fume hood, 100 µL of 0.5 N HCl were added to each vial to eliminate the unincorporated inorganic $NaH^{14}CO_3$. The scintillation vials were left uncapped in the fume hood until the filters were dry (approx. 48 h) and 5 ml of Ecolite® scintillation fluor was then added to each vial. The vials were stored in the dark for >24 hours before the samples were counted using a Beckman® Model #LS 6500 liquid scintillation counter. Each vial was counted for up to 10 minutes while the counter operated in an external standard mode to correct for quenching.

The specific activity of the ^{14}C stock was determined by adding 100 µL 14C-bicarbonate solution to scintillation vials containing 100 µL of ethanolamine and 5 ml Ecolite® scintillation cocktail. Rates were calculated according to Parsons et al. (1984) to obtain hourly primary productivity and were vertically integrated according to procedures of Ichimura et al. (1980). Daily primary productivity was calculated by multiplying hourly primary productivity by the incubation time and by the ratio of the solar radiation during the incubation to the solar radiation of the incubation day.

Chl *a* corrected for phaeopigments was determined by *in vitro* fluorometry (Yentsch and Menzel 1963). Water samples (0.5-1 L) were filtered using parallel filtration onto 47 mm diameter 0.2, 2.0 and 20.0 µm polycarbonate Nuclepore™ filters using a vacuum pressure differential of <100 mm of Hg. Samples were stored at –20°C prior to analysis. Chl *a* was extracted from the sample in 5 ml of 90% acetone and stored covered in the freezer for 20-24 h. The fluorescence of the acetone extract was measured before and after the addition of three drops of 10% HCl in a Turner Designs™ Trilogy fluorometer calibrated with a solution of commercially available Chl *a*. Calculations for Chl *a* were made using the equations of Parsons et al. (1984). The average phytoplankton biomass of the euphotic zone was determined by calculating the mean of all sampling depths. Areal biomass (mg/m^2) was calculated by vertical integration of all depths according to procedures of Ichimura et al. (1980).

2.5 Kokanee

2.5.1 Habitat

Estimates of pelagic habitat area for kokanee at maximum and minimum annual pool elevations and kokanee survey periods were derived from Appendix 5 of Sebastian et al. (2010). The area estimates were originally interpolated to one metre pool elevation increments by Sebastian et al (1995) for nine habitat sections in Kinbasket Reservoir and two sections in Revelstoke Reservoir based on pre-impoundment contour mapping. To conform with the limnology sampling, two additional habitat zones were identified near the forebay areas of Revelstoke and Mica Dams, while the Lower Columbia and Old Kinbasket Lake sections were combined into a single zone referred to as the Lower Columbia (Figure 1). In Kinbasket Reservoir the Main Pool is located upstream of the Forebay and represents a junction of three upstream reaches, Canoe, Wood and Columbia, which have been described in clockwise order in Table 2.

Table 2. Kinbasket and Revelstoke Reservoirs showing habitat zones based on kokanee distribution and limnology sampling stations.

Zone	Description	Hydroacoustic Transects	Limno Stations
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 40m contour	1-4	
Upper Canoe	40m contour to Valemount	NS	
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	NS	
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	NS	

NS = not sampled

2.5.2. Hydroacoustic Surveys

Kokanee hydroacoustic surveys were conducted at night within 5 days of the new moon from mid-July to mid-August, 2008-2011. Surveys consisted of 30 transects in Kinbasket Reservoir and 20 transects in Revelstoke Reservoir as outlined in Sebastian et al. (2010). Due to adverse sampling conditions (e.g. high winds and dense debris fields) not all transects could be accessed all years. Acoustic survey data were collected using a Simrad model EK60 120 KHz split-beam echosounder. Transducers on planers were towed alongside the boat at a depth of 1 m and data collected continuously along survey lines at 4 - 8 pings/s while cruising at 2 m/s (7.2 km/hr). The acoustic survey data were stored on a Panasonic "Toughbook" PC laptop and then analyzed using SONAR 5-Pro Echo Processing Software Version 5.9.9 (Balk and Lindem 2009). Population estimates were extrapolated only to pelagic habitat area since all sampling was done in deep water. Detailed methods for system specifications and data processing can be found in progress and data reports by Sebastian et al. (2010) and Johner and Weir (2012).

2.5.3 Trawl Surveys

Surveys in Kinbasket Reservoir typically consisted of 2 trawls in the Main Pool and one trawl in Lower Canoe Reach. Due to generally low fish densities and an often limited window of suitable weather and debris conditions, the strategy was to maximize catch by focusing effort at depths where highest densities of fish were observed on the echosounder. Trawl sampling was confined to areas where there was sufficient water depth between submerged trees and the night-time fish layer for safe operation of the trawl gear. The trawls were typically of one hour duration and fished either one 7 m layer for 1 hr or two adjacent 7 m layers with individual layer durations of 30 minutes. The trawl net was a 15 m long dual cable beam-trawl with a 3 m wide by 7 m high opening towed at ~0.8 m/s. The net consisted of graduated mesh panels from 10 cm at head bar to 0.6 cm at cod-end. Net depths were determined using a Notus trawl depth sensor and a global positioning system (GPS) was used to determine distances travelled and resulting trawl sample volumes.

Trawling in Revelstoke typically consisted of one trawl near the forebay downstream of the Martha Creek boat launch and an additional 1-2 trawls further upstream but still in the lower Revelstoke basin. Trawl durations were approximately one hour with either a single 7 m depth layer of one hour duration or two consecutive 7 m depth layers of 30 minutes each. Fish were kept on ice until morning and then sampled for length, weight, sex, and scales for age determination. Scale analyses were performed at the Ministry of Environment laboratory at the Fraser Valley Trout Hatchery in Abbotsford BC.

2.5.4 Spawner surveys

Kokanee have been enumerated annually by spawner surveys in up to 11 index streams for Kinbasket Reservoir since the mid 1990's based on Oliver (1995). Index tributaries include Kinbasket, Wood, Bush, and upper Columbia Rivers and Dutch, Toby, Horsethief, Forester, Luxor, Succour and Camp Creeks. On Revelstoke Reservoir, kokanee counts were conducted on seven streams in the 1990s while only a single stream system, Downie Creek and its tributary Standard Creek, continue to be enumerated. Aerial survey methods are described in detail by Johner and Weir (2012). Flights were conducted during the approximate peak of spawning activity during the last week of September/first week of October. Due to external circumstances, from 2010 onward one of the key areas with the highest annual counts (i.e., Upper Columbia River) could no longer be enumerated by helicopter and is no longer available as an index.

Individual stream counts are subject to considerable variability from stream to stream and year to year depending on water clarity, weather and flow stage. For showing general trends in abundance and distribution spawner counts were combined into three stream groups (i.e., Upper Columbia mainstem, tributaries to upper Columbia and tributaries entering Kinbasket Reservoir) and then recent cumulative counts (2008-11) were compared with the longer term average (2001-2011).

Biological sampling of spawners captured by dip-net has been conducted at Camp Creek (1998, 2000-2011) and Luxor Creek (2007, 2009-2011) for Kinbasket Reservoir and at Standard Creek (2007, 2009-2011) for Revelstoke. Sex, fork length and age data were collected for estimating mean length and age composition. Spawner ages were determined from otolith interpretations following protocols in Casselman (1990).

3.0 RESULTS

3.1 Hydrology

The major inflow to Kinbasket Reservoir is provided by the Columbia River from the south (30%, Pieters and Lawrence 2013a). However, tributaries along the Upper Columbia Reach, also contribute significantly to the total inflow (29%) and together with the Columbia River give 59% of the inflow to Kinbasket Reservoir at the outlet of Bush Pool (Figure 1). The Middle and Lower Columbia Reaches together contributes a further 15%. In contrast the contributions from the northern part of Kinbasket Reservoir – Canoe Reach – are only 18% with the Canoe River entering at the north end contributing only 3%, and the remainder of Canoe Reach 15%. 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 in July and August.

Revelstoke Reservoir is operated run-of-the-river, a type of hydroelectric generation which provides little storage, 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).

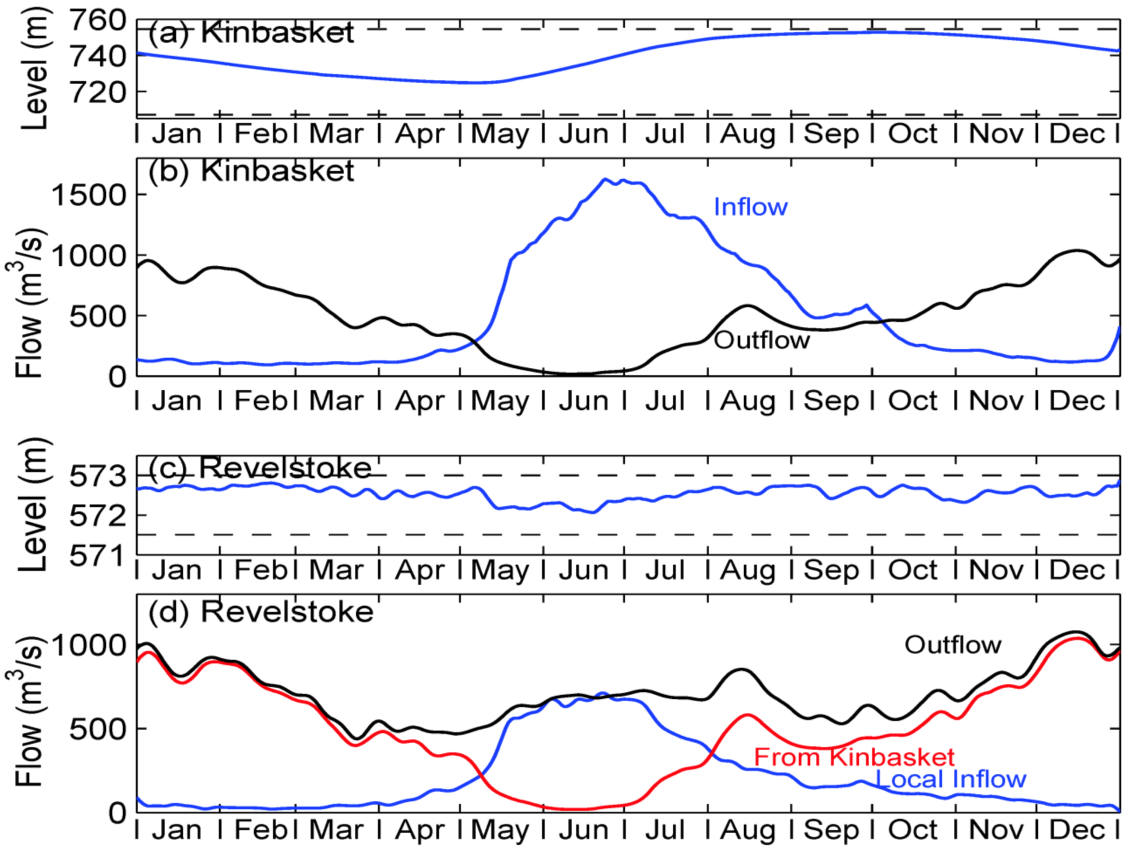


Figure 2. (a) Average water level, and (b) average inflow and outflow for Kinbasket Reservoir, 2008-2011. (c) Average water level; and (d) average local inflow, inflow from Kinbasket Reservoir, and outflow for Revelstoke Reservoir, 2008-2011.

The year to year variation in the natural flow during the study period is illustrated using the Columbia River at Donald as shown in Figure 3**.** Other gauged tributaries (Beaver and Goldstream Rivers), as well as the computed local inflow to both Kinbasket and Revelstoke Reservoirs are similar (Pieters and Lawrence 2013a). In 2009 and 2010, the flow is below average in spring and summer; in 2011 it is slightly above average in summer.

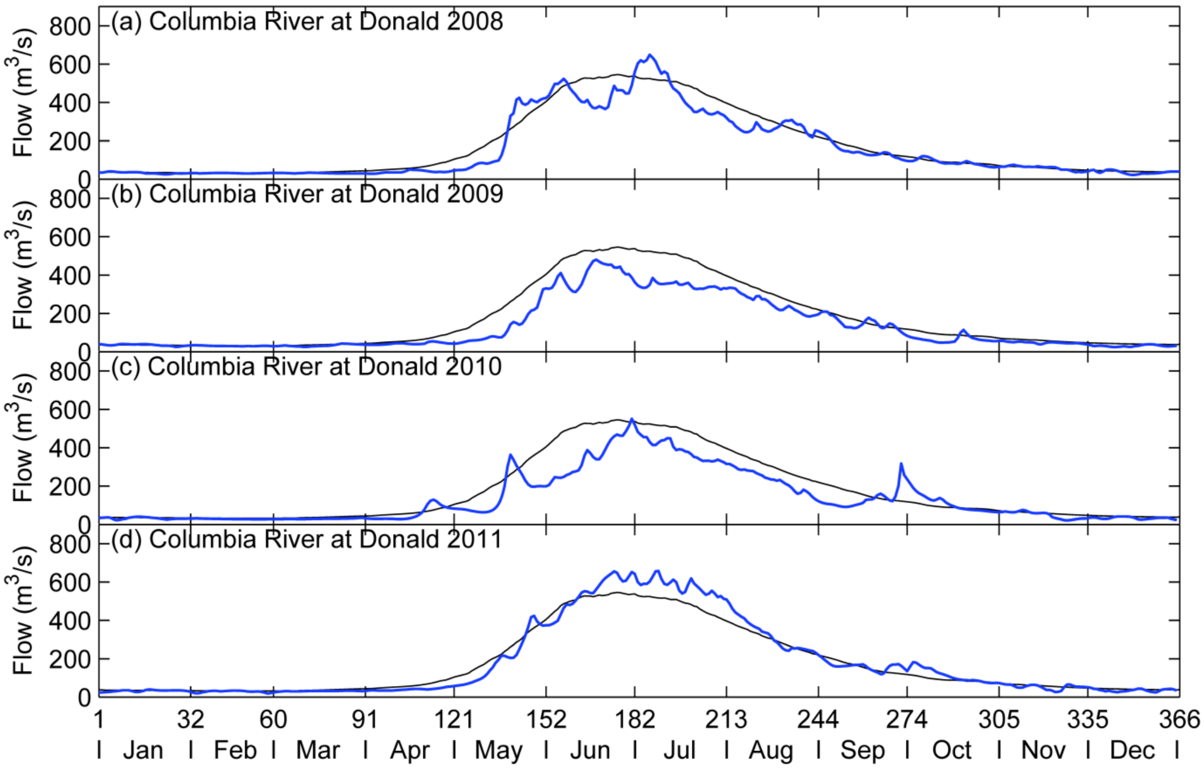


Figure 3. Columbia River at Donald, 2008-2011. The light line is the daily average, 1945-2011.

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. Flow in the first year of the study, 2008, was slightly below average, while the flow in year 2 and 3 (2009 and 2010) were both significantly below average. In 2011 flow was slightly above average as a result of significantly higher flow during July and August.

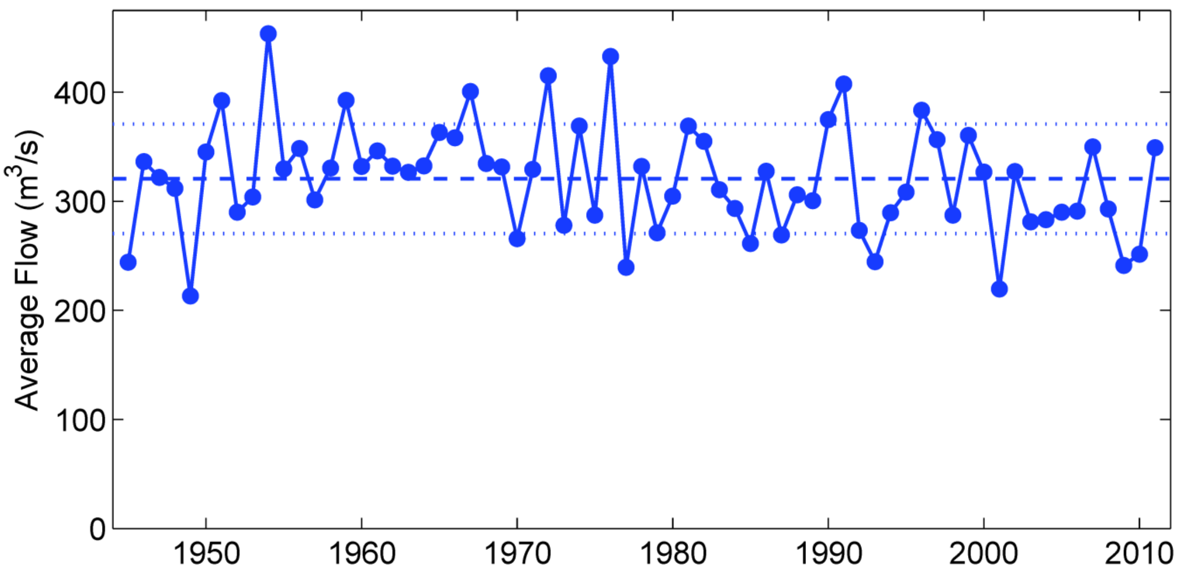


Figure 4. Average flow of Columbia River at Donald through the productive season, Apr-Oct, 1945-2011. The dash line marks the average, the dotted lines mark ± 1 standard deviation.

The water level in Kinbasket Reservoir is shown in Figure 5a. While the difference between the normal maximum and normal minimum water level is 47 m (707.41 to 754.38 m ASL), drawdown in any given year averages 25 m. There are periods of time when the water level is relatively low throughout the year (e.g. 1992-1994) and at other times it is relatively high (e.g. during the study period 2008-2011). The minimum and maximum water levels are shown in Figure 5b, along with the corresponding dates in Figure 5c. During the study period, the minimum water level occurred significantly later than average, in early May, and the area of the reservoir at minimum water level was 240 to 320 km^3, only 55-75% of the area at maximum water level later in the year.

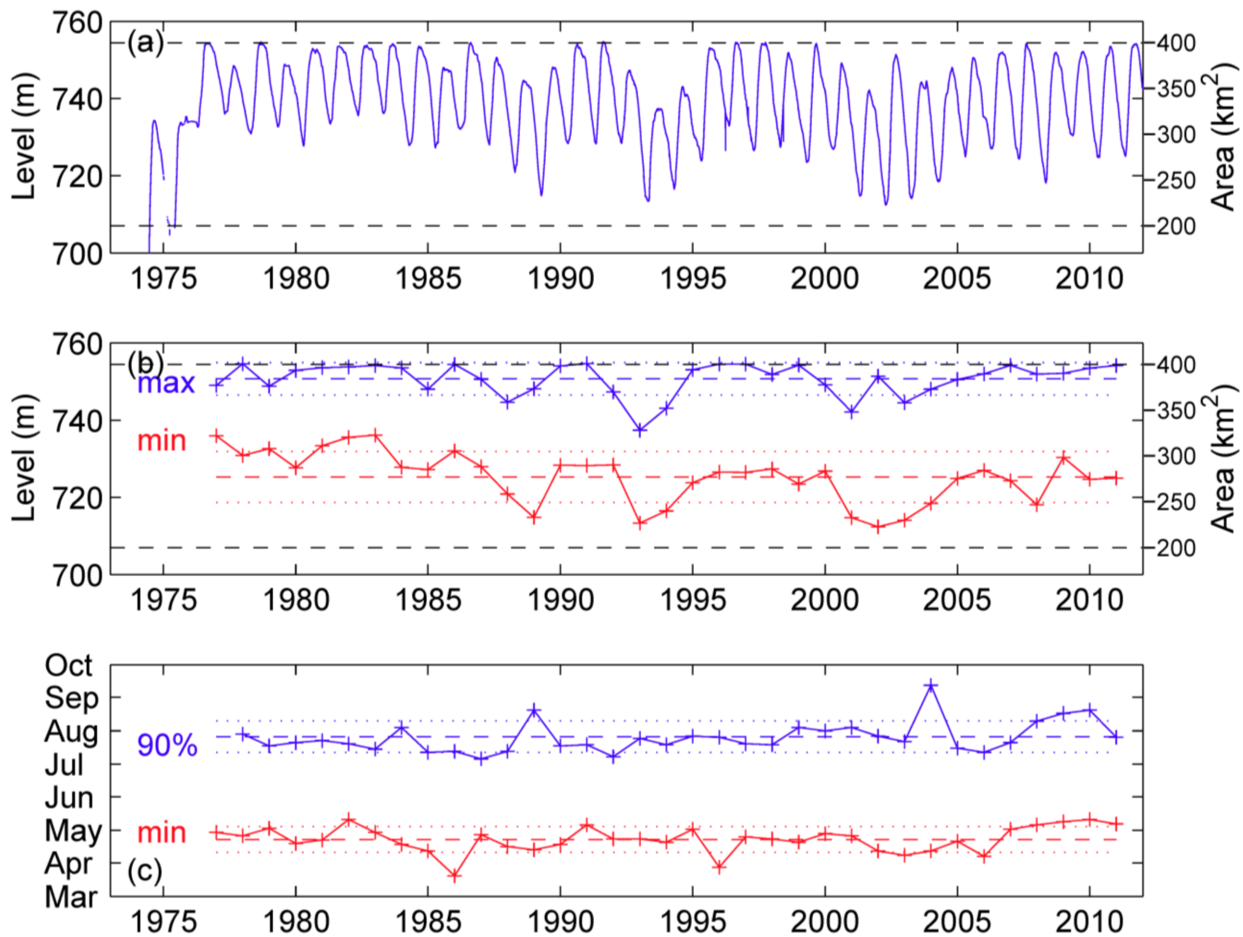


Figure 5. (a) Water level in Kinbasket Reservoir, 1973-2011. (b) Minimum (red) and maximum (blue) water level for 1977-2011. (c) Date of minimum (red), and 90% maximum (blue) water level for 1977-2011. The time to 90% full is shown as the time to the maximum water level can occur later in some years. 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.

The outflow from Kinbasket Reservoir for the study period is shown in Figure 6. Of particular note is the very low flow during late May to early July, as the reservoir was filling. While outflow increased in summer and fall, it remained below average in 2008 to 2010. Outflow from Revelstoke Reservoir for each of the study years is relatively steady on a seasonal time scale (Figure 2d). However, there is significant variation 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 increases rapidly around 6AM, and then decreases 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**.** Of note is initiation of a continuous minimum outflow of 142 m^3/s from Revelstoke Reservoir begun officially on 20 December 2010 with the start of fifth turbine

(REV5); however the actual minimum discharge has generally been slightly higher at 150-160 m^3/s to improve operation of the units.

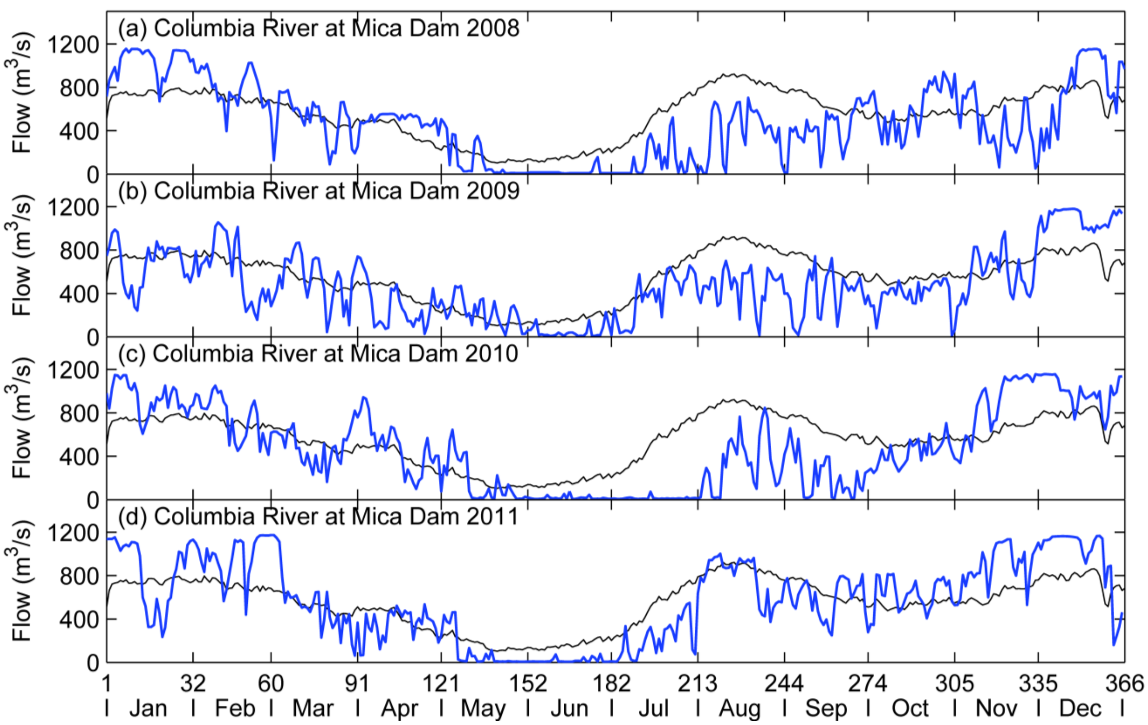


Figure 6. Daily average outflow from Kinbasket Reservoir, 2008-2011. Black line gives average, 1976-2011.

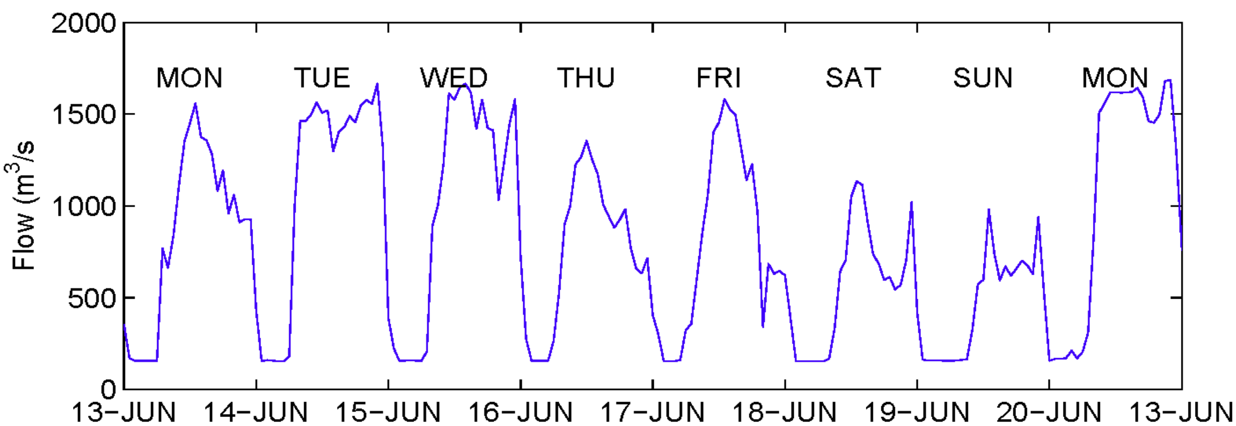


Figure 7. Hourly outflow from Revelstoke Reservoir over 8 days, 13-21 Jun 2011.

The mean monthly air temperature at Revelstoke Airport is shown for the study period in Figure 8. Spring and summer temperature was notably below average in 2011. The characteristics of each study year are summarized in Table 3.

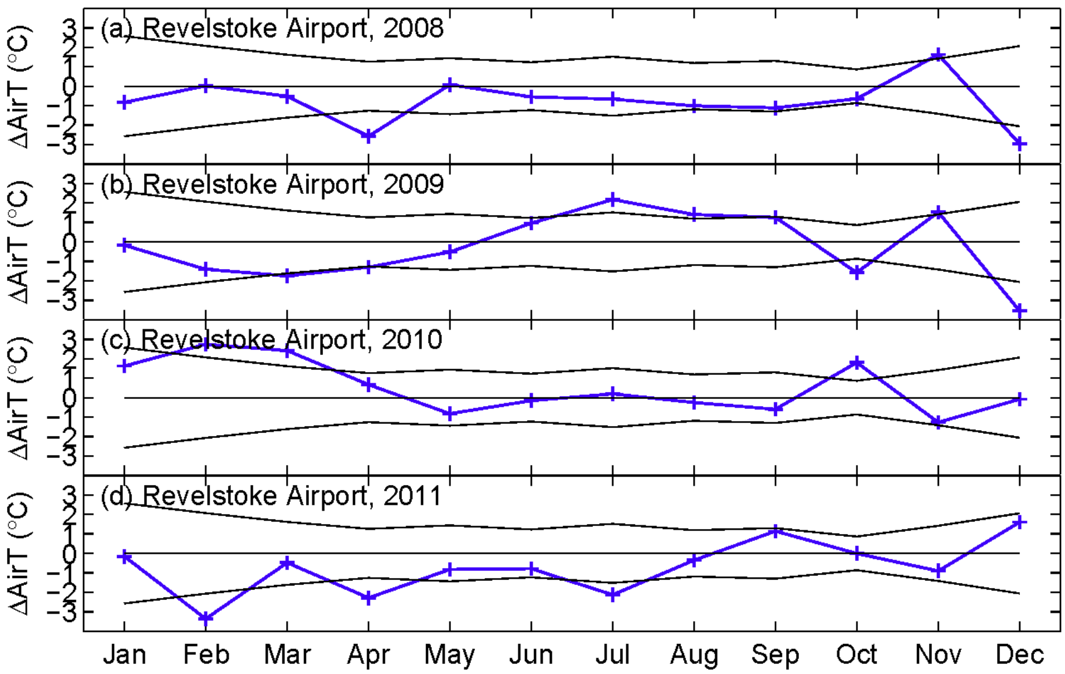


Figure 8. Difference between the monthly average air temperature and the long term mean at Revelstoke Airport, 2008-2011. Black lines show the mean and the mean ± 1 standard deviation for 1991-2011.

Table 3. Summary of meteorological and hydrological conditions during study years.

2008	Strong La Nina (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 Nina (Aug 2007 - Feb 2008)
	Columbia Region Snow Basin Index (April 1st), 78%
	Flow generally below average
2010	Strong El Nino (Jan-Mar 2010)
	Columbia Region Snow Basin Index (April 1st), 84%
	Flow generally below average
2011	Strong La Nina (Jul 2010 - Apr 2011)
	Columbia Region Snow Basin Index (April 1st), 101%
	Flow average
	Colder than average from April to July

3.2 Tributary nutrients

The tributary chemistry from the two surveys is summarized in Table 4. The 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 µg/L. Total dissolved phosphorus was also low, around 5 µg/L. Total phosphorus (TP) was highly variable, reflecting the glacial origin of many of the tributaries, and is likely of inorganic origin with 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.

Table 4. Summary of tributary chemistry surveys, 2008 & 2009.

Station/ Parameter	***Units***	***KIN Median***	***KIN Min***	***KIN Max***	***REV Median***	***REV Min***	***REV Max***
NO_2+NO_3 (NN)	µg/L	64	25	113	80	1.6	146
TP*	µg/L	12	2.7	115	7.2	2.5	49
TDP	µg/L	4.1	1.5	11	4.8	0.5	18
SRP	µg/L	1.4	0.7	3.5	2.1	0.9	5.7
NN:TDP		16	4.2	52	16	0.42	64
Conductivity	µS/cm	71	24	160	35	10	118
Alkalinity	mg$CaCO_3$/L	64	9.5	180	31	6.1	115
pH	pH units	7.4	6.6	8.2	7.1	6.3	8.0
Turbidity	NTU	7.6	0.4	96	0.9	0.1	68

* With colour correction.

Nitrate is the dominant form of nitrogen in the tributaries. Nitrate values vary significantly between tributaries, from 2 to 140 µg/L, with an arithmetic mean of 70 µg/L. However, data from the reference tributaries show that nitrate changes significantly with time of year. For example, data from Beaver River for 2009-2011 are shown in Figure 9. Nitrate doubled from winter levels of 200 µg/L to 400 µg/L during the start of freshet, but then decline rapidly to summer values around 50 µg/L. Nitrate concentrations gradually increase through fall, returning to winter levels in December. A similar pattern is observed in the other natural reference tributaries (Pieters and Lawrence 2013a), 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 and NO_3 are shown for the reference tributaries in Figures 10 and 11. Because only one sample was collected from the reference tributaries in 2008, this year is excluded. For the remaining 3 years there are no strong trends across the natural inflows; for example in 2011, [NO_3] is highest in Goldstream River, while it is lowest in the Columbia at Donald (Figure 11). Ongoing 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.

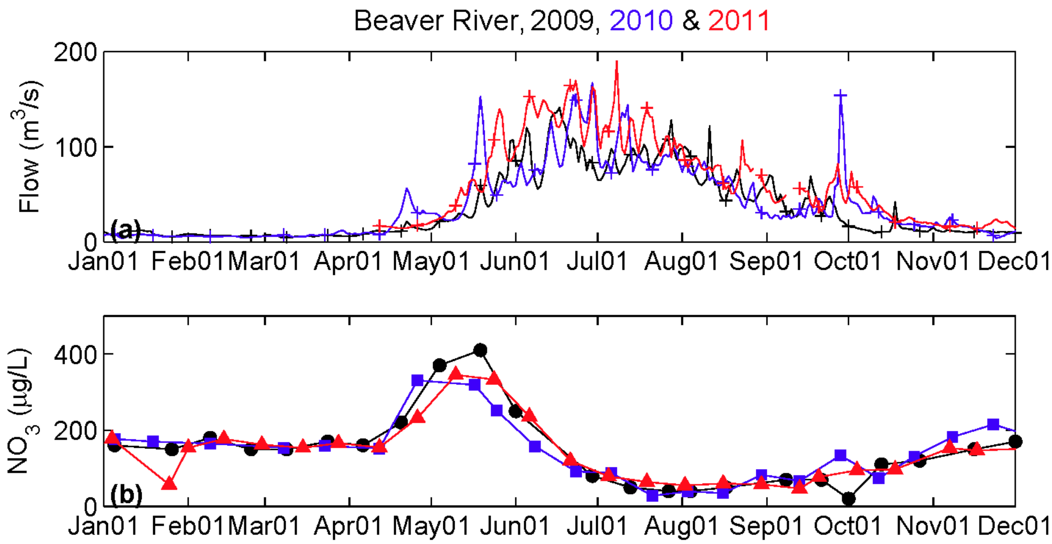


Figure 9. (a) Flow and (b) nitrate concentrations for Beaver River, 2009-2011. Note the increase in nitrate at the start of freshet, followed very low values in summer.

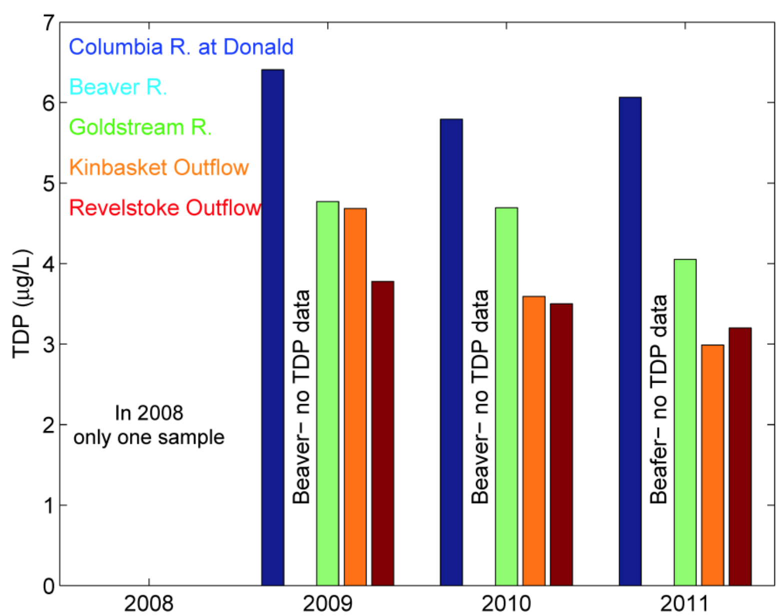


Figure 10. Estimated volume weighted concentration of TDP from reference tributaries, for April to October, 2009-2011.

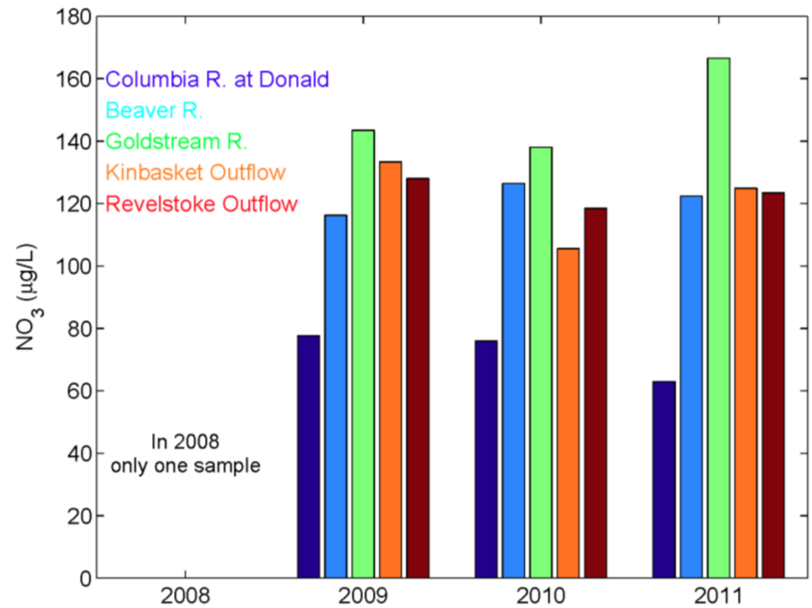


Figure 11. Estimated volume weighted concentration of NO_3 from reference tributaries, for April to October, 2009-2011.

3.3 Reservoir Light and Temperature

The depth of the 1% light level defines the photic zone; the average is shown in Figure 12 a, b for Kinbasket and Revelstoke, respectively. The photic zone begins around 20 m in depth and declines in June to 15 m in Kinbasket and 10 m in Revelstoke, and then gradually increases in depth again through summer and fall. These deep photic zone depths are consistent with oligotrophic conditions.

Secchi depths average 6.9 m and 6.1 m in Kinbasket and Revelstoke Reservoirs, respectively, with highest readings in the Forebay stations which experience the greatest settling and least amount of glacial input. In contrast, Secchi depths in reaches highly influenced by turbid tributaries have been as low as 2 m in Kinbasket Reservoir (Wood Arm in 2011, see Bray 2013). Seasonal values decline into freshet (June-July) and peak in fall (September) often with small declines in October as a result of high precipitation events.

The temperature during the monthly surveys is summarized in Figure 12 c, d for both reservoirs. To the extent that comparisons can be made based on monthly survey data, the temperature and stratification was similar during the study period with the exception of 2011 where the 1 and 10 m temperature in Revelstoke was colder than average during the summer. The moorings installed in 2012 will provide data for better comparison of temperature between future years.

An example of the temperature and conductivity along Kinbasket Reservoir is shown in Figure 13; on 15-16 September the stratifications was relatively uniform across the reservoir (Figure 13a). However, the conductivity provides a tracer which shows low-conductivity inflow in Canoe Reach in contrast with the higher conductivity inflow to the Columbia Reach (Figure 13b).

An example of reservoir temperature along Revelstoke Reservoir is given in Figure 14. The temperature shows three layers, a warmer surface layer, an intermediate temperature water (10°C) from 15 to 60 m, and a cold (5 °C) deep water below 60 m (Figure 14a). The conductivity shows higher conductivity water (150 µS/cm) below 60 m remaining from winter, with lower conductivity above 60 m as a result of fresh tributary inflow during snowmelt. However, at the time of these observations there is also a high inflow from Kinbasket Reservoir; this inflow is cool and has a conductivity intermediate to that in Revelstoke. This Kinbasket water forms an interflow in Revelstoke Reservoir, which short circuits below the photic zone to the Revelstoke outlet (Figure 14b).

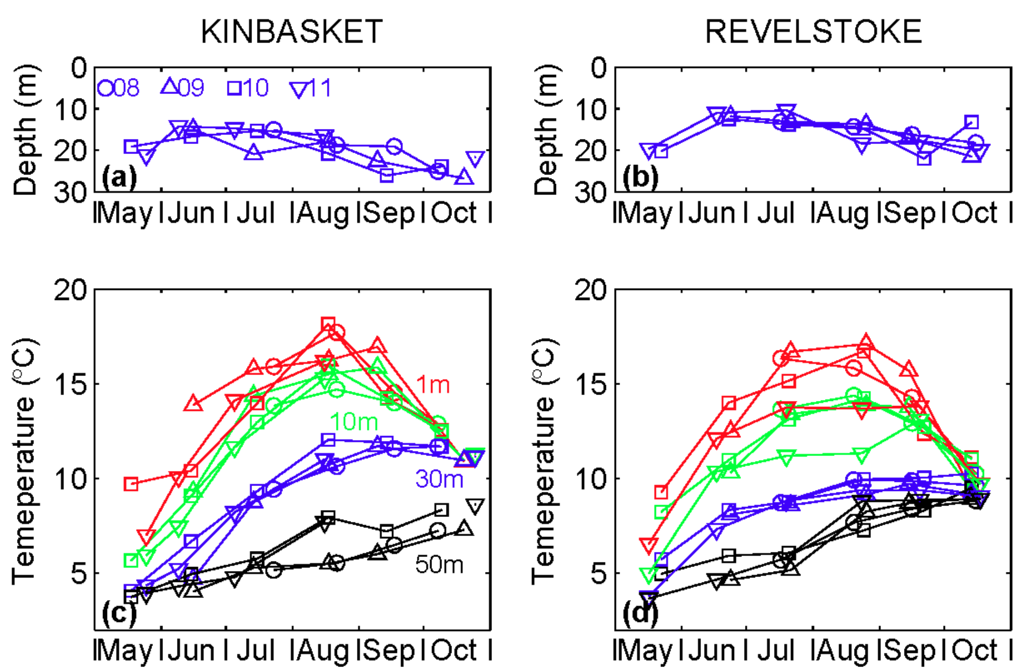


Figure 12. (a,b) Average depth of the 1% light level, 2008-2011. (c,d) Average temperature at 1 m (RED), 10 m (GREEN), 30 m (BLUE) and 50 m (BLACK), 2008-2011.

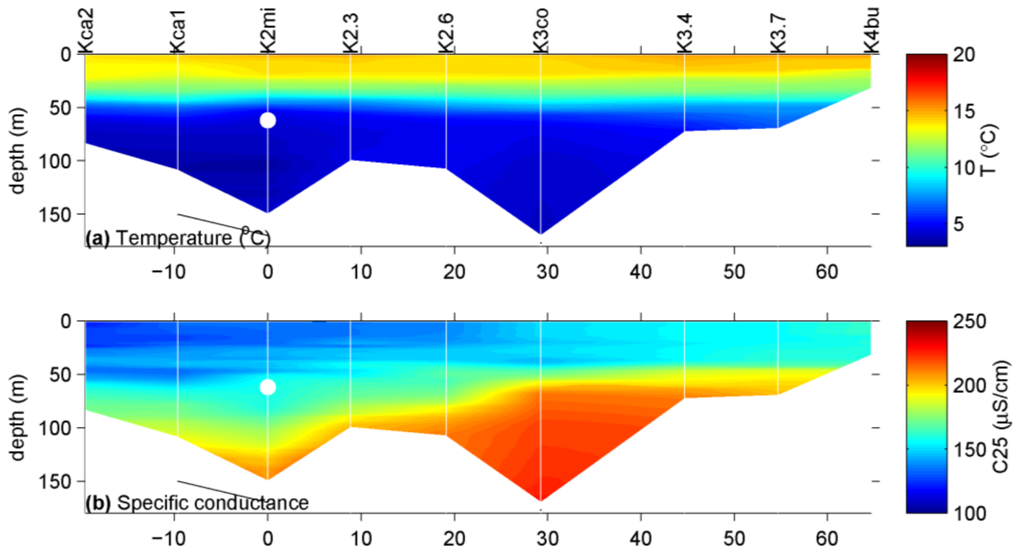


Figure 13. (a) Temperature and (b) conductivity in Kinbasket Reservoir, 15-17 September 2008. The outlet is marked at 62 m is marked with a circle. White lines mark the location of the CTD casts.

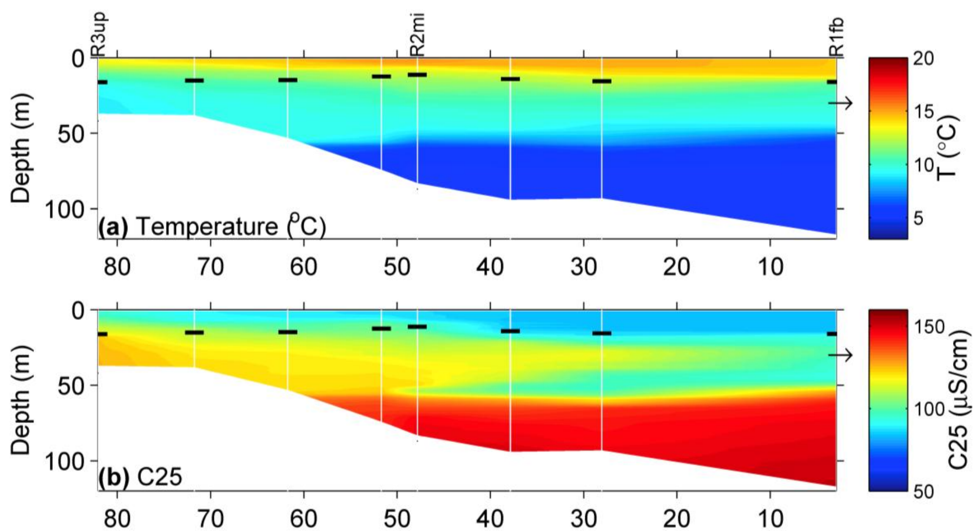


Figure 14. (a) Temperature and (b) conductivity (C25) in Revelstoke Reservoir, 8-9 September 2008. The inflow from Kinbasket Reservoir, which has slightly elevated conductivity, forms an interflow between 15 and 60 m depth which exits through the outlet marked at 28 m on the right. White lines mark the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

3.4 Reservoir Chemistry

Mean annual values for reservoir water chemistry are summarised in Table 5. Both reservoirs are considered ultra-oligotrophic with severe nutrient limitation according to Wetzel's (2001) classification of epilimnetic phosphorus levels.

Nitrite+nitrate (NN) varied little among years or within reservoirs with Revelstoke Reservoir having consistently higher NN values (mean=119 µg/L) over Kinbasket Reservoir (mean=104 µg/L). TP and TDP are more variable across seasons and stations and are consistently higher in Kinbasket Reservoir (Figure 15; Table 5). This results in Revelstoke Reservoir having higher NN:TDP ratios, indicating a greater degree of phosphorus limitation. Average soluble reactive phosphorus (SRP) varied little between reservoirs and years with a total range of 0.3 - 3.2 µg/L.

Mean TDP in Kinbasket over the study period (4.5 µg/L) is similar to Williston Reservoir TDP in 2000 (4.7 µg/L) (Stockner et al. 2005) although Williston had a higher TP (mean of 7.4 µg/L). Seasonal averages of TP and TDP in Arrow Lakes Reservoir (ALR) between 1997 and 2007 have ranged from 2 to 4.25 µg/L , TP from 2 to 4 µg/L (Schindler et al. 2010).

With the exception of Kinbasket in 2011, TP and TDP have declined annually in both reservoirs across the study years. Unusually high results for TP and TDP at Columbia Reach and Wood Arm stations in August 2011 (values in the 10-16 µg/L range throughout the profile depth) may be a result of sample contamination or lab error. However, even with these months removed from the calculations, 2011 mean TP and TDP for Kinbasket remain higher than 2010. For Kinbasket Reservoir this trend in TP and TDP follows inflow magnitude (Figure 3), with decreasing phosphorous following decreasing inflow.

Seasonally, NO_2+NO_3 usually peaks in June in both reservoirs and declines steadily through the remainder of the season. TDP tends to peak in July in Kinbasket coincident with high inflows, although the monthly trend is not as consistent among Revelstoke Reservoir stations, especially closer to the south end (Forebay) (Figure 16).

Table 5. Summary of mean values for reservoir chemistry and biological sampling, 2008-2011.

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	105	105	103	103	119	118	121	104	119
TP	µg/L	5.5	5.2	5.5	5.7	4.4	4.6	4.5	5.5	4.5
TDP	µg/L	4.3	4.4	4.7	4.6	3.7	3.7	3.8	4.5	3.8
SRP	µg/L	1.5	1.4	1.3	1.5	1.6	1.4	1.5	1.4	1.5
NN:TDP		29	27	28	26	38	36	38	27	38
Conductivity	µS/cm	121	114	119	139	93	91	89	123	89
Alkalinity	mg $CaCO_3$/L	131	123	130	154	99	98	95	135	95
Silica	mg/L	1.2	1.2	1.2	1.2	1.4	1.4	1.6	1.2	1.5
Secchi Depth	m	7.3	6.6	6.9	6.3	7.3	6.1	4.9	6.8	6.1
Primary Production	mg C/m^2/ day	34.9	-	-	-	23.1	23.7	-	34.9	23.4
Phytoplankton										
Density	#/L	2290	2300	3029	2376	2696	2844	2327	2499	2622
Biomass	µg/L	0.17	0.14	0.16	0.13	0.13	0.11	0.10	0.15	0.11
Zooplankton										
Density	#/L	16.55	12.44	11.03	11.48	7.87	8.73	4.49	12.88	7.03
Biomass	µg/L	43.78	33.36	30.28	31.04	29.01	39.40	17.19	34.61	25.53

N.B. Mean values are based on months/stations sampled. Not all months and stations were sampled each year.

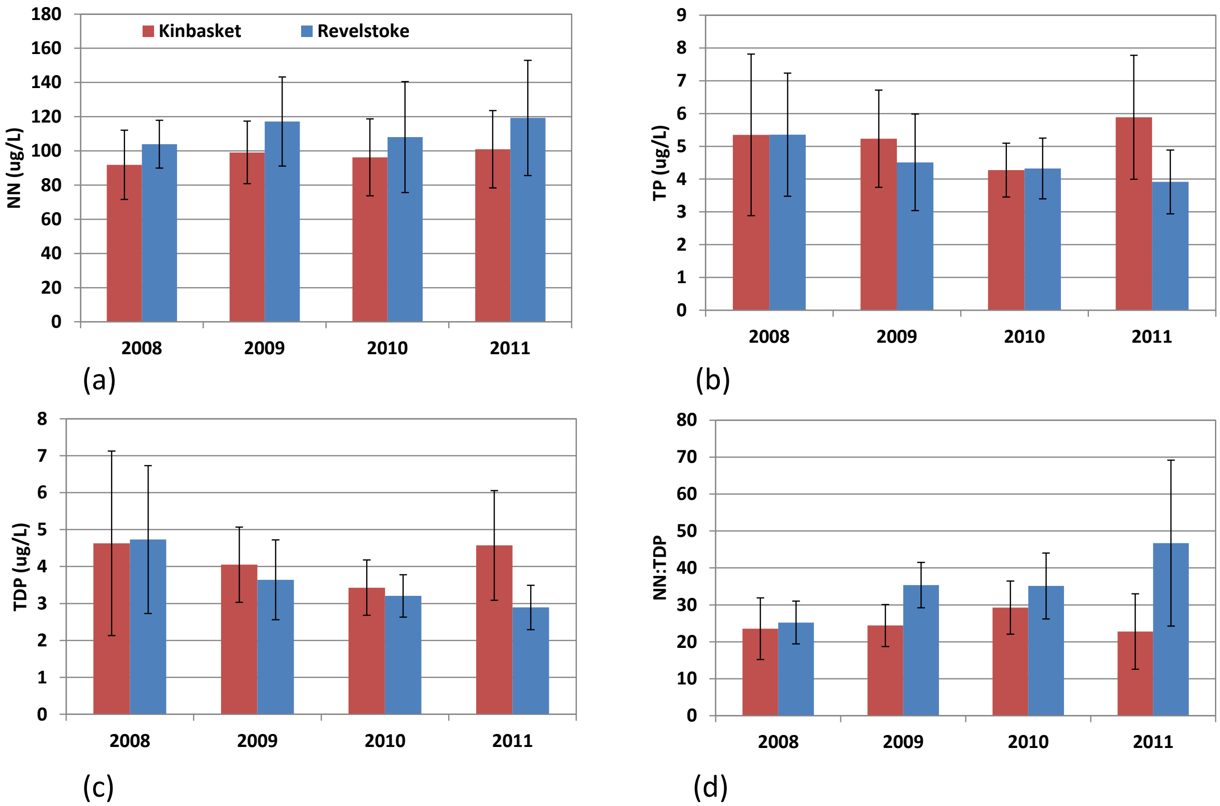


Figure 15. Summary of Revelstoke and Kinbasket Reservoirs epilimnetic nutrient chemistry 2008-2011 from all stations at combined 0-20 m depths. (a) nitrate-nitrite, (b) total phosphorus, (c) total dissolved phosphorus, (d) NN:TDP ratio. Error bars are ± SD.

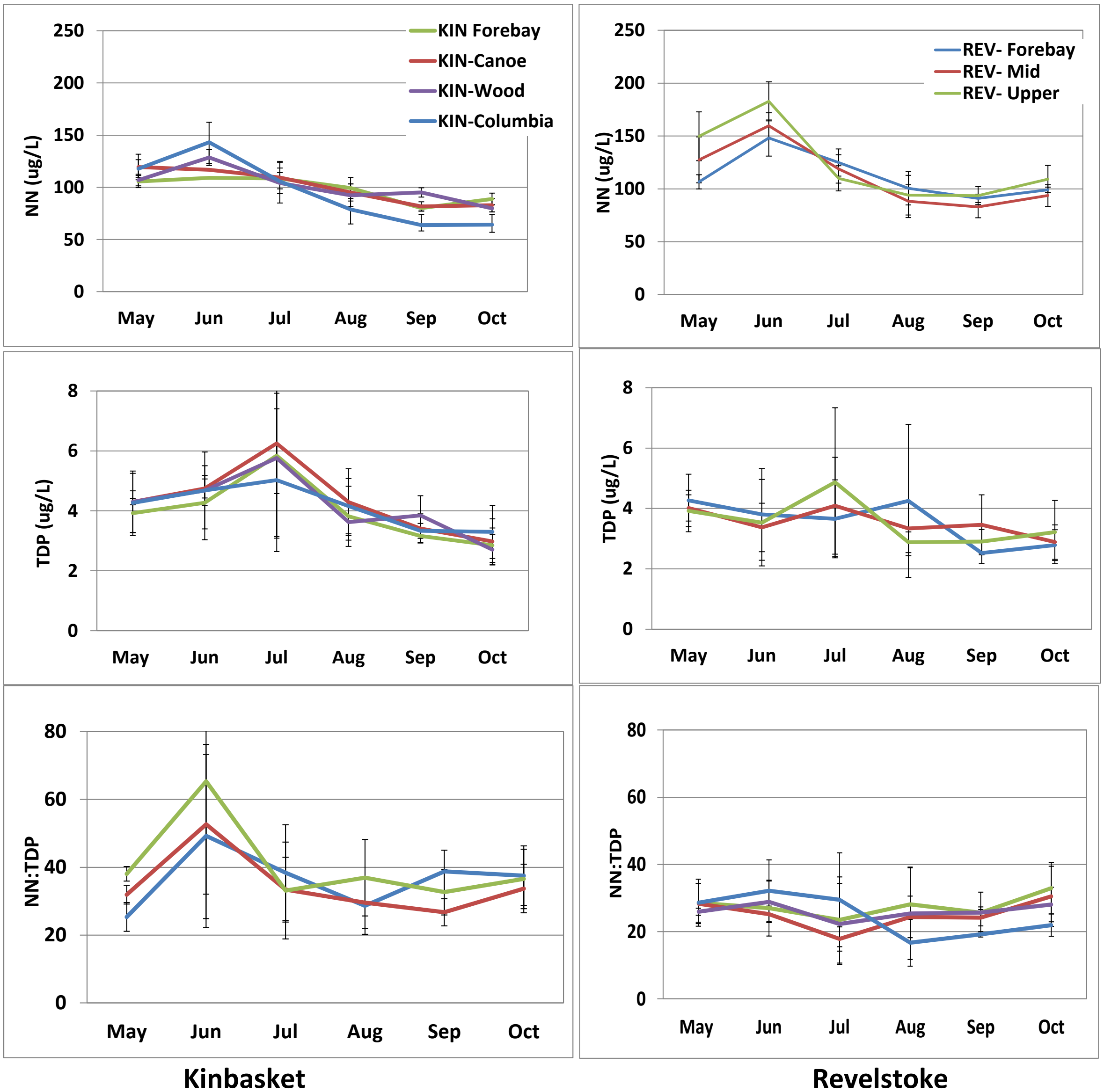


Figure 16. Mean monthly NN, TDP, and NN:TDP in Kinbasket and Revelstoke Reservoirs, 2008-2011.

3.3 Primary Production

The optical properties of lakes and reservoirs are important regulatory parameters in the physiology and behavior of aquatic organism (Wetzel 2001). 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 been stable over the three year study period, ranging seasonally from 0.18 to 0.47 cm^{-1} or 82% transmission m^{-1} to 53% transmission m^{-1} with lower transmission early in the growing season and increasing as the season progresses (Figure 17). 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, (all years) the attenuation coefficient in Kinbasket was 0.28 cm^{-1} and at Revelstoke Forebay and Revelstoke Middle, 0.32 cm^{-1} and 0.34 cm^{-1} respectively.

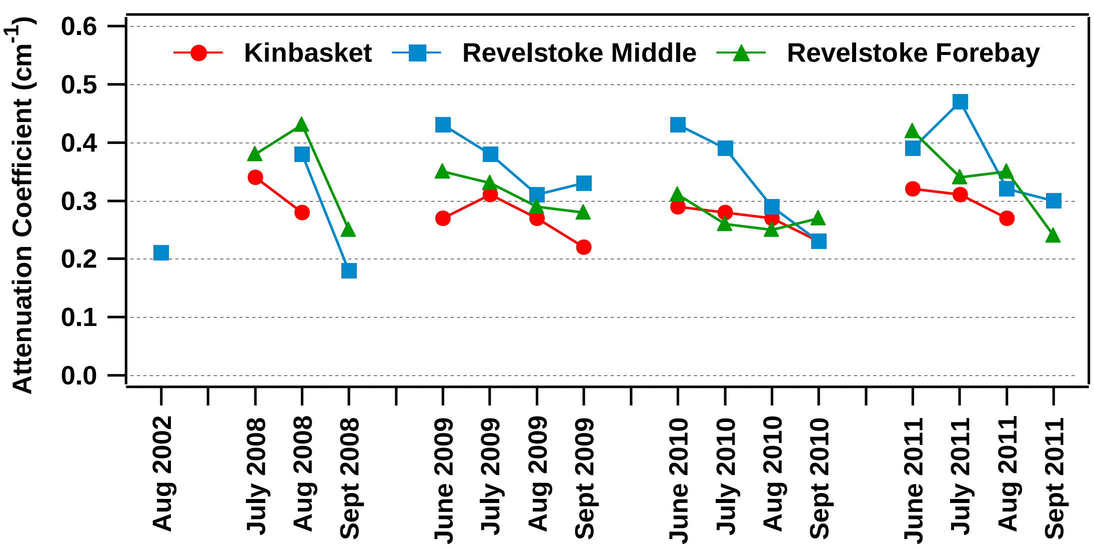


Figure 17. Attenuation coefficients (cm^{-1}) in Kinbasket, Revelstoke Middle and Revelstoke Forebay from 2002-2011. Attenuation coefficients were calculated from Secchi disk depths in 2002 and 2008 and from the vertical profiles of photosynthetically available radiation in 2009-2011.

3.3.1 Chlorophyll

Chlorophyll concentrations in Kinbasket and Revelstoke Reservoir have been remarkably stable over the three year period where concentrations have consistently been low with discrete concentrations ranging from slightly less than 1 µg/L to slightly higher than 2.0 µg/L (Figure 18). Generally the lowest concentrations are measured in Revelstoke Middle with concentrations between <0.2 µg/L to approximately 1.5 µg/L with the notable exception of a small bloom measured in 2011. On average the 2009-2011 mean chlorophyll concentration are higher in Kinbasket than in Revelstoke, averaging 1.45 µg/L in Kinbasket and 0.92 µg/L at Revelstoke Middle and 1.02 µg/L at Revelstoke Forebay which are indicative of ultra-oligotrophic conditions (Wetzel 2001).

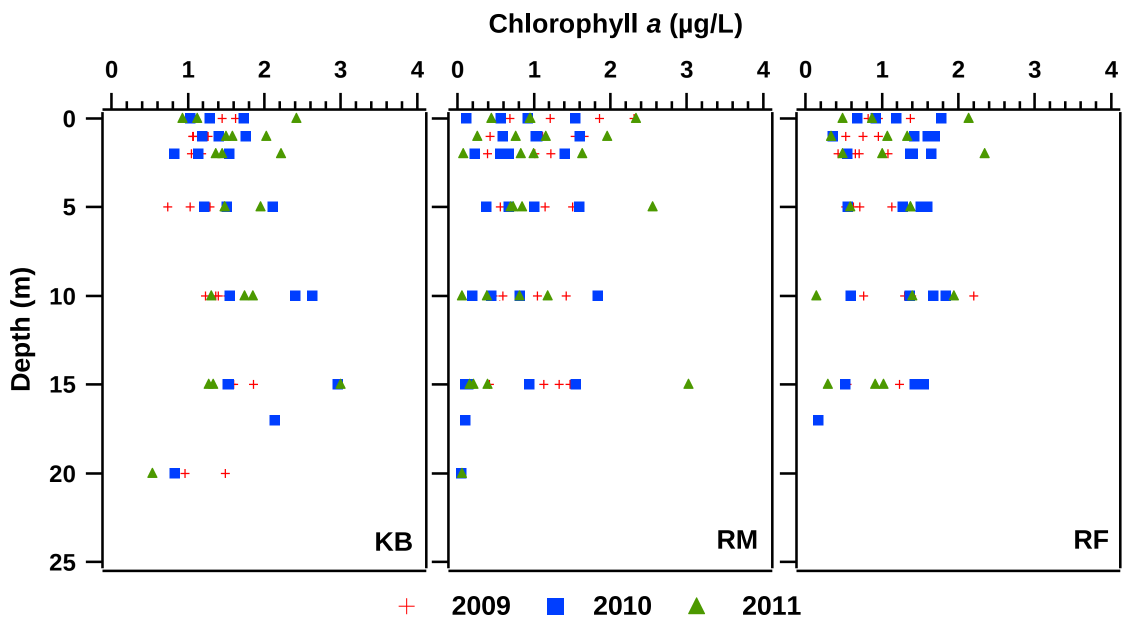


Figure 18. Vertical profiles of chlorophyll a (µg/L) in Kinbasket, Revelstoke Middle and Revelstoke Forebay in 2009-2011. Data are not available for 2008.

Depth integrated chlorophyll concentrations have been consistently low, rarely exceeding 30 mg Chl a/m^2 in either Kinbasket or Revelstoke Reservoir (Figure 19). Very little seasonal or interannual variability is apparent in Kinbasket Reservoir whereas at Revelstoke Middle and Revelstoke Forebay the biomass is very dynamic during the season where for example, chlorophyll at Revelstoke Forebay increases from ~10 mg/m^2 in June to ~37 mg/m^2 in July (Figure 19). During all study years the biomass was highest at Kinbasket, generally greater than 20 µg/L whereas at Revelstoke Middle and Revelstoke Forebay the biomass is ~ 15 µg/L (Figure 20). No apparent trend was noted for Revelstoke Reservoir where in 2009 biomass was higher at Revelstoke Forebay compared to Revelstoke Middle in contrast to 2010 where biomass was higher at Revelstoke Middle and in 2011 biomass was similar at the two stations. The 2009-2011 seasonal averages were 23.7, 15.1 and 15.5 for Kinbasket, Revelstoke Middle and Revelstoke Forebay, respectively.

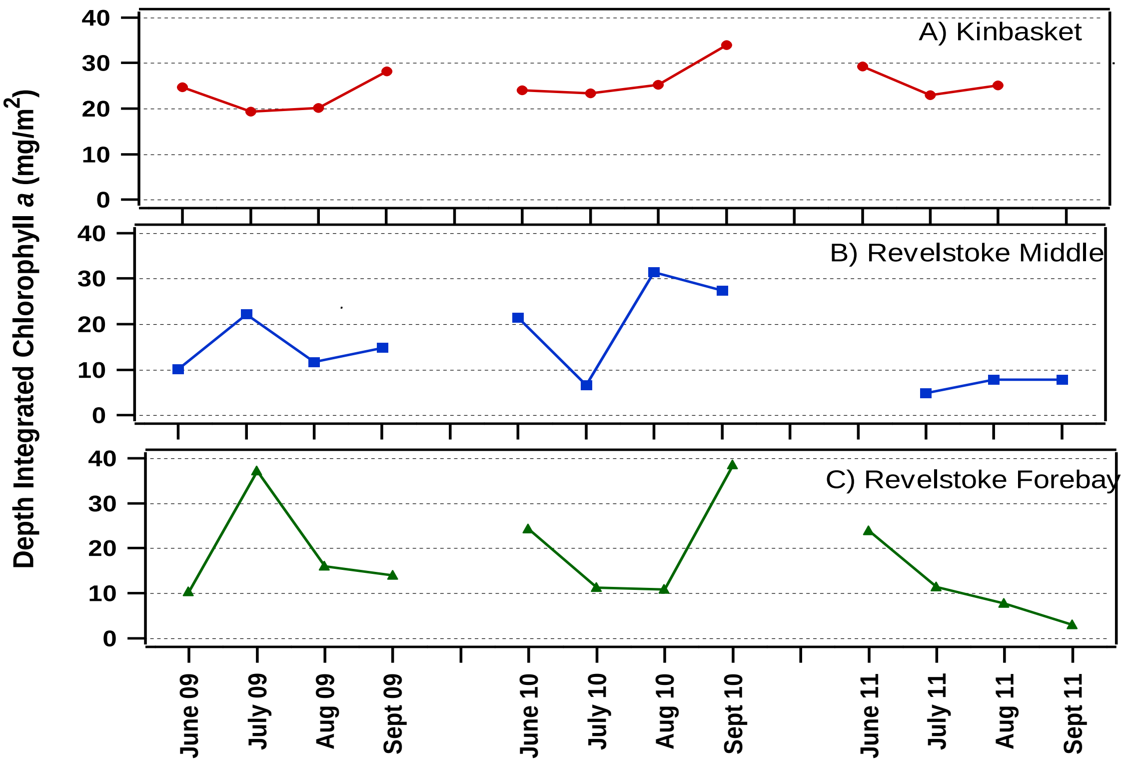


Figure 19. Monthly depth integrated (1-100% surface PAR) chlorophyll (mg Chl *a*/m^2) concentrations in A) Kinbasket and B) Revelstoke Middle and C) Revelstoke Forebay in 2009-2011.

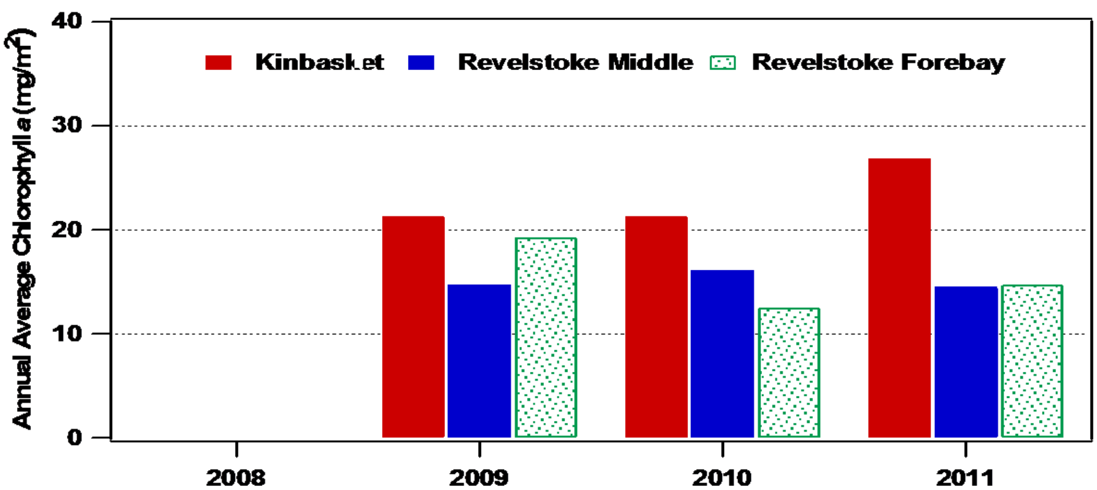


Figure 20. Annual average depth integrated chlorophyll *a* (mg/m^2) in Kinbasket, Revelstoke Middle and Revelstoke Forebay in 2009-2011. Data were not collected in 2008.

On average, the size distribution of the chlorophyll biomass has also been remarkably stable over the study period where picoplankton (0.2-2.0 µm) and nanoplankton (2.0-20.0 µm) have accounted for 85% of the total biomass while microplankton, cells >20 µm in size, has accounted for just 15% of the total biomass (Figure 21). In all years, the phytoplankton community in Kinbasket and Revelstoke was dominated by picoplankton (39-58%) followed by nanoplankton (32-44%) followed by microplankton (8-22%). This size distribution of the phytoplankton assemblage is typically seen in oligotrophic lakes and reservoirs where small algal species are common.

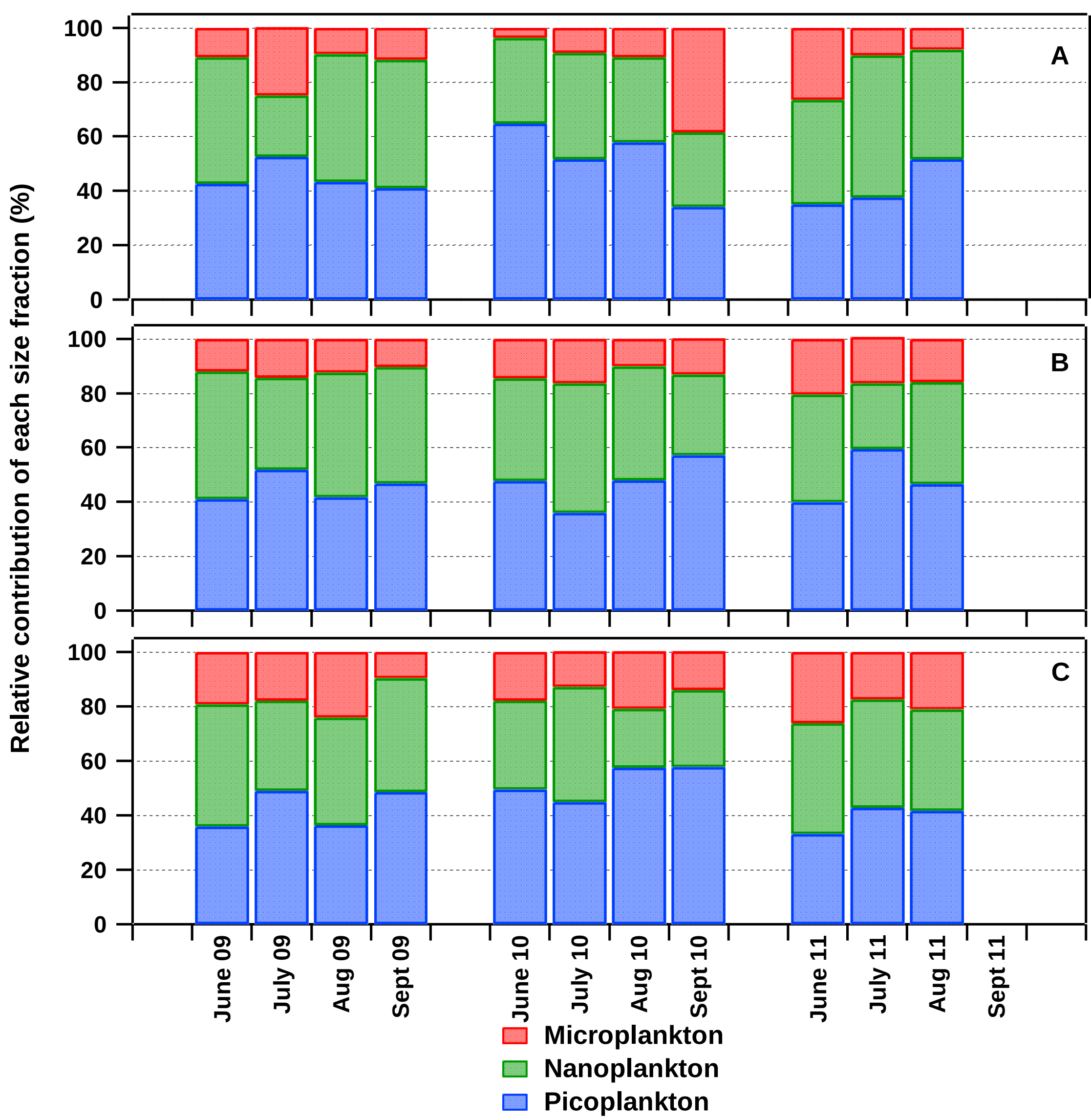


Figure 21. Monthly relative contribution of picoplankton (0.2-2 µm), nanoplankton (2.0-20 µm) and microplankton (>20 µm) to depth integrated chlorophyll in A) Kinbasket, B) Revelstoke Middle and C) Revelstoke Forebay in 2009-2011.

3.3.2 Primary productivity

In all study years, the annual average primary productivity of the total phytoplankton assemblage was extremely low, never exceeding 50 mg C/m^2/d particularly in Revelstoke Reservoir where rates were usually less than 40 mg C/m^2/d (Figure 23). The highest monthly rates were measured in Kinbasket Reservoir in July 2008 at 84.4 mg C/m^2/d and in September 2010 at 72.9 mg C/m^2/d while the lowest primary productivity of 6.9 mg C/m^2/d was measured in Revelstoke Forebay in June 2009 (Figure 22). Primary productivity of phytoplankton in reservoirs can vary seasonally as shown in Kinbasket Reservoir while in Revelstoke Reservoir the productivity is much more stable over the study period.

On average, primary productivity was highest in Kinbasket in 2008-2010 while in 2011 productivity at Kinbasket and Revelstoke Middle were similar at ~32 mg C/m^2/d (Figure 23). It is important to note that this apparent trend may be due to the lack of data for Kinbasket in August and September 2011. In Revelstoke Reservoir, productivity was higher at Revelstoke Forebay in 2008 and 2009 while starting in 2010 a shift was measured where productivity was higher at Revelstoke Middle compared to Revelstoke Forebay. The 2008-2011 annual averages were 34.9, 23.1 and 24.2 mg C/m^2/d for Kinbasket, Revelstoke Middle and Revelstoke Forebay, respectively. Primary productivity is often used for determination of the trophic classification based on the assumption that littoral and allochthonous sources are small relative to pelagic sources (Wetzel 2001). These low primary productivity rates measured in Kinbasket and Revelstoke are further indications of ultra-oligotrophic conditions.

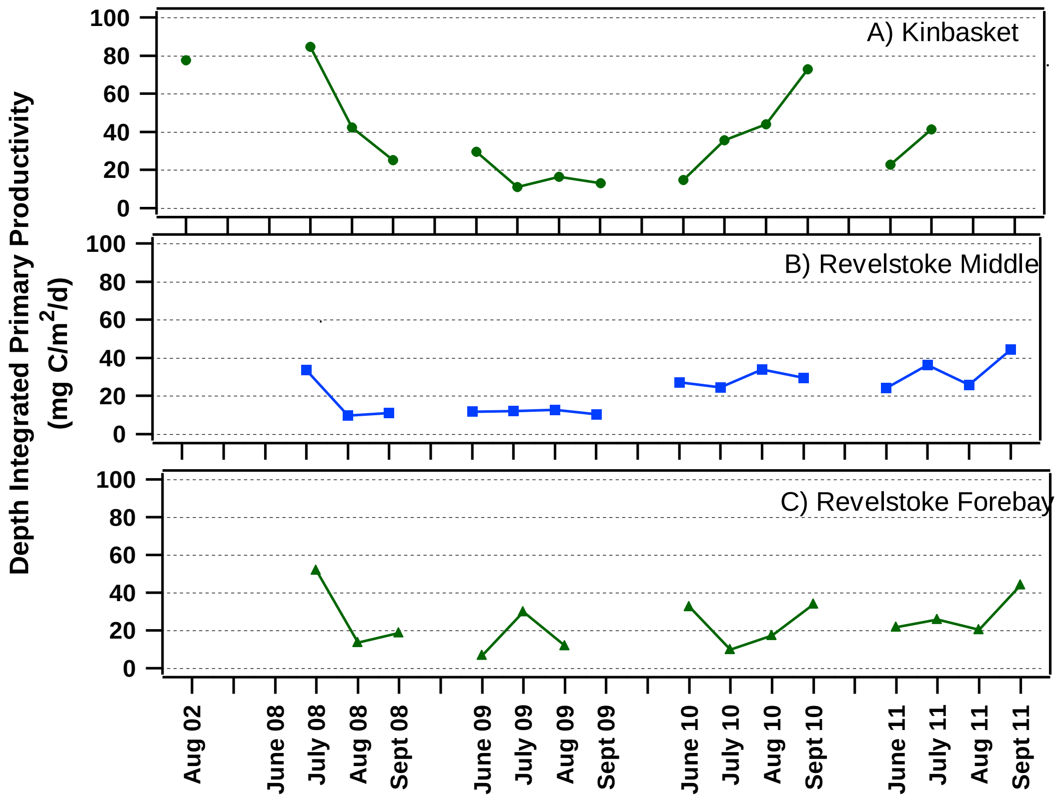


Figure 22. Monthly depth integrated (1-100% surface PAR) primary productivity (mg C/m^2/d) concentrations in A) Kinbasket and B) Revelstoke Middle and C) Revelstoke Forebay in 2008-2011.

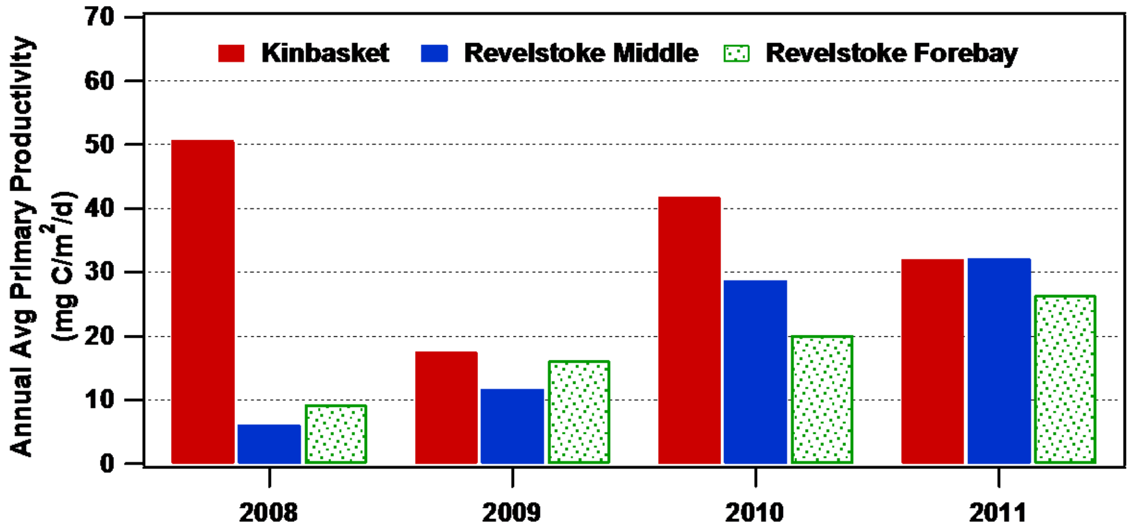


Figure 23. Annual average depth integrated primary productivity (mg $C/m^2/d$) in Kinbasket, Revelstoke Middle and Revelstoke Forebay in 2008-2011.

In all study years, picoplankton (0.2-2.0 µm) and nanoplankton (2.0-20.0 µm) dominated the primary productivity of Kinbasket and Revelstoke Reservoirs accounting for between 60-90% of productivity while microplankton (2.0-20.0 µm) are the least productive generally 10-30% of productivity (Figure 24). Size fractionation of the primary productivity has revealed some changes over the three year study period. The relative contribution of picoplankton has increased from 2009-2011 at all three station while nanoplankton productivity and microplankton productivity has decreased (Figure 24).

In Kinbasket Reservoir, picoplankton accounted for 15% of the total productivity in 2009 and in 2010 picoplankton productivity increased to 33% and again in 2011 to 44%. Similarly at Revelstoke Forebay picoplankton productivity increased from 20% in 2009 to 32% in 2010 and up to 59% in 2011.

Nanoplankton, the phytoplankton fraction preferred by herbivorous zooplankton, at the start of the study period accounted for greater than 50% of the production in both Kinbasket and Revelstoke and on average accounts for 39% and 28% 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 notable exception in June 2009 at Revelstoke Forebay (Figure 24). Food chains dominated by picoplankton tend to be less efficient at transferring the carbon up the food chain to higher trophic levels and the decrease in nanoplankton productivity may suggest impacts to upper trophic level productivity.

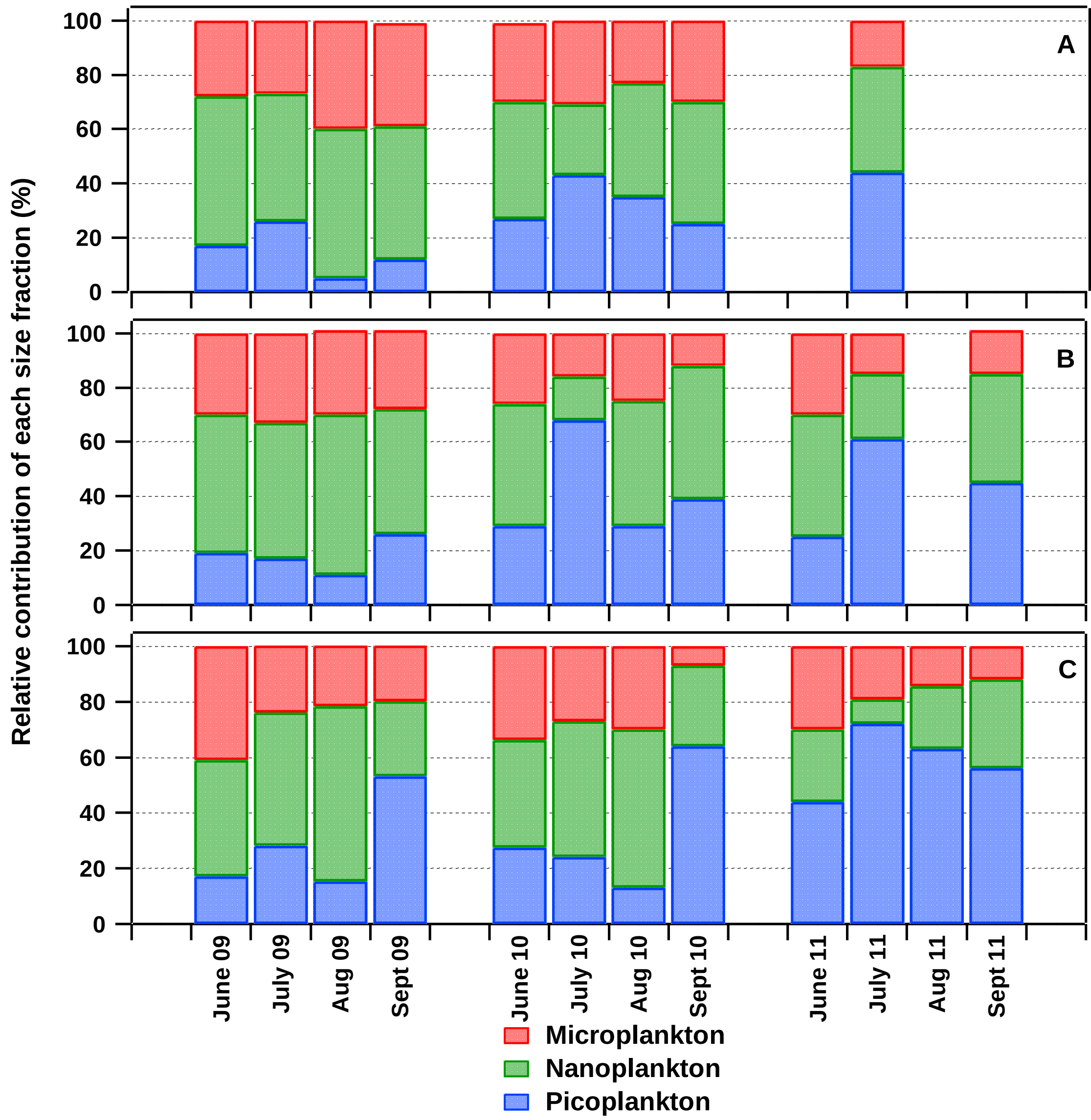


Figure 24. Monthly relative contribution of picoplankton (0.2-2 µm), nanoplankton (2.0-20 µm) and microplankton (>20 µm) to depth integrated chlorophyll in A) Kinbasket, B) Revelstoke Middle and C) Revelstoke Forebay in 2009-2011. Fractionation was not completed in 2008.

3.4 Phytoplankton

Inter-annual comparison of the average total density of phytoplankton shows an increase in density since 2008 in Kinbasket Reservoir (Figure 25; Table 6), but not in Revelstoke Reservoir (Figure 26; Table 7). Simple regression analysis indicates that the trend in Kinbasket is highly significant (R^2=0.99, p<0.01). The Revelstoke data set from 2008 to 2011 does not have a significant increasing trend by year (R^2=0.87, p=0.13); however, visual examination of the data does show increasing mean values through time.

Table 6. Mean seasonal phytoplankton density and biovolume by major taxonomic group and year for Kinbasket Reservoir.

		Density (NCU/ml)				Biovolume (mm^3/L)			
Station	**Group**	**2008**	**2009**	**2010**	**2011**	**2008**	**2009**	**2010**	**2011**
Kin Forebay	Bacillariophyte	500	928	493	106	0.0870	0.1250	0.0739	0.0214
	Chryso & Cryptophyte	534	677	1042	1378	0.0480	0.0690	0.0141	0.0395
	Chlorophyte	78	137	324	138	0.0070	0.0160	0.0314	0.0122
	Dinophyte	37	59	49	30	0.0200	0.0400	0.0073	0.0096
	Cyanophyte	412	414	889	1242	0.0060	0.0050	0.0176	0.0080
	Sum of all Groups	**1561**	**2218**	**2797**	**2894**	**0.1680**	**0.2550**	**0.1443**	**0.0907**
Canoe Reach	Bacillariophyte	314	740	343	142	0.0550	0.1030	0.0590	0.0309
	Chryso & Cryptophyte	504	527	1316	1553	0.0420	0.0490	0.0214	0.0400
	Chlorophyte	63	113	285	130	0.0110	0.0100	0.0343	0.0160
	Dinophyte	28	56	49	30	0.0160	0.0360	0.0054	0.0104
	Cyanophyte	388	630	1141	1478	0.0060	0.0050	0.0190	0.0102
	Sum of all Groups	**1298**	**2066**	**3133**	**3333**	**0.1300**	**0.2040**	**0.1390**	**0.1074**
Wood Arm	Bacillariophyte	380	835	552	152	0.0690	0.1070	0.0811	0.0359
	Chryso & Cryptophyte	621	598	1374	2386	0.0570	0.0510	0.0109	0.0613
	Chlorophyte	71	124	237	325	0.0140	0.0180	0.0463	0.0263
	Dinophyte	56	49	38	35	0.0360	0.0350	0.0044	0.0129
	Cyanophyte	504	603	874	2096	0.0070	0.0070	0.0154	0.0174
	Sum of all Groups	**1632**	**2208**	**3075**	**4994**	**0.1830**	**0.2180**	**0.1582**	**0.1538**
Columbia Reach	Bacillariophyte	345	999	337	220	0.0650	0.1520	0.0521	0.0328
	Chryso & Cryptophyte	502	465	1247	1789	0.0440	0.0400	0.0111	0.0328
	Chlorophyte	53	135	178	154	0.0090	0.0110	0.0349	0.0128
	Dinophyte	41	39	33	28	0.0230	0.0290	0.0053	0.0095
	Cyanophyte	312	473	775	1990	0.0040	0.0050	0.0124	0.0135
	Sum of all Groups	**1242**	**2110**	**2569**	**4181**	**0.1380**	**0.2370**	**0.1158**	**0.1013**

Table 7. Mean seasonal phytoplankton density and biovolume by major taxonomic group and year for Revelstoke Reservoir.

		Density (NCU/ml)				**Biovolume (mm^3/L)**			
Station	**Group**	**2008**	**2009**	**2010**	**2011**	**2008**	**2009**	**2010**	**2011**
Forebay	Bacillariophyte	542	710	251	124	0.0700	0.1050	0.0324	0.0153
	Chryso & Cryptophyte	816	586	870	1861	0.0690	0.0460	0.0159	0.0474
	Chlorophyte	127	177	226	320	0.0180	0.0320	0.0337	0.0242
	Dinophyte	30	44	39	37	0.0140	0.0440	0.0032	0.0143
	Cyanophyte	1029	899	554	2229	0.0090	0.0080	0.0145	0.0139
	Sum of all Groups	**2544**	**2416**	**1940**	**4570**	**0.1800**	**0.2360**	**0.0998**	**0.1150**
Middle	Bacillariophyte	208	625	214	106	0.0410	0.0920	0.0261	0.0151
	Chryso & Cryptophyte	796	576	1104	1684	0.0810	0.0540	0.0102	0.0318
	Chlorophyte	66	117	125	596	0.0080	0.0140	0.0329	0.0227
	Dinophyte	61	63	32	31	0.0350	0.0450	0.0054	0.0111
	Cyanophyte	446	520	1028	2244	0.0050	0.0060	0.0106	0.0119
	Sum of all Groups	**1576**	**1901**	**2502**	**4661**	**0.1700**	**0.2110**	**0.0851**	**0.0925**
Upper	Bacillariophyte	220	367	79	115	0.0320	0.0540	0.0073	0.0128
	Chryso & Cryptophyte	669	618	1332	2011	0.0580	0.0600	0.0089	0.0427
	Chlorophyte	81	142	122	102	0.0080	0.0160	0.0386	0.0088
	Dinophyte	53	61	52	18	0.0300	0.0340	0.0059	0.0060
	Cyanophyte	482	505	1099	2232	0.0060	0.0050	0.0173	0.0121
	Sum of all Groups	**1505**	**1693**	**2684**	**4477**	**0.1340**	**0.1630**	**0.0780**	**0.0824**

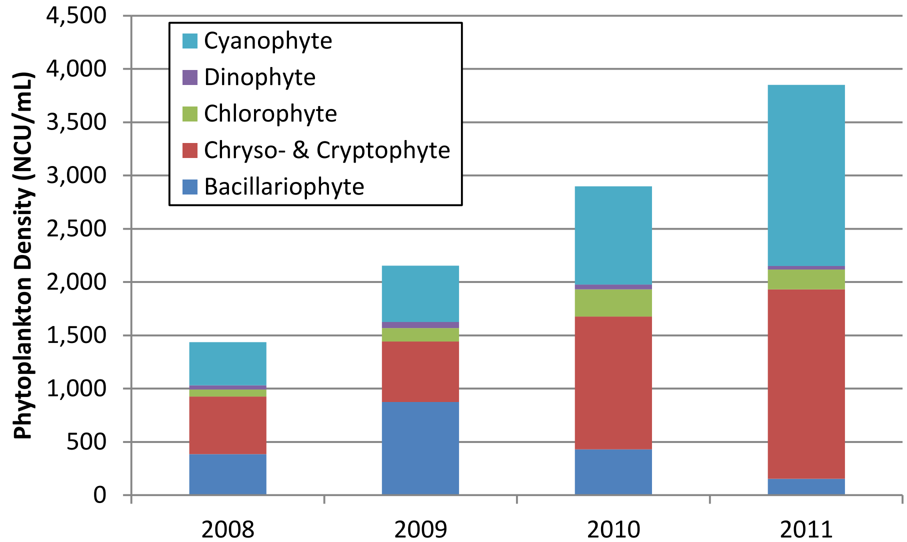


Figure 25. Mean seasonal phytoplankton density by major taxonomic group for Kinbasket Reservoir.

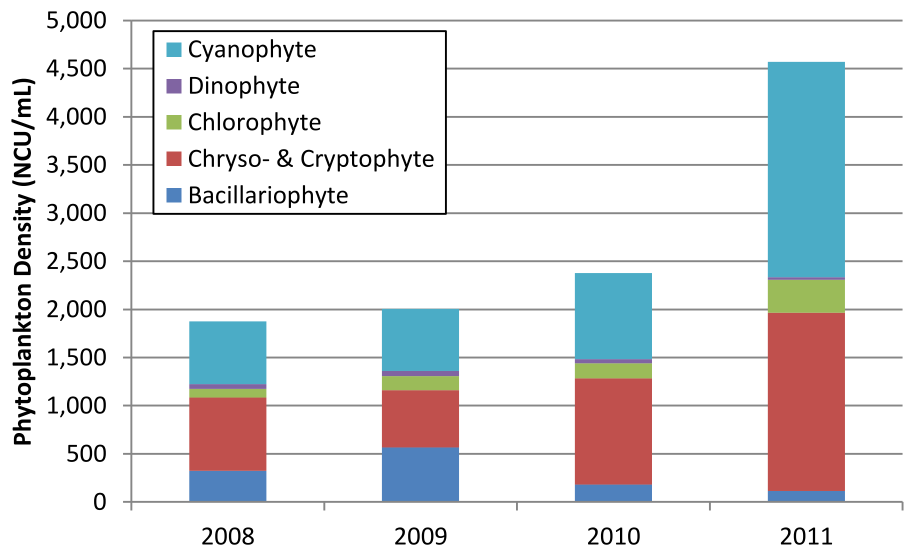


Figure 26. Mean seasonal phytoplankton density by major taxonomic group and year for Revelstoke Reservoir.

With the exception of 2009, a decreasing trend in biovolume appears to be present with visual examination of the phytoplankton (Figure 27; Table 6 and Figure 28; Table 7). A simple regression analysis indicates that the biovolume changes in Kinbasket and Revelstoke reservoirs are not significant (R^2=0.33; p>0.40 and R^2=0.52; p=0.28) respectively. The lack of significance is primarily due to the increase in biovolume observed in 2009. Subsequent years have shown a reduction in mean biomass in each year.

The increase in density without an increase in biomass indicates that the system is becoming numerically dominated by smaller taxa. Examination of the taxonomic data shows that the increase in abundance is caused by the increase in two small taxa, small micro-flagellates, genus unknown, assigned to the Chrysophyceae and Cryptophyceae group or flagellate group and Synechococcus (coccoids) a member of the Cyanophyte or blue-green group. The increase in density has occurred in every year from the baseline in 2008 to the samples collected in 2011 (Figure 29). If these two taxa are removed from the data set the overall phytoplankton density and composition on the group level has remained relatively unchanged (Figure 30).

The picoplankton densities are showing similar trends, but to a lesser degree than the phytoplankton densities (Figure 31). Heterotrophic bacteria densities in the epilimnion (2-10m) of Kinbasket Reservoir have increased significantly since 2008 (p=0.08). The Kinbasket hypolimnion (15-25m) and both depth classes of Revelstoke did not have a statistically significant increase through time. Study of heterotrophic bacteria gives us insight into the trophic structure of the biological community and how nutrients and energy flow through the food web.

The pico-cyanobacteria densities did not have an apparent trend; however, there was a large spike in pico-cyanobacteria densities in 2011. 2011 may be an anomaly or it may be an indicator that the conditions within the systems were different in 2011 resulting in a bloom of pico-cyanobacteria.

The increases observed in the smaller taxa within the system are indicative of a system that is undergoing change, either in inorganic nutrient concentrations or other changes such as water temperature. Due to their small size the nanoplankton and picoplankton can utilize nutrients at lower concentrations than larger taxa. They are also capable of responding rapidly to small changes in the conditions within systems. Due to the biological interactions with both the biotic and abiotic conditions within a system, changes in the plankton community are often detected prior to changes in water chemistry values. This is especially true of nutrients in oligotrophic systems.

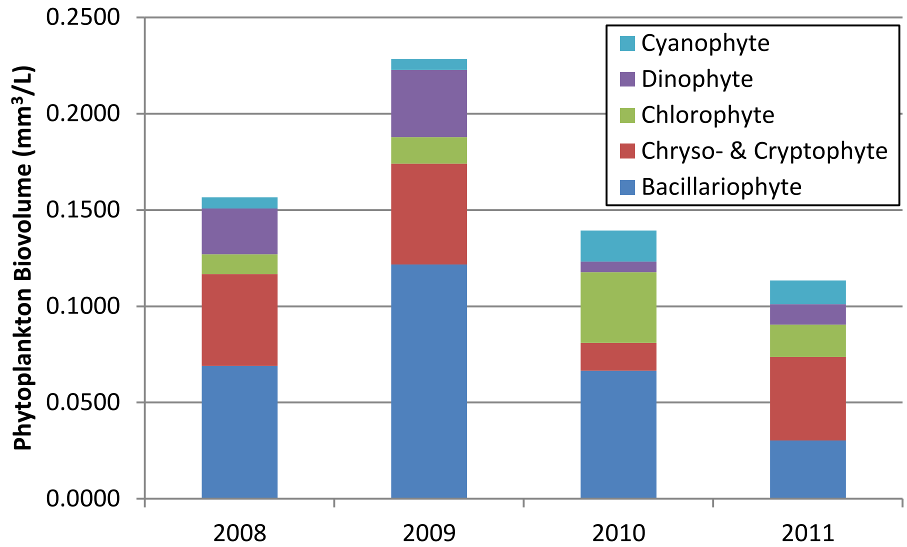


Figure 27. Mean seasonal phytoplankton biovolume by major taxonomic group and year for Kinbasket Reservoir.

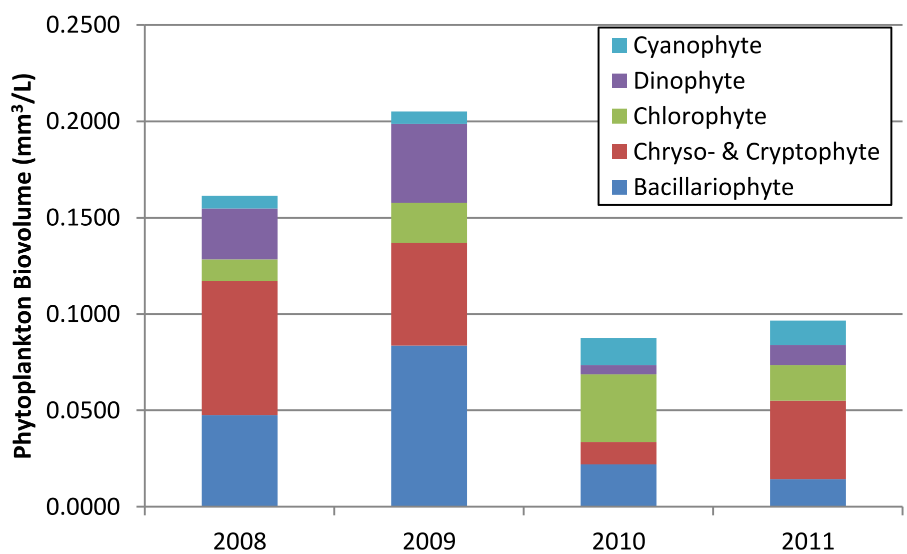


Figure 28. Mean seasonal phytoplankton biovolume by major taxonomic group and year for Revelstoke Reservoir.

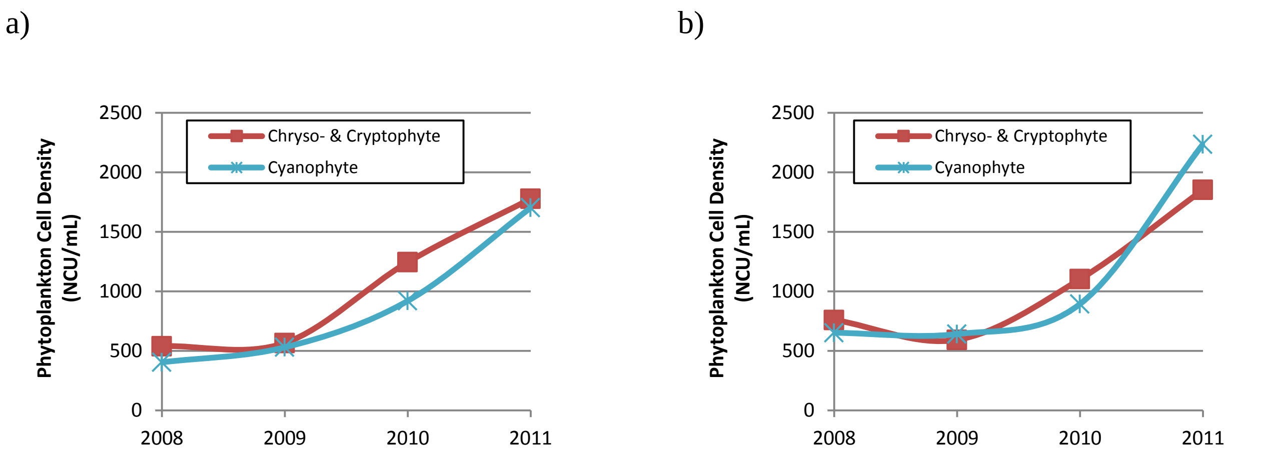


Figure 29. Chrysophyte/Cryptophyte and Cyanophyte densities by year for (a) Kinbasket and (b) Revelstoke Reservoirs.

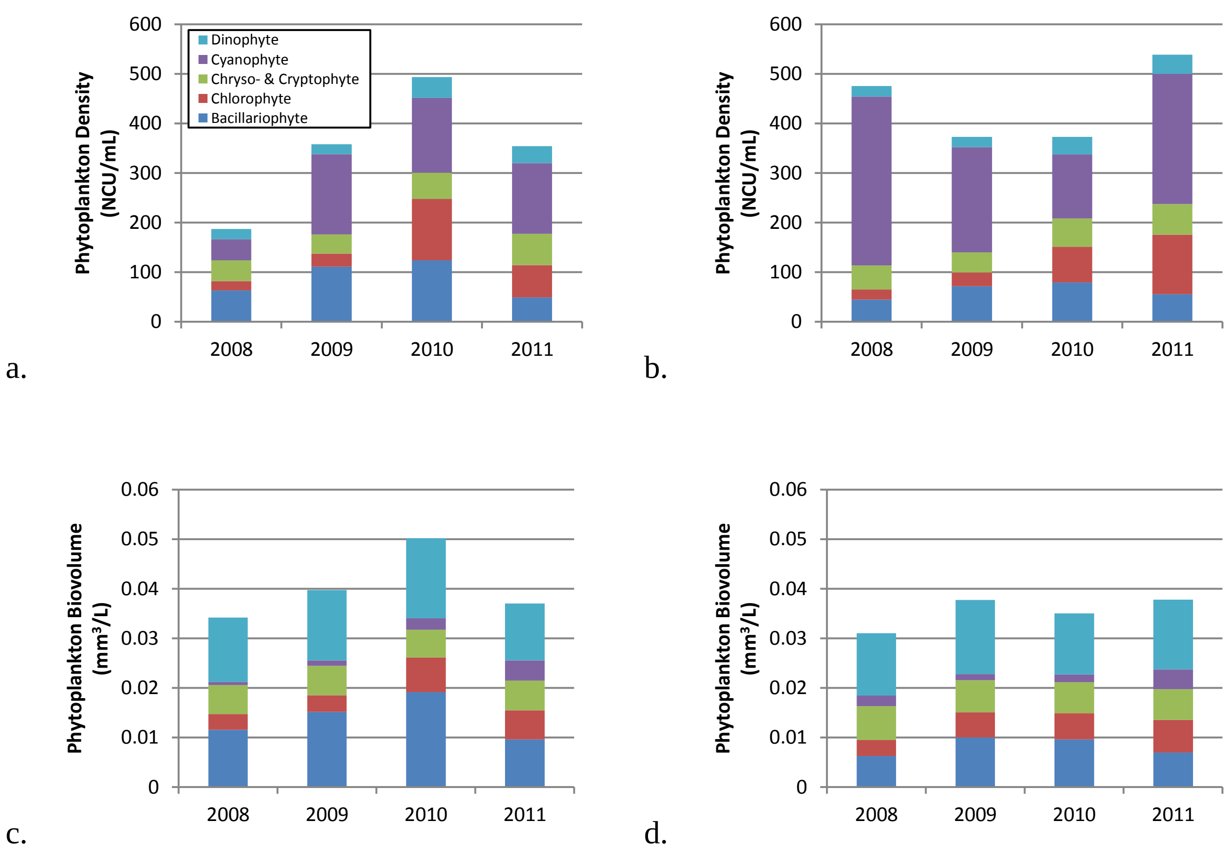


Figure 30. Mean seasonal density and biovolume by year for Kinbasket (a and c) and Revelstoke (b and d) without micro-flagellates or Synechococcus.

Kinbasket | Revelstoke

Heterotrophic Bacteria

Pico-cyano Bacteria

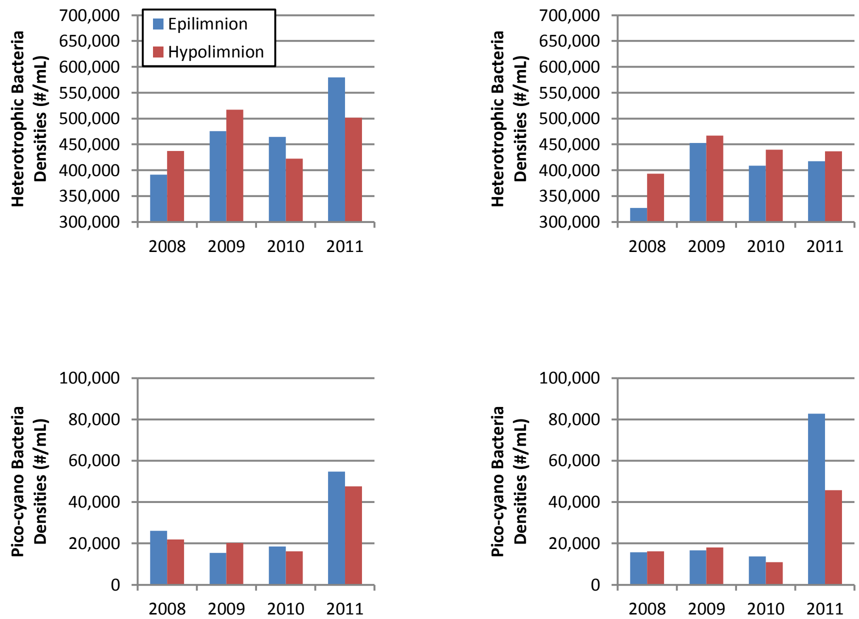


Figure 31. Heterotrophic and pico-cyano bacteria densities by strata and year for Kinbasket and Revelstoke Reservoirs.

3.5 Zooplankton

3.5.1. Kinbasket Reservoir

Eleven species of Cladocera were present in Kinbasket Reservoir from 2008 to 2011 (Table 8). *Daphnia galeata mendotae* (Birge), *Daphnia schoedleri* (Sars), *Daphnia rosea* (Sars), *Bosmina longirostris* (O.F.M.) and *Scapholeberis mucronata* (O.F.M.) were present in all four years, while other species were observed sporadically. *Daphnia* spp. were not identified to species for density counts.

Four calanoid copepod species were identified in Kinbasket Reservoir (Table 8). *Leptodiaptomus sicilis* (Forbes) and *Epischura nevadensis* (Lillj.) were present in samples during each sampling season, while *Leptodiaptomus ashlandi* (Marsh) and *Aglaodiaptomus leptopus* (Forbes) were observed rarely. *Diacyclops bicuspidatus thomasi* (Forbes), a cyclopoid copepod species, was seen throughout the study period.

Table 8. List of zooplankton species identified in Kinbasket Reservoir in 2008-2011. "+" indicates a consistently present species and "r" indicates a rarely present species.

	2008	2009	2010	2011
Cladocera				
Alona sp.			r	
Bosmina longirostris	+	+	+	+
Chydorus sphaericus		+	+	
Daphnia galeata mendotae	+	+	+	+
Daphnia rosea	+	+	+	+
Daphnia schoedleri	+	+	+	+
Diaphanosoma brachiurum		+	+	
Holopedium gibberum	r	r	r	
Leptodora kindtii	+		+	+
Macrothrix sp.		r		
Scapholeberis mucronata	+	+	+	+
Copepoda				
Aglaodiaptomus leptopus	r			
Diacyclops bicuspidatus	+	+	+	+
Epischura nevadensis	+	+	+	+
Leptodiaptomus ashlandi		r	r	r
Leptodiaptomus sicilis	+	+	+	+

Kinbasket Zooplankton Density - Seasonally averaged zooplankton density in Kinbasket Reservoir fluctuated over the four year period. It decreased from 16.77 individuals/L in 2008 to

11.12 individuals/L in 2009, then increased to 14.86 individuals/L in 2010, and decreased again in 2011 to 7.97 individuals/L (Table 9, Figure 32). Zooplankton density was numerically dominated by copepods, which averaged 76-80% of the zooplankton community followed by cladocerans other than *Daphnia* accounting for 11-17% and finally *Daphnia* spp. accounting for 4-11%.

Copepods prevailed during the whole sampling season in all four years, with populations peaking during the summer (Figure 33). The number of Cladocerans varied seasonally as well as spatially along the reservoir. Cladocerans other than *Daphnia* were most numerous in July each year, except in 2011 when its density peak was recorded in August. *Daphnia* spp. was present each year, during the whole sampling season at each station. In each study year the monthly averaged density of *Daphnia* spp. for the whole reservoir increased gradually during the sampling season reaching its peak in September (Figure 34). The highest density of *Daphnia* was found in September 2010 at Kinbasket Forebay with 4.62 individuals/L. The relative contribution of *Daphnia* spp. was highest at Kinbasket Forebay in 2009 at 14% and in 2011 at 10%. In 2008, Daphnia accounted for the greatest proportion of density at Canoe Reach with 7%, and in 2010 at Columbia Reach with 11% (Figure 35).

Table 9. Seasonal average zooplankton density and biomass in Kinbasket Reservoir 2008-2011. Density is in units of individuals/L; biomass is in units of μg/L.

Density		**2008**	**2009**	**2010**	**2011**
#/L	Copepoda	13.24	8.67	11.30	6.34
	Daphnia spp.	0.66	1.20	1.31	0.54
	Other Cladocera	2.86	1.25	2.25	1.10
	Total	**16.77**	**11.12**	**14.86**	**7.97**
%	Copepoda	79	78	76	80
	Daphnia spp.	4	11	9	7
	Other Cladocera	17	11	15	14

Biomass		**2008**	**2009**	**2010**	**2011**
μg/L	Copepoda	32.46	15.86	17.00	10.54
	Daphnia spp.	9.58	14.70	18.68	7.78
	Other Cladocera	3.94	1.74	2.72	1.42
	Total	**45.98**	**32.30**	**38.40**	**19.74**
%	Copepoda	71	49	44	53
	Daphnia spp.	21	46	49	39
	Other Cladocera	9	5	7	7

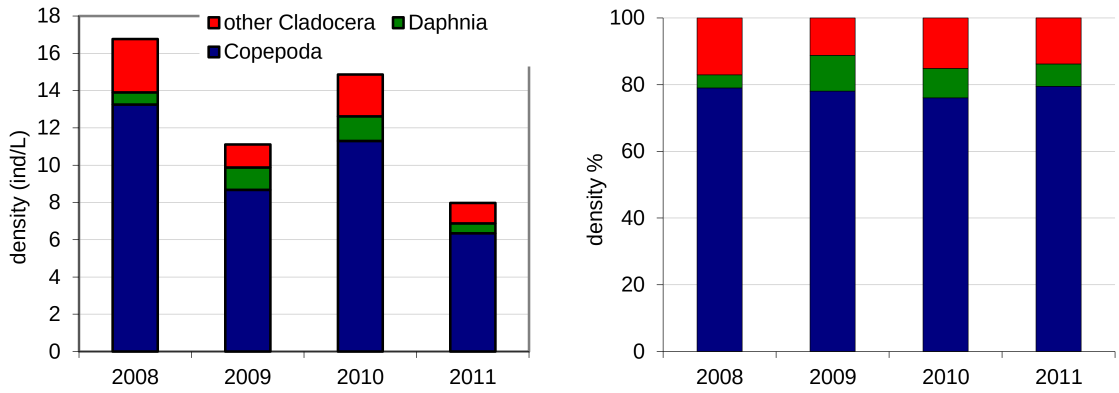


Figure 32. Seasonal average zooplankton density in Kinbasket Reservoir, 2008-2011

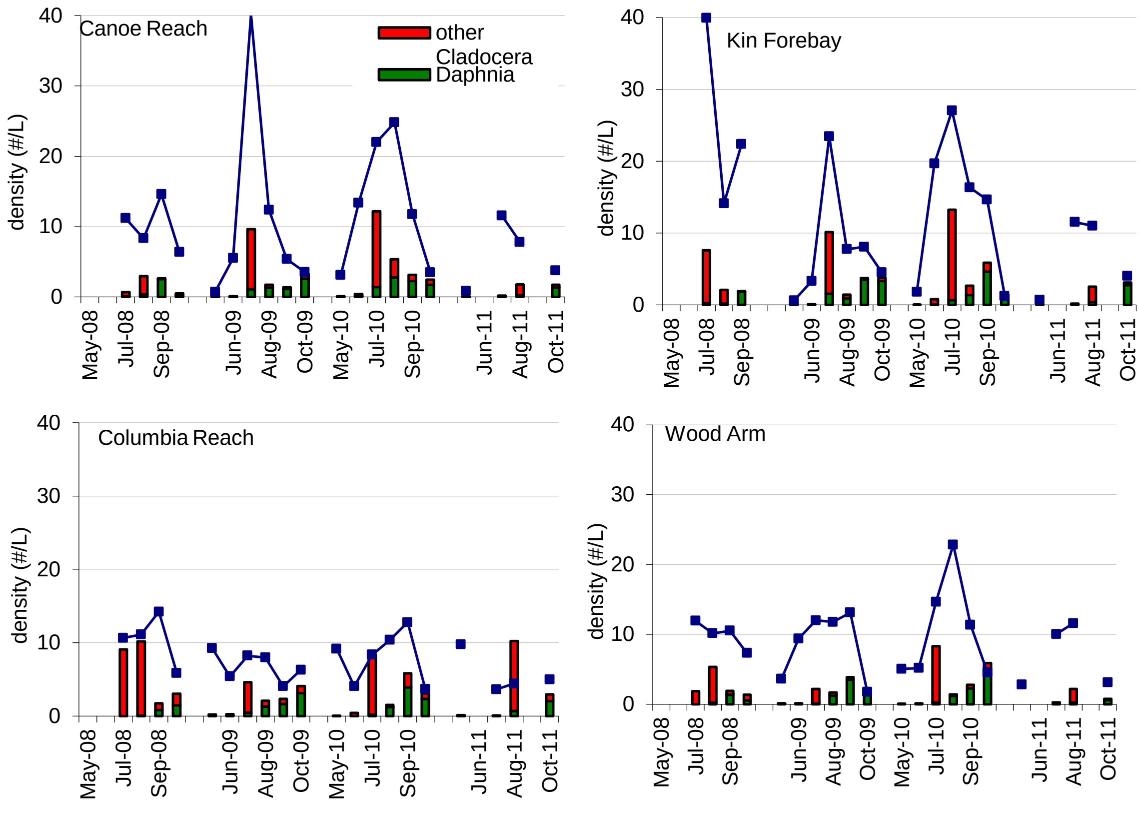


Figure 33. Density of cladoceran and copepod zooplankton at Canoe Reach, Kinbasket Forebay, Columbia Reach and Wood Arm in Kinbasket Reservoir in 2008-2011**.**

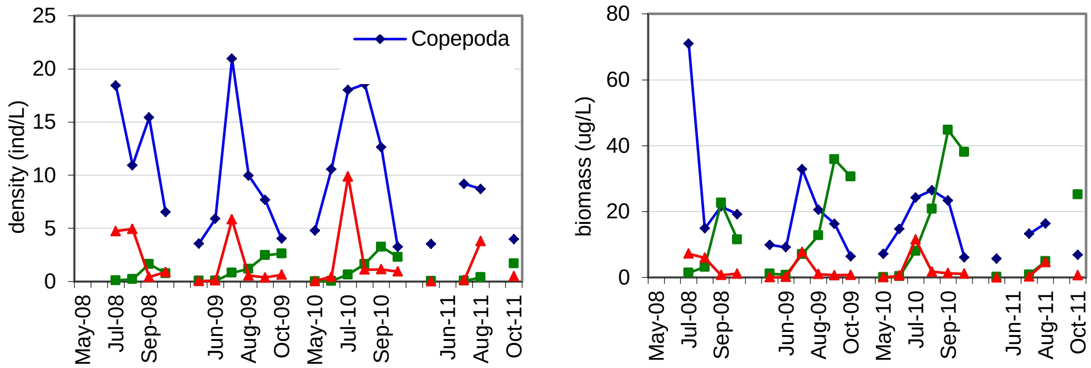


Figure 34. Average monthly zooplankton density the whole Kinbasket Reservoir in 2008-2011.

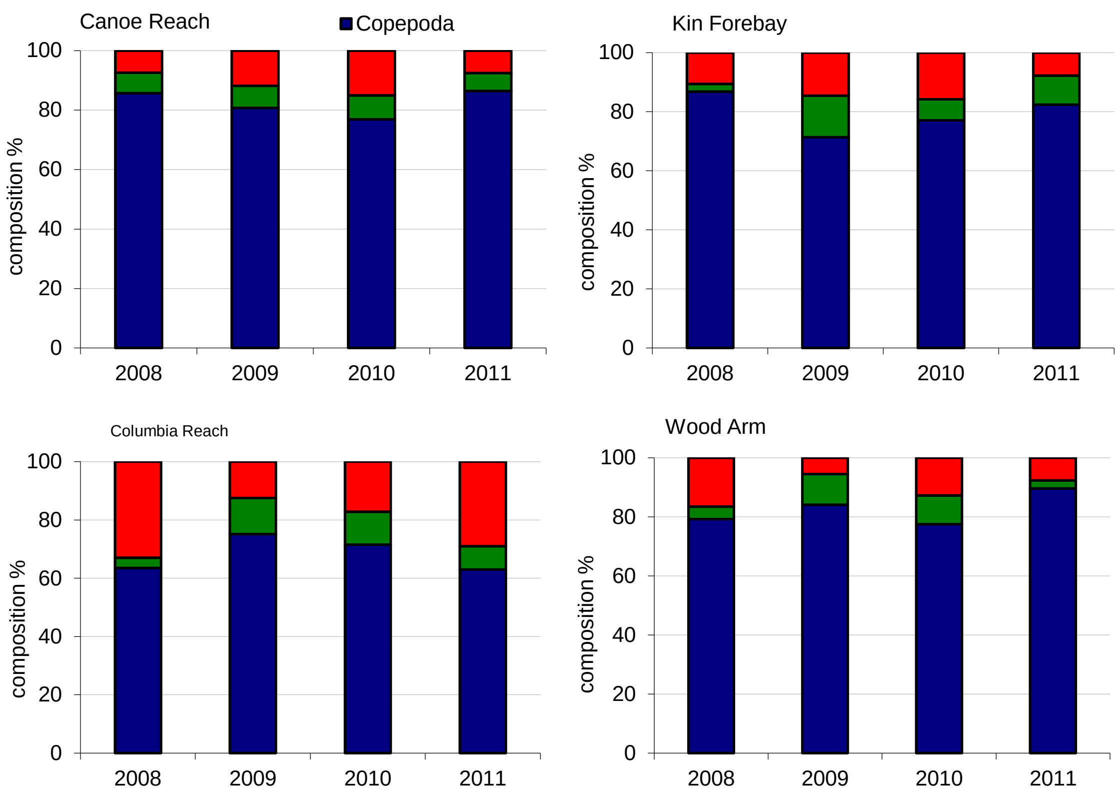


Figure 35. Seasonally averaged relative contribution of each zooplankton group to density at four stations in Kinbasket Reservoir, 2008-2011.

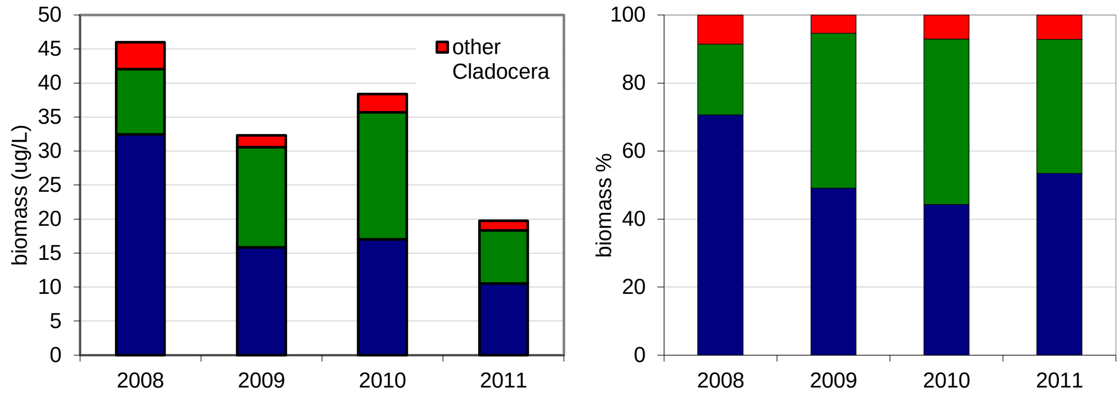


Figure 36. Seasonally averaged relative contribution of each zooplankton group to biomass in Kinbasket Reservoir, 2008-2011.

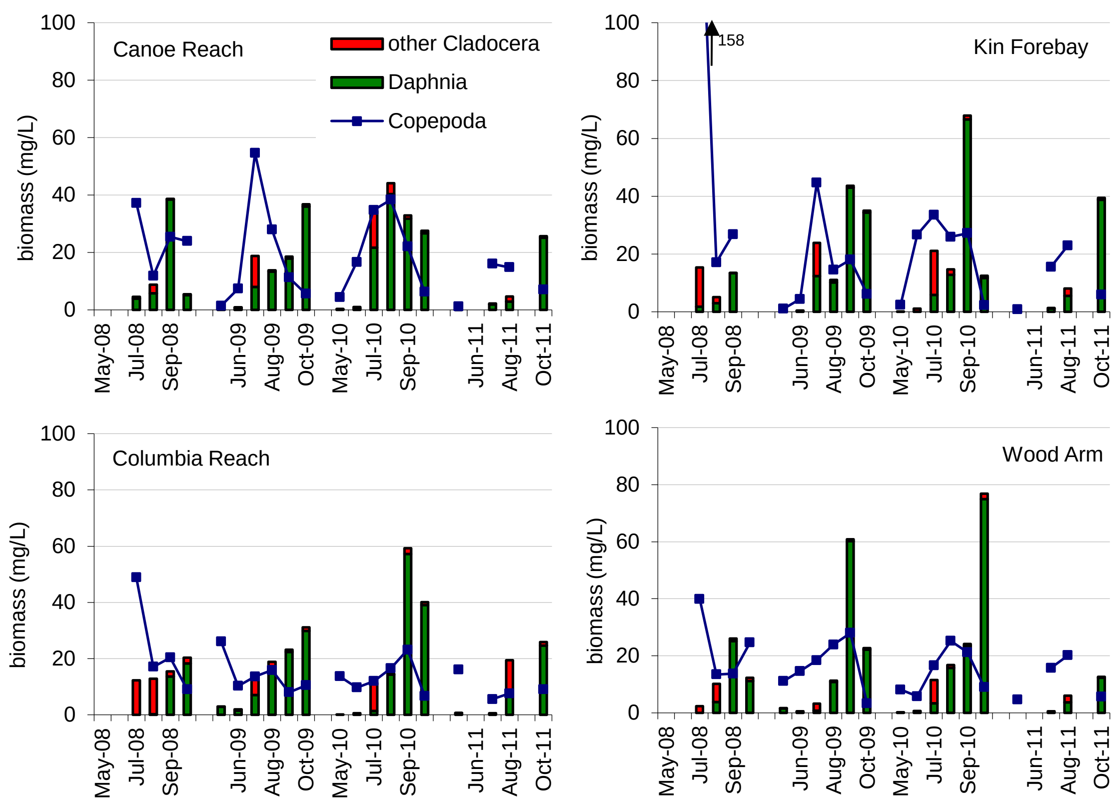


Figure 37. Biomass of cladoceran and copepod zooplankton at four sampling stations in Kinbasket Reservoir in 2008-2011.

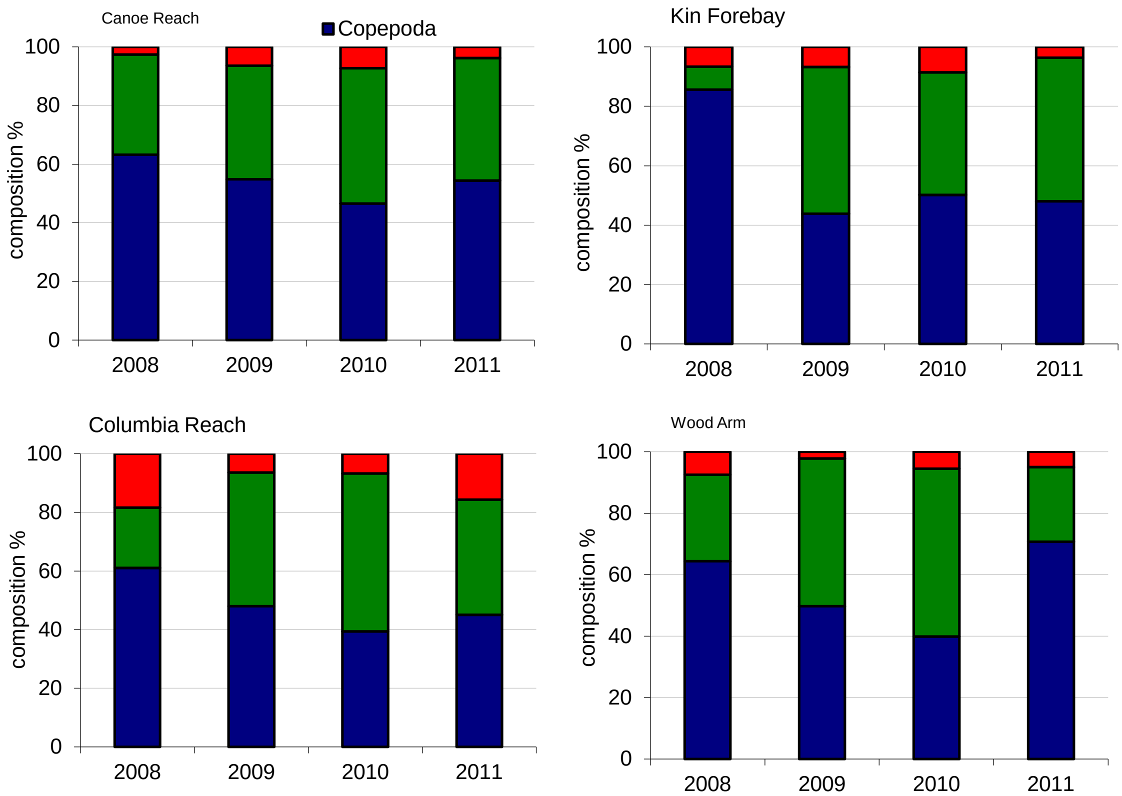


Figure 38. Seasonal average percentage of zooplankton biomass composition at four sampling stations in Kinbasket Reservoir in 2008-2011.

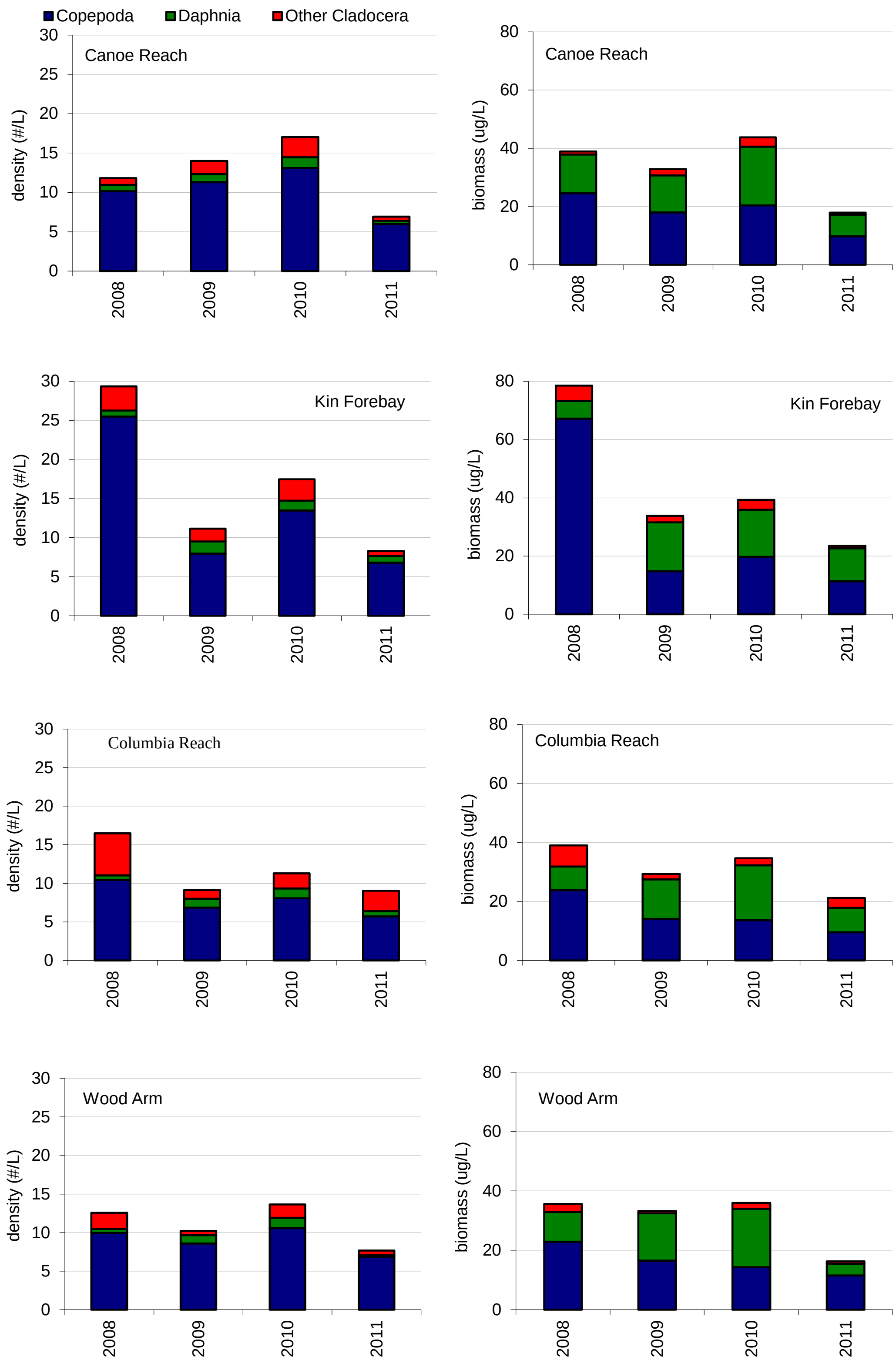


Figure 39. Seasonal average zooplankton density (left) and biomass (right) at four sampling stations in Kinbasket Reservoir 2008-2011.

Among the sampling stations, the proportion of seasonal average *Daphnia* biomass in 2009 and 2011 was the highest at Kinbasket Forebay with 49% and 48%, in 2008 at Canoe Reach with 34%, and in 2010 at Wood Arm with 55% (Figure 38). The most stable zooplankton community was at Canoe Reach, where both density and biomass of all three zooplankton groups were relatively static during the study years 2008-2011 whereas zooplankton composition, density, and biomass fluctuated widely during the study period at the other three stations (Figure 39).

Zooplankton Fecundity - Fecundity features of the two most common zooplankton species *D. bicuspidatus thomasi* and *Daphnia* spp. were studied during the sampling season. In Kinbasket Reservoir, *D. bicuspidatus thomasi* females were gravid throughout the sampling period and the proportion of gravid females was stable during four years averaging11% in 2008, 17% in 2009, 13% in 2010 and 15% in 2011. On average, from 2008 to 2011, gravid females carried 11.2, 13.9, 14.3, and 14.8 eggs, respectively (Table 10).

Table 10. Fecundity data for *D. bicuspidatus thomasi* in Kinbasket Reservoir in 2008-2011. Values are seasonal averages, calculated for samples collected between July – October 2008 and May - October 2009, 2010 and 2011.

	2008	2009	2010	2011
Proportion of gravid females (%)	11	17	13	15
# Eggs per gravid Female	11.2	13.9	14.3	14.8

In Kinbasket Reservoir *Daphnia* gravid females were present from July to October in all study years except in 2009 when gravid *Daphnia* started to appear as early as May. The proportion of gravid females decreased from 19% in 2008 and 2009 to 12% in 2010 and even further in 2011 to 9% (Table 11). On average the number of eggs per gravid female fluctuated around 2 eggs/gravid female during the study years.

Table 11. Fecundity data for *Daphnia* spp. in Kinbasket Reservoir in 2008-2011. Values are seasonal averages, calculated for samples collected between May - October 2009, 2010 and 2011 and July – October 2008.

	2008	2009	2010	2011
Proportion of gravid females (%)	19	19	12	9
# Eggs per gravid Female	1.91	2.04	1.52	2.08

3.5.2. Revelstoke Reservoir

Thirteen species of Cladocera were present in Revelstoke Reservoir during the study period from 2008 to 2011 (Table 12). *Daphnia galeata mendotae* (Birge), *Daphnia pulex* (Leydig), *Daphnia rosea* (Sars), *Bosmina longirostris* (O.F.M.), *Holopedium gibberum* (Zaddach) and *Leptodora kindtii* (Focke) were common. Other species were observed sporadically. *Daphnia* spp. were not identified to species for density counts.

Three calanoid copepod species were identified in Revelstoke Reservoir (Table 12). *Leptodiaptomus sicilis* (Forbes) and *Epischura nevadensis* (Lillj.) were present in samples during the whole season in each year, while *Leptodiaptomus ashlandi* (Marsh) were observed occasionally. One cyclopoid copepod species, *Diacyclops bicuspidatus thomasi* (Forbes), was seen in Revelstoke Reservoir.

Table 12. List of zooplankton species identified in Revelstoke Reservoir in 2008-2011. "+" indicates a consistently present species and "r" indicates a rarely present species.

	2008	2009	2010	2011
Cladocera				
Alona sp.			r	r
Alonella nana			r	
Biapertura affinis	r			
Bosmina longirostris	+	+	+	+
Ceriodaphnia sp.	r			
Chydorus sphaericus	r		r	r
Daphnia galeata mendotae	+	+	+	+
Daphnia rosea	+	+	+	+
Daphnia pulex	+	+	+	+
Diaphanosoma brachiurum		r		
Holopedium gibberum	+	+	+	+
Leptodora kindtii	+	+	+	+
Scapholeberis mucronata	r	r	r	r
Copepoda				
Diacyclops bicuspidatus	+	+	+	+
Epischura nevadensis	+	+	+	+
Leptodiaptomus ashlandi	+	+	+	+
Leptodiaptomus sicilis	+	+	+	+

Revelstoke Density and Biomass - Zooplankton density fluctuated over the course of the study period. Zooplankton density was high in 2008 and 2010 at 8.85 individuals/L and at 8.27 individuals/L moderate in 2009 at 6.41 individual/L and lowest in 2011 at nearly half the densities observed in 2008 and 2010 at 4.59 individuals/L (Table 13). Copepods were consistently the most abundant group in each year fluctuating from a high of 7.08 individuals/L in 2008 or 80% of the zooplankton community to a low of 3.53 individuals/L or 77% of the zooplankton community in 2011 (Table 13). The highest annual average density of *Daphnia* was also seen in 2008 with 0.77 individuals/L and has been decreasing annually from 2008 to 2011. On average Daphnia spp. has accounted for 6-11% of the zooplankton community over the study period. Density of other Cladocerans (mainly *Bosmina* and *Holopedium*) also fluctuated during four study years ranging from a high of 1.17 individuals/L in 2010 to a low of 0.73 individuals/L in 2009 (Table 13, Figure 40).

Total zooplankton biomass, averaged for the whole reservoir decreased from 36.76 µg/L in 2008 to 16.05 µg/L in 2011. Copepods biomass has ranged from a high of 47% of the total biomass in 2008 and 40% in 2010, to a low of 33% in 2009 and 2011. *Daphnia* biomass has decreased annual from a high in 2008 of 14.75 µg/L or 40% of the total biomass to a low of 4.23 µg/L or just 26% of the total biomass in 2011. Other cladocerans peaked in 2010 at 7.37 µg/L or 30% to a low of 4.22 µg/L or 17% of total biomass in 2009 (Table 13; Figure 41).

Table 13. Seasonal average zooplankton abundance and biomass in Revelstoke Reservoir 2008-2011. Data are averaged for May to October in 2009, 2010 and 2011, and July to October in 2008. Density is in units of individuals/L; biomass is in units of µg/L.

Density		**2008**	**2009**	**2010**	**2011**
#/L	Copepoda	7.08	4.96	6.63	3.53
	Daphnia spp.	0.77	0.72	0.47	0.25
	Other Cladocera	1.00	0.73	1.17	0.81
	Total	**8.85**	**6.41**	**8.27**	**4.59**
%	Copepoda	80	77	80	77
	Daphnia spp.	9	11	6	6
	Other Cladocera	11	11	14	18
Biomass		**2008**	**2009**	**2010**	**2011**
µg/L	Copepoda	17.32	8.02	9.83	5.35
	Daphnia spp.	14.75	12.30	7.56	4.23
	Other Cladocera	4.69	4.22	7.37	6.47
	Total	**36.76**	**24.54**	**24.76**	**16.05**
%	Copepoda	47	33	40	33
	Daphnia spp.	40	50	31	26
	Other Cladocera	13	17	30	40

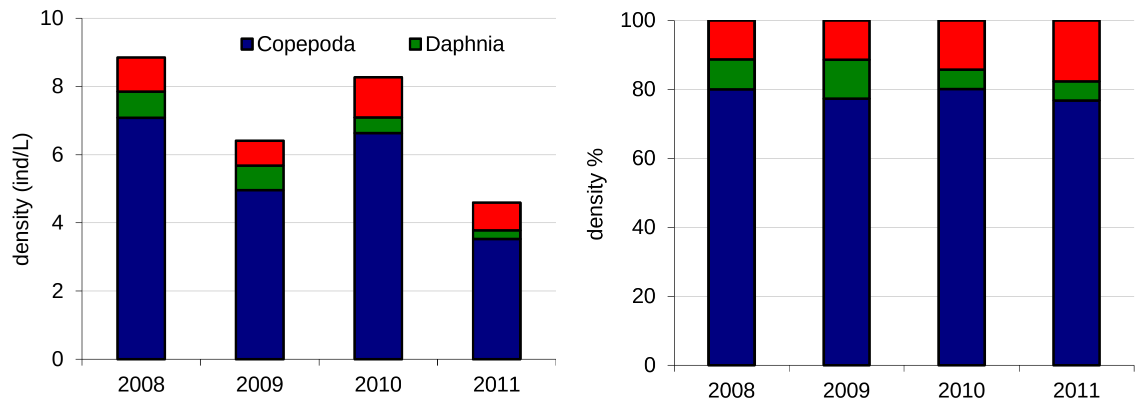


Figure 40. Seasonal average composition of zooplankton density in Revelstoke Reservoir in 2008 – 2011.

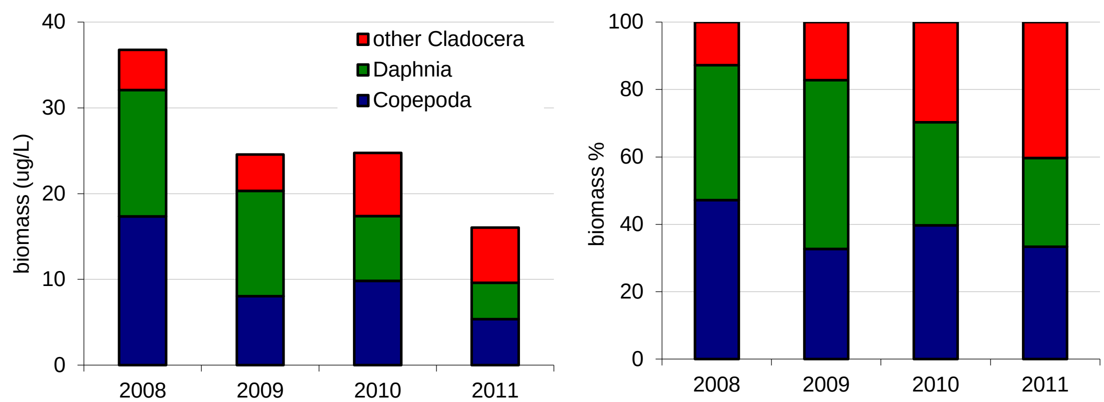


Figure 41. Seasonal average composition of zooplankton biomass in Revelstoke Reservoir in 2008 – 2011.

During each year zooplankton densities in Revelstoke Reservoir were low at the beginning and at the end of the sampling season, with seasonal peaks during the late summer (Figure 42). Seasonal average zooplankton biomass followed the same trend as density. During each sampling year, except 2009, zooplankton biomass increased in May reaching maximum biomass from July to September and then decreased again at the end of the sampling season. In 2009 large *Daphnia* continued to increase in density in October which was mirrored in a biomass increase at the end of the sampling season (Figure 42**).** The highest total zooplankton density and biomass were recorded in July 2008 at Rev Forebay station with 28.54 individuals/L, and 90.53 µg/L (Figure 43 and Figure 44**).**

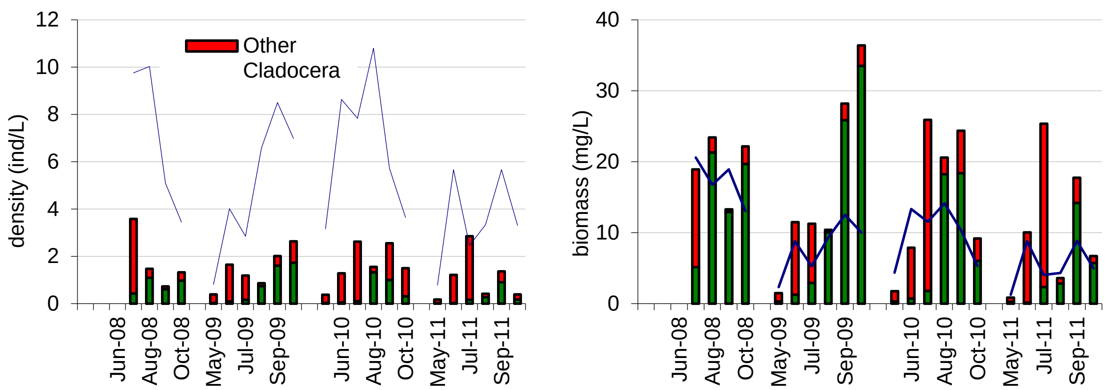


Figure 42. Monthly average zooplankton density and biomass in Revelstoke Reservoir in 2008 – 2011.

The seasonal pattern of density and biomass of each zooplankton group was similar in all four study years. The number of Copepoda increased at the beginning of the season, then decreased in July, and increased again in the late summer. The number of other Cladocera fluctuated during the season. After a peak in July, a decrease of cladoceran density occurs in August, followed by a slight increase in September (Figure 42). Other Cladocerans were composed mainly of *Holopedium* and *Bosmina.* The highest number of other cladocerans was found in July 2008 at REV Forebay with 8.25 individuals/L due to a peak of *Bosmina* with 6.16 individuals/L. Regardless of their small size, other cladocerans contributed 13%-30% in 2008-2010, and in 2011 made up the majority of the total zooplankton biomass contributing to 40% (Table 13).

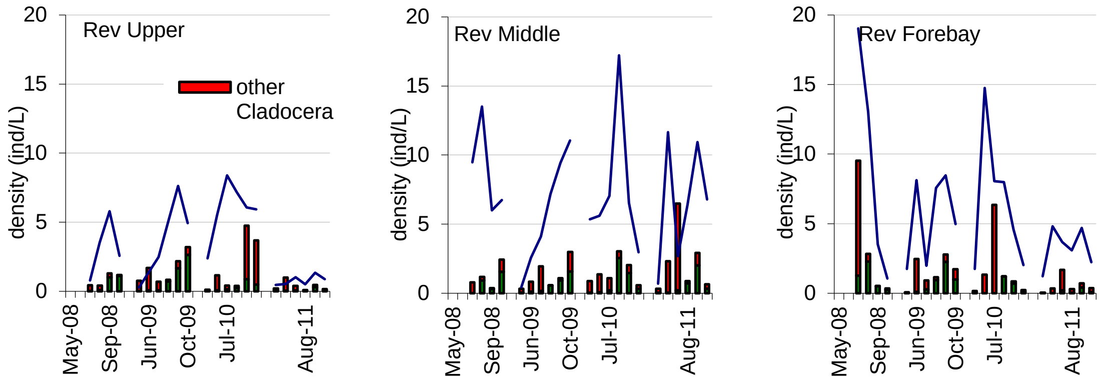


Figure 43. Zooplankton density at three sampling stations in Revelstoke Reservoir 2008 – 2011.

The seasonal fluctuation pattern of *Daphnia* was similar in each sampling season. *Daphnia* were present in samples with low number from May to July, and then increased sharply in August and September (Figure 43). *Daphnia* biomass followed density fluctuations. The highest *Daphnia* biomass during the four study seasons was found at Rev Upper station with 53.64 µg/L in October 2009, when *Daphnia* accounted for 85% of the total zooplankton biomass (Figure 44).

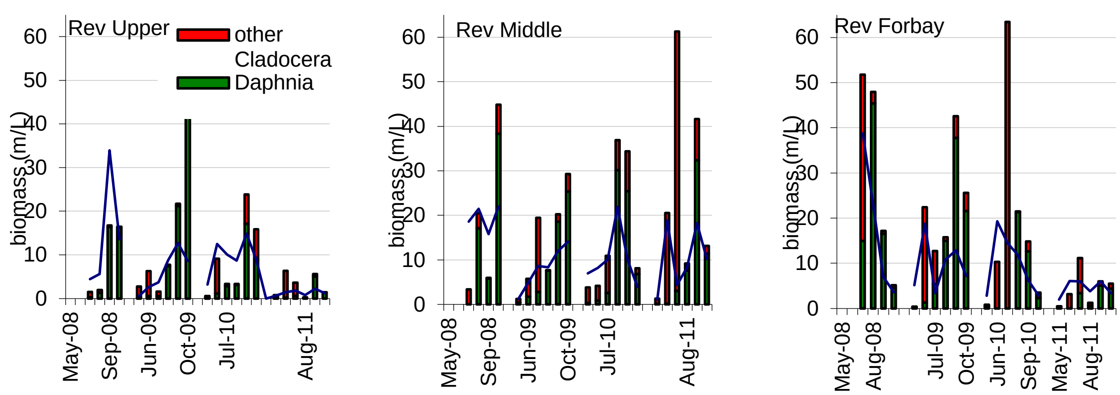


Figure 44. Zooplankton biomass at three sampling stations in Revelstoke Reservoir 2008 – 2011.

Zooplankton Fecundity - Fecundity features of the two most common zooplankton species *D. bicuspidatus thomasi* and *Daphnia* spp. were studied. *D. bicuspidatus thomasi* females were gravid throughout the sampling season in all four years and averaged 13-18% (Table 14). The highest proportion was found in May 2011 at the Rev Middle station at 34%. On average, gravid females carry up to about 11.2-18.5 eggs in the four study years (Table 14).

Table 14. Fecundity data for *D. bicuspidatus thomasi* in Revelstoke Reservoir in 2008-2011. Values are seasonal averages, calculated for samples collected between July and October in 2008 and May to October in 2009 - 2011.

	2008	2009	2010	2011
Proportion of gravid females (%)	18	15	13	16
# Eggs per gravid female	11.18	15.17	17.36	18.51

Daphnia spp. gravid females were observed in Revelstoke Reservoir throughout the sampling season in each year. The proportion of females that were gravid was variable across the seasons and along the reservoir. The proportion of gravid females averaged 20% in 2008, 13% in 2009 and 9% in 2010 and 2011 (Table 15). The seasonal average number of eggs per gravid female was 1.76-2.66.

Table 15. Fecundity data for *Daphnia* spp. in Revelstoke Reservoir 2008-2011. Values are seasonal averages, calculated for samples collected between May and October in 2008 and May to October in 2009 - 2011.

	2008	2009	2010	2011
Proportion of gravid females (%)	20	13	9	9
# Eggs per gravid Female	2.66	2.00	1.76	2.41

3.6 Kokanee

As trends can only be seen in longer term data, the CLBMON 2 monitoring in Phase 1 was designed to take advantage of seven years of hydroacoustic and trawl survey data collected previously under the “Large Rivers” Program of BC Hydro. With the recent four years of monitoring in 2008-2011, the approach has been to use the entire eleven years (2001-2011) 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.

3.6.1 Kokanee Habitat

Kokanee prefer pelagic or deep water habitat defined as areas with at least 20 m of depth (Pennak 1989). The pelagic habitat in Kinbasket Reservoir changed significantly with annual and seasonal changes in pool level; springtime or minimum annual pool elevation ranged from 712 to 730 m above sea level and averaged 721 m over the past eleven years of kokanee surveys. This represents a range of 24-42 m below the full pool elevation of 754 m. The pelagic area during springtime ranged from 145 to 197 km^2 and averaged ~174 km^2 over this same period (Table 16). These springtime habitat areas are expected to result in the maximum densities of age 1-3+ kokanee and may be an important factor in determining the reservoir's annual carrying capacity for kokanee.

As the reservoir filled from June through late summer the main reservoir pelagic area increased by an average of 58 km^2 (33%) and a further 64 km^2 (37%) 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 Zones in Figure 1 and Table 2 have been considered marginal for kokanee production since they are barely deep enough to afford protection from predators and have to be re-colonized with age 1-3+ kokanee every summer as they refill. The annual increase in total pelagic area ranged considerably from 89 km^2 in 2001 (57% increase) to 156 km^2 in 2002 (108% increase). The large fluctuation in pool levels in 2002 occurred following the driest year on record in 2001 and largest drawdown in spring 2002 in preparation for the large freshet in 2002 that led to near full pool elevations by August of 2002.

Compared to the 11 year average, both the average minimum and average maximum pool levels have operated ~3 m higher during the 2008-11 study period. The highest spring level occurred in 2009 (a dry year – see Figure 4 and full pool was reached in 2007 and again in 2011, exceptionally wet years as indicated by mean annual discharge data from the Columbia River at Donald (Johner and Weir 2012).

Table 16. Estimates of pelagic habitat area available to kokanee at annual minimum and maximum pool elevations in Kinbasket Reservoir, 2000-2011. Minimum and maximum values denoted by blue and red font respectively.

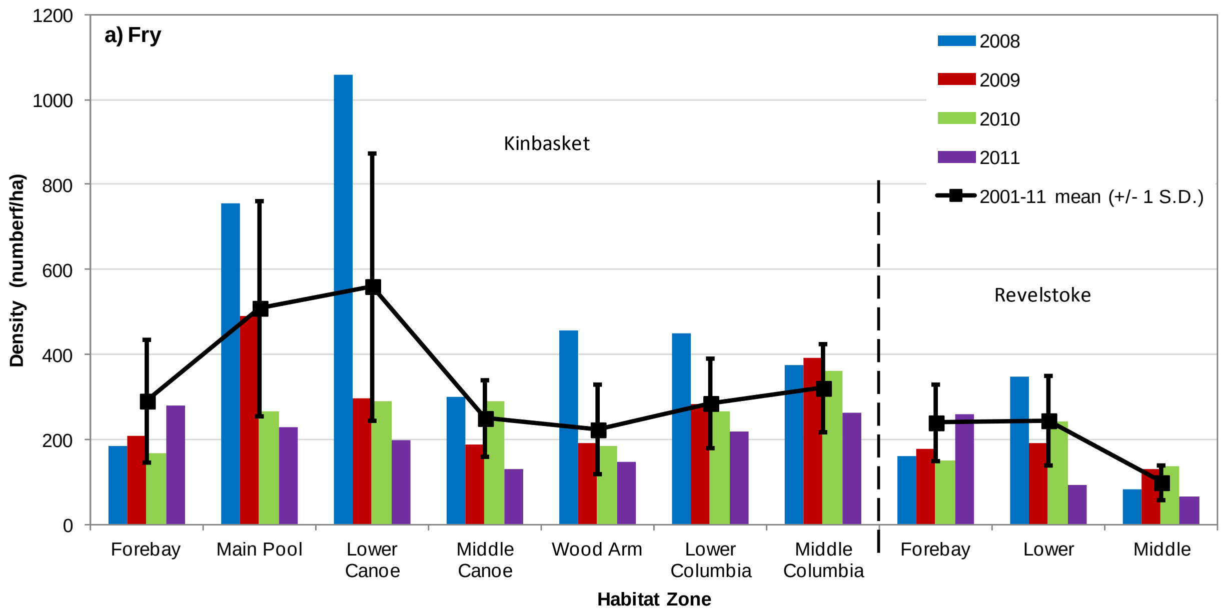
Year	Minimum pool elevation and habitat area			Maximum pool elevation and habitat area for kokanee					
	Low pool elevation (m)	Relative elev. [1] (m)	Pelagic habitat area [2] (km^2)	High pool elevation (m)	Relative elev. [1] (m)	Increase in main pelagic area [3] (km^2)	Increased marginal pelagic area [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
Ave[5]	721	-33	174	750	-4	58	64	122	296
Ave[6]	*724*	*-30*	*183*	*753*	*-1*	*52*	*77*	*129*	*312*

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 is considered marginal for kokanee as depth is greater than 20m but <35 m.
5. Refers to average of 2001-2011 survey years
6. *Italicized averages are for the recent study years 2008-2011*

Pool elevations during summertime hydroacoustic surveys were very similar to maximum pool estimates for most years. Exceptions were in 2004, 2008 and 2010 when the reservoir continued to fill well after the summer sampling was completed.

In terms of climate affect, over the last 11 years of continuous kokanee time series, 2001 was extremely dry at nearly 2 S.D. below the 66 year mean for the summer growth period, followed by 2009 and 2010 which were also very dry years at > 1 S.D. below average (Figure 4). Above average summer flow occurred in only two of the last 11 years and these flows were well within the range of ±1 S.D. from the average. With five out of six of the remaining years also below average, this eleven year period can be characterized as having growth season flows well below average (Figure 4). The general trend of increasing water levels to near full summer pool elevation over the past five of eleven years does indicate a change in dam operations given the drier than average climate over the same period (Table 16, Figure 4 and Figure 5a).

Longitudinal Distribution of Kokanee – As indicated earlier, Kinbasket Reservoir was divided into 9 habitat zones of which seven were sampled. Density distributions for the four study years (2008-2011) are compared with the eleven year average for the seven zones in Kinbasket Reservoir and 3 zones in Revelstoke Reservoir (Figure 45). During a relatively high abundance year for kokanee in 2008, fry densities fell outside one standard deviation from the eleven year mean in three of seven zones (Lower Canoe, Wood Arm and Lower Columbia zones). The same year, age 1-3 densities were higher than average in two zones; Lower Canoe and the main pool. The other noteworthy year was 2011, when fry densities were below one standard deviation from average in 3 of 7 zones in Kinbasket and 1 of 3 zones in Revelstoke. In 2011, the age 1-3+ densities were even lower with 5 of 7 stations below average in Kinbasket and 1 of 3 stations below average in Revelstoke Reservoir. Both the Main Pool and Lower Canoe zones (representing very large open water habitat areas) appear to be most sensitive to changes in kokanee abundance.



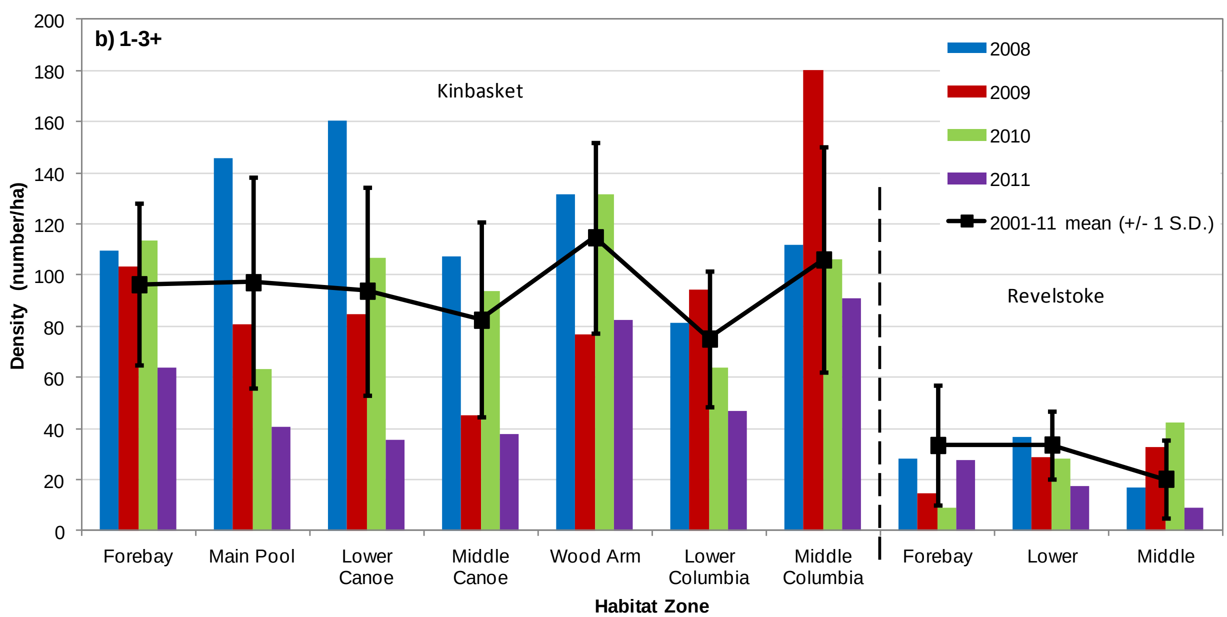


Figure 45. Longitudinal density distribution of a) age 0+ and b) age 1-3+ kokanee in Kinbasket and Revelstoke Reservoir during 2008-2011 compared with the 11 year average. Note the error bars on the 11 year average represent ±1 standard deviation.

3.6.2 Trends in kokanee abundance

Kinbasket Reservoir fry typically averaged around 7.6 million with a one standard deviation range of ±40% or 4.6-10.6 million (Figure 46a). Only one year (2007) showed unusually high fry numbers at 15 million. The fry density fell below 40% or 1 S.D. of the mean in 2011, only one year of eleven. Fry abundance estimates over the 2008-2011 study period have shown variability approximately equal to ± one standard deviation of the long term mean.

The age 1-3 fish appeared to be considerably less variable than fry with a mean of 1.9 million ±22% (1.5-2.4 million) (Figure 46b). The abundance of age 1-3 kokanee was higher than average in 2001 and 2008 and lower than average in 2002 and 2011. The highest abundance of 2.68 million in 2008 followed the highest fry abundance on record in 2007 indicating this strong cohort persisted beyond their first winter. The reason for the elevated fry numbers in 2007 can be traced to a relatively strong spawner return in 2006 (BC Hydro data on file) combined with large spawner size, since they were almost entirely age 3+ in 2006 (Johner and Weir, 2012). Recent declines in fry and age 1-3 fish follow a period of lower spawner returns and smaller spawner size largely due to younger age at maturity (i.e., 100% age 2+ returns in 2009 and 2010) (Table 18).

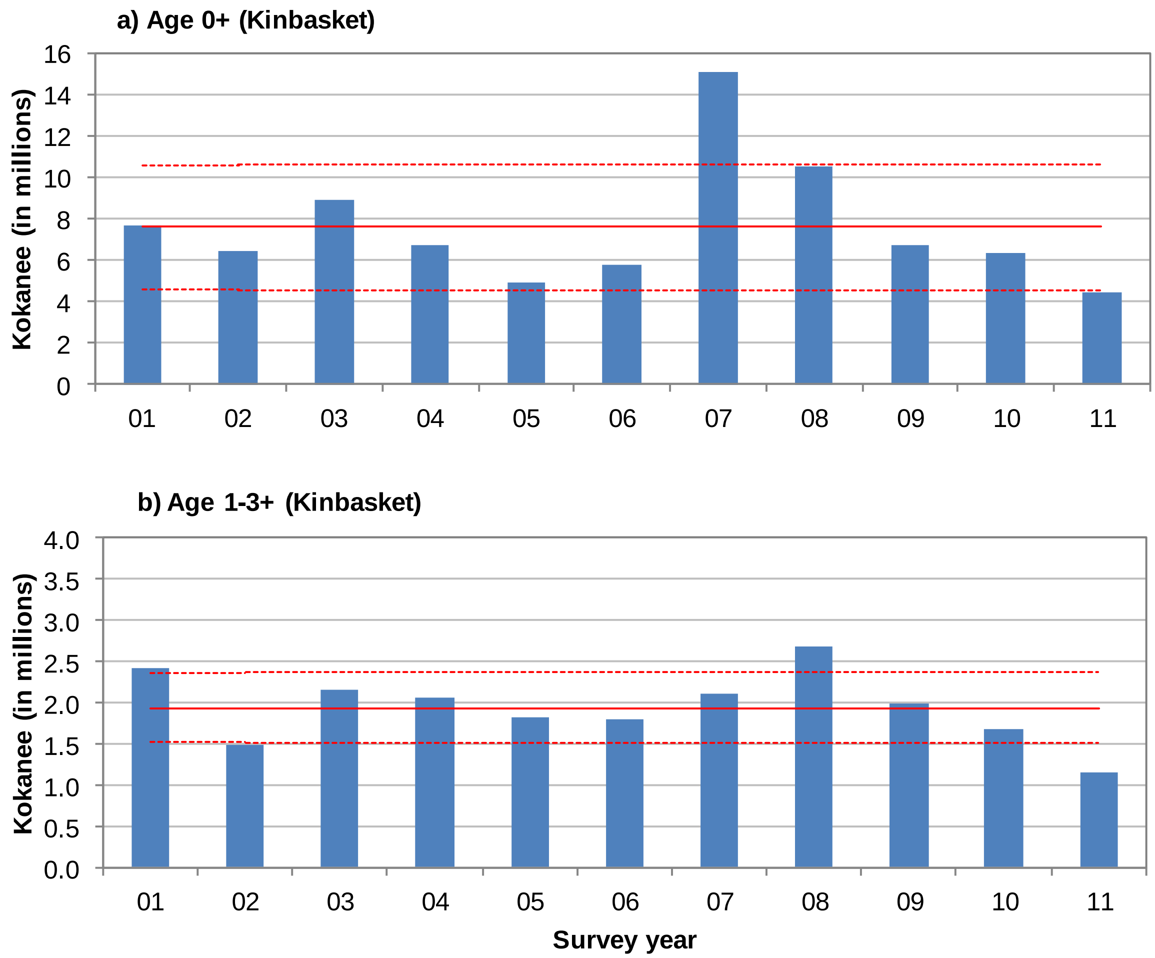


Figure 46. Trends in abundance for a) age 0+ (fry) and b) age 1-3+ kokanee in Kinbasket Reservoir based on summer time hydroacoustic surveys, 2001-2011. Note solid red line indicates 11 year average and red dotted lines indicate ± 1 standard deviation of the 11 year average.

Revelstoke Reservoir fry typically averaged around 1.16 million ±28% (0.84 – 1.48 million) (Figure 47a). High fry numbers occurred in 2003 and 2008. Low years occurred in 2001 and 2011. Fry abundance appeared surprisingly stable in Revelstoke reservoir with 1 standard deviation of only ±28% of the mean, compared with ±40% on Kinbasket Reservoir.

The age 1-3 fish were very low in numbers and more variable than fry with a mean of 0.21 million ±44% (0.12-0.31 million). For age 1-3 kokanee, higher than average numbers occurred in 2003 and 2006 and lower than average in 2001, 2004 and 2011 (Figure 47b). It is worth noting that one of the highest fry abundance years in 2003 was followed by one of the lowest age 1-3 abundance years in 2004. The opposite pattern is also evident when the lowest fry year in 2000 was followed by above average year for age 1-3 fish in 2002. In Revelstoke Reservoir, there seems to be no predictable relation between fry recruitment and cohort strength in years following as discussed later in this report.

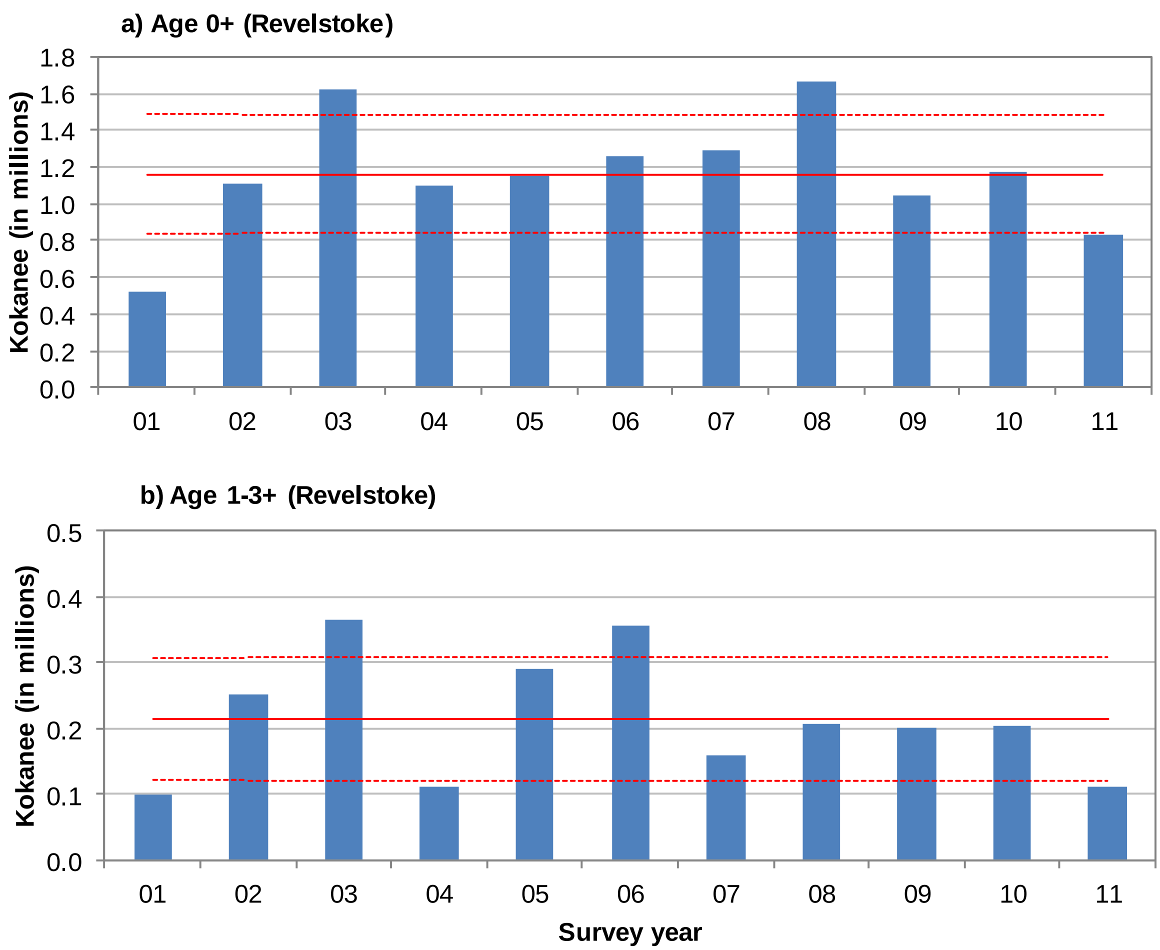


Figure 47. Trends in abundance for a) age 0+ (fry) and b) age 1-3+ kokanee in Revelstoke Reservoir based on summer time hydroacoustic surveys, 2001-2011. Note solid red line indicates 11 year average and red dotted lines indicate ± 1 standard deviation of the 11 year average.

3.6.3 Spawner abundance

Spawning tributaries are widespread in the Kinbasket watershed and were grouped for summary purposes into 1) Upper Columbia River mainstem, 2) Upper Columbia River tributaries and 3) other tributaries which flow directly into the reservoir. The eleven year average (2001-2011) spawner count for all streams combined was ~238,000 while the recent (2008-11) counts totalled 98,700 suggesting a decline of nearly 60% for the recent survey years (Table 17). This is misleading, since counts were much lower with discontinuation of the counts within the

Columbia River mainstem in 2010 due to external circumstances. A more valid comparison of stream total counts excludes the Columbia River mainstem and suggests a decline of around 34% for the recent study period compared to the 11 yr average. Most of this decline was due to lower counts in the Columbia River tributaries, while returns to other (group 3) tributaries were within 10% of the eleven year average and therefore were relatively static. Table 17 serves to highlight the magnitude of the contribution of the Columbia River mainstem to kokanee production in Kinbasket Reservoir, as the mean count from 2001-11 is 1.5X all other tributaries combined. Note that a number of circumstances affect the precision and accuracy of the spawner counts on each tributary to varying degrees across years; in particular poor weather, high water and low visibility (see discussion). For this reason spawner counts have been grouped and averaged over time in Table 17 in order to mute the effect of variable sampling conditions on longer term trends.

Table 17. Summary of cumulative spawner counts for Kinbasket tributaries comparing the recent counts to the eleven year average.

Group	Description	2001-2011 Mean count (no.)	S.D.	Proportion of total spawners	2008-2011 Mean count (no.)	% difference for 2008-2011 period
1	Columbia River mainstem	143,000	88,000	60%	36,300 [1]	-75% [1]
2	Columbia River tributaries[2]	43,600	28,400	18%	15,600	-64%
3	Other Kinbasket tributaries[3]	51,500	25,000	22%	46,800	-9%
	Total all index tributaries	238,100		100%	98,700	-59%
	Total without mainstem	95,100		40%	62,400	-34%

1. Recent declines for Columbia mainstem are misleading since count were discontinued in 2010
2. Columbia R tributaries include Luxor, Forester, Toby and Horsethief creeks
3. Other Kinbasket tributaries include Bush River, Wood River and Camp Creek

3.6.4 Kokanee growth and age at maturity

Kokanee growth in BC large lakes is typically monitored through trends in trawl size at age for all age groups in the lake and then compared with spawner length and age information to verify age at maturity. Limited catches of age 2+ trawl fish did suggest a period of increased growth in 2006 which agrees with the large average size of spawners in 2006 and 2007. However, the trawl sample sizes were often too low in Kinbasket to show reliable year to year trends in kokanee size-at-age for age 1+ and 2+ kokanee (Sebastian et al. 2010; Johner and Weir 2012). Except for age 0+, no growth information was available from trawling in Revelstoke as catches of age 1-3 kokanee were sporadic.

Otolith age interpretations from spawners currently provide the best indicator for kokanee size, growth and age at maturity in Kinbasket and Revelstoke reservoirs. Camp Creek (a tributary of Canoe River at the north end of Kinbasket Reservoir) provided the best long term data for showing trends in spawner size and growth (Table 18). Periods of good growth for both age 2+ and 3+ spawners occurred in 2002-2003 indicated by red values (> one standard deviation of the mean). A second period of good growth for age 3+ is suggested for 2006 with only one age 2+ fish captured. Periods of relatively low growth indicated in blue occurred for age 2+ spawners in 2008-09 and for age 3+ in 2011.

Age data from Camp Creek spawners indicates age at maturity is highly variable between age 2+ and 3+, with a mix of both ages occurring most years (Table 18). Only in 2006 and 2007 were the spawners almost entirely age 3+. Age at maturity changed to nearly exclusively age 2+ for three consecutive years from 2009-11, a pattern unique in the time series.

Additional samples more recently collected from Luxor Creek (entering the Upper Columbia River) suggests the possibility of some slight differences in growth but more importantly in age at maturity (e.g. 2007) between the kokanee populations in the north and south end of Kinbasket Reservoir . However, sample sizes were small and four years of data are insufficient to draw firm conclusions on differences in growth and age structure.

Standard Creek (Revelstoke) kokanee spawners have been sampled for four years; 2007 and 2008-11. Over this period, spawner size has declined for both age 2+ and 3+ spawners, however the sample size was small some years (Table 18). Age at maturity has varied from 7-31% age 3+, indicating a trend similar to Kinbasket over the study period of primarily 2+ spawners, although not as dramatic. Kokanee size at age was much larger in Revelstoke than Kinbasket, presumably due to much lower kokanee densities.

Table 18. Trends in length at age, age composition, average female length and theoretical fecundity for kokanee spawners in Camp Creek 1998-2011 and for Luxor and Standard creeks in 2007 and 2009-2011.

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
Mean	238	264	260	372	334	1	47%	248	410
S.D.	12	11						18	84
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
Mean	226	263		96	5		5%	225	310
S.D.	16	11						19	74
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
Mean	270	301		59	18		23%	276	549
S.D.	15	22						19	109

1. Fecundity was derived from female length based on an empirical relation by McGurk (2000)
2. Camp and Luxor Creeks represent Kinbasket north end and south end populations, respectively.
3. Standard Creek, tributary to Downie Creek represents Revelstoke Reservoir spawners.
4. Red indicates years with large spawner size and blue indicates small spawner size defined as outside the bounds of ± 1 standard deviation of the mean.

4.0 Discussion – Ecological Productivity (CLBMON-3)

Discussion for CLBMON-3 and CLBMON-2 (below) is focused on progress to date towards answering the management questions. Both programs span 12 years, and this, the first four year synthesis, addresses the data collected to date, trends based on this limited data, and provides preliminary insight into the function of the reservoirs. The discussion also describes how the larger question of reservoir operations and their influence on pelagic production and kokanee populations will be addressed.

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

Data are being collected from five reference tributaries to address the question of long term trends in nutrient input. From the limited data to date (3 years) there are no evident trends. We intend to continue collection of data from these five reference tributaries and periodic full surveys throughout the program to address this question.

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

One important factor controlling the use of nutrients from tributaries is whether these nutrients enter the photic zone. We have developed some simple models to estimate whether tributary inflow enters the photic zone (Pieters and Lawrence, 2012). The next step is to apply these simple models to Kinbasket and Revelstoke Reservoirs in order to provide some basic estimates. Also important is the amount of time that nutrients are available in the photic zone. To fully address this question requires integrating a wide variety of information observed over a variety of years with different flow conditions; we will be pursuing a variety of avenues to address this over the next four years.

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

With the limited productivity data available to date it is difficult to assess long term trends or changes overtime. Limited data prior to 2008 (Stockner and Korman 2000) suggested that production in Kinbasket and Revelstoke was low and likely dominated by small sized phytoplankton cells, and that microbial populations were likely controlled by limited nutrient availability.

The primary productivity results have shown that productivity in Kinbasket Reservoir from 2008-2011 is indeed low with a mean rate of 34.9 mg C/m^2/d, ranging from a high of 50.6 mg

$C/m^2/d$ in 2008 to a low of 17.5 mg $C/m^2/d$ in 2009 which confirms the ultra-oligotrophic nature of Kinbasket Reservoir. From the limited data available, no trends are evident.

Primary productivity in Revelstoke Reservoir from 2008-2011 is also low with a mean rate of 23.1 mg $C/m^2/d$ at Revelstoke Middle and 24.2 mg $C/m^2/d$ at Revelstoke Forebay. At this early stage in the monitoring program there is some indication that the productivity of Revelstoke Reservoir may be increasing slightly over the time series. Although the increases in productivity have been modest and are still indicative of ultra-oligotrophic conditions, a fivefold increase was observed at Revelstoke Middle whereas at Revelstoke Forebay a threefold increase was observed.

While it is important to determine trophic status of the two reservoirs it is also equally important to characterize the size dynamics of primary productivity in order to further our understanding of how the nutrient dynamics are driving the structure and function of the food web in the two reservoirs. Size fractionated primary productivity information is available for 2009-2011. In all study years, picoplankton and nanoplankton were the most productive fractions in Kinbasket and Revelstoke where they accounted for between 60-90% of the total productivity while microplankton were the least productive fraction accounting for between 10-30% of total productivity. Although there are limited data available to date, some trends are evident over the three year study period. In both reservoirs, the contribution by picoplankton, small 0.2-2.0 µm sizes cells, has increased approximately 3 fold over the study period. In 2011, picoplankton productivity accounted for 44% of total productivity while in Revelstoke picoplankton productivity accounted for 59% of total productivity.

Additional data from primary productivity assays and phytoplankton taxonomy will be examined to determine if the trends observed in the past four years continue into 2012 and beyond. Four years of data makes it difficult to identify increasing or decreasing trends between years. With the collection and analysis of additional data sets statistically significant trends may be determined.

4. If changes in pelagic productivity are detected, are the changes affecting kokanee populations?

The link between the base of the food chain to kokanee is mediated by a number of functional groups and processes that are currently in the process of being documented by the monitoring program. At this point, it is difficult to determine with certainty if trends in phytoplankton primary productivity are due to the limited data available (4 years of primary productivity data and only three years of size fractionation data). To date, the data suggest a small increase in productivity in Revelstoke Reservoir while no trends in total productivity are noted in Kinbasket Reservoir. With the limited data available it is difficult to determine how the small increases in productivity in Revelstoke Reservoir will impact upper trophic levels; however, as the magnitude of the change is very small this increase is predicted to have limited impact on upper trophic levels. Phase II of the monitoring program will provide data to assess this prediction. The change noted in the size structure of the productivity is important to continue monitoring as increasing picoplankton production can lead to less efficient transfer of carbon up the food chain. The decline in nanoplankton production over the study period is of concern because nanoplankton is the fraction readily consumed by Daphnia spp., the preferred food source for kokanee.

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. We are currently in the early part of Phase II of the monitoring program and are improving our understanding of the state of pelagic production in Kinbasket and Revelstoke. Prior to this program few data were available on trophic status and even less information was available for the factors controlling productivity in the reservoirs. One important factor known to control pelagic productivity is nutrient supply and availability. These will be examined using simple models developed to estimate whether tributary inflow enters the photic zone (Pieters and Lawrence 2012) (see question 2).

Our coordinated monitoring approach is at the early stages of the program and additional years of monitoring will lead to a greater understanding of how the ultra-oligotrophic ecosystem functions in Kinbasket and Revelstoke. Once we have a clearer understanding of the dynamics of the reservoir to link physical, biological, and chemical processes, we can move to determining 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 (e.g., Arrow Lakes Reservoir, Kootenay Lake, Okanagan Lake, Williston Reservoir)?***

Measurement of primary productivity is labour intensive, and therefore, limited data are available for other systems. Kootenay Lake is the only lake or reservoir with comparable primary production data collected annually since 2004. It is possible, however, to compare the current primary productivity data set with data from earlier studies for systems such as Williston Reservoir or Slocan or Okanagan Lakes.

Kinbasket Reservoir is similar to nearby oligotrophic Slocan Lake and Okanagan Lake in terms of chlorophyll and productivity where biomass is ~ 30 mg/m^2 and where primary productivity is less than 100 mg $C/m^2/d$. The lower biomass and primary productivity rates measured in Revelstoke Reservoir are similar to Elsie Lake and Williston Reservoir, two ultra-oligotrophic systems. Although not surprising, Kinbasket and Revelstoke primary productivity are an order of magnitude lower than nearby Arrow Reservoir and Kootenay Lake, both systems with nutrient restoration programs where rate of production between 296-353 mg $C/m^2/d$ are common.

While primary productivity data are limited it is possible to examine and compare other chemical and biological parameters from other systems as indicators of productivity. For instance, we will compare the phytoplankton community structure and zooplankton populations from nearby Arrow Lakes Reservoir to Kinbasket and Revelstoke.

7. ***Does the addition of Mica Units 5 and 6 influence pelagic productivity?***

This management question is related to CLBMON-56, the addendum resulting from the Mica 5/6 Environmental Assessment. As work did not begin until 2012 on this component, this question will not be addressed here. The inclusion of more detailed reservoir temperature profile data collected under CLBMON-56 will assist in answering this question in future synthesis reports.

8. ***Are there operational changes that could be implemented to improve pelagic productivity in Kinbasket Reservoir?***

While it is too early to answer this management question, the Study Team is making progress to address this long term goal of the water license monitoring program. The monitoring program is documenting the current status of the reservoirs at a number of trophic levels, from primary productivity to kokanee. Next steps include working towards developing predictive models that can be used to both identify key linkages or functional groups and to provide feedback on effects of potential changes in reservoir operation on pelagic production. The study team is working together closely and are meeting on an annual basis to review findings, discuss progress to date, and refine work plans to address data gaps in subsequent years of the monitoring program.

5.0 Discussion – Kokanee Populations (CLBMON-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 separated into two groups: age 0+ (fry) and age 1-3+ based on their different acoustic size. The rationale is that fry indicate either a recruitment or environmental change in the current year while the age 1-3+ group represent conditions over a longer period including the winter/spring low-water habitat conditions. Changes observed in age 1-3+ fish, but not in current year fry, could provide evidence of a winter or spring habitat limitation. In addition to distribution and abundance, other biological characteristics examined were trends in recruitment, growth, age and size at maturity.

Annual distribution - In Kinbasket Reservoir the longitudinal distribution of fry indicates that 5 of the 7 zones have very stable fry densities that reach a state of equilibrium at around 200-300 fry/ha (±20%) regardless of recruitment levels. In contrast, the Main Pool and Lower Canoe zones exhibit substantial variability with an 11 yr mean of ~550 fry/ha ±50%. For these two zones, low fry years have nearly the same densities as all other zones, while the highest year (2008) reached densities of three times higher at ~800-1000 fry/ha. In other large lakes, concentrations of fry can be explained by proximity to recruitment sites (Andrusak et al. 2008) or a response to elevated local productivity in fertilized lakes (e.g. fertilizer application zone at the north end of Kootenay Lake). However neither of these explanations applies to Kinbasket Reservoir where the majority of fry production comes from the Upper Columbia River, nearly 275 km south of the Main Pool (Oliver 1995, Sebastian et al. 2010) and other measures show no indication of elevated trophic level production in Lower Canoe.

Passive drift can help to explain the distribution of fry in Kinbasket Reservoir. Since the majority of inflow (~68%) during the May-June freshet period enters the reservoir via the Columbia Reach, there are net inflows into other reaches including the Main Pool and Canoe Reach while the reservoir fills and while the outflows at Mica Dam are essentially shut down. Since this is likely concurrent with fry migration from natal streams to deeper pelagic habitat, passive drift of fry in the Columbia Reach could result in concentrations of fry ending up in the Main Pool and Lower Canoe. With changes in fry abundance from year to year, most of the difference occurs in the Main Pool and Lower Canoe zones. If fry “drift” with currents, it would help explain why fry densities at the Forebay (where there is little outflow) would be lower than in the Main Pool and Lower Canoe zones most years.

Notably, three (09-11) of the four years within the 08-11 study period for the Lower Canoe zone and two (09-10) of four years for the Main Pool zone show densities of fry well below the 11 year mean (Figure 45). Those years the kokanee fry densities were relatively uniform across all zones in Kinbasket Reservoir. The cause(s) for the abnormal distribution some years is not evident, but may be related to a combination of factors including time of emergence, cohort strength, and annual spring/summer flow characteristics. Time of emergence data calculated in the future by daily water temperature collection via tidbit loggers placed in spawning site gravel through the incubation period may lead to greater understanding of distribution patterns.

By contrast, the distribution of age 1-3+ fish in Kinbasket is fairly consistent across all reservoir zones with an average density of ~100 fish/ha (±40%), with some variability evident in the highest and lowest years from 2008-11 (Figure 45b). Unlike fry, there was no tendency for accumulations in the Main Pool or Lower Canoe suggesting their distribution is largely determined by something other than passive drift. In other kokanee systems, age 1-3+ distribution is thought to be largely determined by food availability. If this is the case in Kinbasket, their distribution suggests that productivity (for older kokanee) is fairly constant throughout the reservoir. Note that distribution plots do not include marginal habitats in the Upper Canoe and Upper Columbia Reaches which we assumed support lower numbers of kokanee based on very limited sampling in Bush Pool (Sebastian et al. 2010).

In Revelstoke Reservoir, the lower two zones (Forebay and Lower Revelstoke) supported fry densities of ~220 fry/ha (±40%), and were similar to the lowest zone densities in Kinbasket found in Wood Arm and Middle Canoe. The Middle Revelstoke zone is narrow and riverine (with relatively higher currents) and had consistently lower densities than the other two zones at around 100 fry/ha (±43%). The fry distribution in Revelstoke is what would be expected given the main fry recruitment area (Downie Creek) enters the Lower zone. The drift of additional fry from upstream reaches, including any fry entrained at Mica Dam, would also contribute to the higher densities in the Lower and Forebay zones.

For age 1-3+, zone densities were very low in Revelstoke compared to Kinbasket and also highly variable within zones at 30 fish/ha (±60%). It is worth noting that variability in the Forebay and Middle Revelstoke zones was much higher (±70-75%) compared with the Lower Revelstoke zone (±40%).

Trends in Abundance - The Kinbasket abundance trend shows a relationship between fry and 1-3+ populations that is typically seen in other systems. Years having high fry abundance were generally followed by a year of elevated age 1-3+ abundance, as would be expected given that age 1+ fish are the largest component of the age 1-3+ group, having experienced less mortality than older fish. Low fry years also tended to be followed by low numbers of age 1-3+ the year following.

To further assess the extent to which overall kokanee abundance is determined by fry recruitment levels, the relation of fry to age 1-3+ abundance in Kinbasket and Revelstoke were compared to other BC large lakes and reservoirs (Figure 48). Kootenay and Okanagan lakes represent large lakes having limited or no direct influence from hydro facilities while Arrow Reservoir represents a hydro reservoir. The high R^2 values for Okanagan, Kootenay and Arrow all indicate that fry recruitment is a major factor determining age 1-3+ abundance the following year. A moderate R^2 for Kinbasket suggests fry recruitment is important, but other factors may also be influencing kokanee production. The slope of the regression lines provides a rough index of relative survival between fry and older age groups (albeit mostly between age 0+ to age 1+ in this example). Slopes suggest the translation (i.e. survival) of fry to older aged kokanee is similar in Okanagan and Kootenay Lake, slightly lower in Arrow Reservoir and much lower in Kinbasket Reservoir. This provides evidence that mortality over the first winter is higher in Kinbasket than in Arrow, Okanagan or Kootenay. A negative slope and low R^2 value shows there is no apparent correlation between fry and older aged kokanee in Revelstoke Reservoir (see Question 2).

Annual spawner counts are typically used to track trends in kokanee abundance and assist in predicting fry recruitment levels the following year. In Kinbasket Reservoir however, the tributaries are wide-spread, require aerial counting and fall flows and water clarity largely determine the reliability of many individual stream counts. With counts in the most important spawner area (Columbia mainstem) being discontinued, it does not appear that combined counts provide a reliable annual index of spawner abundance. However, counts do provide valuable qualitative information and when averaged over periods of one or two kokanee life cycles will capture the overall trend (i.e., upward or downward). Due to its small size and good water clarity in fall, Camp Creek remains a good long term index count although, with only 6% of the total spawner numbers, it does not likely represent spawner abundance for the entire Kinbasket Reservoir. In Revelstoke Reservoir, similar problems with water clarity and occasional high flows present difficulties for enumerating kokanee in Downie Creek, the key spawning index stream for this system. Due to these uncertainties, index spawner counts have not been included in this report and other avenues for assessing trends in kokanee recruitment are being investigated (i.e., growth and age at maturity; next section).

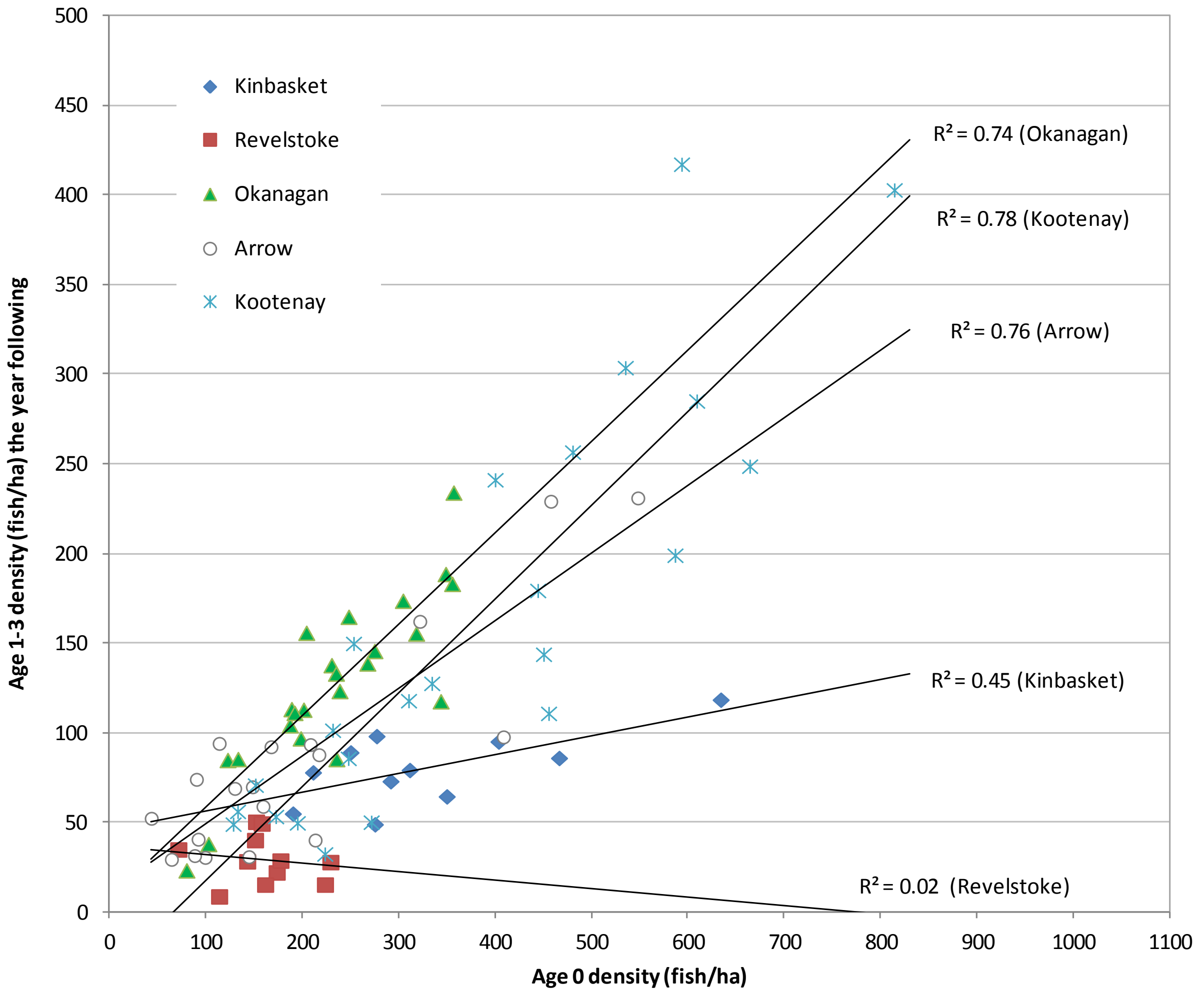


Figure 48. Relationship of kokanee age 0+ density to age 1-3+ density the year following for Kinbasket and Revelstoke reservoirs compared to Arrow Reservoir and Kootenay and Okanagan Lakes.

Spawner size and fry recruitment - The relationship of fecundity to spawner length for kokanee has been well documented by McGurk (2000) and others. Consequently, 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 surprisingly good relation (R^2 = 0.63) between spawner length in Camp Creek and the acoustic estimate of fry density the following summer (Figure 49). Not surprisingly there was no relation between relative abundance of spawners in Camp Creek and fry density in the reservoir. It appears that Camp Creek may be reasonably representative of system wide annual spawner size, and we speculate that size more than spawner numbers, may be controlling annual fry recruitment levels.

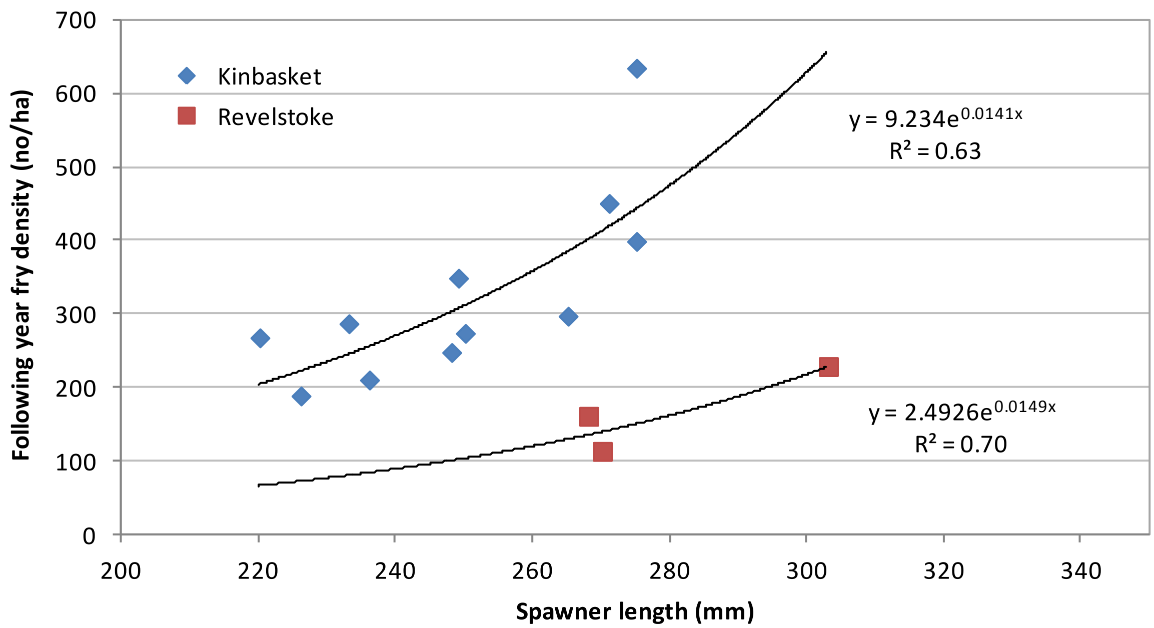


Figure 49. Relation of kokanee fry density to average spawner size the previous year for Kinbasket and Revelstoke kokanee. Note: Only 3 years in Revelstoke is likely insufficient to establish a relation so high R^2 is misleading.

Growth and age at maturity - The age of the spawners in Camp Creek was quite variable over time and the proportion of age 3+ fish showed a strong positive correlation with the overall size of females and therefore with fecundity and potential egg deposition (Table 18**;** Figure 50). From limited data it appears that the proportion of age 3+ in the spawning population largely determines future fry recruitment. The recent declines in spawner size was primarily a result of the switching from dominance of age 3+ spawners to almost entirely age 2+ spawners and is key to recent declines in both fry and older aged kokanee in 2010-11.

The shift in age at maturity to 2 yr olds for 3 consecutive years from 2009-11 is unprecedented in the time series (Table 18**)** and has not been observed in other large lakes in BC (MFLNRO data on file). Changes in age at maturity in other systems have been related to large shifts in productivity (e.g. Kootenay and Arrow Lakes); however in these systems changes to 2 yr old age at maturity did not persist to this degree. What is influencing the change in age at maturity in Kinbasket is not well understood but appears to be an important driver in recruitment and kokanee productivity. Further investigation into factors affecting kokanee age at maturity is important in identifying limitations on kokanee production in these reservoirs.

A sample of spawners from Luxor Creek, a tributary to the Upper Columbia River, was found to have matured at age 2+ in 2007, whereas the Camp Creek fish were larger and matured at 3+ the same year. This is interesting and assuming it is not sampling bias (e.g. spawners not collected across entire spawning period) suggests that these two stocks possibly reared in different parts of the reservoir with different productivity for at least part of their lives. Kinbasket is a large reservoir and to date collection of fish samples has been limited to trawl sampling in the main pool and lower Canoe Reach. Due to very low densities, trawling has produced very limited sample sizes for 1-3+ kokanee, which has limited the ability to validate age at maturity by size at age of all ages. Additionally, there are no data on fish from different parts of the reservoir to investigate differential growth based on location. In particular, it would be valuable to ascertain the extent to which kokanee are using Bush Pool.

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

Given the tendency of kokanee populations to exhibit density dependent growth responses, kokanee productivity is often best measured with estimates of biomass, an index that combines both abundance and size (weight). In order to estimate biomass, an adequate number of size samples is required for all age classes in each year, along with an estimate of age structure. Unfortunately, given the challenges in adequately sampling the older (1-3+ in-lake) age classes in Kinbasket and Revelstoke discussed earlier (low densities, hazardous conditions for trawl sampling), the necessary data was not available to estimate biomass for the first four years of the study period. Given this situation, kokanee productivity is best represented by abundance, with additional insight provided by spawner size data from samples collected at Camp, Luxor, and Standard Creeks. Going forward, pelagic gillnetting may prove useful as a sampling method to acquire greater insight into size at age by increasing sampling size, while age structure may be generalized based on data from other BC large lakes. Whether this provides sufficient data to resolve size at age and biomass estimation issues will need to be weighed against the increase in effort required on an ongoing basis. One of the advantages of pelagic gillnetting is that it can enable biological samples to be obtained from areas either too shallow (Upper Columbia) or too hazardous to trawl.

The role of reservoir operation as it relates to kokanee productivity cannot be categorically defined given the available data after year four (2011). However, there are some interesting signals in the data that may indicate operational affects are occurring on both Kinbasket and Revelstoke Reservoir. In Figure 48, the much lower slope on Kinbasket compared with Kootenay, Okanagan and even Arrow Reservoir indicates that fry survival to age 1+ is lower than in other systems but still driven by recruitment. With Revelstoke however, a negative slope with an R^2=0.02 indicate no relation at all between fry and older kokanee. There is a strong likelihood that factors other than recruitment are determining the low and variable abundance of age 1-3 kokanee in Revelstoke. Factors causing increased mortality of age 1-3+ kokanee (but not fry) could lead to a breakdown of the more typical recruitment controlled population dynamics. Possible causes of increased mortality could be predation, harvest or changes in lower trophic productivity, although it seems unlikely that these factors would be highly variable from year to year. It seems more likely that flows and entrainment could have a variable impact on kokanee abundance, although no correlations with flow were evident.

These relationships are built on relatively few data points for Kinbasket and Revelstoke, and will benefit from additional years data. Future years of exceptionally low or high abundance for fry and 1-3+ will provide contrast in the data and further insight into these population structures and the mechanisms affecting survival.

In order to explore the role of reservoir operation on kokanee productivity, basic relationships were examined between kokanee and high level indices of other variables including flow and lower trophic level productivity. The most intriguing relationship is demonstrated in Figure 50**,** which plots kokanee density against zooplankton seasonal average density and biomass density for both Kinbasket and Revelstoke Reservoirs. The fit for Revelstoke is remarkable whereas the relationship is marginal at best for Kinbasket zooplankton abundance and virtually non-existent for biomass density. The high R^2 value is intriguing in itself, but perhaps most informative is the contrast between the two reservoirs. Note that the kokanee densities presented are for all ages; fry and 1-3+ densities were plotted separately for both reservoirs with the same general results.

Two general scenarios might describe the relationships presented in Figure 50; scenario one – zooplankton abundance/biomass strongly controls kokanee survival in Revelstoke and is the primary driver of kokanee abundance, and scenario two – exogenous factor(s) that control kokanee in Revelstoke also control zooplankton to a similar magnitude. Conversely, the opposite is then true of both scenarios for Kinbasket, or the affect is somewhat muted.

Scenario 1 is the most intuitive, however does not hold up well under scrutiny. This scenario indicates that recruitment is not the predominant limiting factor on kokanee production in Revelstoke (at least under the kokanee numbers found to date), but rather it is zooplankton abundance/biomass. Zooplankton biomass certainly plays a role in recruitment levels in kokanee populations, as food availability (and quality) is arguably the major contributor to density dependant growth responses in kokanee populations. Changes in zooplankton abundance/biomass, either through external factors or grazing effects, are reflected in changes in size at age of kokanee which culminates in variable size at maturity, which is directly related to fecundity. The key consideration is that reductions in food availability for kokanee would first be expected to suppress growth before causing mortality, in which case the relationship between kokanee density and zooplankton biomass would not be expected to be as close it is for Revelstoke. The relationship would presumably be more in line with that found for Kinbasket, as changes in food availability would take time to culminate in changes at the population level. Additionally, Revelstoke 1-3+ kokanee are consistently much larger than Kinbasket kokanee based on size at age and spawner size data (Johner and Weir 2012), which indicates that food availability is not excessively limiting, for at least the larger age classes.

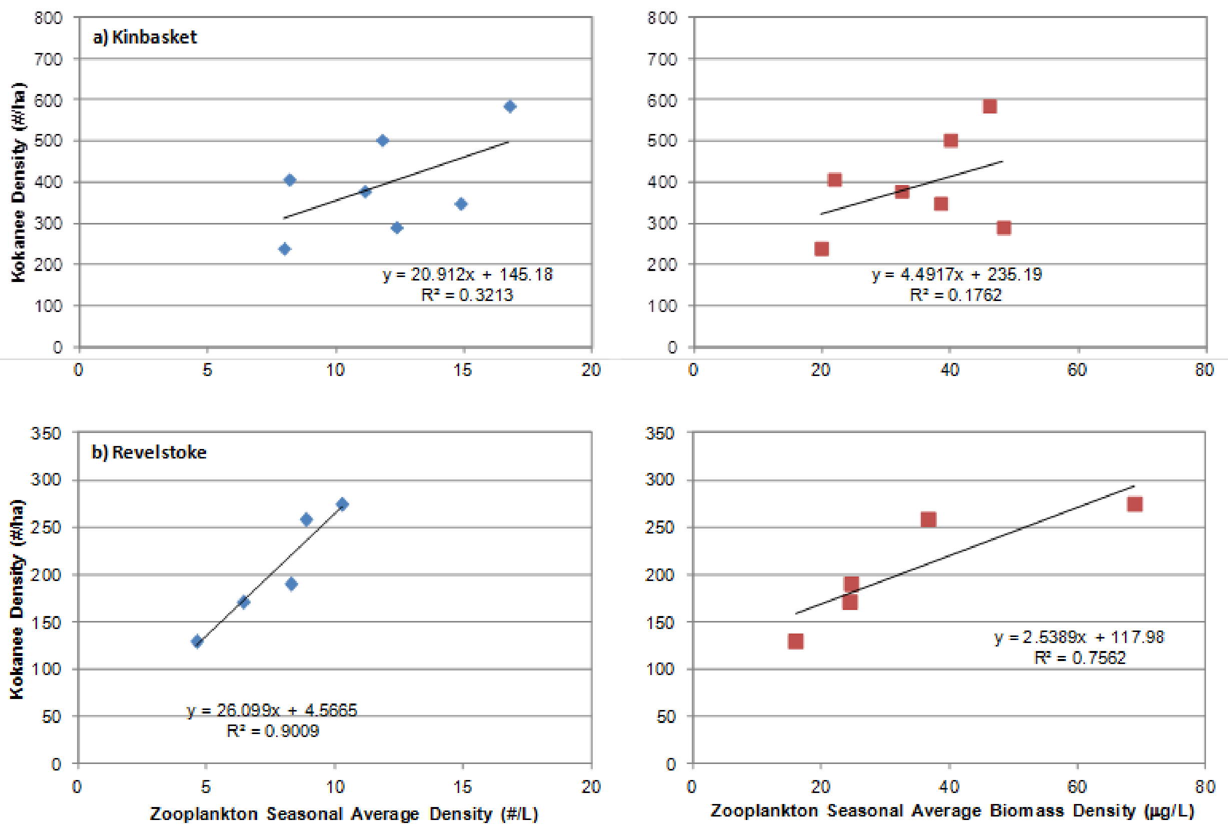


Figure 50. Relationship between mid-summer Kokanee densities and seasonal average Zooplankton density and biomass density for a) Kinbasket Reservoir and b) Revelstoke Reservoir for all years with data (Rev=2003, 08-11; Kin=2003-05, 08-11).

Scenario 2 suggests that an outside factor is exerting a controlling influence on both kokanee and zooplankton, and notably in Revelstoke to a much greater extent than Kinbasket. Among the factors considered, flow and entrainment were thought likely to affect both zooplankton and kokanee abundance in Revelstoke, given its riverine nature, short water residence time, outlet depth, and flow dynamics discussed earlier in this report. Kinbasket was deemed less likely to be vulnerable to significant flow/entrainment impacts on a kokanee population level given its large size, kokanee distribution, longer water residence time, and deep outlet depth. Monthly average outflow at Revelstoke was considered as a potential proxy for water residence time and entrainment rate of both zooplankton and kokanee, and was compared with kokanee populations for Revelstoke. While his did not demonstrate a significant relationship, this should be investigated in greater detail in the future.

Variable entrainment rates, both into and out of Revelstoke, for kokanee fry and 1-3+ could affect apparent survival rates and kokanee productivity on a population level. Entrainment studies were in progress at Revelstoke and Mica concurrent with the first four years of the CLBMON 2 & 3 study period. Future integration of the entrainment study results, in conjunction with additional time series data, should allow for greater insight into operational variables that may be causing the recruitment driven population control to break down in Revelstoke, as well as any effect there may be on Kinbasket kokanee.

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

With a limited time series it appears that inflow may influence kokanee productivity in Kinbasket Reservoir. Using the mean annual discharge (MAD) at Donald as an index of annual inflow**,** Figure 51a shows a weak correlation (R^2 = 0.22) with the annual abundance of age 1-3+ kokanee. Since no relationships were evident between previous fall and early spring low flows, it appears that high flows and particularly high flows in the summer growth period showed the best regression fit with age 1-3+ abundance (Figure 51b). Removing one year (2008), improved the R^2 values for both MAD and mean summer flow relations to kokanee abundance. The 2008 data point represents the highest 1-3+ kokanee abundance in the time series which lies well outside the normal range as defined by 1 S.D. of the mean (Figure 46). To further test if this correlation was spurious, regressions with kokanee fry and total combined kokanee (all ages) showed no relation to flow data. For Revelstoke, outflows, a surrogate for residence time and a possible link to entrainment rates, were tested to see if high flows led to decreased kokanee abundance; however, no relationships were evident.

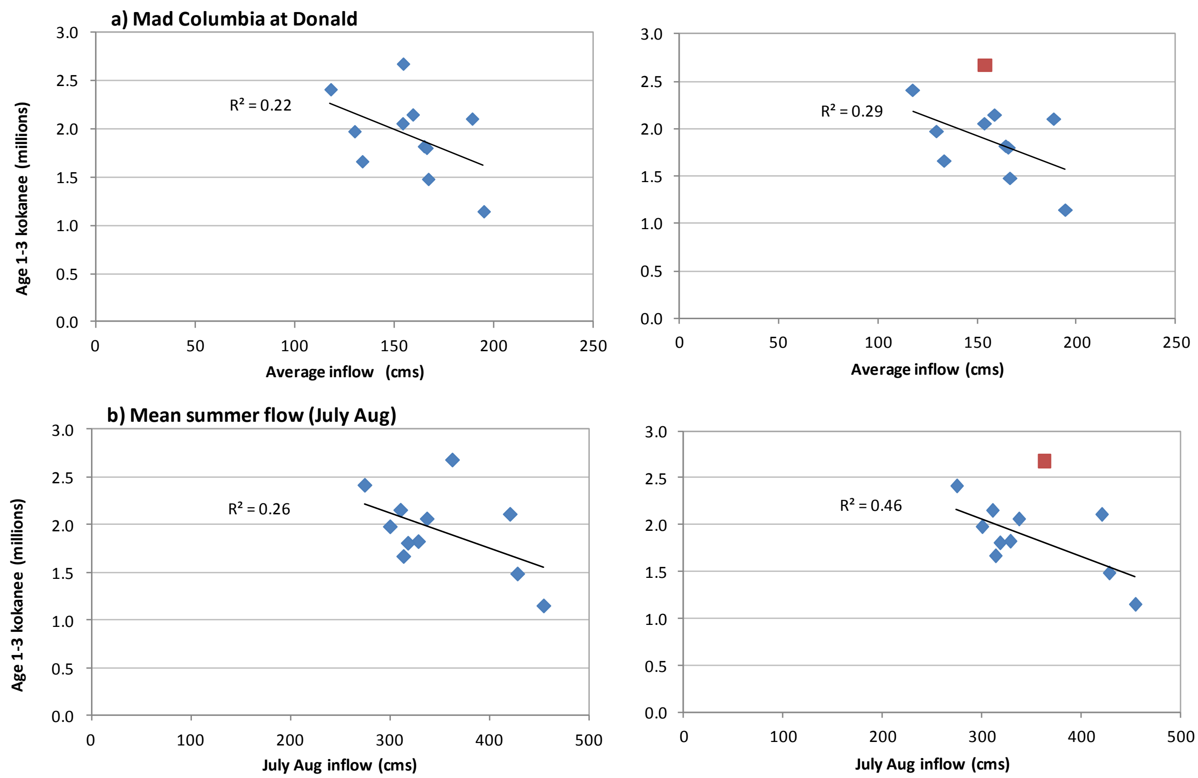


Figure 51. Relationship of age 1-3+ kokanee abundance to a) Mean annual discharge of Columbia River at Donald and to b) average summer flow (July and August) of Columbia River at Donald. Note: plots on the right show improved R^2 value with removal of 2008 year (outlier).

Annual fluctuations in pool elevation have a significant effect on habitat areas in Kinbasket Reservoir (Table 16). To test if water levels and resulting habitat changes in pelagic habitat area showed any relation to kokanee abundance, regressions between both lowest annual and highest annual pool elevations and kokanee abundance were done. Similar to low winter flows, no correlations were found between minimum spring pool elevation and kokanee (age 1-3+) abundance. However a slight correlation was found between maximum annual pool elevation and the abundance of age 1-3+ fish (Table 16; Figure 52). As with high summer flows, the regression showed a negative slope suggesting high water levels may be less productive for kokanee. Also similar to flow relations, removal of the 2008 data point improved the relation from R^2 = 0.26 to R^2 = 0.47 (Table 16; Figure 52). With ten of eleven years showing a negative relation with pool level, this will be further investigated to determine if the relation holds up with more years of data. The strength of the relation is largely influenced by three low water years (2001, 2003 and 2004). If the reservoir continues to operate near full pool, additional years may not change or contribute significantly toward verifying this relation, and lower productivity may become the new average condition for this reservoir.

The ecosystem functions associated with higher water levels that may negatively affect kokanee production are not immediately evident. Martinez and Wiltzius (1995) found in a Colorado Reservoir that higher levels were associated with colder temperatures and later emergence of Daphnia, resulting in smaller kokanee and reduced recruitment. Whether this relationship is relevant to Kinbasket Reservoir should become evident given the inclusion of future years' data in the relationship, as well as with the addition of temperature data collected through CLBMON 56.

It is also possible that the lower abundance of age 1-3+ fish at maximum pool levels may be the result of fish spreading out into marginal areas (Bush Pool and Upper Canoe Reach) as depths reach a minimum for sustaining kokanee. It is not currently known if predation rates are higher in these areas. Some future assessment of kokanee use in marginal habitats may be required to assess this habitat factor which may be affecting kokanee production and help to verify if high pool levels negatively impact kokanee production.

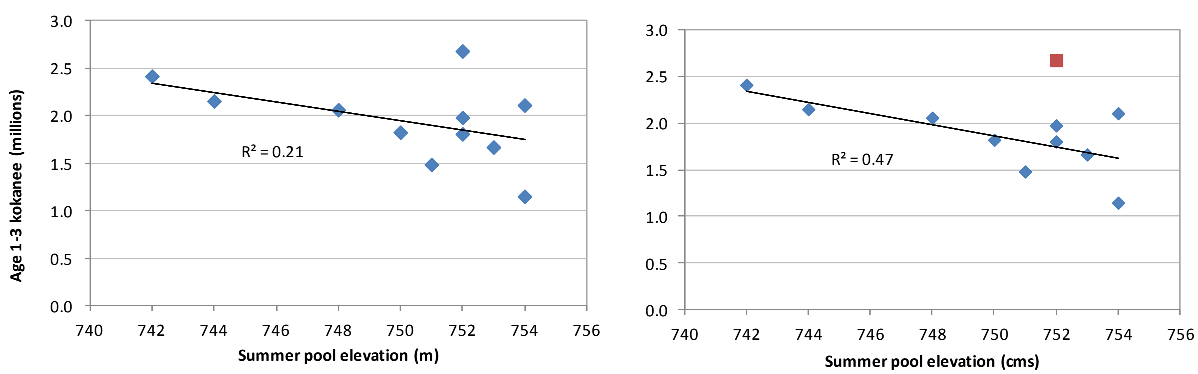


Figure 52. Relationship of kokanee age 1-3 abundance to summer maximum pool elevation in Kinbasket Reservoir. Note: plot on right shows improved R^2 value with removal of 2008 year (outlier).

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

Addressing this question requires a greater 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 & 3). Data collected to date is providing interesting insights into these questions and continuation of the time series, and with some minor adjustments (see Recommendations), will allow for a better understanding of what drivers may be exerting positive or negative influences on the kokanee population over time, and what options may be available to benefit kokanee.

6.0 Recommendations

Summary (CLBMON-3) – continue regular reservoir and tributary sampling program for physical and biological parameters with annual protocol refinements to establish long term trends, attempt to conduct sampling in shoulder months (April/Nov) as possible and early season more often.

1. Regular and consistent monitoring applying established protocols is critical for developing a credible time series data set and determining long term trends. *It is recommended that 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*.

2. While logistical constraints often drive the ability to sample on Kinbasket and Revelstoke Reservoirs, especially in the shoulder seasons; i.e., April and November, it would be advantageous to conduct regular reservoir sampling in these months when possible to provide bounds for the productive season. Early season data (including May) is the most sparse and it is important to ensure more data points are not missed. *It is recommended to include April and/or November sampling when possible to the sampling plan*.

Summary (CLBMON-2) - improve spawner counts, collect more biological data on spawners, increase sample sizes for age 1-3 fish in both reservoirs using pelagic gillnetting in addition to trawling, further develop acoustic size distributions to track cohorts and estimate kokanee biomass directly and determine fry emergence times by installing temperature recorders in key spawning streams.

1. Spawner index counts are an essential part of kokanee monitoring in order to assess annual recruitment levels. Historical counts indicate that the Upper Columbia River mainstem has supported the majority of kokanee spawners in Kinbasket Reservoir (42-82% of total counts) since annual enumeration began in 1996. The time series counts at this location can no longer be done from helicopter. Loss of this key spawning site has been problematic for continuity of counts. *It is recommended that feasibility of alternate methods for enumerating kokanee spawners in the Columbia River mainstem be investigated and additional costs determined.*

   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* in order to verify if the distribution has changed from that reported by Oliver (1995).

2. In the meantime it is essential to continue spawner counts and biological sampling at key index streams including Camp and Luxor Creeks. Since age at maturity has been identified as an important factor for assessing fry recruitment levels, *it is recommended that 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*. Limited data suggests Luxor Creek may be different from Camp Creek in terms of kokanee growth and age at maturity suggesting a possibility of differences between populations in the north and south end of Kinbasket Reservoir.

   It is also important to establish if spawner size and age structure in Luxor Creek is representative of the mainstem Columbia River kokanee. *It is recommended that biological samples be obtained from the Columbia River* in the vicinity of Riverside Golf Course in Fairmont for comparison with Luxor and Camp Creek kokanee. For capturing spawners in the Columbia River it may be necessary to try small mesh gillnets if currents are too swift for pole seining.

   If it can be established that samples from Luxor Creek adequately represents spawner size, age structure and relative abundance for southern tributary kokanee then it may be possible to sample only Luxor Creek in future where fish are relatively easy to enumerate and sample. It may be possible to avoid costly efforts to count mainstem Columbia spawners annually providing an alternative to recommendation 1.

3. Kokanee size at age is a key indicator of how kokanee are responding to their environment. Trawl sampling has been labour intensive, is limited to the main pool and lower Canoe Reach, and does not collect large enough sample sizes of age 1 and age 2 kokanee to provide reliable indices of size at age all years. Acknowledging that densities are marginally too low for effective trawl sampling, *it is recommended that some alternate methods be explored 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* as a means of capturing kokanee to obtain more length and age data. It is acknowledged that size bias with gillnetting can be an issue, however, as an index of size at age for monitoring trends in growth, gillnet data could prove to be very useful. The ability to extend sampling to other reaches could help to address questions on growth conditions in different parts of the reservoir. Gillnet data could

also help validate age structure inferred from hydroacoustic size distributions (see recommendation 4)

4. Age structure can provide valuable information used to separate effects of climate from effects of operational changes on kokanee. Reliable indices of age structure would enable detection of exceptionally strong and weak cohorts which can be tracked through the population. The failure of a strong cohort to result in a strong spawning year, for example, would assist in identifying conditions which negatively impact kokanee survival. Accompanying data from physical and trophic level monitoring will be used to assess whether changes in kokanee survival are a result of climatic extremes or operational impacts. *It is recommended that the feasibility acoustic surveys to track general size groups of individuals through the population using acoustic size binning be further investigated*. It is acknowledged that larger samples of pre-spawning fish will be needed in order to validate acoustic interpretations using fish from trawl and gillnet catches.

5. Along with abundance, biomass is a key parameter for assessing the relative productivity of a system for kokanee. The current standard for assessing kokanee status in large lakes relies on age proportions from trawl surveys to apportion the population by age or size groups. Without adequate representation of all the age groups from trawling, this method must rely on fish size groups (not age). A method to develop biomass estimates directly from acoustic data has been developed for Alouette Lake but is considered preliminary. *It is recommended that this method be applied to Kinbasket acoustic size distributions to develop some 'relative' biomass estimates for 2008-2011.* Prior to 2008, the EY500 split beam data would require re-analyses to develop population estimates by 1 dB size bin used for estimating kokanee biomass. *If biomass estimates for 2008-11 seem reasonable, then it is recommended that some of the earlier data be re-analyzed and compared with recent biomass estimates*.

6. Given the uncertainties in fry migration patterns and how this can effect population level distributions and abundance, it would be useful to determine emergence times for kokanee in the variety of streams providing recruitment to the reservoir. *It is recommended that temperature recorders be installed in known spawning streams to determine relative emergence timing based on thermal units from spawning time.* This information could be useful in understanding when and how fry enter, move through and emigrate from these reservoirs. This will help to answer questions on the role of flows and entrainment in maintaining existing populations of kokanee in answer to management questions 2 and 3 (see 7).

7. Where possible, *it is recommended that results from recent entrainment studies be tied in with the next synthesis report* to assist in answering management questions 2 and 4.

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