Columbia River Project Water Use Plan

Revelstoke Flow Management Plan

Mid-Columbia River Ecological Productivity Monitoring

Implementation Year 2016

Reference: CLBMON#15b

Columbia River Water Use Plan Monitoring Program: Middle Columbia River Ecological Productivity Monitoring

Study Period: 2016

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June 2017

PROGRAM NO. CLBMON-15B

MIDDLE COLUMBIA RIVER ECOLOGICAL PRODUCTIVITY MONITORING, 2007-2016

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ACRONYMS AND ABBREVIATIONS

AFDW	ash free dry weight
AICc	Akaike information criterion corrected for small sample sizes
ALR	Arrow Lakes Reservoir
BC Hydro	British Columbia Hydro and Power Authority
BRX	Brilliant Expansion
Caro Labs	Caro Environmental Laboratories (Kelowna, B.C.)
CFU	colony forming unit
chl-a	Chlorophyll-a
Didymo	*Didymosphenia geminata*
EPT	*Ephemeroptera* (mayflies), *Plecoptera* (stoneflies), *Trichoptera* (caddisflies)
FFI	Fish Food Index
HBI	Hilsenhoff Biotic Index
QA/QC	Quality assurance, quality control
km	kilometer
L	litre
LCR	Lower Columbia River
m	metre
m ASL	metres above sea level
max	maximum value
MCR	Middle Columbia River
min	minimum value
n	sample size
NMDS	Non metric multidimensional scaling
RVI	relative variable importance
SD	standard deviation
UTM	Universal Transverse Mercator

DEFINITIONS

The following terms are briefly defined as they are used in this report.

Term	Definition
Accrual rate	A function of cell settlement, actual growth and losses (grazing, sloughing)
Autotrophic	An organism capable of synthesizing its own food from inorganic substances, using light or chemical energy
Benthic	Organisms that dwell in or are associated with the sediments
Benthic production	Production originating from both periphyton and benthic invertebrates
Catastrophic flow	Flow events that have population level consequences of >50% mortality
Cyanobacteria	Bacteria-like algae having cyanochrome as the main photosynthetic pigment
Diatoms	Algae that have hard, silica-based "shells" frustules
Eutrophic	Nutrient-rich, biologically productive water body
Flow	The instantaneous volume of water flowing at any given time (e.g.,1200 m^3/s)
Freshet	The flood of a river or stream from melted snow in the spring
Functional Feeding group	(FFG) Benthic invertebrates can be classified by their foraging mechanisms as functional feeding or foraging groups
Heteroscedasticity	Literally "differing variance", where variability is unequal across the range of a second variable that predicts it, from errors or sub-population differences.
Heterotrophic	An organism that cannot synthesize its own food and is dependent on complex organic substances for nutrition.
Linear Regression Model	Linear regression attempts to model the relationship between two variables by fitting a linear equation to observed data
Macroinvertebrate	An invertebrate that is large enough to be seen without a microscope
Mainstem	The primary downstream segment of a river, as contrasted to its tributaries
Microflora	The sum of algae, bacteria, fungi, *Actinomycetes,* etc., in water or biofilms
Morphology, river	The study of channel pattern and geometry at several points along a river
Picoplankton	Minute algae that are less than 2 microns in their largest dimension
Peak biomass	The highest density, biovolume or chl-a attained in a set time on a substrate
Periphyton	Microflora that are attached to aquatic plants or solid substrates
Phytoplankton	Algae that float, drift or swim in water columns of reservoirs and lakes
Ramping of flows	A progressive change of discharge into a stream or river channel
Riffle	A stretch of choppy water in a river caused by a shoal or sandbar
Riparian	The interface between land and a stream or lake
Substrates	The bottom material (boulder cobble sand silt clay) of a stream or lake.
Taxa Taxon	Taxonomic group(s) of any rank, such as a species, family, or class.
Thalweg	A line connecting the lowest points of a river, usually has the fastest flows

Suggested Citation:

Larratt., H., R. Plewes, J. Schleppe, A. Duncan. 2017. CLBMON-15b Middle Columbia River Ecological Productivity Monitoring, Annual Report 2016. Okanagan Nation Alliance with Ecoscape Environmental Consultants Ltd. & Larratt Aquatic Consulting Ltd. 68 pp.

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Keywords:

Middle Columbia River, Ecological Productivity, Minimum Flows Management

ACKNOWLEDGEMENTS

Numerous employees of BC Hydro have been instrumental in the successful implementation of this project. They have provided helpful suggestions and discussions that have assisted in our understanding of the complexities of MCR. We also want to thank Michael Zimmer, Project Manager for ONA and other Ecoscape personnel, whom over the years have greatly contributed to this project. Sue Salter of Cordillera Consulting processed and identified the benthic invertebrate samples. Dr. Jason Pither provided valuable support with statistical analyses and data interpretation in 2010 through 2012. Dr. John Stockner contributed valuable QA/QC by providing confirmation of periphyton identifications in 2010 - 2012. The field crews of Golder Associates Ltd. and Triton Environmental Consultants Ltd. are also acknowledged for the collection and field-processing of fish stomach samples that were used in previous years. Finally, we acknowledge our families and spouses who continue to be understanding of the commitments required to successfully undertake this project.

CLBMON 15B Status of Objectives Management Questions and Hypotheses After Year 10

Objectives	Management Questions	Management Hypotheses	Year 10 (2016) Status
A key environmental objective of the minimum flow release is to enhance the productivity and diversity of benthic communities. The benthic community of MCR is viewed as a key monitoring component in the Revelstoke Flow Management Program because the productivity and diversity of the benthic community may reflect ecosystem health, and the benthic community supports juvenile and adult life stages of fish populations. Therefore, the objectives of this monitoring program are to 1) provide long term data on the productivity of benthic communities and 2) assess how the recommended minimum flow releases influence benthic productivity as it relates to the availability of food for fishes in the MCR.	Q.1. What is the composition, distribution, abundance and biomass of periphyton and benthic invertebrates in the section of MCR subjected to the influence of minimum flows?	Ho_1: The implementation of the 142 m^3/s minimum flow release does not change the spatial area of productive benthic habitat for periphyton or benthic invertebrates in the MCR.	Ho_1: The hypothesis is rejected, but only under certain operating conditions. Theoretically, the spatial area supporting benthic communities should increase with minimum flows because productive habitat is directly dependant on submergence. The spatial area of productive habitat is determined by the BC Hydro operating regime. The operating regime creates three typical bands of growth that moved across the channel in relation to mean low flows and duration of daily high flows. During certain operating regimes, the total productive area is determined by factors such as high daily average flows, backwatering from Arrow Lakes Reservoir, and weather conditions. To explicitly determine the spatial area of habitat covered by minimum flows, a more complex spatial model is required that considers all aspects of the operating regime due to the strong correlations between submergence and the total area of productive habitat. Developing this spatial model will allow more specific conclusions and will provide useful information for considering alternative operating regimes. A preliminary concept for a spatial model is presented in this document and will be developed in the coming years.
	Q.2. What is the effect of implementing minimum flows on the area of productive benthic habitat?	Ho_2: The implementation of the 142 m^3/s minimum flow release does not change the total biomass accrual rate of periphyton in the MCR.	Ho_2: This hypothesis is rejected. Given no other operating constraints, we conclude that minimum flows in combination with daily, weekly, monthly and annual operating regimes positively affect the total biomass within the MCR. Peak or total biomass was greatest in permanently wetted areas adjacent to the channel edge at average low flows and in areas directly below average low flows. The overall benefits of minimum flow are greatest under the following conditions: • Periods of low daily flows (400 to 600 m^3/s) that exceed 24 hours with low humidity and >10-15^{o}C or <0^{o}C average daytime temperatures • Repeated exposure events in excess of 12 hours, particularly during more extreme temperatures.

CLBMON 15B Status of Objectives Management Questions and Hypotheses After Year 10			
Objectives	Management Questions	Management Hypotheses	Year 10 (2016) Status
	Q3.What is the effect of implementing minimum flows on the accrual rate of periphyton biomass in the MCR? Is there a long term trend in accrual?	Ho_{3A}: There are no changes in accrual rates of periphyton at channel elevations that remain permanently wetted by minimum flow releases.	Ho_{3A}: The hypothesis is accepted. Accrual rates in permanently wetted areas that occurred in the mid-channel, with the highest water velocity and depth during high flows did not appear to have a different accrual rate under current minimum flows management when compared to pre-implementation of minimum flows. The physical characteristics such as velocity, light, and substrate were more important determinants of periphyton accrual than minimum flows within these areas. Thus, minimum flows are expected to have minimal effects on accrual. Peak flows associated with REV 5 or other high water events appear to reduce periphyton accrual rates and standing crop in permanently submerged habitats.
		Ho_{3B}: There are no changes in accrual rates of periphyton at channel elevations that are periodically dewatered during minimum flow releases.	Ho_{3B}: The hypothesis is accepted, but only under certain conditions. We conclude that minimum flows do not affect areas that are periodically dewatered (located above the minimum flow line), but they do have an effect in areas that were regularly exposed before the minimum flow operating regime because increased accrual would have occurred as observed in time series sampling in the spring and fall. Daytime submergence, seasonal patterns, algal immigration from Revelstoke Reservoir and operating cycles were also important determinants of periphyton accrual and must also be considered.
	Q.4. What is the effect of implementing minimum flows on the total abundance, diversity and biomass of benthic organisms in the section of the MCR subjected to the influence of minimum flows? Is there a long term trend in benthic	Ho_{4A}: The implementation of the 142 m^3/s minimum flow release does not change the total abundance / biomass / diversity of benthic invertebrates in the MCR.	$H4_{A}$: The hypothesis is rejected, but only under certain operating conditions. Permanently submerged areas were the most productive and diverse, but frequently submerged varial zone areas also had comparable levels of productivity and diversity. The area of productive invertebrate habitat was bounded by average daily low flows and its upper limit was determined by average daily submergence. Determining the benefits of minimum flows is not currently possible because of other confounding factors such as the duration of daily high flows. Without any other operating constraints, minimum flows do affect the total abundance, biomass and diversity of benthic communities because they establish a minimum area of productive habitat and ensure there are organisms for recolonization in addition to those provided by tributary inflows. However, other factors such as the life history strategies of different benthic invertebrates or periphyton species may also be equally or possibly even more important to overall productivity.

CLBMON 15B Status of Objectives Management Questions and Hypotheses After Year 10

Objectives	Management Questions	Management Hypotheses	Year 10 (2016) Status
	productivity?	Ho$_{4B:}$ There are no changes in abundance/biomass/diversity of benthic invertebrates at channel elevations that remain permanently wetted by minimum flow releases.	Ho$_{4B:}$ The hypothesis is accepted. We conclude that minimum flows have not affected abundance/biomass/diversity in permanently wetted areas. However, our data suggest that other aspects of operation, such as high peak flows associated with high water events may be important determinants of invertebrate production. Thus, consideration of all aspects of flow regulation must occur in conjunction with minimum flows to understand potential effects.
		Ho$_{4C:}$ There are no changes in abundance/biomass/diversity of benthic invertebrates at channel elevations that are periodically dewatered by minimum flow releases.	Ho$_{4C:}$: The hypothesis is accepted, but only under certain operating conditions. We conclude that minimum flows do not affect areas periodically dewatered located above minimum flow, but they probably had an effect in areas that were regularly exposed before the minimum flow operating regime because the data indicate that benthic invertebrate abundance, diversity, and biomass are positively associated with submergence. Daytime submergence, seasonal patterns and operating cycles were also important determinants of benthic accrual and must also be considered.
	Q5. If changes in the benthic community associated with minimum flow releases are detected, what effect can be inferred on juvenile or adult life stages of fishes?	Ho$_{5}$: The implementation of the 142 m^3/s minimum flow release does not change the availability of fish food organisms in the Middle Columbia.	Ho$_{5}$: This hypothesis is rejected, but only under certain operating conditions. Food for fish was assessed using a Fish Food Index (FFI) in 2013 and the total biomass of EPT and Dipteran taxa in 2014 to 2015. The FFI consisted of three parameters for each benthic taxon, 1) invertebrate abundance, 2) relative invertebrate biomass, and 3) fish food preference for a given benthic taxon. The overall benefits of minimum flow are greatest under the following conditions: • Periods of low daily flows that exceed 24 hours with freezing or high average daytime temperatures; • Dewatering periods greater than 12 hours. Substrates submerged for 450 to 500 hours (10 to 11 hours per day) during daytime hours had the greatest availability of preferred fish food items, that are generally EPT and Diptera. EPT and Dipteran biomass was greatest in areas submerged for at least 750 to 1000 hours over at least 46 days. Both periphyton and invertebrates showed similar responses, suggesting that overall productivity and food for fish is directly affected by the operational cycles that create either submerged or dry conditions, where increased periods of submergence result in an overall increase in productivity. In addition to the area wetted by minimum flows acting as a species reservoir, tributaries such as the Jordan River may be important donors of invertebrate species utilized by fish and these donations would assist with MCR recovery from exposure events.

EXECUTIVE SUMMARY

Aquatic habitats in the Middle Columbia River (MCR) are heavily influenced by flow releases from Revelstoke Reservoir. To lessen the effect of these variable flow releases, the Columbia River Water Use Plan supported implementation of a year-round minimum flow of 142 m^3/s from Revelstoke Dam (REV) to the MCR. The objective of the minimum flow strategy is to enhance the productivity and diversity of benthic communities in the MCR by increasing the permanently wetted area. The goal of CLBMON-15b Ecological Productivity Monitoring is to provide long-term data on benthic productivity in the MCR using artificial substrate samplers to assess how minimum flow influences benthic communities and availability of food for fish. Data were collected from 2007 to 2010, pre-implementation of minimum flows, and from 2011 to 2016, post-implementation of minimum flows. A fifth generating unit (REV 5) was added in December 2010, increasing the maximum flow discharge from 1699 to 2124 m^3/s. This report summarizes the findings of all study sessions to date, with a focus on Spring 2016.

Minimum flows provide benefits to benthic invertebrate and periphyton communities in the MCR by ensuring a portion of the channel area remains wetted and productive at all times. However, the benefit of minimum flows is dependent on flow management. Minimum flows benefit productivity most during periods when average daytime flows over the preceding 30 to 70 days are lower (e.g., 400 to 600 m^3/s versus 1200 to 1600 m^3/s). A small shift in water releases would increase the area of productive habitat and could occur under an operating regime that included brief excursions to <10 m^3/s flow, provided that flows of 400 to 600 m^3/s occurred every day for at least 9 daytime hours.

Habitat conditions of the MCR occurred in three distinct zones of varying submergence - the permanently submerged zone, the lower varial zone and the upper varial zone. The permanently wetted zone showed high periphyton productivity and accrual rates despite periodic thinning by high water velocities. Immediately above the minimum flow elevation was the most productive zone, the lower varial zone. The final zone was the less productive upper varial zone, located at elevations that were frequently dewatered. Over the years of study, the boundaries between these three zones shifted in response to growth conditions provided by the operational flow regimes over the preceding 30 to 70 days. Flows during the week preceding sample collection had the greatest effect on the benthos. Benthic productivity in the permanently submerged and lower varial zones were influenced by water temperature. Warmer water temperatures in Spring were correlated with higher productivity (chl-a). For both periphyton and invertebrates, productivity was greatest at mid-channel elevations extending from just below the elevation of minimum flow to slightly above it within the lower varial zone. Like all large rivers, diatoms dominated the periphyton, but diversity was lower than for unregulated rivers of similar size and latitude.

Distinguishing between the benefits of minimum flows and variation in the operating regimes observed over the study period was difficult. Daytime submergence and high average daily flows were key factors in determining overall MCR benthic productivity. Varial zone areas submerged for at least 9 to 12 hours per day (400 to 500 hours over the deployment period) were typically as productive as areas constantly submerged by minimum flows. However, productivity in the varial zones was dependent upon additional factors such as daytime air temperature and operating regime. Submergence times in excess of 1000 hrs over the deployment period appear

to increase productivity compared to those submerged for less time. Further, the benefits of minimum flows were lessened by backwatering from Arrow Lakes Reservoir when it submerged habitats in the varial zone substrates that would otherwise have desiccated. In the absence of other operating constraints. Minimum flows benefit the benthic productivity in the MCR, but alternative operating regimes that have higher average daily flows without permanent minimum flows may also provide habitat conditions that are equally productive.

Overall benthic community structure was stable at the family taxonomic level across all sites of variable submergence, with similar representation between years. However, there were some taxonomic differences between the three zones. For example, filamentous green algae were more prevalent near the edge of permanently wetted areas (T2), and in the lower varial zone (T3/T4) where stable substrates were present. EPT taxa and chironomids appeared to be more abundant along the edge of minimum flow (T2) or in the lower varial zone (T3), as suggested by our modelling of permanently submerged habitats (Schleppe et al. 2014). These data support the assertion that flow management exerts a powerful influence on the MCR periphyton community.

Benthic invertebrates were more sensitive to exposure than periphyton. Dewatering periods greater than 24 hours during warmer spring temperatures caused substantial stresses and die-off in the benthic community, such as those observed in Spring 2011. For periphyton, exposures exceeding 36-48 hours were usually required before similar effects were observed. Mortality from exposure of either invertebrates or periphyton was most dependent upon weather patterns at the time of the event.

Peak production of either benthic invertebrates or periphyton in the MCR was not achieved within two months from the time of first wetting and may take longer than six months to fully develop if sites experience frequent dewatering, particularly in the spring when growth rates are slow. A theoretical growth curve for chl-a was derived for MCR that had a peak biomass of 1.2 µg/cm^2 in Spring and 2.69 µg/cm^2 in Fall. Spring periphyton growth was enhanced by early, warm spring weather.

Results from previous years showed substrates submerged for 10-11 hours/day in daylight hours had the most preferred fish food items, which generally include EPT (Ephemeroptera, Plecoptera and Trichoptera) and Dipteran taxa. Similarly, the biomass of EPT+Dipterans was greatest in areas submerged for 750 - 1000 hours over the previous 46 days.

Submergence was consistently identified as the single most important determinant of benthic production in the MCR. However, many factors affect the total area of productive habitat and need to be considered in conjunction with the effects of minimum flows. Factors such as Arrow Lakes Reservoir backwatering, operational flow patterns, peak flows exceeding 1800 m^3/s, seasonal cycles, and species tolerances were all important determinants of benthic productivity and should be considered when reviewing future operational flow regime guidelines.

The proposed spatial productivity model for MCR will use a Telemac 2D model and will be validated using previously collected productivity data from Reaches 3 and 4. Modelled daily productivity of invertebrate abundance, invertebrate biomass, and chl-a will be used to determine the total area and quantity of production in MCR. This model would refine our understanding of the effects of minimum flows on the area of productive benthic habitat.

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Appendix B – Digital Data

The digital appendix contains summary statistics of data in Excel.

Appendix C – Supplemental Methods and Results

Appendix D – Spatial Productivity Model

1.0 INTRODUCTION

Aquatic habitats in the Middle Columbia River (MCR) are heavily influenced by variable flow releases from the Revelstoke Dam (REV), and to a lesser extent, by backwatering from Arrow Lakes Reservoir (ALR), and tributary inflows. In 2007, introduction of the Columbia River Water Use Plan (WUP) supported implementation of a year-round minimum flow from REV of 142 m^3/s to mitigate the effects of variable flow releases. In December 2010, BC Hydro (BCH) added a fifth generating unit (REV 5), that increased the maximum possible flow discharge of REV from 1699 to 2124 m^3/s.

One component of the WUP involved assessing how the productivity and diversity of benthic communities would change as a result of the implementation of a minimum flow operating regime. It was hypothesized that an increase in the area of permanently wetted channel downstream of the Revelstoke Dam would result in increased benthic production, thereby increasing food availability for fish and ultimately improving fish abundance (WUP, BC Hydro 2005).

CLBMON-15b Ecological Productivity Monitoring forms one component of a broader monitoring project under the Revelstoke Flow Management Program, designed to assess the effectiveness of minimum flows at improving habitat conditions for fish. The monitoring schedule consists of four years of monitoring prior to implementation of minimum flow / REV 5 operations (2007-2010), and up to ten years of subsequent monitoring under the new operating regime.

In the study years prior to the implementation of minimum flows, water releases from Revelstoke Dam varied from 8.5 m^3/s to 1700 m^3/s, depending on power demands, and could result in sudden water fluctuations between 3 to 5 vertical meters. With the initiation of REV 5 and the minimum flows operating regime (2011-present), flows have ranged from 142 m^3/s to 2124 m^3/s. These variable water releases and backwatering from the downstream Arrow Lakes Reservoir (ALR) largely determine the extent of submergence of river substrates in the MCR.

The results from the Ecological Productivity Monitoring will be integrated with other BC Hydro monitoring programs, including Physical Habitat Monitoring (CLBMON15a), Fish Population Indexing Surveys (CLBMON16), Juvenile Habitat Use (CLBMON17) and Adult Habitat Use (CLBMON18). The findings from these monitoring programs will be used collectively to evaluate if minimum flows provide benefits for fish, and if there is an advantage to the establishment of a long-term minimum operating release requirement for Revelstoke Dam. Specifically, the data collected in CLBMON15b will serve to quantify long-term trends in the productivity of periphyton and benthic invertebrates and will provide valuable information pertaining to the ecological health of the riverine environment downstream of the Revelstoke Dam.

This report summarizes Years 1 through 10 of the monitoring program, and focuses on Spring 2016 (Year 10) sampling session. At this time, the project is proposed to transition from understanding the specific effects of submergence due to minimum flows and important environmental factors (e.g., velocity, light, and depth), to understanding the spatial effects of the operating regime on productivity.

1.1 Objectives, Questions, and Hypotheses

The three main objectives of the Ecological Productivity Monitoring program are as follows (BC Hydro 2010):

- To design and implement a long-term program for tracking the productivity and diversity of key benthic community taxa (periphyton and invertebrates) within the MCR;
- To assess the response of the MCR benthic community taxa, both periphyton and invertebrates, to a minimum flow release from Revelstoke Dam and REV 5 operations; and
- To investigate and quantify the relationship between habitat attributes and benthic composition, abundance, and biomass with the section of the MCR most likely to be influenced by minimum flows and REV 5 operations.

The first objective was satisfied by the basic study design developed by Perrin et al. (2004). A conceptual model was developed (Figure 1-1) to address the second and third objectives, and to understand the potential interactions of the complex factors affected by changes in flow. With each study session, our understanding of the relative importance and role of each parameter increases. This model highlights the many variables and complex interactions that can influence benthic productivity and ultimately food for fish. Species specific life histories, such as diurnal timing and habitat selection for egg laying insects versus hydropeaking frequency, are also an important consideration (Kennedy et al. 2016), and this has not been fully explored because it would add further, complex interactions. Greyed boxes with bolded text indicate the parameters under assessment in this study to address BC Hydro's management questions. At the forefront of the model are BC Hydro operations that determine quantity and duration of water release. Flows directly influence factors including velocity, turbulence, depth, submergence, scour, etc. and therefore have a direct effect on benthic productivity.

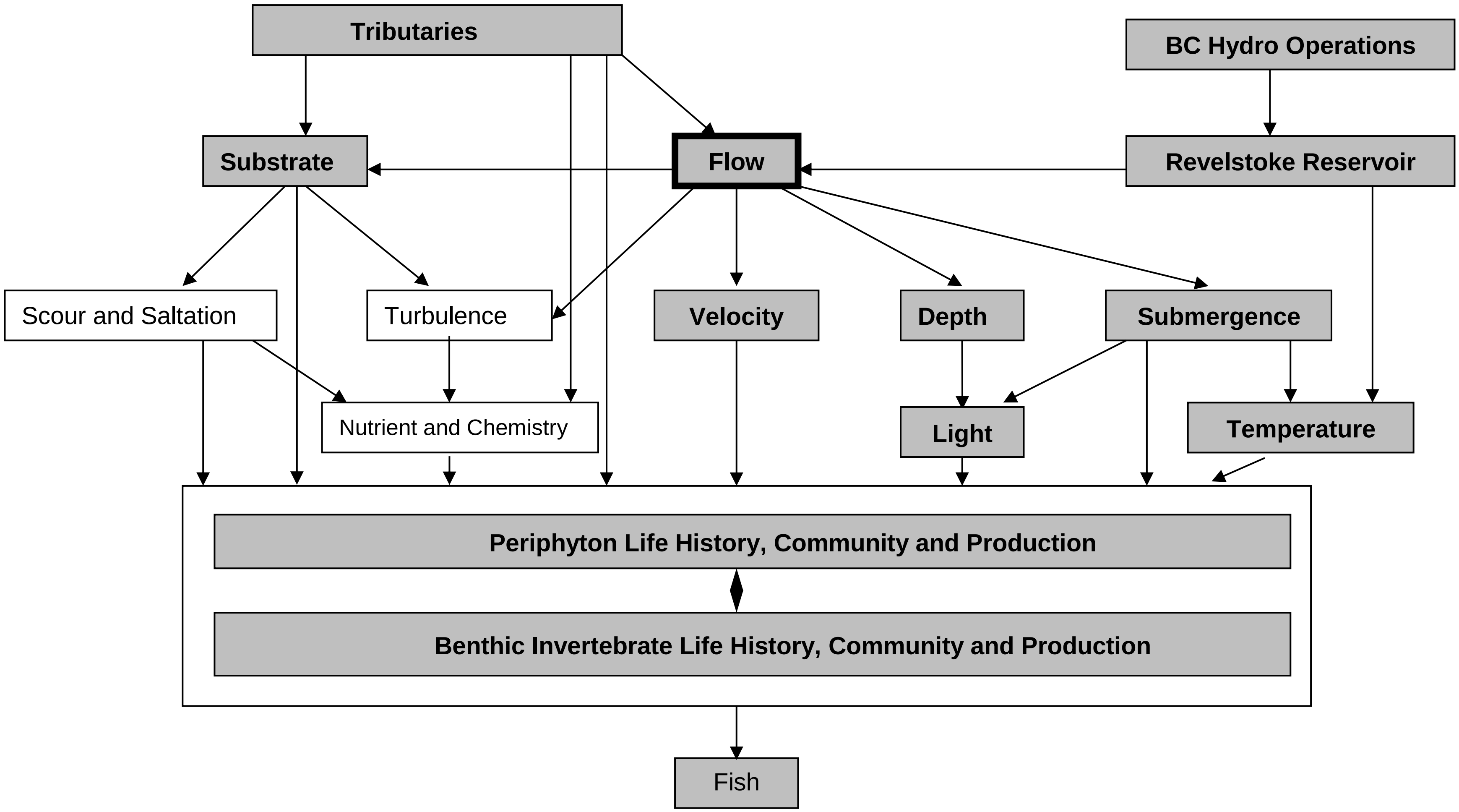


Figure 1-1: Conceptual interactions model of habitat variables and benthic production as they relate to food for fish in MCR. Parameters shaded in grey, with bolded text represent parameters under assessment in this study.

BC Hydro developed five management questions with related hypotheses to address the three main objectives comprehensively (BC Hydro 2010). Table 1-1 lists each of the management questions/hypotheses and relevant components of this study that address them. Although several of the hypotheses/questions refer to the implementation of the minimum flow release, we understand as per the Request for Proposals, that the evaluation of minimum flow release is to include the operational changes associated with the commencement of REV 5 operations.

Statistical models were used to understand the physical responses of periphyton and benthic productivity to flows. In a complex system like the MCR, the effects of minimum flows and REV 5 flows could not be isolated from each other and the larger flow regime. In lieu of this approach, we identified relationships between benthic production and spatial features directly influenced by flows including area of wetted habitat, and frequency and duration of submergence. From this, we were able to infer the effects of the operating regime including minimum flows. This approach is advantageous because it allows consideration of alternative operating regimes that may be as, or more, beneficial than minimum flow from both a productivity and a financial perspective. The intent of the data collection is to facilitate the extrapolation of benthic and periphyton productivity in the river as a whole and to enable estimation of the spatial area of productive habitat in the MCR under a minimum flow or alternative operating regime. The ultimate goal is to identify and describe what habitat attributes are most influential and to identify how implementation of different operational regimes may affect benthic productivity in MCR including both a minimum flow and a REV 5 operating regime.

Table 1-1: Key Management Questions and Hypotheses, with Pertinent Components to Address Them

Key Management Questions	Management Hypotheses:	Study Components to Address Management Questions/Hypotheses
Q1. What is the composition, distribution, abundance and biomass of periphyton and benthic invertebrates in the section of MCR subjected to the influence of minimum flows? Q2. What is the effect of implementing minimum flows on the area of productive benthic habitat?	Ho_1. The implementation of the 142 m3/s minimum flow release does not change the composition, distribution, abundance, biomass, or spatial area of productive benthic habitat for periphyton or benthic invertebrates in MCR.	Artificial sampler arrays are deployed across the range of flows/elevations of the MCR. Data collection includes: • Abundance –periphyton & invertebrates • Diversity – taxonomy indices for periphyton and invertebrates • Production/Biomass – chlorophyll-a (chl-a), ash-free dry weight (AFDW)/dry weight (DW), biovolume, benthic invertebrate biomass • Natural substrate comparisons Productive habitat area is considered using the analogous measure submergence as a surrogate for minimum flow. Statistical models using a variety of parameters describing submergence are tested for the different measures of production. Future data analysis will attempt to directly link submergence time to the total spatial area of productive benthic habitats
Q3. What is the effect of implementing minimum flows on the accrual rate of periphyton biomass in the MCR? Is there a long-term trend in accrual?	Ho_2. The implementation of the 142 m3/s minimum flow release does not change the total biomass accrual rate of periphyton in MCR. Ho_{2A}. There are no changes in accrual rates of periphyton at channel elevations that remain permanently wetted by minimum flow releases. Ho_{2B}. There are no changes in accrual rates of periphyton at channel elevations that are periodically dewatered by minimum flow releases.	Artificial samplers and time series samplers are deployed across the range of submerged habitat areas on the MCR. Data collection includes: • Abundance • Diversity – taxonomy indices for periphyton and invertebrates • Production/Biomass – chl-a, AFDW/DW, biovolume • Nano-flora heterotrophic plate counts (HTPC) Periphyton production (both accrual and peak biomass) are assessed using a variety of different measures of productivity. Periphyton productivity is considered using the analogous measure submergence as a surrogate for minimum flows because this data is easier to use in models. Periphyton models are developed to test the effects of submergence on periphyton peak biomass. Future data analysis will attempt to directly link submergence time to the periphyton productivity in three areas of the river, those permanently submerged, those in varial zone areas, and those in floodplain areas of MCR.
Q4. What is the effect of implementing minimum flows on the total abundance, diversity and biomass of benthic organisms in the section of MCR subjected to the influence of minimum flows? Is there a long-term trend in benthic productivity?	Ho_3. The implementation of the 142 m3/s minimum flow release does not change the total abundance/biomass/diversity of benthic invertebrates in MCR. Ho_{3A}. There are no changes in abundance/biomass/diversity of benthic invertebrates at channel elevations that remain permanently wetted by minimum flow releases. Ho_{3B}. There are no changes in abundance/biomass/diversity of benthic invertebrates at channel elevations that are periodically	Artificial samplers are deployed across the range of submerged habitat areas on the MCR. Data collection includes: • Abundance • Diversity – taxonomy indices for periphyton and invertebrates • Production/Biomass – biomass Invertebrate production is assessed using a variety of different measures of productivity. Benthic productivity is considered using the analogous measure submergence as a surrogate for minimum flows because this data is easier to use in models. Invertebrate models are developed that test the effects of submergence on invertebrate biomass, abundance, and diversity. Future data analysis will attempt to directly link submergence time to the invertebrate productivity in three areas of the river,

	dewatered by minimum flow releases.	those permanently submerged, those in varial zone areas, and those in floodplain areas of MCR.
Q5. If changes in the benthic community associated with minimum flow releases are detected, what effect can be inferred on juvenile or adult life stages of fishes?	Ho_4. The implementation of the 142 m3/s minimum flow release does not change the availability of fish food organisms in the Middle Columbia.	Potential effects of minimum flow on food for fish are considered using an index of fish food availability. The Fish Food Index (FFI) consists of three parameters, Relative Abundance, Relative Biomass, and Fish Food Preference for each different benthic taxon. Higher index values indicate a higher prevalence of preferred benthic species available as food for fish. This index is useful because it considers availability (abundance), biomass, and fish preference of benthic invertebrates as food. The fish food index is used in statistical models where a variety of measures of submergence (analogous to minimum flow) are used to test fish food availability.

2.0 METHODS

2.1 Study Area and Sampling Locations

The MCR is a section of the Upper Columbia River adjacent to the town of Revelstoke, British Columbia, encompassing approximately 38.5 km of river between the Revelstoke Dam and the Upper Arrow Lake Reservoir (ALR) near Galena Bay. The MCR is sectioned into four Reaches, and this study focused on Reaches 4 and 3, that have more riverine-like conditions than Reaches 2 and 1. Reach 4 extends approximately 5 km from the Revelstoke Dam to the confluence of the Jordan River. Reach 3 starts at the confluence of the Jordan River and extends approximately 3.5 km downstream to the confluence with the Illecillewaet River (Figure 2-1).

Reach 4 is characterized by a trapezoidal river channel with moderate to steep banks that confine the thalweg. The depth along the thalweg ranges from 1 to 5 m depending on flows. Reach 4 encompasses large areas of stable substrate consisting predominantly of larger gravels, cobble and boulder, and lesser amounts of sands, pebbles and smaller gravels that occur beneath and within the interstitial spaces of the cobble-armoured surface. The bankfull width in Reach 4 ranges from 147 – 223 m (Perrin and Chapman 2010a). Big Eddy occurs at the interface of Reaches 4 and 3, immediately downstream of the Jordan River. It consists of a large, 250 m wide, deep eddy bounded along the right bank by a vertical rock face. This habitat unit provides > 6 m deep water refuge during periods of lower flow and could be considered its own reach due to the unique habitat it provides.

Upper Reach 3 starts immediately below Big Eddy, where the river turns 120° and the channel thalweg occurs on the left bank with a floodplain area on the right bank. The right riverbed is flat with gravel substrates and has a bankfull width of approximately 360 m. Further downstream, the 2 to 8 m deep thalweg occurs in the center of the channel and substrates become progressively finer and more mobile. The lower section of Reach 3 extends below the bridges, and the side-braided channels can become exposed when the water elevation in the ALR is <434 m and discharge from the Revelstoke Dam is minimal. The main channel bankfull width of Reach 3 is 489 m (Perrin and Chapman 2010a). Substrates in Reach 3 are finer than Reach 4 with sand, gravel and cobbles predominating throughout the reach.

The main tributaries that influence MCR are the Jordan and Illecillewaet Rivers. The Illecillewaet River is the largest tributary in the study area of MCR. The lower Illecillewaet receives secondary treated sewage effluent from the Town of Revelstoke.

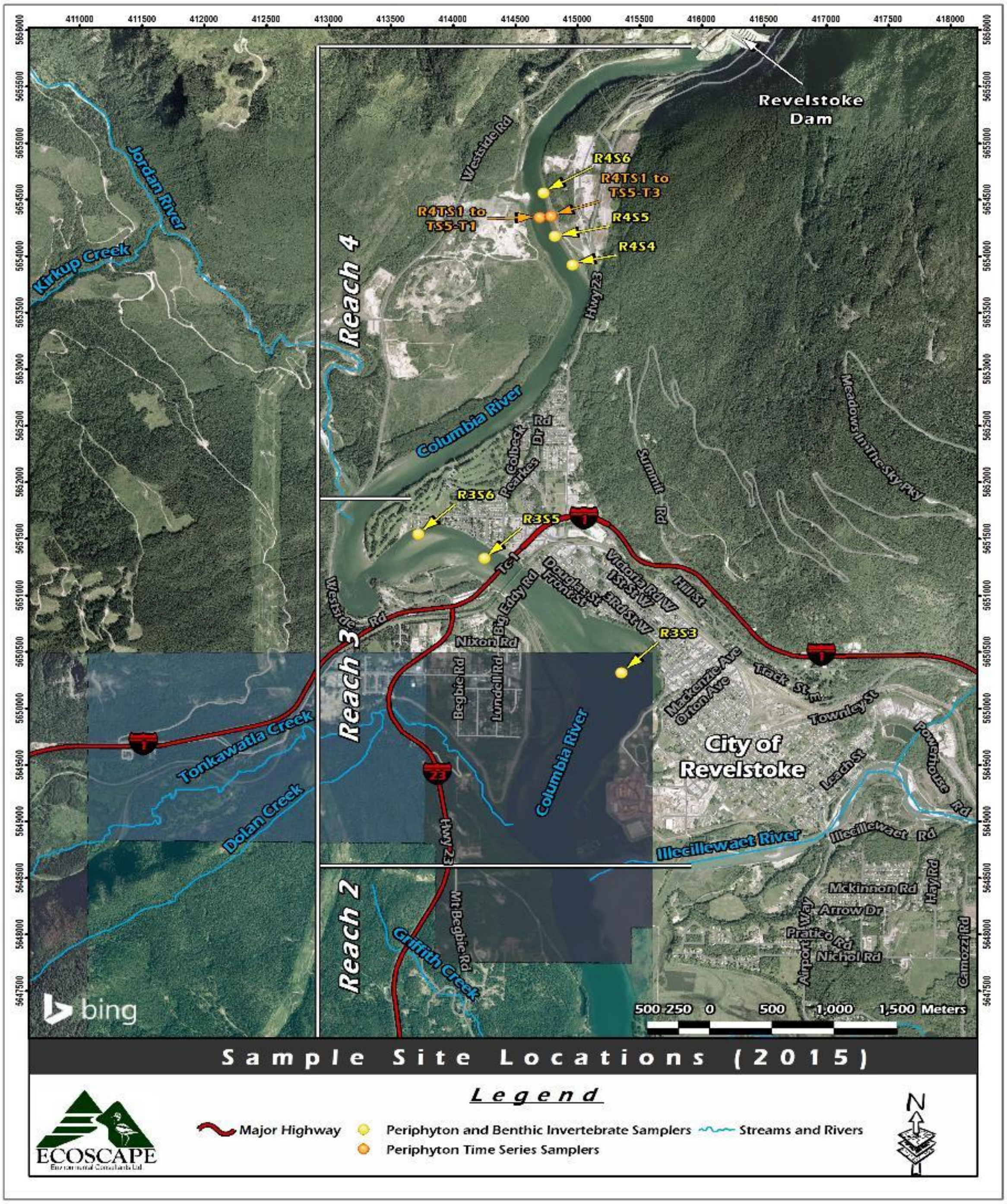


Figure 2-1: **Map of the study area and sampling locations. Site labels are defined in Table 2-2**

2.1 Periphyton and Invertebrate Community Sampling Using Artificial Samplers

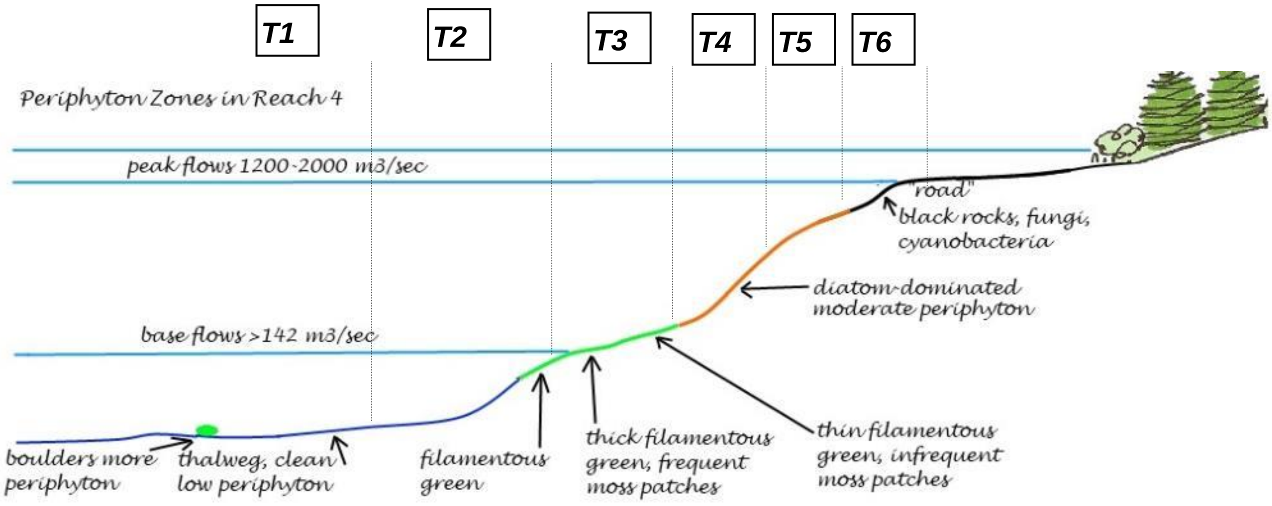
2.2.1 Artificial Sampler Design and Deployment

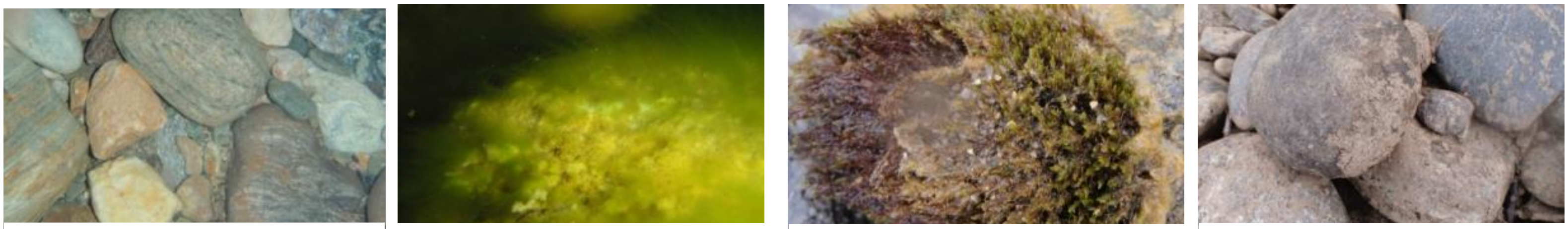
Year 10 of the CLBMON 15-b study involved a spring (2016) sampling session, where artificial samplers were placed in the river and left for a minimum of 44 days (Table 2-1). Data for earlier years are available in previous CLBMON15b reports, however the sample sites used in 2016 were consistent with previous years, and the same naming system was used to reference sampling sites. Site references include Reach, Site, and Transect. Samplers were deployed in Reach 3 (R3) at S3, S5, and S6. Reach 4 (R4) samplers were deployed at sites S4, S5, and S6.

Sampling sites at transect depths T1 through T6 were deployed in Reaches 3 and 4 as shown in Figures 2-2 and 2-3. Transect position refers to the position of the sampler within the river cross-section, as explained in Table 2-1. During the fall 2010 sampling session, a T7 position in the infrequently wetted floodplain was also used. This sampler elevation was subsequently deleted, and new sampling sites in Reach 4 at the bedrock (BR) location were studied instead. However, in Spring 2016 Big Eddy (BE), bedrock (BR), Backwater areas (BW) sites were not sampled.

Table 2-1: Description of transect depths sampled in Reach 3 and 4.

Reach	Sampler	Relative depth/zone	Submergence	Years Sampled
3 and 4	T1	Mid channel / thalweg	Permanently submerged by minimum flows	2010-2016
	T2			2010-2016
	T3	Mid channel / lower varial zone	Submerged by flows from 200 to 800 cm/s	2010-2016
	T4			2010-2016
	T5	Upper varial zone	Submerged by flows > 1000 cm/s	2010-2016
	T6			2010-2016
	T7	Infrequently wetted floodplain		2010





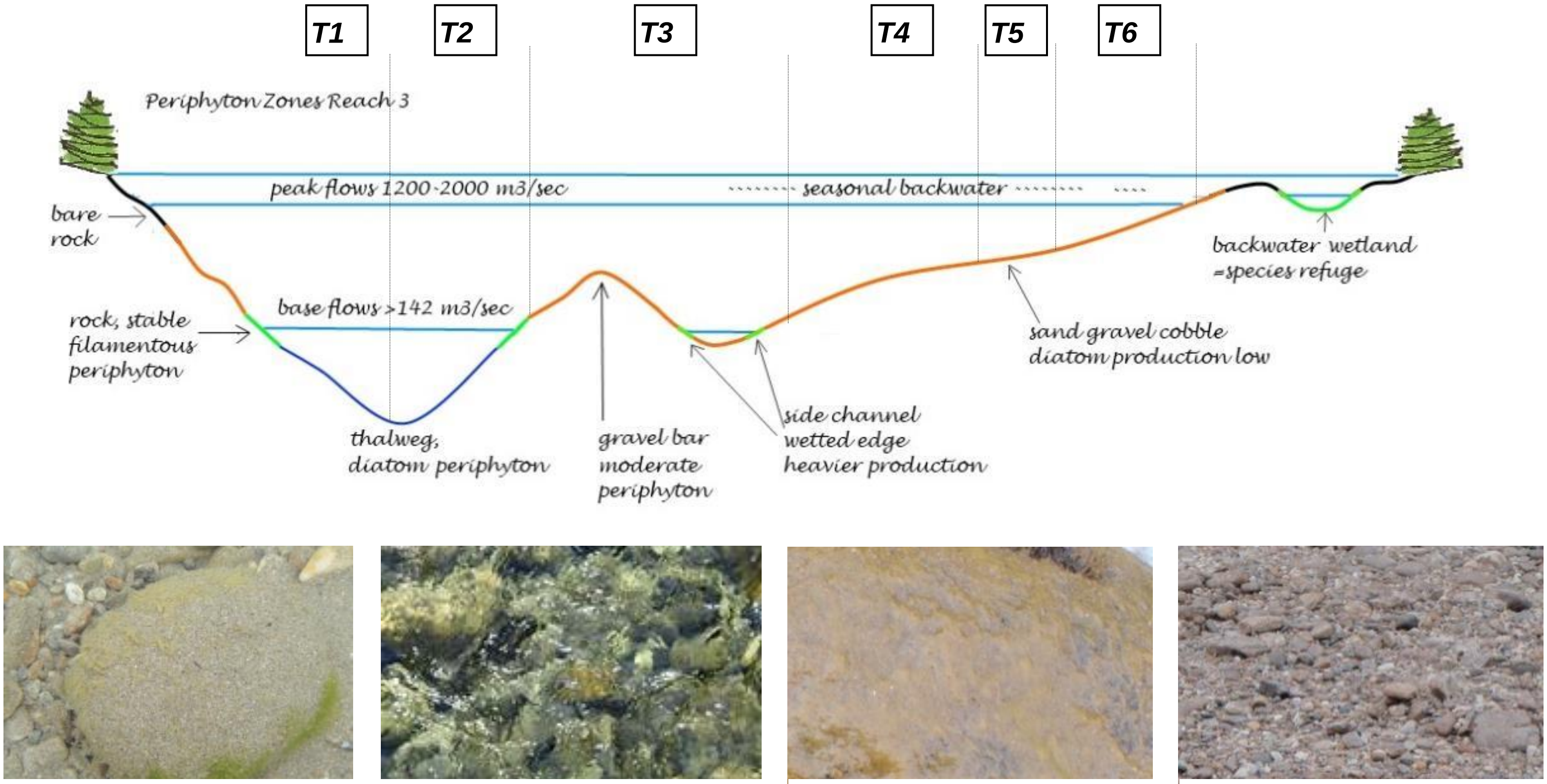
thalweg
(low periphyton

filamentous green zone

filamentous green + moss zone

diatom dominated zone

Figure 2-2: **Conceptual drawing of transect positions and periphyton establishment in MCR using data collected from fall 2010 and 2012 in Reach 4**



filamentous green+, sand

thalweg, diatom periphyton

wetted edge heavy diatom zone

low diatom, bacteria zone

Figure 2-3: **Conceptual drawing of periphyton establishment in MCR using data collected from Fall 2010 and 2011 samples in Reach 3**

Samplers and associated rigging were assembled and deployed April 11-13, 2016. One day was spent preparing gear, followed by deployments in both Reaches 4 and 3 when flows were minimal to moderate. Figure 2-4 illustrates our standard artificial sampler design which did not deviate from previous years, with the exception of time series samplers. Time series samplers had a concrete weight 10 m from the sampler and float attached to the rear of the plate using rope rather than the sampler anchor. At the time of deployment, the elevation and location of each artificial sampler was recorded using a Trimble R8 RTK survey system, using Survey Controller software for data collection to obtain the geodetic elevation of each sampler.

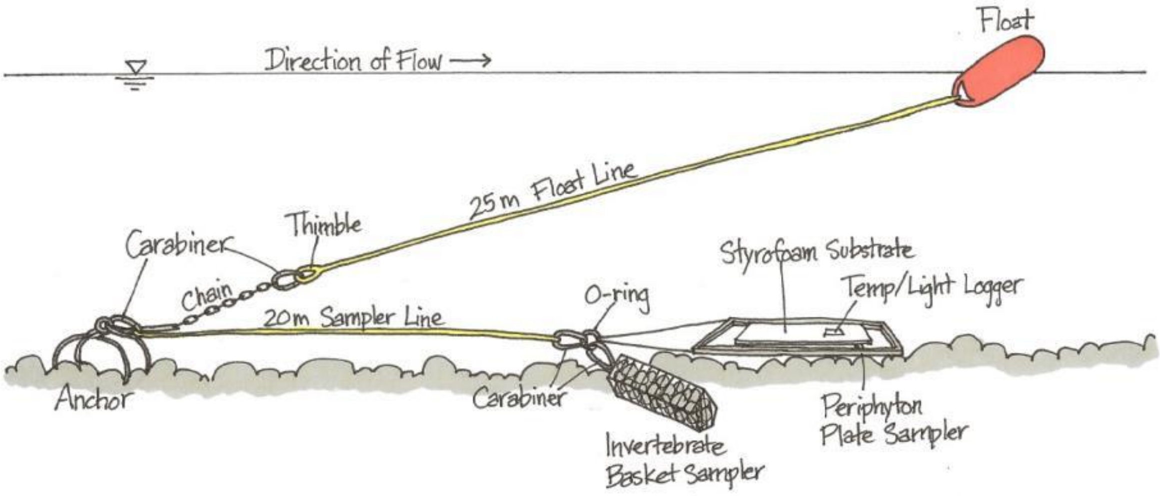


Figure 2-4: **Schematic drawing of the artificial substrate sampler used in MCR**

Table 2-2: Summary of samples collected from artificial sampler deployment and retrieval in 2016

Season	Reach	Site	Periphyton Samplers		Invertebrate Basket Samplers	
Spring (April 11 – May 25 2016)	Reach 4 (R4)	Site 6 (S6)	6	6 (100)[1]	6	6 (100)
		Site 5 (S5)	6	6 (100)	6	6 (100)
		Site 4 (S4)	6	6 (100)	6	6 (100)
	Reach 3 (R3)	Site 6 (S6)	6	6 (100)	6	6 (100)
		Site 5 (S5)	6	4 (67)	6	4 (67)
		Site 3 (S3)	6	6 (100)	6	6 (100)
2016 Totals			**60**	**34 (94.5)**	**60**	**34 (94.5)**

Notes: [1] The success of weekly retrieval of time series samplers was dependent on flow conditions. Some weekly Styrofoam punches were not taken due to high flows, or the inability to pull plates. The number retrieved reflects the samplers pulled on the final time series trip.

2.2.2 Time Series Samplers

The purpose of time series collections is to understand the rates of periphyton accrual and to detect differences that may exist between permanently submerged areas and periodically dewatered areas within the varial zone. In 2010, time series samplers were deployed across the river at transect positions from T1 through T7. In these positions, observed accrual rates were very complex in response to rapid flow changes, weather during dewatered periods, and varying degrees of exposure. Subsequent effort was focussed in two key areas to develop better statistical models: the deep area permanently wetted by minimum flows (T1) and the lower varial zone (T3/T4), located above the permanently wetted edge. In Spring 2016, five time-series samplers were deployed in Reach 4 in both T1 and T3/T4 transect positions.

Varial zone time series samplers represent the conditions between T3 and T4 locations because samplers cannot be accurately placed, retrieved and re-deployed at the same location/depth during each sample collection. These time series samples are therefore considered representative of accrual in the varial zone rather than a discrete sampling location.

Time series samplers were retrieved once per week following deployment. During each weekly sample, the light/temp loggers were wiped clean with a paper towel so light measurements during time series sampling. Every week, two periphyton punches were randomly collected from the Styrofoam and were immediately packed on ice and placed in the dark until they could be delivered to Caro Labs Kelowna for chlorophyll-a analysis. Taxonomy of time series samples has not been conducted since 2013.

2.2.3 Artificial Sampler Retrieval

Artificial samplers remained in the river for a total of 44-45 consecutive days in Spring 2016. This deployment period matches earlier MCR deployments and is within the incubation period required for attainment of peak biomass defined by Perrin et al. (2004). Spring samplers were retrieved either by boat, wading or by foot on May 24-25 2016.

Four Styrofoam punches were randomly collected from each sampler to assess the following metrics:

1) Chlorophyll-a to give an estimate of live autotrophic biomass;
2) Ash-Free Dry Weight (volatile solids) / total dry weight to give an estimate of the carbon component (Stockner and Armstrong, 1971);
3) Taxa and biovolume to give an accurate estimate of live and dead standing crop (Wetzel and Likens, 1991); and
4) A second sample was frozen as back-up, in case a sample was damaged.

At the time of collection, Styrofoam punches were placed in pre-labeled containers and stored on ice in the dark until further processing.

During sampler retrieval, 1 litre composite samples of river water from Reach 4 and Reach 3 were collected mid-river and analysed for drift algae originating from Revelstoke Reservoir Confirmation of the source of algae taxa was made by comparing drift sample results to existing reservoir algae data and to their published growth habits.

Benthic invertebrate baskets were retrieved similar to previous years following guidelines developed by Perrin et al. (2004). A 250 µm mesh net was placed beneath baskets while still in the water column to collect any invertebrates that could have been lost as baskets were lifted from the water. The net was inverted and contents were rinsed into a labeled bucket with pre-filtered river water. The retrieved baskets were placed immediately in the labeled buckets until further field processing. Use of the net was conditional on safety of the crew and was not used when water velocity was high and the ability to safely retrieve the sampler was difficult.

Upon completion of sampler retrievals from each site, individual rocks from each basket were scrubbed with a soft brush to release clinging invertebrates. Washed rocks were then rinsed in the sample water before being placed back in the basket and stored for re-use in future years. The contents from each bucket were then captured on a 100 µm sieve, rinsed into pre-labeled containers and preserved in alcohol for analysis.

2.2.4 Post Processing of Periphyton Samples

Four Styrofoam punches were obtained from each artificial substrate. One 6.6 cm^2 punch was frozen and delivered to Caro Analytical Labs in Kelowna, BC, for the processing of low-detection limit fluorometric chl-a analysis. A larger 56.7 cm^2 punch was chilled and transferred to Caro Labs in Kelowna, BC for analysis of dry weight and ash free dry weight. The remaining 6.6 cm^2 punches were used for taxonomic identification that was completed by H. Larratt, with QA/QC and initial taxonomic verifications provided by Dr. J. Stockner. Fresh, chilled samples were examined within 48-hrs for protozoa and other microflora that are difficult to identify from preserved samples. The final punch was preserved using Lugol’s solution and was stored until taxonomic identification and biovolume measurements could be taken. Species cell density and total biovolume were recorded for each sample. A photograph archive was compiled from MCR samples. Detailed protocols on periphyton laboratory processing are available from Larratt Aquatic.

2.2.5 Post Processing of Invertebrate Samples

Following retrieval, fixed benthic invertebrate samples were transported to Cordillera Consulting in Summerland, BC. Samples were sorted and identified to the genus-species level where possible. Benthic invertebrate identification and biomass calculations followed standard procedures. Briefly, field samples had organic portions removed and rough estimates of invertebrate density were calculated to determine if sub-sampling was required. After samples were sorted, all macro invertebrates were identified to species and all micro portions were identified following The Standard Taxonomic Effort lists compiled by the Xerces Society for Invertebrate Conservation for the Pacific Northwest (Richards and Rogers 2011). A reference sample was kept for each unique taxon found. A sampling efficiency of 95% was used for benthic invertebrate identification and was determined through independent sampling. Numerous identification keys were referenced in the identification of benthic invertebrate taxa and a partial list of references is provided in Schleppe et al. (2012). Species abundance and biomass were determined for each sample. Biomass estimates were completed using standard regression from Benke et al. (1999) for invertebrates and Smock (1980) for Oligochaetes. If samples were large, subsamples were processed following similar methods. Detailed protocols on invertebrate laboratory processing are available from Cordillera Consulting.

2.3 Variable Descriptions and Analytical Methods

2.3.1 Determination of Submergence

Water and air temperature data obtained from the HOBO light/temperature loggers was the primary dataset used to determine how long an artificial sampler was submerged. Four HOBO light/temperature loggers were placed in the upland areas above the high water level within Reaches 4 and 3 to measure air temperature. Similar to Schleppe et al. (2011), a script that considered a temperature difference of ± 0.5ºC was used to compare samplers from permanently submerged locations with samplers across a transect. A sampler was considered exposed to air when the logger temperature differed from the permanently submerged logger by more than ±0.5ºC. This analysis of submergence was only partially reliable as there were times during the deployment when the air and water temperatures were within 1.5 ºC of each other (Schleppe et al. 2010).

To ensure that the determination of submergence was accurate, the entire database was reviewed for each session and professional judgment and field experience were used to assess whether a plate was submerged or exposed. During this review, the following criteria were used to assess whether a plate was submerged: flow, average air temperature from HOBO loggers, average water temperature, transect location, average air temperature from Environment Canada data, light intensities of exposed versus submerged samplers, and time of day. Temperature data from sites of exposure had notable highs, and we expect that localized effects such as metal frame heating may help separate similar temperature points between exposed and submersed samplers on sunny days. Data corrections were generally greatest on sites exposed to the air for longer periods.

2.3.2 Variables and Statistical Analyses

The focus of the 2016 analysis was gaining additional insights to help develop the proposed spatial productivity model. Methods used in previous years are discussed in Appendix C. Permanently submerged (T1) accrual data was used to develop theoretical growth curves using a nonlinear least-squares regression for fall and spring in the MCR. The asymptote was set to a chl-a sampler that had been incubated for 6 months.

Response variables that will be used in the spatial productivity model were modeled this year. For benthic invertebrates, biomass and abundance were modeled for samplers that were frequently submerged (T1-T4), whereas for periphyton only chl-a was modeled for frequently submerged samplers. These models used the same explanatory variables that were used in Schleppe and Larratt (2016) and in listed in Table 2-3. The methods of selection of explanatory variables are discussed in Appendix C. These three response variables were selected because they have growth and death curves. Year, site, and total submergence time were used as random variables. The purpose of considering total submergence time as a random effect is to attempt to isolate productivity drivers independent of submergence. Production data was transformed using either log10 or square root to adhere to the assumptions of least-squares multiple regression (i.e. normal distribution of residuals and heteroscedasticity of residuals). Seasonal data is complicated because it interacts with many of the other predictor variables, and was therefore considered independently using a separate suite of models to reduce the need to utilize complicated interactive effects within the spatial model.

The relative support for the effects of these explanatory variables was evaluated using an all model combinations approach. Model uncertainty was assessed using AICc and multi-model averaging (Burnham and Anderson 2002; Anderson 2008). We used the MuMIn package in R (Barton 2016) to compete models based on Δ AICc values and AICc weights (w_i), and to calculate multi-model averaged parameter estimates from 95% confidence sets for each response variable (Burnham and Anderson 2002; Grueber et al. 2011). The relative variable importance (RVI) is the sum of AICc weights from all models containing the variable of interest, with variables having RVI values above 0.6 considered to be of high importance in subsequent interpretations. We also calculated pseudo R^2 for high ranking models, derived from regressions of the observed data versus fitted values (see Cox and Snell 1989; Magee 1990; Nagelkerke 1991; Piñeiro et al. 2008 for details) which gives an indication of the proportion of the variance in response variables explained by an individual model. These analyses were conducted after standardizing continuous explanatory variables by subtracting global means from each value (centering) and dividing by two times the SD (scaling), to compare among all parameters and interpret the main effects in conjunction with interaction terms (Gelman 2008; Schielzeth, 2010).

Model averaging has been used instead of traditional regression methods such as stepwise multiple regression because traditional regression methods consider only one model as correct, even if alternative models are equally plausible. The model averaging approach is more objective because it simultaneously evaluates the merits of all the different working hypotheses relating operations, including minimum flow, to invertebrate and periphyton production (Johnson and Omland 2004). By objectively evaluating multiple alternative hypotheses, we are more likely to achieve an accurate understanding of how operations influence benthic production.

All statistical tests were conducted using R (R Development Core Team 2015), and model averaging was completed using the R package “MuMIn” (Barton 2016). In all analyses, independence of each sampler was assumed both within each transect and across sites. This assumption does not reflect the hierarchical sampling structure of Year / Reach / Site / Transect previously established. Modelling has improved from previous years because high collinearity among predictors was addressed after the 2012 study period. It is acknowledged that this approach may not entirely address all of the variation within or between sites due to the hierarchical nature of the sampling but since the study focus is on understanding important trends rather than using models predictively, this should have little effect on conclusions reached. Finally, we acknowledge that each of the identified predictors probably plays some role in production and it is difficult to select the most appropriate predictor in cases when two are highly correlated but affect biological productivity differently. This is why different predictor/explanatory variable model combinations have been considered throughout this assessment and previous reports provide valuable insight into some of the information relied upon within this annual report.

Table 2-3: Variables used in the prediction of periphyton and benthic invertebrate response in relation to BC Hydro operations and physical conditions during deployment. The full set of variables developed in 2010 were prepared for 2016. Environmental predictors used in the final models presented in 2016 are shown in bold, while the non-bold variables were considered but subsequently removed.

Variable	Definition
max_daily_light	Average daily maximum light intensity (lux)
Num_Days_Incubated	Number of days of deployment
tot_exp_hrs	Total time exposed (hrs) or out of the water
mean_exp_hrs_per_day	Average time exposed (hrs) or out of the water
min_exp_hrs_per_day	Minimum number of hours spent out of the water in one day
max_exp_hrs_per_day	Maximum number of hours spent out of the water in one day
max_cum_exp_hrs	Maximum cumulative (hrs) period of time exposed or out of the water
exp_ratio	Ratio of the total hours exposed to the total time deployed
num_time_sub_x	Number of times the site was submerged for more than nine continuous hours
tot_sub_time_hrs	Total time spent submerged (hrs) in the water
mean_sub_time_hrs_day	Average time (hrs) submerged or in the water
min_sub_time_hrs_day	Minimum number of hours spent in the water in one day
max_sub_time_hrs_day	Maximum number of hours spent in the water in one day
max_cum_sub_hrs	Maximum cumulative time (hrs) spent in the water
sub_ratio	Ratio of total hours submerged to the total time deployed
avg_daily_light	Daily light intensity averaged across the duration of time deployed
max_tot_daily_light	Total accrued light intensity over the duration of deployment (sum of all light intensity)
cum_max_int_sub	**Sum of the maximum observed light intensity each day over the course of deployment**
avg_day_cum_int_sub	The average daily light intensity average over the duration of deployment while submerged
sub_tot_light	Total accrued light intensity while submerged
tot_time_sub_light	Total time (hrs) spent in the light and water
avg_daily_time_water_light	Average time spent in the water and light per day over the duration of deployment
tot_exp_night	Total time spent exposed each night
mean_temp	Average temperature over the duration of deployment
max_temp	Minimum observed temperature over deployment
min_temp	Maximum observed temperature over deployment
avg_temp_sub	**Average temperature while submerged**
avg_temp_exp	Average temperature while exposed
avg_resElv	Average reservoir elevation over the duration of deployment
min_resElv	Minimum reservoir elevation over the duration of deployment
max_resElv	Maximum reservoir elevation over the duration of deployment
avg_flow	Averaged flow over the duration of deployment
min_flow	Minimum flow over the duration of deployment
max_flow	Maximum flow over the duration of deployment
velocity	**The average velocity of two data points observed at the sampler during higher flows (i.e., >1000 m^3/s)**
substrate_score	
distance_to_thalweg	**The thalweg of MCR was determined as the center of the channel at a normal operating range of 400 m^3/s to 800 m^3/s. The distance to the thalweg was then measured perpendicular from each site to the constructed thalweg line using GIS.**
Rel. Abundance Cobble / Boulder	Relative abundance of cobble and boulder substrates
Site Class	An initial attempt was made to classify observed site level effects. Sites tested included Backwater (BW's), Bedrock (BR's), and Main stem large (upstream large substrate Reach 4), and Main stem small (downstream Reach 3 and Big Eddy).
Rel. Abundance of Silts, Sands (Fines), and Gravels	Relative abundance of silts, sands, and gravels in MCR
Embeddedness Score	Embeddedness was assigned a score of 1 (0-5%), 2 (5-25%, 3 (25-50%), 4 (50-75%) or 5 (75-100%)

2.3.3 Time Series and Artificial Sampler Assumptions

Community losses along the edges of the artificial substrate were assumed to be negligible. The effects of edges on the artificial substrate, such as the edge between tape adhesive and artificial Styrofoam sampling substrate, were considered in the same manner. Our visual observations of periphyton growth on the samplers support this assumption but we do not have empirical data to otherwise confirm it. In any case, we did not draw samples from the plate perimeters if possible, however, Styrofoam damage over the deployment occasionally necessitated collecting a sample near the edge.

The effects of foraging invertebrates were assumed to be randomly distributed over the artificial substrate within and between all sites. It is acknowledged that invertebrates may spend more time foraging along the edges of substrata and therefore disproportionately affect productivity along the perimeter of artificial samplers. Therefore, we avoided collecting samples from substrate edges unless no other viable alternative was available. Foraging intensity on MCR samples is still considered to be a small effect, reducing any potential data-skewing. Further, it is probable that invertebrate distributions around plates were clumped, reducing the potential for effects across multiple replicates. Finally, the populations of invertebrates in the MCR were low relative to other large rivers, and we have not used power analysis to determine if the sample size is adequate.

Our analysis assumed that artificial substrates did not bias results toward a given algal taxa nor did they bias towards those taxa actively immigrating at the time and location of the sampler submergence. Although we have made this assumption, data collected suggests that artificial substrate types and natural substrates do respond differently within the MCR. Future investigations may be required to accurately relate artificial samplers to natural substrates and determine if artificial substrates are indicative of actual riverine conditions.

Sampler assessments were not intended to address immigration, sloughing, or any other aspects of the periphyton or invertebrate community. Thus, artificial substrate samples that were obviously biased due to sloughing from rock flipping, etc. were excluded from collection. For invertebrate analyses, this means we have not considered emigration or immigration from within or between sites and that specific operational patterns have not unduly affected any one community or result in changing densities of invertebrates due to mortality over the duration of deployment. In cases where periphyton artificial substrates were damaged, but sufficient material was available for a sample, it was collected and not treated differently than any other sample except in cases when the sample was biased due to slough or the substrate sampler was inverted by flows. For invertebrates, damaged samplers were not analyzed as they were considered biased. These field decisions were easy to make because large boulders rolling over artificial substrates, or those dragged upside down, left distinct trails of compressed Styrofoam or because sampling baskets were broken open. This field decision reduced the potential area available to sample, but we do not suspect that it biased the results. It is acknowledged that substrate mobility and periphyton sloughing/drift are important components of periphyton production in the MCR.

3.0 RESULTS

3.1 Biophysical Characteristics of the Middle Columbia River

3.1.1 Light and Temperature in Submerged areas of MCR

Overall water temperature ranges in Spring 2016 were consistently higher than temperatures collected in 2010 through 2015 (Figure A-1). Like other years, numerous small spikes in temperature were observed. Reservoir conditions upstream are the most probable factor affecting the daily variation in observed temperature because downstream river temperatures were most dependent upon upstream reservoir conditions and the temperature/flow of tributaries (Larratt et al. 2013; Olson-Russello et al. 2015). During the spring deployment, initial river temperatures were cooler and ranged from 4 to 5ºC, and increased near the end of deployment to around 7.5ºC.

Jordan River inflows appeared to raise the temperature of Reach 3 in Spring. Temperatures of exposed plates in the spring usually exceeded water temperatures (Figure A-1) On the LCR, winter river temperatures were more dependent upon the temperature of the upstream reservoir, while during the fall, riverine temperatures were more dependent upon air temperature due to seasonal patterns (Olson-Russello et al. 2015).). If similar trends exist on the MCR, it is probable that springtime water temperatures are more dependent on reservoir temperature, whereas fall water temperatures are more dependent on air temperature, recognizing that summer weather determines the upstream reservoir temperature.

Light intensity patterns during Spring 2016 were similar to 2010 – 2015 (Figure A-2). In accordance with the physics of light transmission through moving water with low suspended solids, light intensity on submerged samplers increased from deep sites at T1 locations to shallow sites at T6 locations in the spring. When samplers were in shallow water, they received more energy to support periphyton production, but these sites were also most likely to be exposed during the variable daily operating regime. Peak light intensities occur around noon, a period when flows were usually high. Light intensities were much greater when samplers were exposed, and were highest at the T6 locations where exposure was the most frequent. Spring light intensities were similar to previous years (Figure A-2).

Figure A-3 presents the spring light logger data when samplers were exposed. It shows the expected reception of far more light than during water-covered periods. The differences between the results at the various transect positions reflects a combination of aspect, riverbank shading and periphyton growth on the sensors.

3.1.2 Pattern of Flow in MCR

Several features in the MCR flow regime directly influenced productivity during the study period. These features are presented in approximate chronological order:

- Minimum flows of 142 m^3/s were maintained from 2011 onwards (refer to Schleppe et al. 2013 for analysis of 2011 and 2012 data).
- 2011 and 2012 were extremely high water years resulting from a combination of higher than normal snowpack and possibly higher discharge from REV 5. Small morphological and biological channel changes were observed. For instance, in

2010 there was a noticeable fungal/bacterial black coloration on substrates in Reach 4, and this was less apparent following the high water years.

- Very high flows exceeding 2000 m^3/s were concentrated in the winter months but also occurred in August of 2011 and 2012. The frequency of these events was greater in 2012 than in 2011, 2013, 2014, 2015 and 2016.
- Flows followed a similar pattern between years, with low flows occurring during evening periods after midnight and high flows occurring during daytime periods from 10 a.m. until 7 p.m. At all other times, flows were either ramping up or down from high or low flow periods (Figure A-6).
- High variability in high, low, and ramping flow periods was observed between years and seasons.
- Daily flow patterns were similar to previous years in spring 2016, with the exception that daily high flows were lower (<300 m^3/sec difference) than what had been observed in 2007 – 2012 pre-implementation years (Figure A-6). The magnitude of flows in Spring 2016 were average compared to previous years. This resulted in slightly deeper average depths of 5 – 8 m at T1 locations and 2 to 3 m at T6 locations.
- The Arrow Lakes Reservoir (ALR) elevation can result in extensive back watering of Reach 3 from early June through October, and can extend into Reach 4 during the summer months (Figure A-7). Backwatering effects have been considered through the submergence variables but these variables do not distinguish between submergence due to backwatering and submergence due to flows in the model analyses. During Spring 2016, back watering occurred in Reach 3 in the last couple of weeks of the spring deployment period.

The 2016 spring flows were similar to previous years when compared to both the pre and post implementation of minimum flows. As REV is a hydropeaking facility, it is hard to generalize flow patterns for daily or weekly comparisons, making summaries of flow trends difficult.

3.2 Periphyton

3.2.1 Overview of MCR Periphyton Biofilms

Periphyton consists of two broad groups of micro-organisms, photosynthetic algae and bacteria, and non-photosynthetic (heterotrophic) bacteria and fungi. Algal periphyton production only occurs while substrates are submerged and exposed to sunlight, while the bacterial biofilm component also grows in the dark (Lear et al. 2008). For both components, growth in MCR slowed dramatically and mortality progressively increased during periods of desiccation. Heterotrophic bacteria counts on the MCR artificial substrates deployed for 44-47 days during fall were relatively low compared to other large North American rivers at 0.2 – 5 x10^6 colony forming unit (CFU)/cm^2. These low counts probably reflect repeated desiccation (Schleppe et al. 2012).

A final contributor to MCR periphyton biofilm production was drift of viable phytoplankton cells originating from the upstream Revelstoke Reservoir, and to a lesser extent, from Arrow Lakes Reservoir during back-watering. Many reservoir algae are physically distinct from true periphyton algae, while others can grow in both standing and flowing environments. These cells adhered to existing periphyton and at times, significantly augmented local productivity (Table A-1).

Collection of AFDW (volatile solids) commenced in 2010. AFDW provides an estimate of all organic components of the biofilm plus detritus. Average MCR ash-free dry weight (volatile solids) samples remained in the typical range for large rivers but with considerable variation from year to year. AFDW has averaged about 0.60 mg/cm^2 in both seasons, but with wider variation in the fall than the spring. With both seasons and all years combined, AFDW remained near 0.50-0.62 ± 0.32-0.57 mg/cm^2 in the permanently submerged substrates from T1 through T4, and peaked (0.83 ± 2.64 mg/cm^2) at T5 in the lower varial zone before declining to 0.49 ± 0.46 mg/cm^2 at T6 in the upper varial zone / floodplain. T5 appears to be a zone of organic accumulation or decomposition. Variable results from year to year are likely flow-driven and they highlight the volatility of conditions in MCR. Field observations of reduced black banding suggest a decline in heterotrophic members of the biofilm in years with longer inundation of the flood plain areas (T5, T6). They may become displaced by algae as periods of substrate submergence increase.

3.2.2 Characteristics of MCR Periphyton Algae

The dominant diatom species in MCR were either rapid colonizing diatoms with firm attachment strategies, or drift species from Revelstoke Reservoir that adhered to the periphyton biofilm. Like most large rivers, MCR species were dominated by diatoms representing between 82 and 98% of the biovolume in all sample sites on both natural and artificial substrates (Schleppe et al. 2013). When all years of study to date are considered, diatoms accounted for 85% of the fall biovolume and 92% of the spring biovolume. Green algae accounted for 14% in the fall with large filamentous species, and only 6% in the spring samples where rigorous conditions including freeze-dry events eliminated all but the single-celled green types. The relative biomass contributions of flagellates ranged from 0.6% in the fall to 1.1% in the spring. Although cyanobacteria were functionally and numerically important, they only accounted 0.1% of total biovolume in the fall and increased to 0.5% under spring conditions that favoured species with rapid reproduction rates. The resultant growth patterns are visible in Figure 3-1, where spring has less growth than fall, and R4 has less growth than R3.

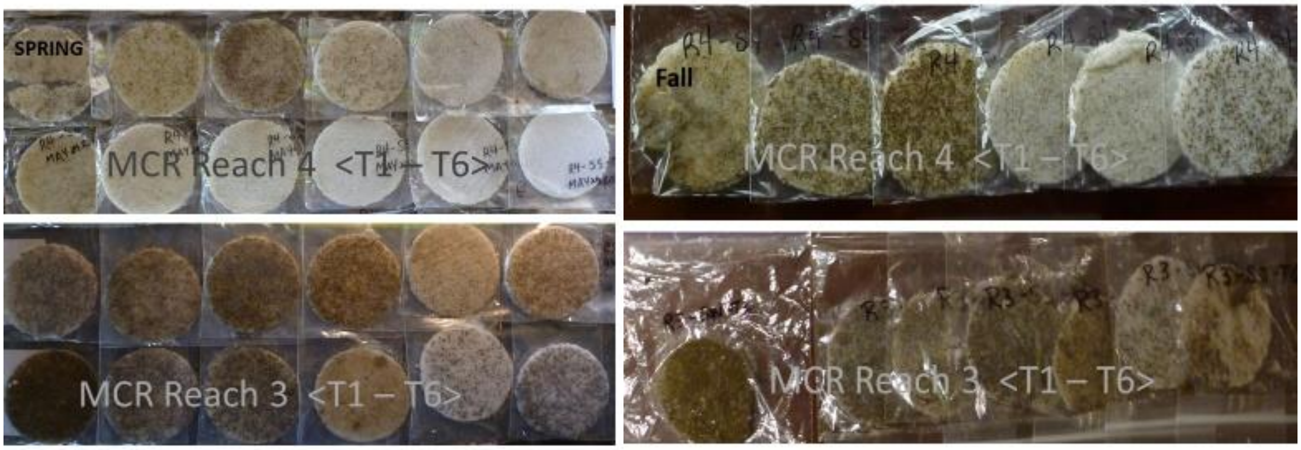


Figure 3-1: Examples of spring and fall incubated Styrofoam from MCR Reach 4 and Reach 3, comparing mainstem sites, all with cobble /sand substrates. The increased periphyton growth on the upper varial zone (T5, T6) of Reach 3 (disks were dark with growth) over Reach 4 (disks remained lighter), results from increased submergence and subsequent growth in part due to Arrow Lakes Reservoir back-watering.

MCR had 5 - 52 species per sample, with all microflora taxa included. Among the true algae, mean taxa richness was 12 ± 4 to 22 ± 5 in the spring and 10 ± 2 to 23 ± 6 taxa in the fall (Digital Appendix B, 3-4). These results suggest that species richness in MCR was lower than is typical for unregulated large rivers of similar latitude.

The taxonomic structure of all river periphyton communities displays a tendency for predominance by a small number of taxa. In 2011, the range of river habitats investigated was expanded to include backwater, Big Eddy and bedrock, but still found many of the same species as occurred at mainstem sites. Over the years of study on the MCR habitats, ten dominant taxa, accounted for 78–99% of abundance (87-91% of total biovolume) in the fall and 78–90% of abundance (86-92% of biovolume) in the spring. The ten dominant taxa distribution was typical in spring 2016, accounting for 88% of abundance and 86% of biovolume.

Overall, Spring 2016 periphyton productivity was higher than most spring sampling seasons, both in terms of chlorophyll-a and biovolume (Figure 3-2).

3.2.2 Drivers of MCR Periphyton Communities

Effects of Reservoir Donation The donation of Revelstoke Reservoir diatoms to MCR periphyton was highly variable from year to year, and relates to production dynamics within the reservoir versus the timing of releases. Drift samples were not collected in the spring of 2016. Phytoplankton taxa that have been detected in mid-river drift samples and therefore were donated by Revelstoke Reservoir accounted for 40-70% of biovolume in fall samples and 20-60% of biovolume in spring samples to date.

Examples of dominant species are provided in Table A-1. They include limnoplanktonic species that can only function suspended in the water column (e.g., *Asterionella*) but persist after they become snared on MCR periphyton, and those that can reproduce after attachment to the periphyton (e.g., *Tabellaria*). Interestingly, most of the limnoplanktonic types were only found in mainstem samples and not in the backwater and Big Eddy samples. This may relate to greater exposure to drifting algae along the mainstem. Similarly, fall R4 samples had 34% more planktonic drift taxa than R3 samples and spring 2015 samples had 43% more in R4 over R3 because the reservoir algae cells progressively settle out. It appears that Fall sampling periods with low productivity have a higher percentage of their productivity derived from Revelstoke Reservoir. Both fall chl-a and total abundance are negatively associated with percent from reservoir (r=-0.26, p<0.001). A statistical association between spring productivity and percent from reservoir was not apparent. Spring chl-a and percent from reservoir has a marginally significant weak negative association (r=-0.13, p=0.06, while the association between spring total abundance and percent from reservoir is not significant (r=-0.09, p=0.18).

EFFECTS OF FLOWS Year-round implementation of 142 m^3/s minimum flows and full in-service operation of REV 5 were initiated on December 20, 2010. Fall samples collected before and after REV 5 are compared in Table 3-1. While species diversity was unchanged, periphyton growth metrics were lower after the flow regime change, with 2012 having the lowest periphyton metrics and the highest flows to date. Both abundance and biovolume decreased significantly, while chl-a did not, implying that a shift to fast-growing photosynthetic bacteria. Bacterial components of the biofilm can be utilized incidentally when invertebrates are foraging.

Table 3-1: Range of periphyton metrics in MCR R4 and R3 in fall 2007 – 2016

Fall (all depths)	abundance cells/cm²	biovolume um³/cm²	chl-a ug/cm²	n
Pre REV 5	$7.18 \pm 3.38 \times 10^5$	$3.78 \pm 3.09 \times 10^{8*}$	1.06±0.71	105
Post REV 5	$5.02 \pm 2.78 \times 10^5$	$2.92 \pm 2.46 \times 10^8$	1.03±0.75	187
% difference	-30%	-23%	-3%	

** biovolume not available prior to 2011, thus only one year's data in this metric*

An increase in filamentous green algae has occurred in R4 and R3 in the fall since the implementation of the new flow regime. These slow-growing algae can form visible mats in the summer where shear is low under stable, lower flows, but their mats are dislodged by high flows and they are intolerant of desiccation. The area wetted by minimum flows should retain short growths that could re-populate dewatered substrates. Filamentous growth in the Reach 4 T2-T4 zone may continue its gradual increase over the years since minimum flows were implemented. Filamentous green algae were also prevalent in the spring 2012 samples but were uncommon during subsequent spring sampling sessions. For example, no filamentous green algae occurred in R4 in Spring 2016, while only trace amounts were found in R3 T1 positions. This review of filamentous green algae distributions supports the assumption that flow management exerts a powerful influence on the MCR periphyton community.

Under the new flow regime, high flows can generate water velocities in the thalweg greater than 2 m/sec (Schleppe et al. 2013). Since 2012 was the highest flow year to date for fall, the growth metrics at T1 positions in 2012 were compared to other years (Figure 3-2). As expected with higher 2012 flows, thalweg T1 periphyton metrics dropped significantly in both reaches during the fall and the spring compared to years with a lower range of flows. In the fall thalweg data, R4 showed a greater difference than R3 between the high flow year (2012) and the typical flow years (Figures A-6 and A-7). Overall water velocities would have been higher in the narrower Reach 4 channel, possibly accounting for the larger fall periphyton declines compared to the wider Reach 3 channel that was frequently back-watered. In the spring, the difference between the reaches was smaller and reversed, so that the difference between 2012 and typical flow years was greater at R3 than R4. The short spring days may have increased the influence of available light, where greater water depth during high flows lowers light penetration to the substrates. Year by year, productivity in R3 and R4 show the same patterns in all growth metrics, however in both the spring and the fall samples, R3 showed greater reactions to flows and growing conditions, while R4 reactions were more subdued.

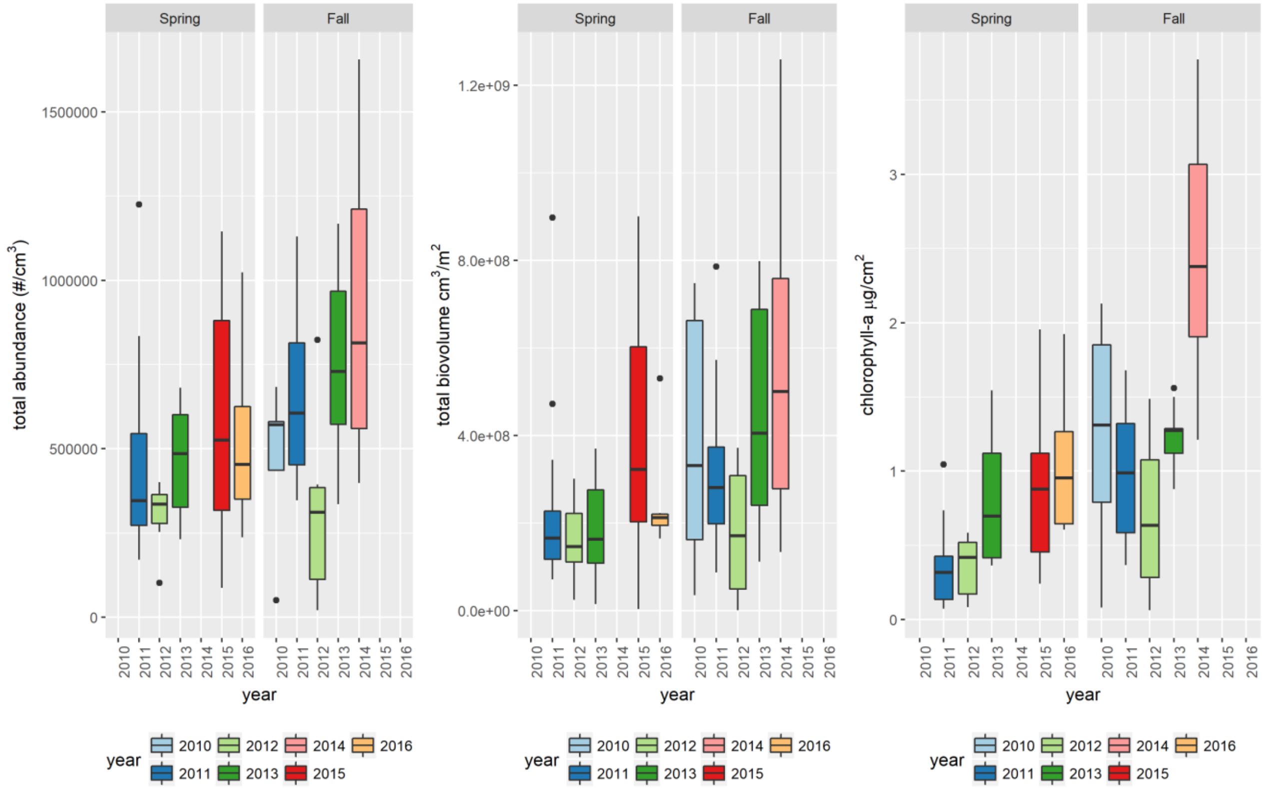


Figure 3-2: Periphyton productivity compared by year and season in Reach 3 and Reach 4 in the Thalweg (T1) zone. Spring 2015, Fall 2011 and Fall 2012 had higher flows than average (Table A-2).

EFFECTS OF WATER DEPTH Throughout MCR and in both seasons, samplers in the permanently wetted and lower varial zone T1 through T3 had greater autotrophic periphyton production, while frequently exposed samplers showed increasing heterotrophic dominance and lower autotrophic production. Most of the organic material at heterotrophic-dominated sites was decomposer microflora and non-viable organic materials such as dead diatoms, leaf litter and detritus. The distribution of algae groups through the range of transect depths was consistent between years and seasons, with slightly declining diatom density but increasing flagellate and cyanobacteria density from deep to shallow water.

When all biovolume measurements were compared to chlorophyll-a (chl-a) results, similar curves emerged (Figure 3-3). Average periphyton productivity decreased with increasing exposure from T1/T2 through T5/T6. For the transect depths that were consistently covered by minimum flows (T1/T2), or adjacent to the wetted edge (T3), algae cell biovolume was stable. The frequently dewatered T6 and T7 locations had the lowest biovolume and chl-a, particularly in Reach 4 because only a select few periphyton species can tolerate frequent desiccation. There were similar patterns of abundance and productivity among depths between spring and fall, but with lower overall production in the spring. In general, substrates that were wetted for periods greater than 9 hours per day experienced rapid periphyton growth (Schleppe et al. 2012).

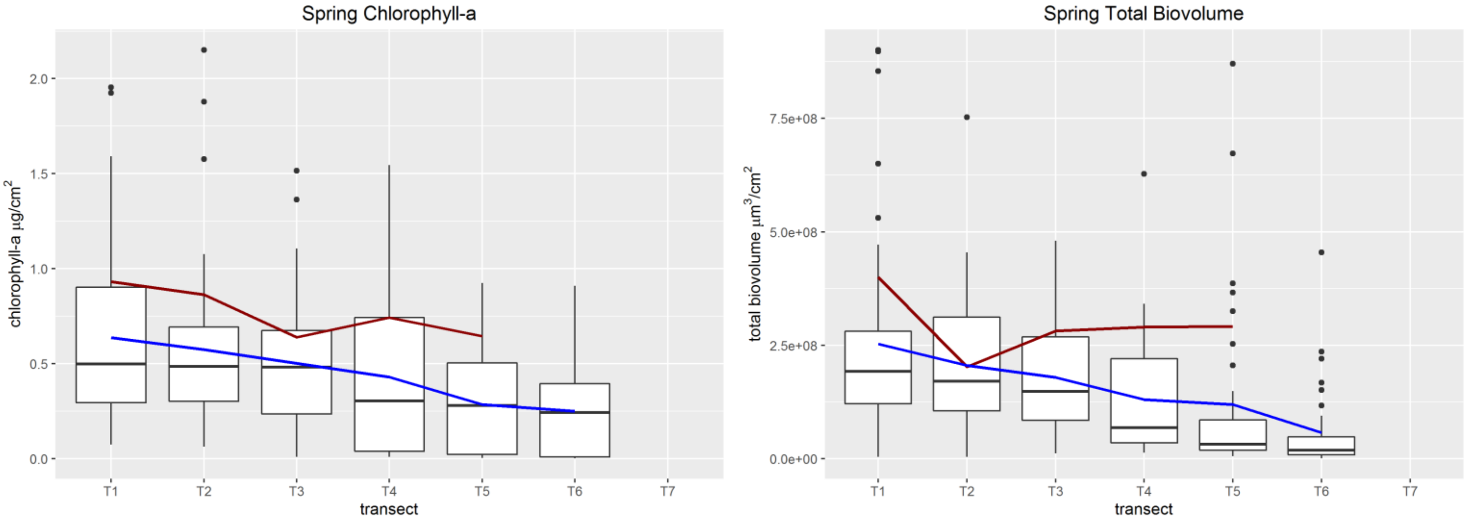


Figure 3-3: **Total biovolume of MCR periphyton and chlorophyll-a in spring for 2010 to 2016 by sampler location (T1 deepest in thalweg to T7 shallowest on floodplain). The blue line represents the mean of all years and the red line represents the mean for spring 2016**

Available light for photosynthesis (PAR) is directly affected by water depth. For example, light data from spring 2015 was lower than spring 2011 or 2012, indicating greater water cover on MCR substrates in that year. In 2016, available light was average, as were flows. The periphyton growth metrics were high, but they would have been affected by the unusually early, warm 2016 spring weather.

EFFECTS OF SEASON There were subtle seasonal shifts in the dominant periphyton taxa in MCR, probably in response to flows, water temperature and freezing conditions. In all spring samples, the same diatoms dominated the periphyton, along with large concentrations of rapidly reproducing single-celled algae. In fall samples, similar diatoms dominated and there was a greater contribution made by filamentous green algae, particularly in fall 2014. Spring samples had lower average species richness of 13 (T6) to 19 (T2) species/sample compared to fall samples at 15 (T6) to 23 (T2) species/sample.

Summary statistics are provided for all five spring sample periods in Appendix B Table A3-4. Spring periphyton growth metrics were stable and low, ranging from 2.54 – 3.84 x 10^5 cells/cm^2 for mean abundance in 2011, 2012, 2013, and 2016 but increased to 4.76 x 10^5 cells/cm^2 in 2015. Biovolume increased from the typical spring values of 1.18 – 1.54 x 10^8 microns^3/cm^2 to 2.79 x 10^8 microns^3/cm^2 in spring 2015, despite high spring 2015 flows. Similarly, chl-a ranged from 0.16 – 0.19 ug/cm^2 chl-a in the first three years, but increased to 0.55 ug/cm^2 in 2013 and to 0.75 ug/cm^2 in spring 2015 and was 0.70 ug/L in spring 2016. The cause of this increased spring periphyton growth is not known but apparently relates to early warm spring weather and was despite moderate to high flows in those years. In all four spring sample periods, average species diversity metrics were stable at 0.71 – 0.81 Simpson's index and at 13 – 21 taxa. Productive spring seasons tended to have low contributions of reservoir algae to the periphyton mat. Overall, spring means and spring maxima among growth metrics were usually significantly lower than fall samples from the same year (2011, 2012, and 2013) and when all study years are averaged.

Periphyton summary statistics are provided for all eight fall sample periods in digital Appendix B. The fall sampling sessions demonstrated a range of mean abundance from 2.73 to 12.5 x 10^5 cells/cm^2 a range of mean biovolume of 0.98 – 6.05 x 10^8 microns^3/cm^2 and a range of mean chl-a of 0.49 to 1.76 ug/cm^2. For all growth metrics, the lowest year was 2012, the highest flow year to date. In all fall samples, the same diatoms were dominant, but with a significant filamentous green component. These slower-growing taxa prefer stable flows with moderate nutrient concentrations.

Table 3-2: Range of periphyton metrics in MCR (R4 and R3) by season, 2007 – 2016

Fall **(all depths)**	**abundance** **cells/cm^2**	**biovolume** **um^3/cm^2**	**chl-a** **ug/cm^2**	**AFDW** **mg/cm^2**	**species** **richness**	**Simpson's** **Index**
2007 – 2010	7.10 x10^5	3.78 x10^8	1.01	0.499	17.2	0.695
2012	2.76 x10^5	1.11 x10^8	0.47	0.400	21.6	0.704
2011 – 2014	5.10 x 10^5	3.45 x10^8	1.03	0.581	22.3	0.703
Spring **(all depths)**	**abundance** **cells/cm^2**	**biovolume** **um^3/cm^2**	**chl-a** **ug/cm^2**	**AFDW** **mg/cm^2**	**species** **richness**	**Simpson's** **Index**
2011 – 2016	3.71 x 10^5	1.74 x10^8	0.55	0.60	17.8	0.78

Over the 2011 to 2016 study period, there has been an increase from <0.01% to 8% in the nuisance algae Didymo in spring samples from both reaches. Throughout MCR, 2015 spring samples showed a typical species assemblage but at higher cell density and much higher chlorophyll-a than in earlier years or in 2016 (Figure 3-3). This increase was also reflected in time series chl-a and in both cases, may relate to warmer water temperatures. There was a stronger effect of water temperature evident in the spring statistical models than in the fall models.

REACH EFFECTS Many growth metrics were higher in Reach 3 than Reach 4 over the years of study, depending factors including flows, back-watering and weather. When the five spring samples sessions are compared by reach, R3 had 16% higher cell abundance, 7% more biomass and 55% higher chl-a than R4 averages. When all fall samples to date are compared, R3 had the same abundance and biovolume as R4, but with 36% higher chl-a than R4 averages. Thus, spring was the season with the greatest difference between R3 and R4 periphyton productivity. Spring has more riverine conditions, hence the effect of flow would be more pronounced than in the fall.

R3 is usually more productive than R4 and spring 2016 was no exception, with 30% higher abundance, 18% more biovolume and 60% more chlorophyll-a. The large difference in chl-a was likely driven by the occurrence of filamentous green algae in R3 samples but not R4 samples.

Substrate changes between R4 and R3 were reflected in shifts among periphyton dominants. For example, species that were either adherent, colony-forming, or non-motile were more common in R4 samples (e.g. *Synedra ulna, Achnanthidium minutissima*), while species that were stalked or motile increased in R3 samples (e.g. *Didymosphenia geminata, Navicula spp.*). These taxa changes were probably driven by increasing sand concentrations in R3. The dry weight of samples was slightly greater (1.6%) in R3 samples compared to R4 samples and indicates that R3 substrates are subject to more sand abrasion

Although species composition changed between reaches, there was no observable difference in the Simpson's index (0.79) and only a negligible 5% difference in species diversity (19.7 – 18.8) between reaches, and this finding was confirmed by statistical modelling provided in the next section. There are numerous mechanisms that account for similarities in species distribution in large rivers such as MCR. These include backwatering and high flow events that can shield and move benthic species to new substrate locations. Additionally, the T1/T2 area that remained wetted by minimum flows together with drifting algae from Revelstoke Reservoir, it can function as a source of organisms to re-colonize exposed habitat areas with the same suite of taxa after catastrophic flow events.

BACKWATERING EFFECTS A final aspect of MCR flow regime affected by both BC Hydro releases and by watershed hydrology is back-watering by Arrow Lakes Reservoir (ALR). This seasonal water cover reduces desiccation on substrates that would otherwise be exposed by low flow releases, particularly in the fall. It should also increase the opportunity for limnoplankton suspended in the ALR water column to drop out onto MCR periphyton. In most years, sampler deployments in spring occurred at the lowest Arrow Lakes Reservoir levels and ended when backwatering was just starting in R3, while fall deployments commenced as backwatering declined in R3 and R4. Both seasonal deployments can be affected by backwatering with R3 receiving the greatest effect. Since the hydrologic regime in the preceding week is always of greater importance to periphyton production than events that occurred further in the past (Schleppe et al. 2013), fall data should provide the best insight into the effects of backwatering on R3 productivity because of the recent loss of backwatering cover on the substrates (declining limb of hydrograph). The data summarized in Figure 3-4 confirms the benefits of back-watering on periphyton, and was confirmed by statistical modelling, presented in the next section.

The Reach 3 upper varial zone is the most variable region for periphyton productivity in MCR. With continuous backwatering, it can exceed the productivity of deeper areas but in seasons without backwatering, it can have minimal productivity. For example, without backwatering, upper varial zone abundance dropped by about 30% and biovolume by 70% in fall 2013, while in fall 2014, the upper varial zone was continuously covered by back watering, resulting in far greater periphyton growth throughout the R3 upper varial zone (Figure 3-4). Another important influence on the R3 upper varial zone is high flows. Very high flows in 2012 apparently curtailed productivity, while in spring 2015, high flows with back watering into R3 allowed moderate productivity. However, in spring 2016, productivity at T5 was low at 1.03 x 10^5 cells/cm^2 and very low at T6 at 0.72 x 10^5 cells/cm^2. These effects of backwatering are accounted for in the statistical models because they consider duration and timing of submergence.

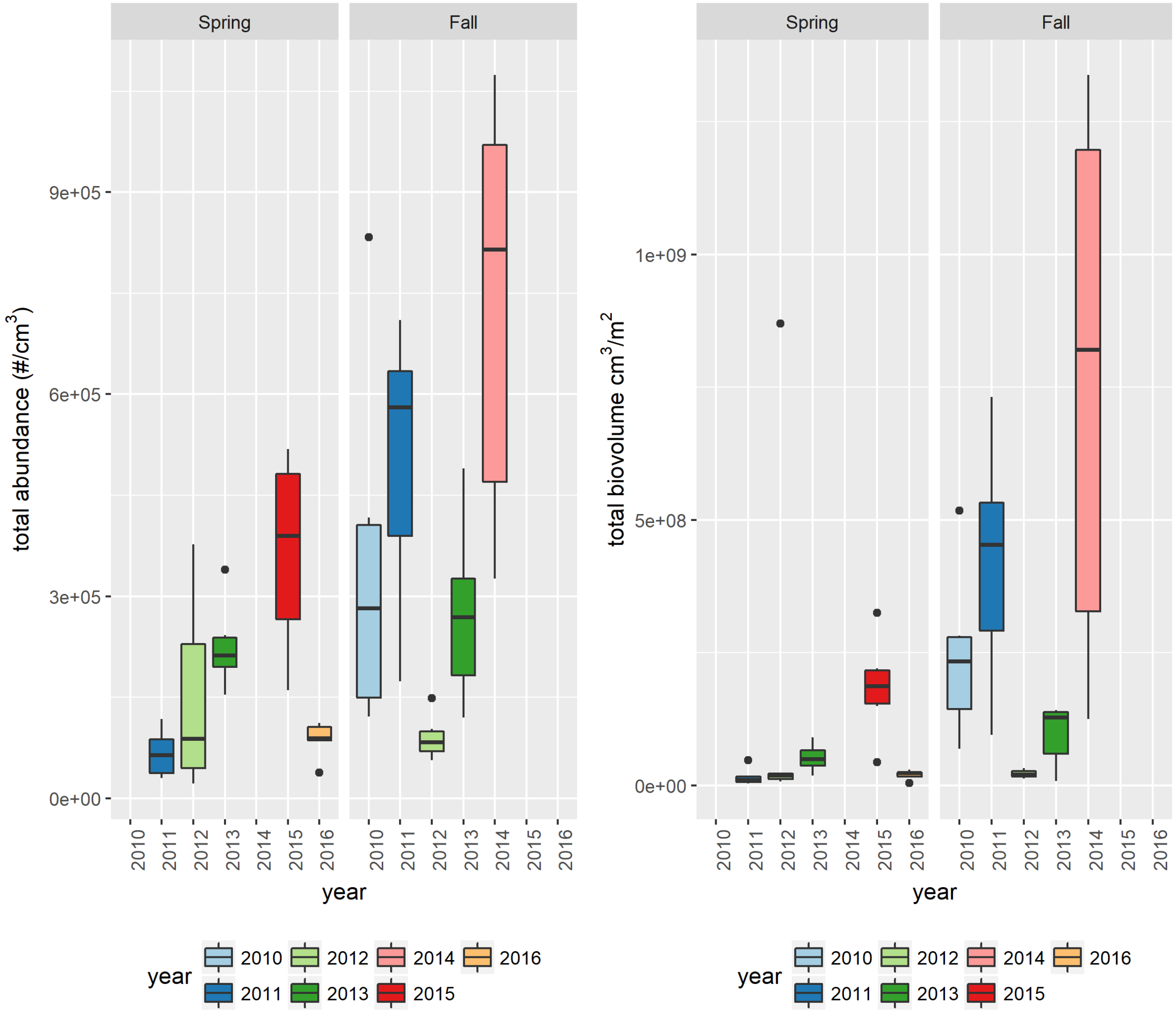


Figure 3-4: Upper varial zone (T5,T6) periphyton productivity in R3, 2010 - 2016 by year and season. All sampling periods were effected by backwatering except Spring and Fall 2013 (Table A-2),

3.2.3 Periphyton Accrual

Time series chlorophyll-a data have been collected since 2009, and it was selected as the measure of periphyton productivity to consider accrual because it is a standard measure of production, it is available for the longest period, and it is highly correlated (R^2 >0.8) with abundance and biovolume in MCR data (Schleppe et al. 2011).

In previous years, a repeated measures ANOVA was used to determine factors influencing growth rates of chl-a. Accrual rates varied among seasons, years, and transects. Overall, the relationship between incubation times and chl-a was much stronger in Fall compared to Spring. This result suggests that accrual rates are more dependent on incubation times and easier to predict in Fall. Permanently submerged samplers (T1) had greater accrual rates than varial zone samplers. For both the spring and fall sampling periods, chlorophyll-a showed a complex curve that was still increasing after 50 days in the water. In MCR, the theoretical growth curve for chl-a should have a logistic shape. In other words, the growth rate is exponential until it reaches a peak biomass and then plateaus.

This year, theoretical growth curves were derived using accrual data from permanently submerged locations (T1). To force the curve to be logistic, the chl-a of samplers that had been incubated for 6 month (180 days) were used as the asymptote. Fall had a higher accrual rate than Spring (Figure 3-5). The peak biomass for spring was 1.2 µg/cm^2, whereas the peak biomass for fall was 2.69 µg/cm^2.

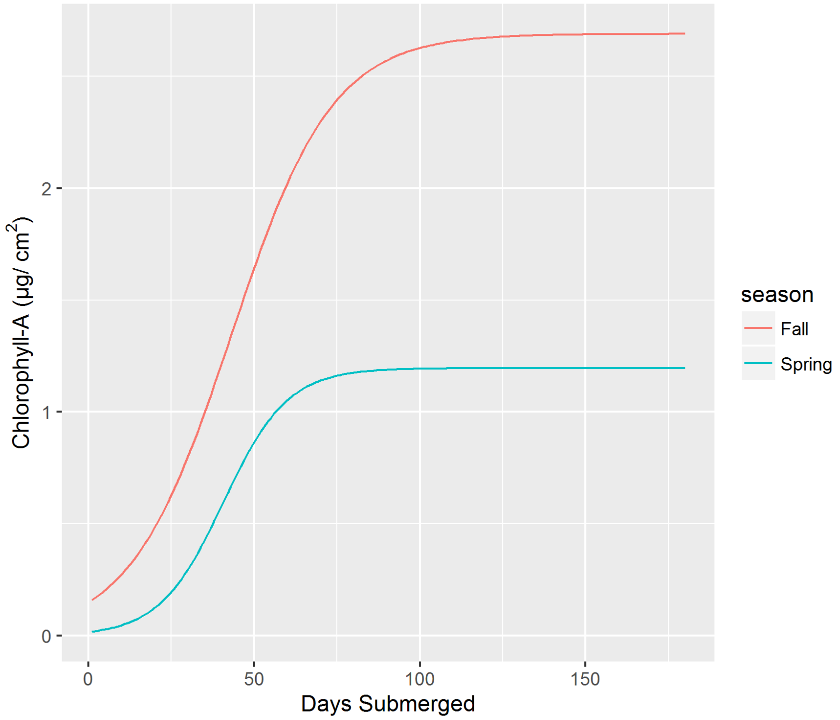


Figure 3-5: **Chl-a growth curve derived from T1 accrual data from 2011 to 2016 and 6 month chl-a samples.**

3.2.4 Periphyton Community Groupings

These analyses were not conducted in 2016, however analyses from 2007-2015 can be found in previous reports for this project. In brief, they suggested that pre and post-implementation of flows explained the most periphyton community variation. However, due to the confounding effects of annual and seasonal differences, it could not be concluded if the implementation of minimum flows has a direct effect on periphyton community composition (Schleppe and Larratt 2016).

3.2.5 Periphyton Production Models

Previous years of this study have used periphyton production models to understand the underlying processes that affect periphyton production. The most important driver of periphyton production in Spring and Fall was hours of submergence. The longer a sampler was submerged the more productive it was. The second most important predictor of periphyton productivity in MCR was the average daily water temperature. The influence of water temperatures on periphyton productivity appeared stronger in Spring compared to Fall. Water temperature affects a range of factors controlling periphyton including the preference of diatoms for cool water and grazing rates. There may be an optimal water temperature for MCR periphyton biomass, possibly in the 8-10^{o}C range (Figure 3-6). Other predictors including substrate score, distance to thalweg, cumulative light intensity, and velocity explained some variation in periphyton metrics.

This year the production models were only run on samplers that were permanently submerged or in the lower varial zone (T1-T4). The purpose of this year's modelling was to identify variables that predict chl-a independent of submergence. Both the spring and fall chl-a models identified water temperature as the most important predictor when the effect of submergence was accounted for in the random intercept of the model. The association between spring chl-a and water temperatures was positive, whereas in fall chl-a decreased with increasing water temperatures (Figure 3-6). Water temperature explained more variation in spring chl-a (R^2=0.33, p<0.001), compared to fall chl-a (R^2=0.12, p<0.001) (Figure 3-7).

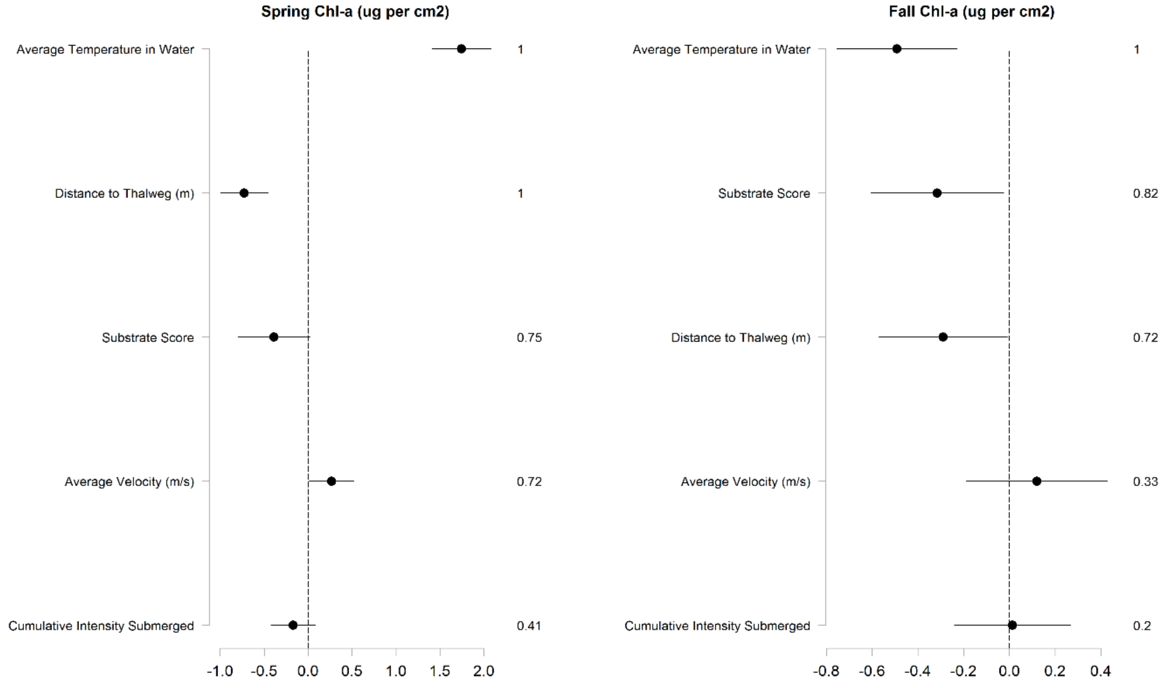


Figure 3-6: **Model averaged parameter coefficients and 95% confidence limits from model averaged linear mixed effects models for chl-a of samplers T1-T4 with total submergence time as a random effect. Each plot represents the probability of a given predictor, described on the left side of the plot, to be in the best AIC model (this probability is described by the RVI value on the right side of the plot). The predictors are also sorted based on this probability. Predictors have been standardized to allow direct comparison of coefficients (x-axis). The corresponding coefficient and its 95% confidence interval are represented on the plot. Those variables with 95% confidence intervals overlapping zero are considered of low significance as the direction of their effects are inconsistent among models.**

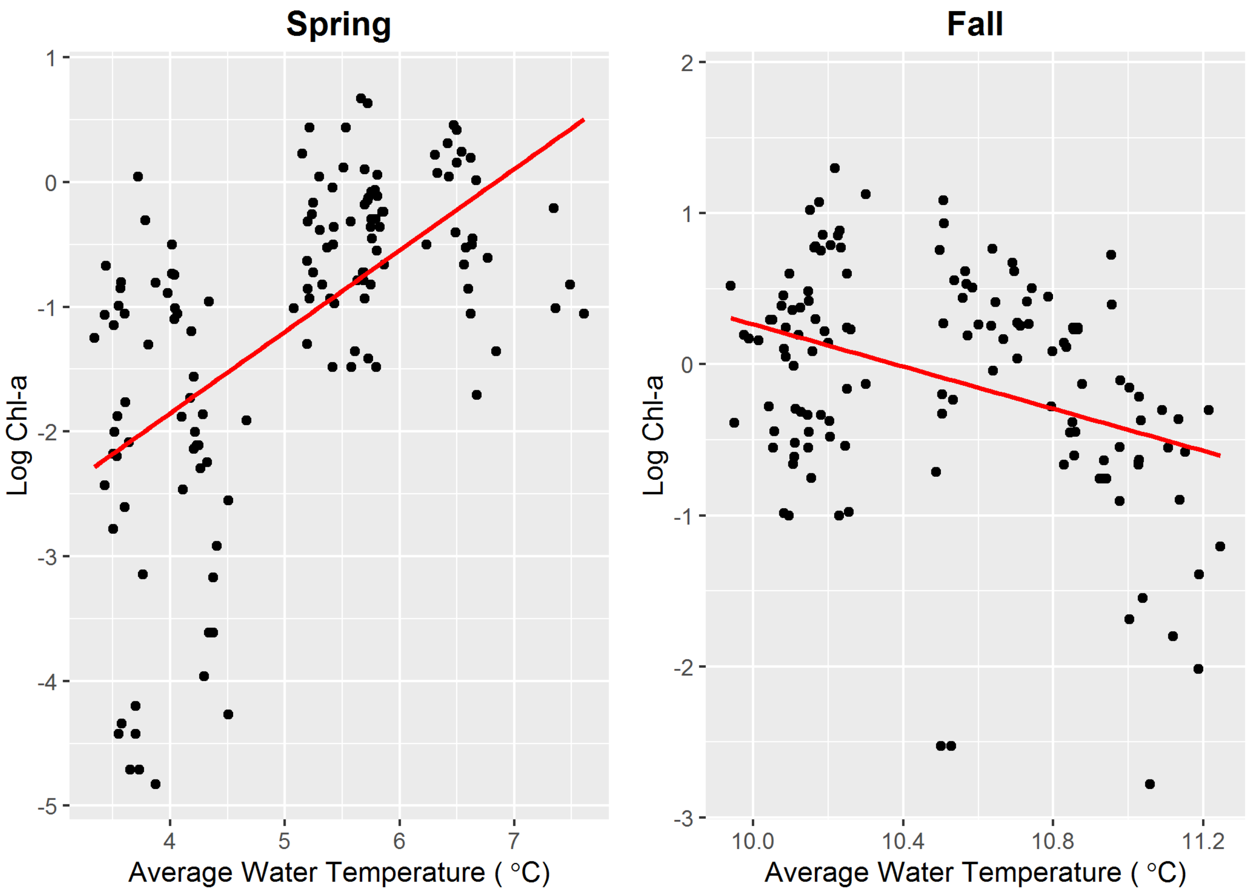


Figure 3-7: **Regression of log chl-a and average water temperatures grouped by season for T1-T4 samplers. Spring had a positive slope (m=0.65, p<0.001, R^2=0.33) and Fall had a negative slope (m=-0.70, p<0.001, R^2=0.12)**

3.3 Benthic Invertebrates

3.3.1 Yearly Comparisons of Benthic Invertebrate Sampling

Relative biomass and relative abundance of benthic invertebrates varied between years at the lowest taxonomic levels of identification (family to genus). Generally, members of *Hydra* sp., Chironomids, and small Tubificid worms were the most abundant, accounting for up to 75% of the total abundance in all years and seasons studied. Although not as numerically abundant, percent EPT measured as relative abundance was consistent across years. However, percent EPT measured as relative biomass increased each year. In other words, the size of EPT increased in recent years, although they had the same percent contribution to the community (Appendix B). These trends were consistently observed in both spring and fall data. In most samples, 10 species made up over 90% of the total abundance or biomass at any sampling location.

Like periphyton, benthic invertebrate abundance and biomass tended to be slightly greater in R3 than R4 during most years and seasons, with standard deviations within a given year/season consistently higher than the mean. Species richness also varied among years with the lowest values in fall months occurring in 2010, and highest in sampling periods of 2014 and 2016. Species richness also appeared to be slightly greater in R3 than R4 in all years and spring 2015 and 2016 had higher species richness than other spring sampling periods (Appendix B). In contrast, while some variability was observed in percent EPT, percent Chironomidae, Simpson's Index, and Hilsenhoff index, these metrics were much more consistent among years and seasons. Benthic invertebrates were usually more abundant in the fall than in spring, however effects of flow, season, or year were not apparent. Chironomidae were much more prevalent than EPT taxa, and accounted for 29-100% of the total abundance in the spring or fall at any site. EPT taxa were most prevalent in 2013-2014, when they accounted for 2-5% of the total abundance in the fall and spring. Greater abundance of EPT taxa was associated with increased submergence of substrates within varial zones. Although the Jordan River was not sampled in 2016, it is likely an important source of invertebrates for areas within Reach 3 and may partially explain the increased diversity observed in R3 sites, similar to the results of Kennedy et al. (2016).

Abundance, biomass, species richness, and percent Chironomidae were highest from the mid channel to the lower varial zone (T1-T3) and declined with decreasing depth and increased exposure in the mid to upper varial zone (T4-T7). Contrary to these trends, Simpson’s indices were relatively consistent across all portions of the channel, and these indices are less prone to variations in abundance than more direct measures such as biomass.

3.3.2 Benthic Invertebrate Community Groupings

Analyses for community groupings for benthics were not analyzed in 2016. Schleppe and Larratt (2016) found that annual differences and pre- and post-implementation of minimum flows explained some community variation. However, it was not possible to separate natural annual variability from differences in operation.

3.3.3 Benthic Invertebrate Production Models

Previous years of this study have used benthic production models to understand the underlying processes that may affect invertebrate production. Similar to the periphyton data, invertebrate production (abundance, biomass, EPT+D) in Spring and Fall increased with increasing daytime submergence. Although submergence was a top predictor for most abundance and biomass for some models other predictors had equal importance. For example, water temperature had an RVI of 1 for both spring and fall abundance models. Daytime submergence was not an important predictor for the fall biomass model, substrate score was the top predictor.

This year, only invertebrate abundance and biomass models were run for the purpose of determining influential predictors independent of submergence, since the importance of substrate submergence is well-established for the MCR. Substrate score was the top predictor of fall and spring biomass, and spring abundance (Figures 3-8 and 3-9). However, regression analysis indicated substrate scored explained a limited amount of variation in biomass and abundance ($R^2<0.10$), most likely because there are multiple confounding factors that make determine the actual effect size very challenging. Water temperature was the top predictor for fall abundance and explained some variation in regression analysis ($R^2=0.24$, $p<0.001$).

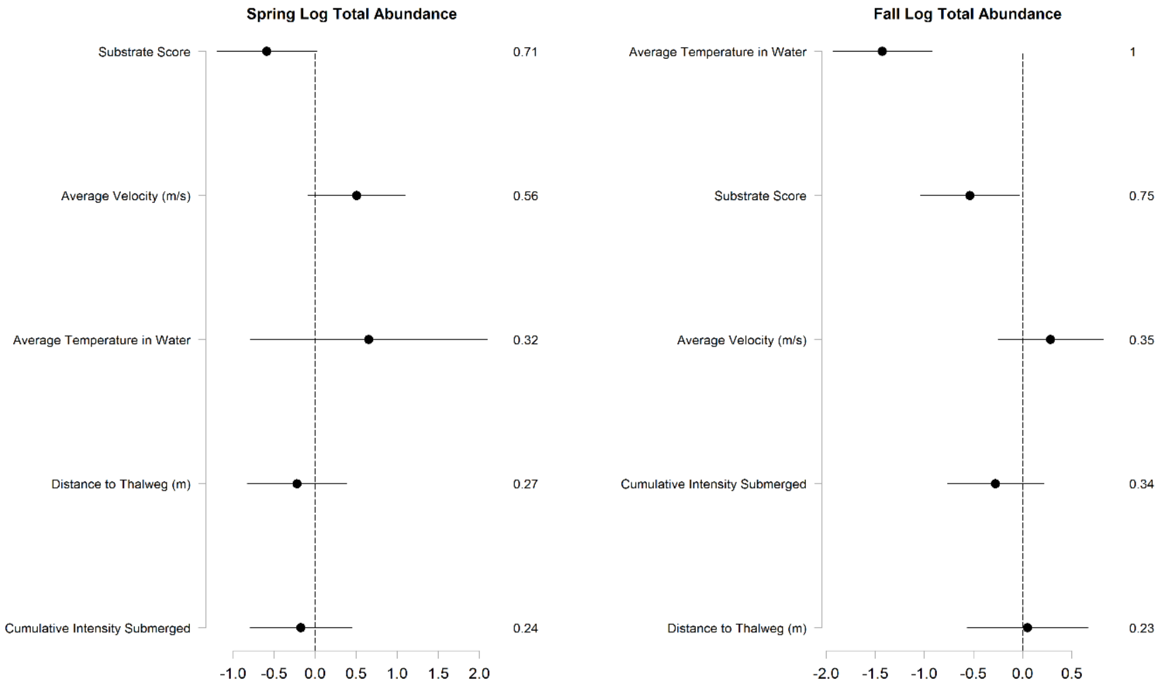


Figure 3-8: Model averaged parameter coefficients and 95% confidence limits from model averaged linear mixed effects models for abundance of samplers T1-T4 with total submergence time as a random effect. Each plot represents the probability of a given predictor, described on the left side of the plot, to be in the best AIC model (this probability is described by the RVI value on the right side of the plot). The predictors are also sorted based on this probability. Predictors have been standardized to allow direct comparison of coefficients (x-axis). The corresponding coefficient and its 95% confidence interval are represented on the plot. Those variables with 95% confidence intervals overlapping zero are considered of low significance as the direction of their effects are inconsistent among models.

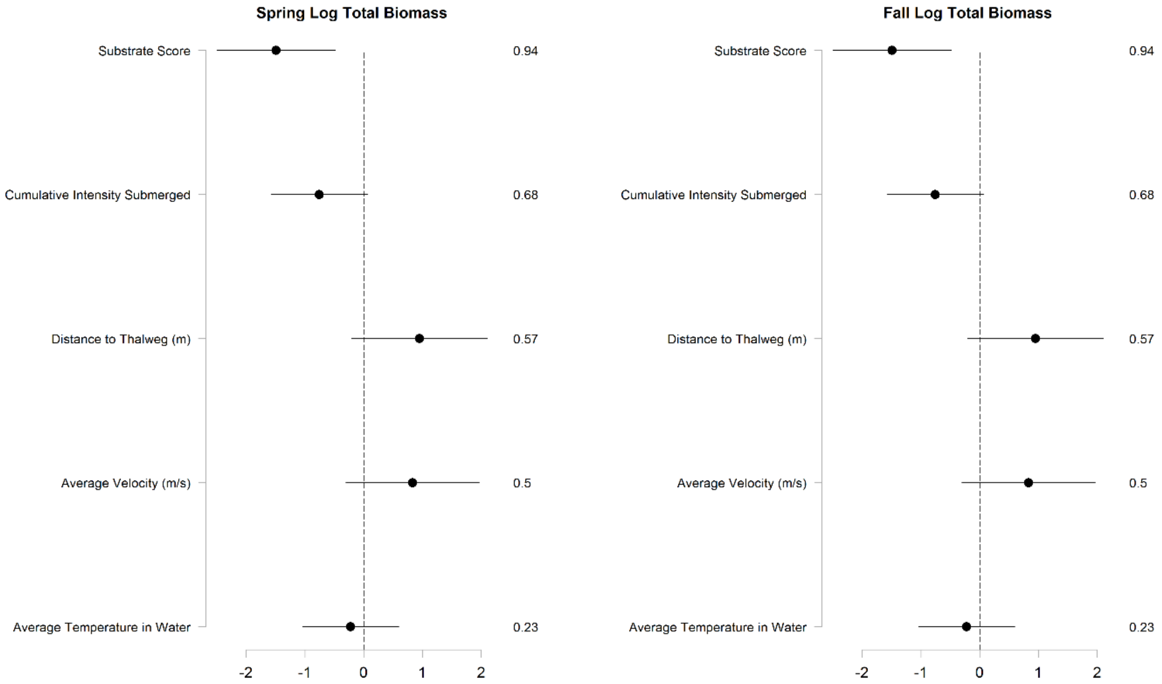


Figure 3-9: **Model averaged parameter coefficients and 95% confidence limits from model averaged linear mixed effects models abundance of samplers T1-T4 with total submergence time as a random effect. Each plot represents the probability of a given predictor, described on the left side of the plot, to be in the best AIC model (this probability is described by the RVI value on the right side of the plot). The predictors are also sorted based on this probability. Predictors have been standardized to allow direct comparison of coefficients (x-axis). The corresponding coefficient and its 95% confidence interval are represented on the plot. Those variables with 95% confidence intervals overlapping zero are considered of low significance as the direction of their effects are inconsistent among models.**

4.0 DISCUSSION

Like in all regulated rivers, periphyton and benthic invertebrate components of the MCR benthic communities are sensitive to changes in habitat conditions, and are good indicators of hydrologic disturbance (Biggs and Close 1989; Blinn et al. 1995). A long-term monitoring program of MCR periphyton and benthic invertebrates is on-going in the MCR to determine the effects of minimum flows and REV 5 flows. The main objective of the 142 m^3/s minimum flow strategy is to enhance the productivity and diversity of benthic communities in the MCR by increasing the permanently wetted area by an estimated 32–37% (Golder 2012). This discussion summarizes the findings from the 2007 to 2016 field surveys and subsequent analyses.

This study seeks to answer the Management Questions for MCR. They are:

> Q.1. What is the composition, distribution, abundance and biomass of periphyton and benthic invertebrates in the section of MCR subjected to the influence of minimum flows?
>
> Q.2. What is the effect of implementing minimum flows on the area of productive benthic habitat?
>
> Q.3. What is the effect of implementing minimum flows on the accrual rate of periphyton biomass in the MCR? Is there a long-term trend in accrual?
>
> Q.4. What is the effect of implementing minimum flows on the total abundance, diversity and biomass of benthic organisms in the section of the MCR subjected to the influence of minimum flows? Is there a long-term trend in benthic productivity?
>
> Q.5. If changes in the benthic community associated with minimum flow releases are detected, what effect can be inferred on juvenile or adult life stages of fishes?

These five Management Questions on the effects of minimum flows and REV 5 flows on MCR productivity are addressed in the following discussion sections.

4.1 Q.1. What is the composition, distribution, abundance and biomass of periphyton and benthic invertebrates in the section of MCR subjected to the influence of minimum flows?

The typical daily pattern of flow in the MCR consists of high flows during the day and low flows at night, corresponding with peak power production and usage in BC. Within this general pattern, flows are highly variable on a day-to-day basis. Freshet flows and storm events augment regulated flows and can cause periods with unusually high flows such as the freshet in 2012. Extreme events (flows in excess of 1800 m^3/s, or minimum flows of 142 m^3/s that extend beyond 48 hours) occur regularly and can result in large-scale die-off of benthic communities. Based on the research conducted to date, we conclude that extreme events, coupled with routine BC Hydro operations, ultimately determine the benthic community structure and area of productive habitat within MCR.

Based on our data to date, minimum flows did not affect periphyton accrual rates in the permanently wetted areas but flows did affect accrual in the varial zones. Similarly, the area permanently wetted by minimum flows supported the most productive and diverse benthic invertebrate communities. None the less, increasing EPT taxa were associated with increased substrate submergence within the varial zones and at times, frequently wetted substrates were as productive as those that were permanently wetted. These findings are discussed in detail in the following sections.

4.1.1 Comparison of MCR to other Large Rivers

Most of the artificial substrate periphyton data collected to date indicates that regularly wetted MCR substrates are moderately productive compared to similar substrates in other rivers of its size. However, the open-celled Styrofoam used in these trials may exaggerate production from 20% (Perrin et al. 2004) to as much as 400% (median = 200%) based on our preliminary natural substrate samples from the upper varial zone (Schleppe et al. 2013). If the artificial sampler data are corrected by the median potential inflation of periphyton production, the corrected results suggest that MCR production is consistent with an oligotrophic or stressed river system (Table 4-1). Furthermore, the natural substrate samples had far higher proportions of cyanobacteria, particularly in the sand from the cobble interstices in Reach 4. The natural cobble samples also had higher proportions of the slower-growing filamentous green algae than the comparable artificial substrate samplers. Other researchers have found a similar under-representation of these algae groups on artificial substrates (Cattaneo and Amireault 1992). An oligotrophic or stressed river is expected to have <20 – 40 species richness (Table 4-1), whereas MCR had 5 - 52 species per sample. The relatively high species richness on inundated substrates may be a result of supplemental taxa imported with flows released from Revelstoke Reservoir. In summary, MCR production is probably low compared to other large unregulated rivers, particularly in regularly dewatered areas, where even the open-celled substrate samples show the low benthic production expected of a stressed river system.

Table 4-1: Summary of average MCR periphyton metrics from spring and fall 2010 – 2016 deployments, with comparison to oligotrophic, typical, and productive large rivers

Metric	Oligotrophic or stressed	Typical large rivers	Eutrophic or productive	MCR Seasonal Averages -50-day deployment (values bolded in bracket = 6 month samples)
Number of taxa (live & dead)	<20 – 40	25 – 60	Variable	5 - 52 **(39-50)**
Chlorophyll-a ug/cm^2	<2	2 – 5	>5 – 10 (30+)	0.41 – 1.04 **(0.59-2.0)**
Algae density cells/cm^2	<0.2 x10^6	1 - 4 x10^6	>1 x10^7	0.35 – 0.56 x10^6 **(0.9 – 13.1x10^6)**
Algae biovolume cm^3/m^2	<0.5	0.5 – 5	20 - 80	1.54 – 3.12 **(0.6 - 5.9)**
Diatom density frustules/cm^2	<0.15 x10^6	1 - 2 x10^6	>20 x10^6	0.32 – 0.51 x10^6 **(0.2-1.0 x10^6)**
Biomass –AFDW mg/cm^2	<0.5	0.5 – 2	>3	0.56 – 0.80 **(0.35-3.5)**
Biomass –dry wt mg/cm^2	<1	1 – 5	>10	26 **(6-99)**
Organic matter (% of dry wt)		4 – 7		3.9 – 6.1 **(2 - 7)**
Bacteria count, HTPC CFU/cm^2	<4 -10 x10^6	0.4 – 50 ×10^6	>50×10^6 – >10^{10}	0.2 – 5 x10^6
Fungal count CFU/cm^2	<50	50 – 200	>200	<250 – 6000
Accrual chl-a ug/cm^2/d	<0.1	0.1 – 0.6	>0.6	0.062 - 1.6 shallow; 0.89 – 2.0 deep

Comparison data obtained from Flinders and Hartz 2009; Biggs 1996; Peterson and Porter 2002; Freese et al. 2006; Durr and Thomason 2009; Romani 2010; Biggs and Close 1998.

Throughout the 2007 – 2016 study period, periphyton communities in MCR occurred in three large zones created by the operating regime over the preceding 30 to 70 days as it interacted with the physical habitat. These zones are: 1) substrates that are permanently submerged, 2) substrates in the lower varial zone, and 3) substrates in the upper varial zone. Despite the establishment of these three distinct benthic communities with variable dominant species, both periphyton and invertebrate communities were relatively stable when viewed at the family taxonomic level. These zones are discussed in detail in the following sections.

4.1.2 Permanently Submerged Areas

Permanently submerged areas were sampled at T1 (thalweg, mid channel) and T2 (channel edge at minimum flow) transect locations. Similar to most large rivers, MCR periphyton production in permanently wetted areas was negatively correlated with velocity and substrate embeddedness, and positively correlated with increasing light intensity and substrate size (Schleppe and Larratt 2016). Peak production occurred near the edge of the permanently wetted channel at T2 locations where shear stress was less, light penetration was greater, substrates were stable, and the effects of scour and saltation were not as pronounced as they were near the thalweg at T1 locations. Furthermore, time series data suggests that extreme high flow events that generated velocities in excess of 2 m/s coincided with thinning of the periphyton community in the T1 thalweg zones. These high velocities were theoretically sufficient to cause shearing of filamentous algae (Flinders and Hartz 2009), and to mobilize sand particles that cause further periphyton thinning through abrasion (Gregory et al. 1991; Goudie 2006; Luce et al. 2010). Overall, the permanently wetted zone productivity is within the range expected for other large rivers that are oligotrophic or stressed (Table 4-1).

4.1.3 Lower Varial Zone (mid-channel)

The second habitat condition that exists in the mid-channel area of MCR was much more variable and dynamic. It occurred above the boundary of the permanently wetted habitat in what is termed the lower varial zone, typified by T3 and T4 sampler locations. The fluctuations between submergence and exposure usually occurred at night and resulted in less desiccation than the equivalent exposure period in daylight hours (Self and Larratt, 2013; Vincent 2007). Further, these areas were submerged during moderate flow events (between 600 to 800 m^3/s), and they occurred more frequently than higher flow events. The heterotrophic components of the biofilm can continue growing in damp substrates in the dark, while the photosynthetic components cannot, resulting in greater heterotrophic contributions to overall production in this zone. The invertebrate community underwent periods of growth and decline depending on how the recent operating regime coincided with their life cycles. The variable hydrologic conditions of MCR tended to select for rapid colonizers and rapid reproducers.

The lower varial zone is productive and an important component of the overall productivity of MCR. However, the time series chl-a accrual rate at T3 positions was significantly slower than T1 positions during most seasons and years (Schleppe and Larratt 2016). In the LCR, the total time spent in variable submergence, prior to a more permanent submergence has also been shown to increase the time required to achieve peak biomass (Olson-Russello et al. 2015). Statistical modelling provides further support of this because factors such as daytime submergence and substrate exposure were all-important predictors of both periphyton and benthic invertebrate community development in the lower varial zone (Schleppe and Larratt 2016). Research below the hydropeaking Glen Canyon Dam in Colorado show similar results, where abundance and diversity of EPT were reduced as a result of daily, post-dusk, flow reductions immediately following egg deposition of substrate-dependant species (Kennedy et al. 2016).

4.1.4 Upper Varial Zone

The frequently de-watered upper varial zone was typified by T5 and T6 locations, and included some samples from T7 located in the floodplain. It was less productive than the lower varial zone because these substrates experience regular daytime fluctuations between submergence and exposure. These conditions resulted in a benthic community that underwent brief periods of growth and frequent collapses determined by the timing and duration of exposures and how they intersected benthic invertebrate life cycles. Although the upper varial zone periphyton community had a similar structure to deeper zones, reduced species diversity and accrual rates indicated stress, particularly to the photosynthetic microflora. Periphyton production commenced and rapid growth occurred after the substrates were wetted during daylight hours for periods in excess of 9 hours (Schleppe et al. 2012). Periphyton production halted when the substrates were dewatered during the day because normal cell processes could not proceed and desiccation stress reduced survival in both invertebrates and periphyton. The upper varial zone became more heterotrophic as the frequency or duration of drying events increased. This finding is also supported by modelling data for the periphyton autotrophic index in previous years that identified the frequency of 12-hour submergence events and total incubation time in the water and light, as important factors (Schleppe et al. 2013).

The floodplain zone commenced beyond the upper varial zone and it was wetted only in very high flows and was not a significant contributor to MCR productivity. It did not produce true aquatic species, but rather it supported a riparian microflora community including aerial cyanobacteria, fungi, and heterotrophic bacteria. The floodplain did donate terrestrial detritus during flows exceeding 1700 m^3/s, but these floodplain benefits occurred infrequently and were mostly associated with allochthonous nutrient input rather than production originating from benthic community development. Infrequent floodplain contributions are typical of larger rivers (Doi 2009).

4.1.5 Varial Zone Boundary Conditions

The boundaries between the productivity zones in MCR were dynamic, and depended upon the average flow regime during the preceding 30-70 days, based on MCR and LCR time series data (Olson-Russello et al. 2015). Growth within these zones occurred rapidly during a 6-month period, when appropriate conditions for benthic community development occurred. The width of the productive lower varial zone expanded during stable flows in the 400 to 800 m^3/s range.

4.1.6 Benthic Community Determinants and Composition

Statistical modelling results previously identified submergence as the top predictor of benthic production and diversity (Schleppe and Larratt 2016). In previous years, benthic invertebrate diversity models explained limited variation. This could be a result of diversity being fairly uniform among sites and transects. The effect of hydropeaking on diversity has not been well studied. However, there is one study that found diversity was less variable below a dam (Hasting, 2014). Other physical parameters including substrate type and velocity were identified as key factors determining periphyton and invertebrate community establishment (Schleppe and Larratt 2016). These physical parameters were more important determinants of community in permanently submerged habitat areas (Schleppe et al. 2014). Other physical factors that may also be important to benthic abundance and diversity that have not been investigated include frequency and magnitude of flow events. During hydropeaking operations, complete dewatering of river-edge substrates used exclusively by some Ephemeroptera and Trichoptera egg-layers, can cause their extirpation (Kennedy et al. 2016). Large peaks in flow on other regulated rivers have been shown to decrease invertebrate species density, diversity and biomass (Robinson et al. 2004) and cause shear stresses sufficient to thin algal communities (Flinders and Hartz 2009). Overall, MCR benthic invertebrate productivity indicates that MCR has signs of stress when compared to other river systems of similar size (Table 4-2).

Table 4-2: Comparison of benthic invertebrate communities in different river systems.

River	Average Annual Discharge (m^3/s)	Mean # of Invertebrates (±SE)	Total # of Taxa	Diversity (Simpson's Index)	Most Abundant Taxa (percent abundance)
MCR (Revelstoke)	955	291(±582)	33	0.58	Orthocladius complex (28) Hydra sp. (24) Orthocladiinae (10) (9.4) Eukiefferiella sp. (6.6)
LCR (Castlegar)-Winter	1,997	4541(±6379)	43	0.7	Simulium spp. (29) Simuliidae (25) Orthocladius Complex (13) Orthocladiinae (9)
LCR (Castlegar)-Summer	1,997	6182(±6548)	51	0.78	Hydropsychidae (33) Hydropsyche (19) Tvetenia spp. (8) Simulium spp. (6)
LCR (Castlegar)- Fall	1,997	5278(±5391)	41	0.77	Hydropsyche (26) Tvetenia spp.(12) Tvetenia discoloripes group (9) Parachironomus (7)
Fraser River (Agassiz)	3,620	829 (±301)	55	0.84	Orthocladiinae (62.7) Baetis spp. (7.2) Ephemerella spp. (5.4)
Thompson River (Spence's Bridge)	781	2108 (±1040.8)	48	0.44	Orthocladiinae (62.7) Baetis spp. (7.2) Ephemerella spp. (5.4)
Cheakamus River	_	1252 (±1149)	6	_	Ephemeroptera Plecoptera Diptera w/o chironomids

Data sources include Plewes *et al.* 2017, Reece & Richardson 2000, Triton Environmental Consultants Ltd. 2008 and this report.

Like most large rivers, MCR periphyton communities were dominated by diatoms representing between 82 and 98% of the biovolume at all sample sites. Other taxa, such as filamentous green algae were more prevalent near the edge of permanently wetted areas (T2), and in the lower varial zone (T3/T4) where stable substrates were present. The small-celled flagellates, cyanobacteria, and colonial greens were numerous but rarely exceeded 1.5% of the biovolume in MCR samples. Finally, in upper varial zone areas, periphyton communities transitioned from producer to consumer organisms, as indicated by the Autotrophic Index at T5/T6 locations. AFDW (volatile solids) results have oscillated over the years and seasons indicating continual adjustments in the balance of producers and consumers, probably in response to habitat drivers, particularly flows.

Benthic invertebrate communities were also dominated by taxa that are more tolerant of disturbance, such as chironomids (Tonkin et al. 2009). These taxa are often over-represented in flow-managed rivers (Bunn and Arthington 2002). EPT taxa and chironomids appeared to be more abundant along the edge of minimum flow (T2) or in the lower varial zone (T3), as suggested by our modelling of permanently submerged habitats (Schleppe et al. 2014).

Although the major taxonomic group contributions of periphyton and benthic taxa remained the same, the dominant species identified in the three zones varied, due to a number of determining factors including: operations, weather conditions, physical habitat constraints and the interaction between life history strategies (Kennedy et al. 2016).

4.1.7 Effects of Flow Ramping

For many reasons, the rates of de-watering (ramping) influence the mode of periphyton and benthic invertebrate recovery and interact with the life history of different taxa. In large rivers, rapid water loss such as ramping down hydro releases restricts or prevents in-situ recovery by reproduction and causes benthic recovery to be driven by recolonization (Stanley et al. 2004; Kennedy et al. 2016). Periphyton originating from the Revelstoke Reservoir is therefore expected to be important to periphyton recovery while drift of invertebrates from tributaries is expected to be important to benthic invertebrate recovery in MCR, similar to other studies conducted on other regulated rivers (Kennedy et al. 2016).

4.1.8 Benthic Recovery from Dewatering

The ever-changing hydrologic patterns in the varial zone induced a benthic invertebrate community that was in a constant state of recovery following periods of exposure of >48 consecutive hours (Schleppe et al. 2012). Periphyton recovery was frequently faster than invertebrate recovery because bacteria and cyanobacteria form organic coatings that pre-condition dewatered substrates, allowing faster recolonization (Stockner 1991; Wetzel 2001, Robson 2000). Our desiccation/re-wetting experiments (2010) indicated that resumption of growth occurred faster for species capable of rapidly producing desiccation-resistant structures such as akinetes or extracellular mucilage. Even with these strategies, the rate of desiccation can exceed the rate at which these structures can be produced, particularly during daytime drying in warm or freezing weather (Stanley et al. 2004). Periphyton species that do not have strategies capable of allowing them to withstand repeated exposure would presumably become eliminated from the varial zones of MCR, resulting in the observed homogeneity of the periphyton community structure throughout the varial zone. Invertebrate recovery after a catastrophic event could take several weeks or more (if at all, may become extirpated) and was dependent upon the life-stage of the invertebrates at the time of the event (Kennedy et al. 2016). Species with specific riverside, substrate-dependent egg-laying strategies such as EPT species are at a greater risk to the effects of hydro-peaking than species that use a different strategy such as Dipterans (Kennedy et al. 2016). Such pressures on the invertebrate and periphyton communities are common to all large rivers, however, BC Hydro operations create a larger, and more dynamic varial zone in the MCR than would otherwise be expected, and these operations can have a subsequently greater effect on populations than those observed in a natural system.

The rates at which recovery occurs is also variable among organisms present in the benthic communities of MCR. Periphyton biofilm recovery is dependent on the reproduction rates of its constituent species. Biofilm bacteria are capable of division every 20-30 minutes and cyanobacteria every 6 – 24 hours. Five hours of saturating light per day can support a diatom division every 2-3 days in summer and every 4-6 days in winter (Capblanco and Decamps 1978; DeRuyter van Steveninick et al. 1992; Gosselain et al. 1994) As a result, bacteria can colonize natural and artificial surfaces within a few hours (Gerchakov et al. 1976; Fletcher, 1980; Dempsey, 1981), while diatoms and other microbes immigrate onto substrates within a day to several weeks (Cundell and Mitchell 1977; Colwell et al. 1980; Hoagland et al. 1993). Invertebrate life cycles also vary by species, with some laying eggs multiple times per season, whereas others may only emerge once during any given year and each taxa uses a different reproductive strategy that may further affect colonization rates (Kennedy et al. 2016). In summary, the effects of desiccation on either periphyton or invertebrates are function of species-specific desiccation tolerance, and how life history and reproductive strategies intersect with the timing and duration of dewatering.

4.1.9 Seasonal Growth Patterns

Benthic communities followed annual and seasonal patterns of growth. Periphyton production metrics measured in the spring were usually less than half of the fall deployments. We expect this is because night outages in the spring exposed both the upper and lower varial zone substrates to freezing temperatures, and because low water temperatures reduce enzymatic activity and slow growth even in the rapidly reproducing bacterial biofilm (Wetzel 2001). The MCR benthic community structure is stable but is still subject to seasonal variation.

4.2 Q.2. What is the effect of implementing minimum flows on the area of productive benthic habitat?

The intent of implementing minimum flows is to increase the spatial area of wetted habitat and subsequently improve benthic community function at these locations. Minimum flows will increase the area of productive habitat because they maintain a minimum area of wetted perimeter. Preliminary results from the HEC-RAS model showed an increase of 32 - 37% in the spatial area of wetted habitats in Reaches 4 and 3 with minimum flows when the ALR elevation was below 425 m (Golder 2012; K. Bray, BC Hydro, pers. comm. 2010). All MCR data indicate that productive benthic habitat was highly influenced by submergence parameters, including duration and timing of flow events. In fact, submergence (or metrics of it) appears to be the most important determinant of benthic communities in the MCR, most notably abundance, biomass, and food for fish.

The most productive areas tended to occur at T2 through T3/T4, and depended directly on submergence. Thus, the wetted edge from minimum flows to slightly above it in the varial zone is important and productive habitat. The position of productive varial zone habitats shifts depending upon the prevailing operating regime, while the area of productive habitat is dependent on river bed topography.

Within this productive zone, Reach 3 was more productive than Reach 4. There could be many factors influencing the higher productivity of Reach 3. Dependent on flows and backwatering Reach 3 has more potential to receive benthic invertebrates from upstream areas, the Jordan River and the ALR. In addition, Reach 3 may be less sensitive to hydropeaking because backwatering and tributaries can dampen the effect of dam operations.

In summary, operating regime must make an overall contribution to benthic community abundance and diversity in areas subjected to minimum flows, but other parameters such as duration of daytime submergence were also important. However, our data also suggest that when the elevation of the ALR was higher, the benefit of minimum flows on the spatial area of productivity was lessened by the effects of backwatering that can extend throughout Reach 3 and into Reach 4. The specific relationships between ALR elevation and the effects of minimum flow have not been fully investigated, but determination of the spatial area of habitat must consider the effects of ALR backwatering as well as minimum flows.

In the MCR, the total area of productive habitat in these three zones depends upon more than just minimum flows. The effectiveness of minimum flows at increasing the area of productive benthic habitat was difficult to determine given the highly variable flow regime, variable episodes of ALR backwatering and the timing of benthos life cycles and flow releases. Despite difficulties in determining the exact benefits of minimum flows to spatial area of productive habitats, we can conclude that minimum flow increased the spatial area of productive habitat because it provided a minimum wetted habitat area that is more productive than pre-minimum flows.

4.4 Q3. What is the effect of implementing minimum flows on the accrual rate of periphyton biomass in the MCR? Is there a long-term trend in accrual?

The 2007 through 2016 data demonstrate that the accrual rate of biomass was not significantly altered following the introduction of minimum flows, and this finding is explored below. However, it is important to acknowledge that minimum flows do safeguard the thalweg areas from desiccation.

Historically, BC Hydro avoided daytime dewatering prior to the establishment of 142 m^3/s minimum flows. After the initiation of this study, the REV 5 turbine also came online. Unfortunately, these events preclude clear before/after periods where we can study the benefits of minimum flows in isolation from other flow changes on the MCR. We therefore contrasted production in the regularly dewatered varial zones with production in the permanently wetted zones to address questions 1 and 3.

The benefits of minimum flows were most evident in the periphyton communities at T2 and T3 locations because these locations occur directly above or adjacent to the wetted edge at minimum flows. Peak production was most apparent at T2 locations because higher velocities at T1 thalweg locations had higher sheer stresses that reduced the periphyton community. However, productivity at T3 locations was similar to T2 locations under the current operating regime of nightly low flow periods with daytime high flows frequently exceeding 800 m^3/s. The lower varial zone (T3/T4) was an important productive area bounded by minimum flows and a mobile upper limit created by average daily submergence during the preceding 30 – 70 days. Unlike the permanently wetted zone, productivity in the lower varial zone was entirely dependent upon submergence caused by the recent operating regime. Extended minimum flow events in excess of one week would cause extensive periphyton losses in the lower varial zone and required a recovery period of several weeks with consistent submergence by flows greater than the 142 m^3/s minimum. Productivity of the frequently dewatered upper varial zone (T5/T6) was consistently less than half of the high productivity zones.

The benefits of a permanently wetted channel area were also affected by prevailing conditions. For example, ALR backwatering, rain or high humidity, and cool air temperatures ranging from 5-10 ºC were all beneficial to periphyton viability on exposed substrates (Stanley et al. 2004). Conversely, dry weather with air temperatures below 0 ^{o}C (spring) or exceeding 15 ºC to 20 ºC (fall) reduced periphyton viability on exposed substrates.

The effects of season and peak flows were also important when considering the benefits of minimum flows. Minimum flows were particularly advantageous during the fall when rates of periphyton recovery were highest, while the benefits were less evident in the spring with slow periphyton recovery rates and high peak flows. Peak flows associated with REV 5 may reduce the benefits of minimum flows if they result in sheer stresses sufficient to thin established periphyton communities in the lower varial zones and thalweg.

Establishment and accrual of periphyton communities in MCR occurred at slow rates similar to other large oligotrophic rivers (Table 4-1). The combined time series data collected across year, season and river depth suggest that accrual on MCR continued linearly to the end of the 46-51 day deployment period (Schleppe and Larratt 2016). Therefore, incubation periods of greater than 46 days are required to achieve peak periphyton biomass in MCR and may require more than 6 months for full development (Wu et al. 2009; Biggs 1989). Further, the daily, weekly, and annual patterns of operation, ALR backwatering and seasonal growth cycles can all affect accrual. Although improved periphyton production stemming from the implementation of minimum flows is already occurring, it is difficult to separate production benefits attributable to minimum flows from the effects of flows resulting from the recent and current operating regimes.

Channel areas covered by minimum flows are not the only areas of MCR that can maintain and act as sources of species to aid recovery. The role of shallows such as backwaters and back-eddies as a source of recruitment and maintenance of some planktonic and periphytic species cannot be doubted (Reynolds and Descy 1996; Butcher 1992). These areas are more abundant in Reach 3 than in Reach 4, and may enable Reach 3 periphyton to recover faster after catastrophic flow events. Many of these areas may also act as impoundments to fish, resulting in mortalities, inferring that trade-offs are probable and should be considered in any flow management decisions.

Patterns of periphyton accrual and recovery in MCR are further complicated by drifting limnoplankton exported by flows from Revelstoke Reservoir. Phytoplankton that becomes trapped in the periphyton matrix (Middleton 2010) can subsidize the population for many kilometers below a dam (Doi et al. 2008; Larratt et al. 2013). In the MCR, this subsidy is important to standing crop and accrual rates. Contributions of phytoplankton to MCR periphyton may also occur from the ALR to Reach 3 during backwatering, but the results of plankton hauls suggested the ALR phytoplankton was impoverished, likely by turbidity (Schleppe et al. 2012). Species contributed by Revelstoke Reservoir appeared to account for a significant proportion of the MCR periphyton, particularly in the fall and at R4. This means phytoplankton events occurring in Revelstoke Reservoir and the timing and depth of reservoir releases exerted an influence on MCR periphyton accrual and recovery rates, as well as community structure.

In summary, these data suggest that MCR periphyton communities may be more dependent upon the overall operating regime (daily, monthly, and annual patterns of flow release, ALR backwatering, etc.) than the specific effects of minimum flow because the normal operating regime determined the wetted edge of the channel during daytime periods, an important explanatory variable in our modelling data.

4.5 Q.4. What is the effect of implementing minimum flows on the total abundance, diversity and biomass of benthic organisms in the section of the MCR subjected to the influence of minimum flows? Is there a long-term trend in benthic productivity?

The responses of benthic invertebrates to minimum flows were very similar to periphyton. Productive habitat included permanently submerged habitat and areas in the lower varial zone adjacent to the edge wetted by minimum flows. Since invertebrate communities were directly dependent upon submergence and physical conditions of MCR for survival, the same explanation can be used to describe where and when invertebrate communities establish.

Like periphyton, the area of varial zone that is productive invertebrate habitat is bounded by minimum flows and its upper limit determined by average daily submergence. However, MCR invertebrate models explained less variation than periphyton models, reducing our ability to understand specific trends (Schleppe and Larratt 2016). This may be due to the following factors that could not be accounted for in our analyses: patchy distribution of invertebrate communities in space and time; potential sampling biases associated with use of rock baskets retrieved from depths of 5 m at high velocities; a low sample size to habitat area ratio when compared to periphyton; the occurrence of microhabitat factors and finally, daily hydropeaking timing on species specific life history and reproductive strategies.

Further, invertebrates are more sensitive to desiccation than periphyton (Schleppe et al. 2012; Golder 2012) and were probably more heavily influenced by daytime exposure because of this, and some species may also have become extirpated due to timing of hydropeaking (Kennedy et al. 2016). The spatial area of the lower varial zone available to invertebrates was probably smaller than that available to periphyton. For these reasons, explicitly determining the effectiveness of minimum flows on improving benthic conditions for invertebrates is difficult, but it is known that minimum flows benefited the invertebrate community and that dewatering of habitat had a direct negative effect on benthic abundance, biomass, and community composition. The permanently wetted area can function as a source of benthic organisms to re-colonize previously exposed habitat areas after extensive low flow events lasting longer than 24 hours.

4.6 Q5. If changes in the benthic community associated with minimum flow releases are detected, what effect can be inferred on juvenile or adult life stages of fishes?

The area of productive MCR habitat is directly correlated with submergence. Our data from previous years suggest that the abundance, biomass, and overall availability of fish food (using the Fish Food Index in 2013 or the EPT+Diptera responses in 2014-2016) were directly dependent upon submergence. Fish food varies depending upon the fish species considered, and generally the EPT taxa and chironomids (Dipterans) are the most important forage for fish. It is for this reason that we have considered both a fish food index and created an EPT+D metric to consider how fish food availability may be affected for different fish foraging groups.

Generally, an increase in wetted productive habitat should cause a subsequent increase in fish food availability, provided there are sufficient populations for recolonization to occur. The overall fish food availability was greatest at T1 through T3 locations and coincided with the areas identified as being the most productive benthic habitats in our models. For these reasons, we conclude minimum flows increased fish food availability, but other key influences on productivity such as frequency and duration of daytime submergence events, and timing of insect life history events (e.g., egg-laying) must also be considered. Substrates submerged for 450 – 500 hours (10 – 11 hours/day during the sampling duration) during daytime hours had the greatest availability of preferred fish food items. Similarly, EPT+D biomass was greatest in areas submerged for at least 500 – 1000 hours over >46 days.

EPT taxa were most commonly observed in areas of boulder or cobble substrate, whereas overall benthic abundance was greatest at sites with finer substrates. Areas of larger substrates should provide more food for the fish that forage on invertebrates. The interaction between minimum flow and substrate type is important. Further analysis is required to understand all the dynamics of fish species, and fish food interactions and how they relate to the implementation of minimum flows and also timing of hydropeaking events. This will be considered in future years by considering the abundance and biomass of invertebrates in a spatial context over the study area.

Since the density of invertebrates is directly related to submergence, productivity, and ultimately food for fish, it is hoped that we can understand the specific effects of minimum flow on invertebrate abundance and biomass, and subsequently infer the effects on food for fish.

5.0 RECOMMENDATIONS

5.1 Spatial Model

Sufficient data have been collected to permit the development of a spatial productivity model. Spatial modelling of MCR would help to inform the first management hypothesis because it provides a method to determine the spatial area of productive benthic habitat (i.e. wetted area).

The following are recommendations intended to further the development of the proposed spatial model, now underway in 2017.

The possibility of using a spatial model of productivity to determine the spatial area of habitat covered by minimum flows was introduced in 2015. The theoretical basis of this model that was developed for the LCR was presented in Schleppe and Larratt (2016). This year the goal was to explore how to best develop and adapt this model for the MCR. As part of this work, two different river models were obtained from BCH and EcoFish and these models were critically evaluated (Table 4-3 and Appendix D). Theoretical periphyton growth curves that were specific to the MCR were developed. The potential for integrating secondary functions into the spatial model that consider other factors (i.e. substrate, light intensity, velocity, and water temperature) was also explored.

The Telemac 2D model will be used instead of the HEC-RAS 1D model because Telemac 2D performs better with complex river geometries because it uses a mesh that covers the whole area of the river, whereas HEC-RAS 1D uses cross sections (Lim, 2011; Gharbi et al. 2016). The use of cross sections means water elevations need to be interpolated between cross sections. The Telemac 2D model will be used as part of the spatial productivity model for the MCR because it is expected the mesh will improve the accuracy of predicted water levels, especially in the area closest to REV. Telemac 2D also provides valuable outputs such as velocity at each mesh cell which could be useful in future model tuning.

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Table 4-3: Comparison of river hydraulic models Telemac 2D and HEC-RAS 1D

Telemac 2D	HEC-RAS 1D
complex	simple
more parameters	less parameters
performs well in floodplains and river beds	performs well in river beds
performs better for complex river geometries and near dams	
assumes variable velocity	assumes uniform velocity

The spatial productivity model will result in daily productivity estimates for chl-a, invertebrate abundance, and invertebrate biomass during the spring and fall. These estimates will allow comparisons of productivity pre- and post-implementation of minimum flows. The model will use existing data for model validation and existing growth and death curves. Productivity data for R3 and R4 collected from 2007-2016 will be used to validate the spatial productivity model for MCR (Appendix D). This year, periphyton growth curves were derived for fall and spring using T1 accrual data from MCR and modelled peak biomass was based on samplers that were incubated for 6 months. T1 locations were chosen because they best represent growth at permanently submerged sites and were not influenced by desiccation mortality like varial zone areas. Similar to the LCR, periphyton growth rates were higher in the fall compared to the spring (Schleppe et al. 2015). The use of death curves and the differences of MCR and LCR are discussed in Appendix D.

Mixed effects models and linear regression was used to identify important factors that could potentially be used as secondary functions in the spatial productivity model. An attempt was made to isolate the effect of submergence on productivity by using total submergence time as a random effect. However, there are probably some relationships between predictors and submergence time. For example, average water temperature is affected by submergence because water temperature is only included if the sampler is submerged. Periphyton production models suggested water temperature has an association with chl-a in Spring and Fall. Although there are other confounding variables such as annual variability and submergence, the spring regression suggests that warmer water temperatures during the deployment period result in higher periphyton production (chl-a). Interestingly, the fall invertebrate abundance and chl-a regressions suggest cooler water temperatures result in higher productivity. Extreme years could be magnifying this relationship between productivity and water temperature. For example, fall 2012 had the highest water temperatures and the lowest productivity. Other important variables such as substrate score do not explain enough variation in benthic production to be considered as secondary functions. Next year water temperature will be considered as a secondary function. However, given the limitations discussed above, the use of the secondary function will be validated before it is integrated into the spatial model.

The proposed spatial productivity model may be limited in predictive accuracies. However, we expect the predicted benthic production will be useful for comparative purposes to consider the effects of submergence because of the strong relationship between productive habitat area and the period of submergence. We expect the model to pick up key differences in benthic invertebrate production pre- and post-implementation of minimum flows. The model will also allow the wetted habitat area to be estimated at any hour, or following specific operational patterns. The predictive capability of this model is also dependent upon the accuracy of wetted history prediction. Factors such as the elevation of the downstream Arrow Reservoir are also important considerations that will be considered and incorporated into the spatial model if possible. It may be possible to consider the downstream reservoir elevation by assuming that any river habitats below the reservoir elevation are submerged. Using an assumption like this may underrepresent actual productive habitat due to backwater effects that are not accounted for, but will help improve the predictive capability of the model.

Table 5-1: Recommended Project Analyses and Actions for 2016 to 2018

General Category of Recommendation CLBMON 15b Reports	Specifics to Consider
Growth and Death Functions	Growth and Death functions have been determined. These will be reconsidered during model spatial model validation.
River Model	A river elevation model has been selected. Determine the appropriate cell or patch sizes (resolution) to run the spatial model at. Once cell size is determined, wetted habitat outputs will be derived. R3 and R4 will be considered and if possible, secondary factors identified will be included in model predictions. The study period will be the time scale considered.
Spatial Productivity Model Development	The selected growth curves are considered representative of MCR conditions. Some secondary functions were identified in this report and will likely be included in the spatial model. The spatial model can only be validated for spring and fall, but theoretical curves for time periods without data could be used to better understand how patterns in flow affect the benthic community. Consider other important parameters that could be added (e.g., life history traits such as insect egg-laying strategy and timing of hydropeaking maxima and minima)
Spatial Productivity Model Results Analysis	Key elements that will be investigated include the areas of productive habitat pre- and post-minimum flows and consideration of large events over the duration of the study period.

5.2 MCR Productivity with implications for Operations

We hope to develop the benefits of the MCR research into tools that BCH can utilize to understand the implications of operations upon MCR productivity. We have attempted to define the length of time desiccation is tolerated under a range of weather conditions and will continue to refine this.

The following questions have been raised by the 2017 research:

1. Since Revelstoke Reservoir donations of phytoplankton are more important for periphyton production in the fall, if Fall periphyton productivity can be linked to food for fish and ultimately to fish biomass/distribution, this could have implications for operations. We propose to attempt to regress periphyton metrics with food for fish metrics in the 2017 report.

2. MCR periphyton communities may be more dependent upon the overall operating regime than the specific effects of minimum flow because the normal operating regime determined the wetted edge of the channel during daytime periods, a key explanatory variable in our modelling data. Further investigation of this effect together with spatial modelling may provide BCH with a tool to help manage flows to best manage MCR productivity. This is a goal of the spatial modelling project for MCR that is currently underway.

3. Larger substrates may benefit the productivity of benthic invertebrates (EPT) that are preferred by fish. The interaction between minimum flow and substrate type is important. This influence will be investigated further using the Spring 2017 data.

4. The dynamics of fish species and fish food organisms and how they relate to minimum flows and the timing of hydropeaking events will be investigated further under CLBMON16.

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APPENDIX A DATA TABLES AND FIGURES

Light and Temperature Figures

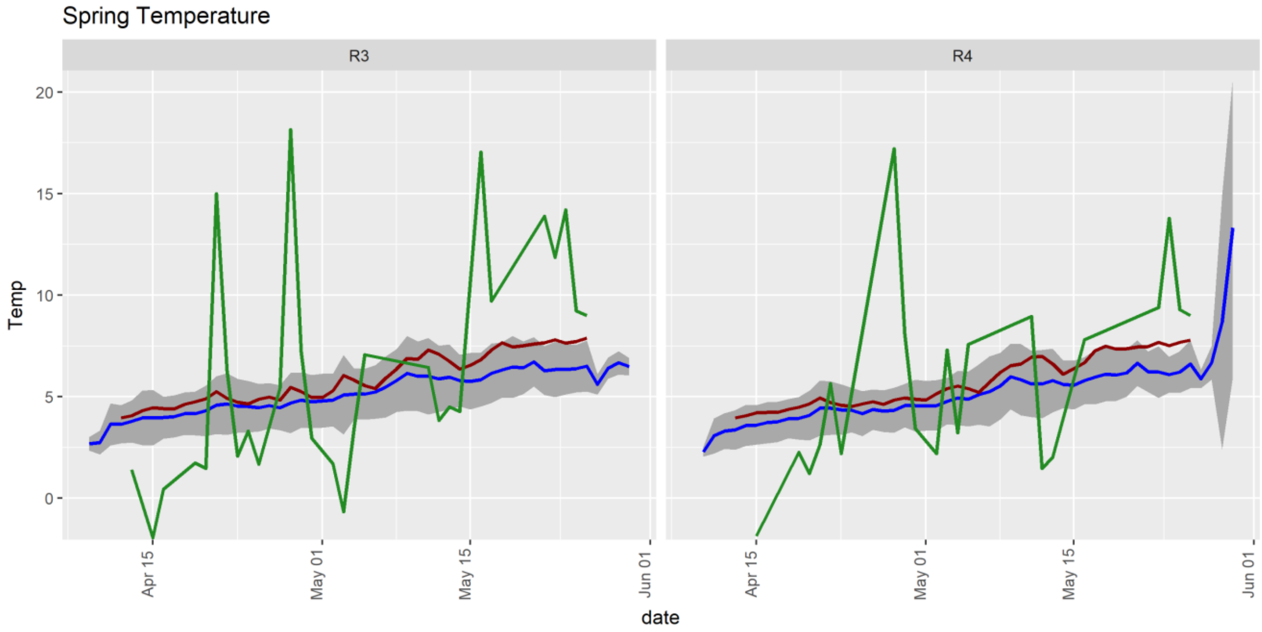

Figure A-1: The pattern of daily water temperature in MCR by reach during the spring study period. The blue line represents the mean from 2011 to 2016 (Spring) and red represents the mean water temperature in 2016 from all submerged samplers. The green line represents the average temperature of exposed sites in Spring 2016. Data were pooled for spring periods between 2011 – 2016 (±SD in grey).

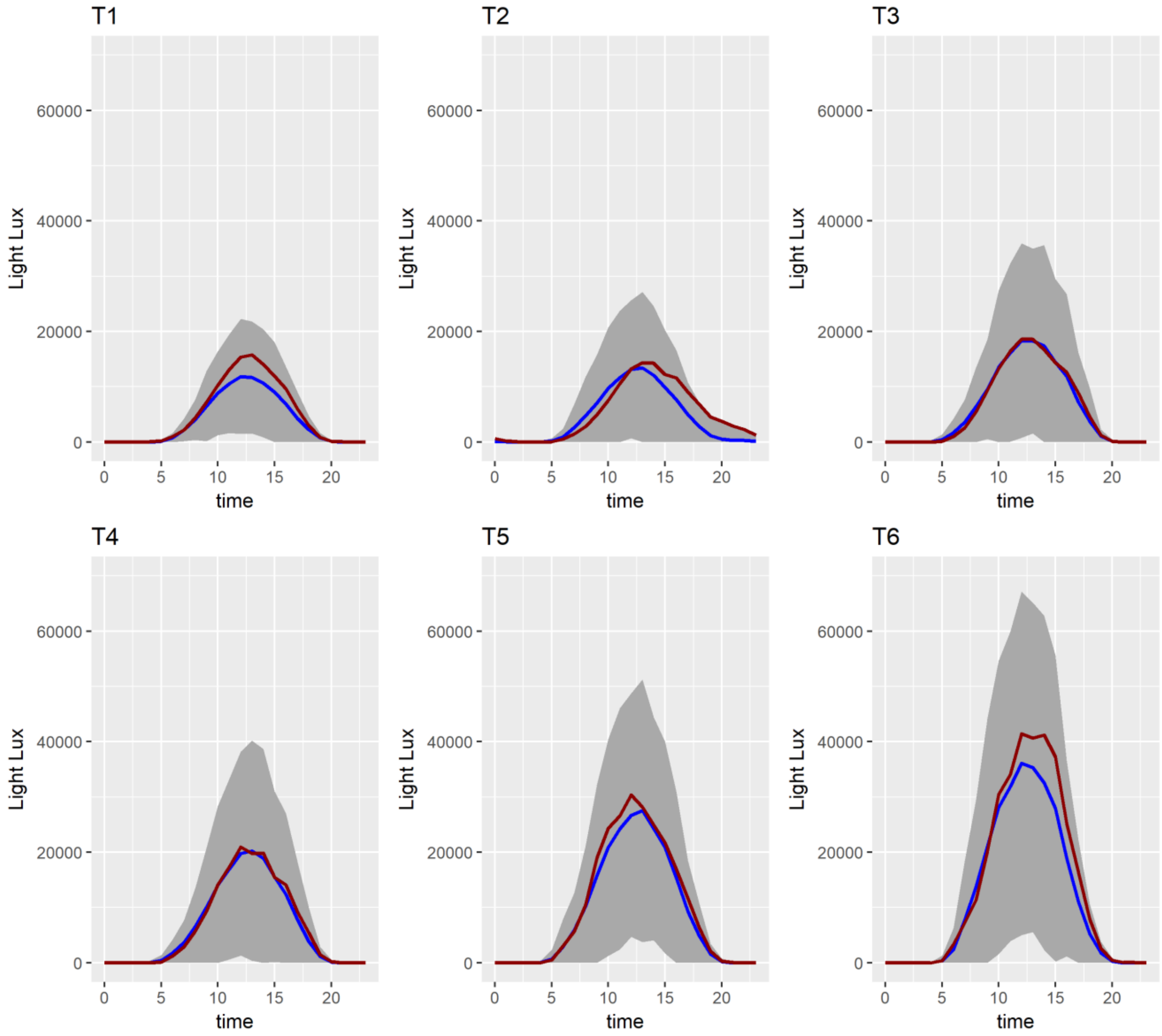

Figure A-2: Spring daily pattern of light intensity (lux) while samplers were submerged in the MCR at varying depths, where T1 is the deepest and T6 is the shallowest for samplers. The blue line represents the mean from 2011 to 2016 (±SD in grey) and red represents the mean 2016 spring data from all submerged samplers. The x-axis is time in hours of the day (0:00 to 24:00).

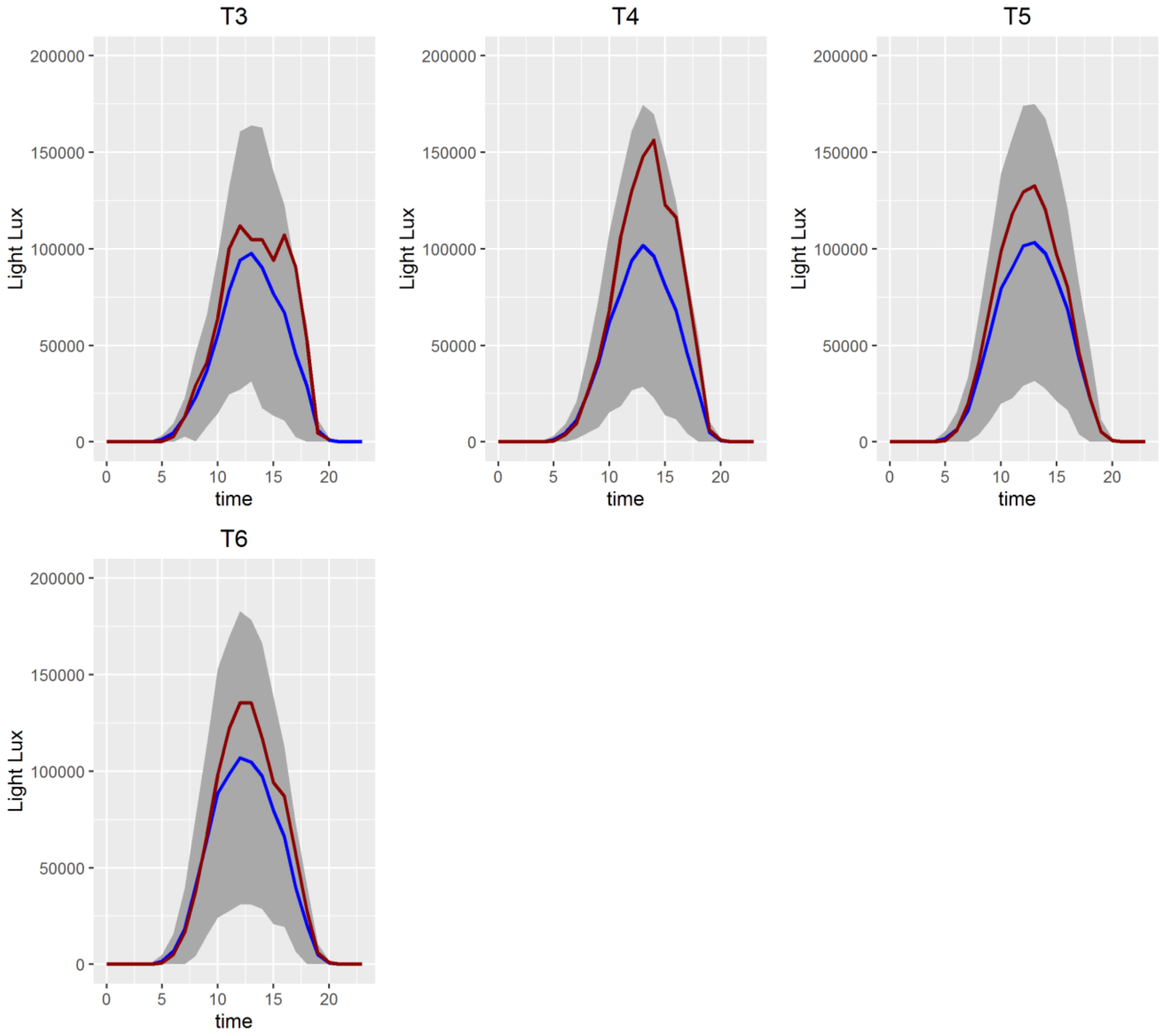

Figure A-3: Spring daily pattern of light intensity (lux) in the MCR when samplers were exposed (out of the water). T3 is the deepest and T6 is the shallowest for samplers. Noting T1 and T2 were continuously submerged so are not included in the above figure. The blue line represents the mean from 2011 to 2016 (±SD in grey) and red represents the mean spring 2016 data from all exposed samplers. The x-axis is time in hours of the day (0:00 to 24:00).

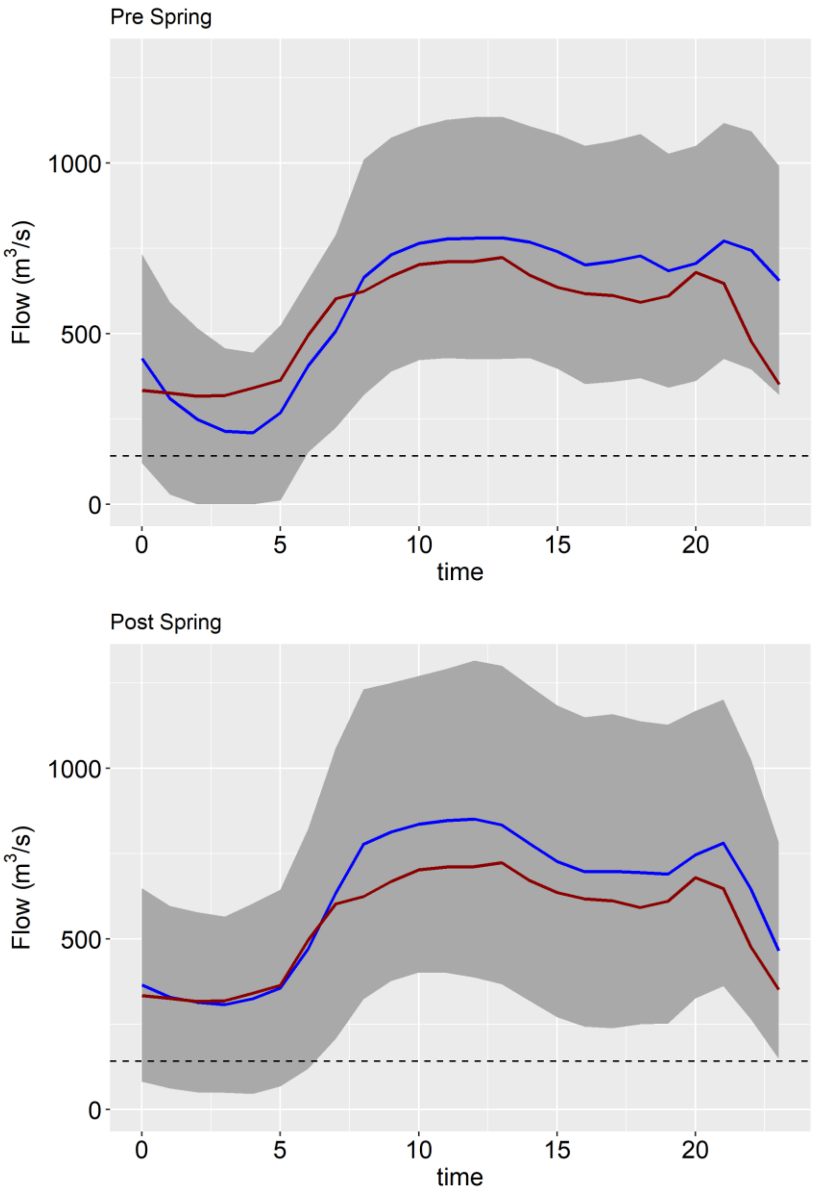

Figure A-4: The pattern of daily flow in the MCR during the spring study periods in pre (2007-2010) and post implementation (2011-2016) of minimum flows. Average hourly flows from 2016 (Spring) are shown in red, while the average of all data pooled (2010-2016) is shown in blue. The standard deviation of average hourly flow across all years pooled is shown in grey. The minimum flows are shown as a black dotted line.

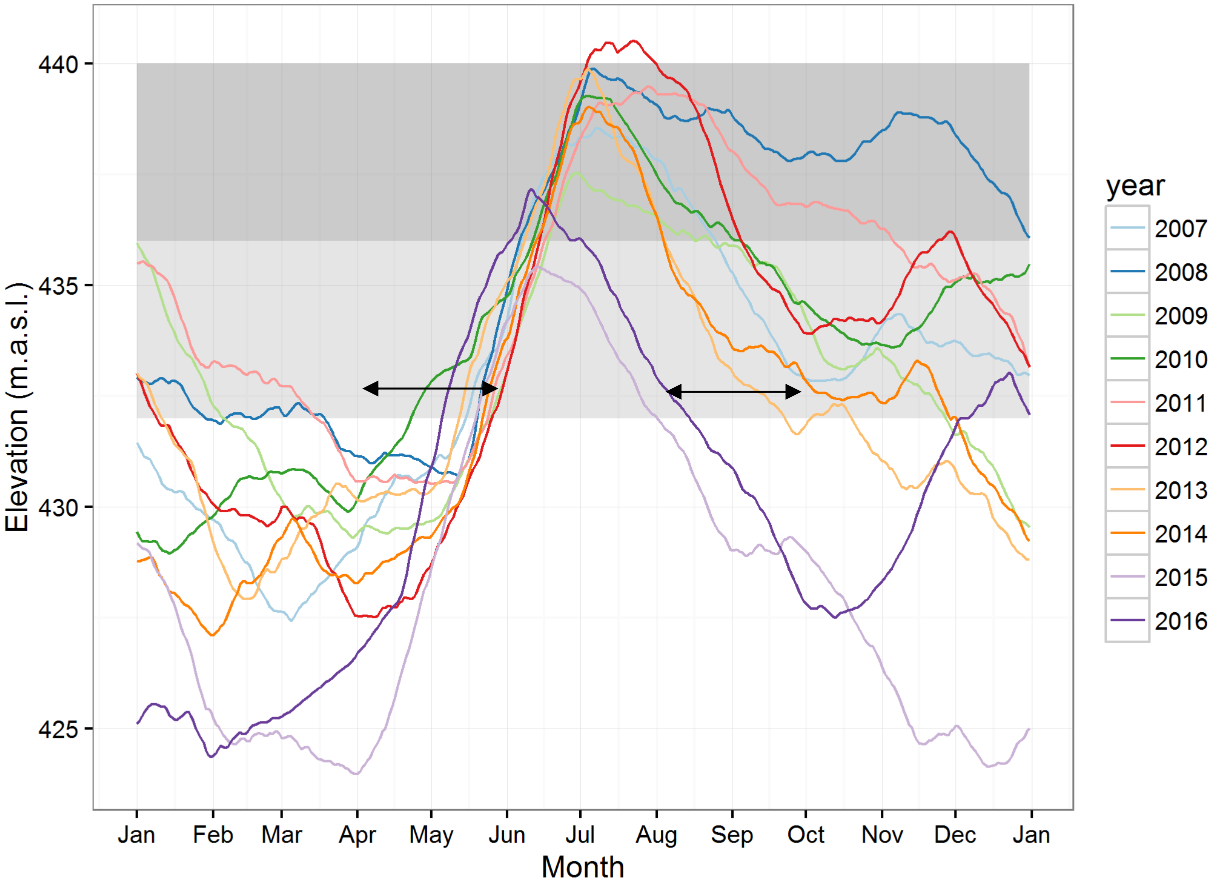

Figure A-5: Backwatering of Arrow Lakes Reservoir (ALR) into MCR Reach 3 and Reach 4 with typical spring and fall deployment periods occurring between the arrows. The vertical axis shows elevations in the normal operating range of ALR. Light grey shading denotes R3 was backwatered; dark grey shading denotes R3 and R4 was backwatered.

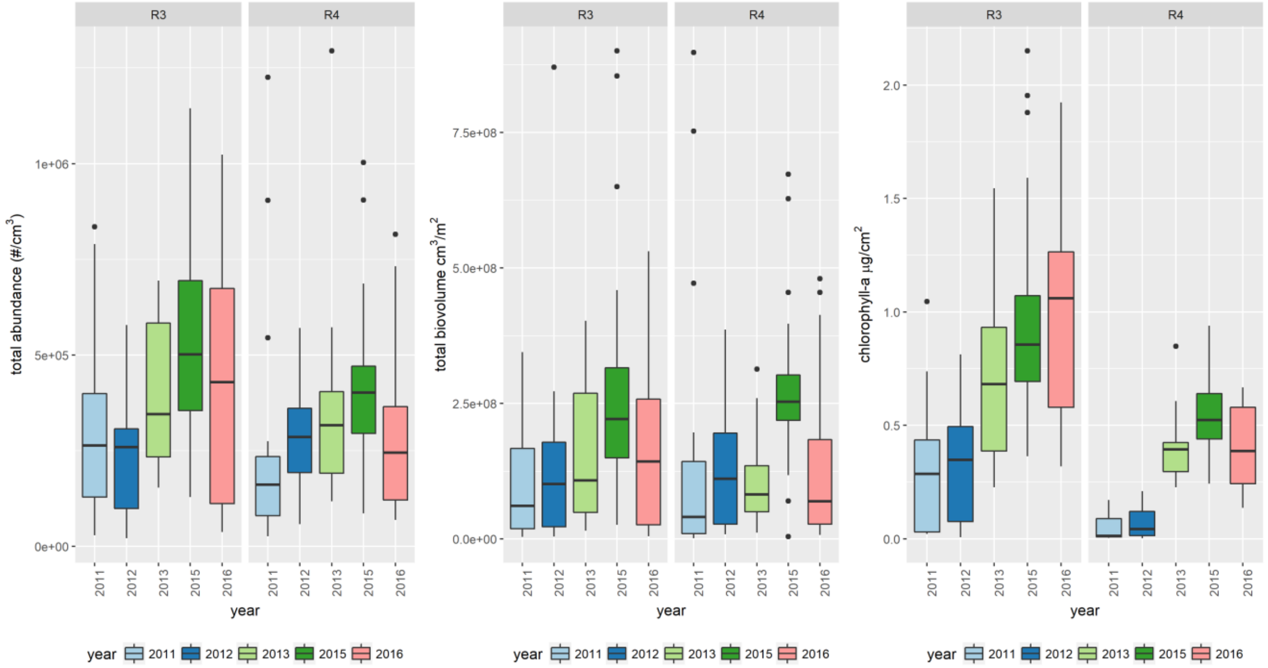

Figure A-6: Productivity metrics for all transects for Spring 2011-2016 compared by reach.

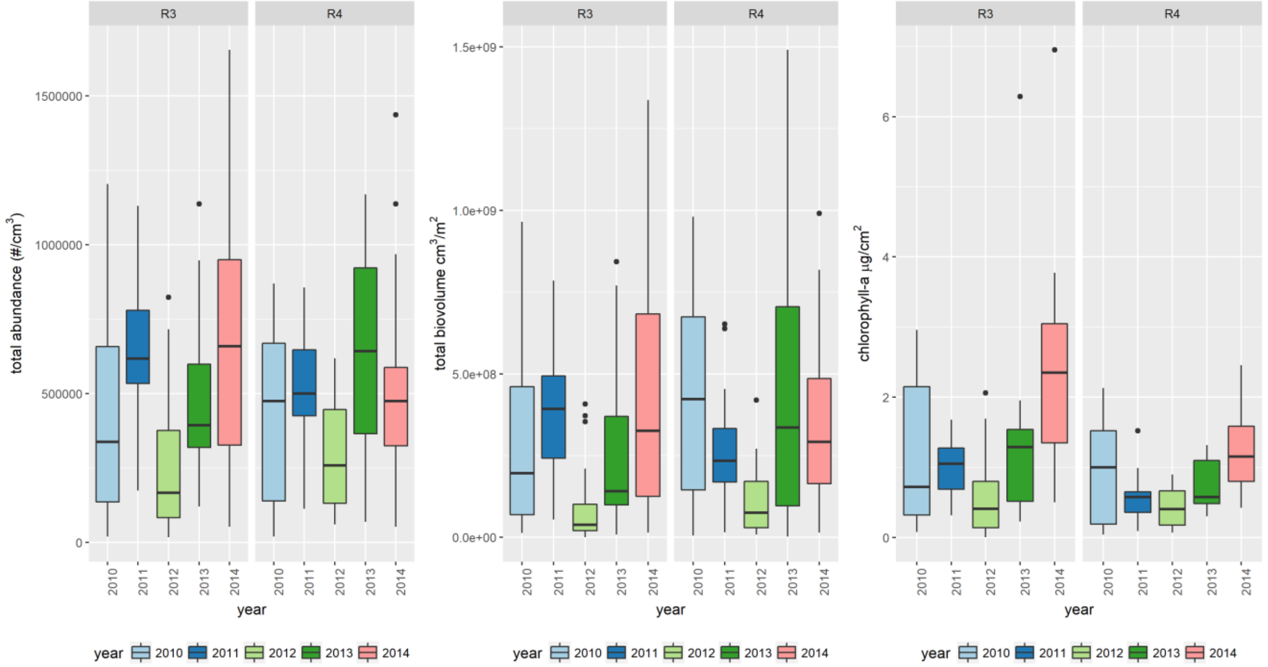

Figure A-7: Productivity metrics for all transects for Fall 2010-2014 compared by reach.

Table A-1: Range of biovolumes in MCR periphyton that are also phytoplankton taxa found in Revelstoke Reservoir and found in MCR drift samples, 2007 – 2015

Revelstoke Reservoir Taxa	Typical Growth Habit	% of periphyton biovolume in MCR Fall	 Spring	Found outside of mainstem
Ankistrodesmus falcatus	limnoplanktonic	0 - <0.1	0	No
Asterionella formosa	limnoplanktonic	0 - 47	0 – 0.03	No
Diatoma tenue var elongatum	planktonic	2-18	12-30	Yes
Fragilariforma spp.	limnoplanktonic	0 - 12	0.4 – 3.0	No
Fragilaria crotonensis	limnoplanktonic	0.1 – 1.4	0 – 0.1	No
Synedra acus (large spp.)	limnoplanktonic	0.1 - 9	0.1 – 5.0	No
Synedra nana	limnoplanktonic	0 – 0.2	0 – 1.8	No
Synedra ulna (large sp.)	limnoplanktonic	0 - 2	0.5 – 14	Yes
Tabellaria fenestrata	planktonic or attached	2-12	0.3 - 6.0	Yes
Tabellaria flocculosa	planktonic or attached	3.5 – 4.1	0.2 – 1.2	Yes

Table A-2: Flow summary table for each deployment period, summary statistics are calculated from mean daily flows.

		flows (m^3/s)							
Year	Season	Min.	1st Quantile	Median	Mean	3rd Quantile	Max.	Flow Class	Backwatering
2010	Fall	193	360	509	498	618	909	average	yes
2011	Fall	356	628	820	802	956	1177	high	yes
2012	Fall	324	630	924	876	1097	1437	high	yes
2013	Fall	156	386	683	652	842	1194	average	no
2014	Fall	316	478	591	653	859	1181	average	yes
2011	Spring	153	309	480	500	671	988	average	yes
2012	Spring	178	386	521	585	799	1037	average	yes
2013	Spring	223	376	553	576	749	1106	average	no
2015	Spring	488	987	1120	1108	1250	1475	high	yes
2016	Spring	186	354	533	577	755	1223	average	yes

Table A-3: Summary of the number of plausible models identified using model averaging (those with a ΔAIC <3) and the range of pseudo R^2 values for selected models for transects T1-T4.

MCR - T1-T4	Fall		Spring	
Response	# of plausible models	range of pseudo R^2	# of plausible models	range of pseudo R^2
Invertebrate Abundance	7	0.27-0.31	13	0.18-0.26
Invertebrate Biomass	11	0.14-0.20	11	0.29–0.33
chlorophyll-a	3	0.23	6	0.69-0.70

APPENDIX B DIGITAL DATA TABLES AND FIGURES

APPENDIX C SUPPLEMENTAL METHODS AND RESULTS

Methods

In previous years of the study (2011-2015), non-metric multidimensional scaling (NMDS) using Bray-Curtis dissimilarity was used to explore variation in benthic community composition. Data were transformed using the Bray-Curtis transformation and cluster diagrams using Ward clustering of the Bray-Curtis matrix were constructed to interpret the data. Finally, a PERMANOVA (Oksanen et al. 2015) was used to determine if groups (either Pre/Post minimum flow, Year, Season, and Transect) were significantly different in composition. NMDS was run at both the genus taxonomic levels for periphyton and at the order level for benthic invertebrates to investigate the effects of small and large scale taxonomic community differences within the study period. Species were related to the community differences by fitting the factors on to the ordination plot using the R function Envfit (Oksanen et al. 2015) in 2014. Only species that were significant ($p<0.05$) and had $r^2 > 0.03$ for invertebrates and $r^2 > 0.1$ for periphyton were considered in this analysis in 2016 (Schleppe et al. 2015). These species describe the most observed variation between sites. Reducing the species that are considered important reduces the ability to identify species-specific responses, but it is helpful to better interpret large-scale shifts in the community.

A repeated measures ANOVA was used to analyze chl-a accrual rates at T1 and T3/T4 locations during spring and fall during previous years. Accrual rates appeared linear over the 44-50 day deployment period for both seasons and transects (Schleppe and Larratt 2016). For the purpose of the spatial productivity model, a logistic growth curve that has a horizontal asymptote is required.

The full set of predictor data developed by Perrin and Chapman (2010b) and those developed in 2010 were collected in 2011 through 2016. Temperature, light and submergence data were used to calculate different predictors or explanatory variables that could test the effects of hydro operations on productivity in MCR (Table 2-3, Schleppe et al. 2011 and 2012). Variables of time are often collinear, but all the variables developed were initially considered. To reduce collinearity, multiple attempts at different model predictor combinations were considered, to choose the most appropriate variables describing submergence without omitting any potentially influential factors that may affect productivity. An exploratory analysis of final production responses to explanatory variables (Table 2-3) was completed for raw and transformed data. The intent of this step was to reveal any general patterns or trends across transects or within response variables prior to any statistical analyses. Methods described by Zuur et al. (2009) were employed to examine multi-collinearity among explanatory variables based on variance inflation factors (VIF) and correlation coefficients, avoiding inclusion of highly collinear variables (correlations coefficients > 0.7) together in descriptive models. Most collinearity in predictors originated from variables of submergence and variables for light. The final set of predictor variables were selected because they were the most interpretable and most useful to address key management questions without overly inflating the variance of models due to high collinearity. A variety of different predictor combinations have been presented in previous year's reports, and although not directly tested, the trends observed in previous years for certain predictors should still be valid because of consistency in data between years.

A fish food index previously used to assess the effects of minimum flows on food for fish was not calculated in 2015. Although it was useful, for the 2015 report the total biomass of EPT and Dipterans were used as an alternative and was investigated to see if similar trends existed using raw data versus a more complicated index for comparative purposes. Since the Fish Food Index was heavily weighted towards EPT and Dipteran species because they are typically the most preferred food across multiple species, this alternative was considered for calculating food for fish. The biggest difference between the two methods is the Fish Food Index considers biomass, preference, and abundance, whereas this method only considers biomass.

Results

EFFECTS OF SEASON There were subtle seasonal shifts in the dominant periphyton taxa in MCR, probably in response to water temperature, freezing conditions and flows. In all spring samples, the dominant diatoms included *Diatoma tenue, Achnanthidium minutissima* and *Synedra ulna* (several varieties) along with large concentrations of rapidly reproducing single-celled algae. In fall samples, *Achnanthidium minutissima*, *Tabellaria fenestrata, Diatoma tenue* and *Synedra spp.* were dominant, and there was a greater contribution made by filamentous green algae, particularly in fall 2014. When species richness was assessed by transect locations, spring samples had lower average species richness of 13 (T6) to 19 (T2) species/sample compared to fall samples at 15 (T6) to 23 (T2) species/sample. Although both seasons may show trends in periphyton community structure, key differences in taxa could not be identified statistically (Schleppe et al. 2015).

APPENDIX D SPATIAL PRODUCTIVITY MODEL

A river hydraulic model is an important component for a spatial productivity model because it determines the water levels on an hourly basis. Considering growth in an hourly fashion is necessary because there is potential for measurable effects due to exposure after only 1 or 2 hours. The water levels are used to determine if a given area in the river is submerged or exposed. Two different hydraulic models for MCR were obtained from BCH and EcoFish. The model from BCH is a Telemac 2D model and the EcoFish model is a HEC-RAS 1D model. The Telemac 2D model has a higher level of complexity than the HEC-RAS 1D model, as a result it requires more technical expertise and computational power (Gharbi et al. 2016). The HEC-RAS 1D model assumes longitudinal flow and constant velocity, whereas the Telemac 2D considers turbulent flow that assumes varying velocities (Lim, 2011). The results of Telemac 2D and HEC-RAS 1D models have been compared for floodplain modelling in the Medjerda River in Tunisia. The water elevations predicted by both models were very similar. However, within 10 km of a dam the Telemac 2D model performed better than the HEC-RAS 1D model (Gharbi et al. 2016).

As part of model validation, the modelled daily productivity will be compared to the collected productivity data. Depending on the results of the model validation, the relationship between predicted and observed values may be used to calibrate the spatial productivity model. It is expected these relationships will be derived on a season and reach specific basis. Model validation was not done for the LCR spatial productivity model because of limited data. Therefore, MCR provides a unique opportunity to test the strength of spatial productivity models.

The use of growth and death curves in the spatial model of productivity was discussed in last year’s report (Schleppe and Larratt, 2016). The original spatial model had periphyton growth curves derived from LCR accrual data. Theoretically, growth curves are typically considered to have a logistic shape. However, the MCR accrual data suggests the growth curves are linear over a 49 to 50-day deployment period. For the purposes of the spatial model, a logistic curve is required because a maximum is reached at some point, whereas linear growth curves continuously grow over the period of consideration. A theoretical growth curve specific to the MCR is required because this system is less productive than LCR and takes longer to reach peak biomass (Table A-2).

There has been no accrual data collected for invertebrate biomass and abundance in the MCR. For the LCR spatial model of productivity invertebrate biomass and abundance curves were generated by combining fall and spring data from the LCR (Schleppe et al. 2015). We acknowledge that LCR has higher benthic invertebrate production than MCR, even when only permanently submerged MCR sites are considered (Table A-2). As a result, the application of the LCR growth curves in the MCR spatial productivity will likely result in an over prediction of invertebrate production. Model validation will be an important step in correcting invertebrate production estimates to be more realistic for MCR.

Table A-4: Comparison of seasonal benthic invertebrate data for MCR permanently submerged locations (T1 and T2) and LCR (Plewes et al 2017).

River	Mean Invertebrate Biomass (±SE) (g)	Mean # of Invertebrates (±SE)	Total # of Taxa	Most Abundant Taxa (percent abundance)
MCR Spring- T1 & T2	0.019(±0.042)	181(±213)	30	Orthocladius complex (61) Hydra sp. (7) Naididae (6) Orthocladiinae (5) Pagastia sp. (5)
MCR Fall- T1 & T2	0.0084(±0.018)	507(±709)	25	Hydra sp. (27) Orthocladius complex (17) Eukiefferiella sp. (14) Orthocladiinae (14)
LCR (Castlegar)- Summer	1.36(±1.50)	6182(±6548)	51	Hydropsychidae (33) Hydropsyche (19) Tvetenia spp. (8) Simulium spp. (6)
LCR (Castlegar)- Fall	1.96(±3.30)	5278(±5391)	41	Hydropsyche (26) Tvetenia spp.(12) Tvetenia discoloripes group (9) Parachironomus (7)

Death curves are another important component to the spatial productivity model, especially in MCR where daily dewatering occurs. Death curves were also derived for benthic invertebrates in the LCR as part of the Brilliant Expansion (BRX) spatial productivity model work (Schleppe et al. 2015). These death curves were derived using only Simuliidae and Trichoptera because they are the dominant taxa in LCR. In MCR, it is likely that the mortality rate of benthic invertebrates as a result of dewatering is less because the dominant taxa (i.e. *Orthocladius sp.*) in MCR are more resilient to dewatering (Table A-4). For the BRX spatial productivity model, periphyton death curves were derived using data from Stanley et al. (2004), and they likely overestimate the rate of mortality (Schleppe et al. 2015).