Columbia River Project Water Use Plan

MIDDLE COLUMBIA RIVER ECOLOGICAL PRODUCTIVITY MONITORING

Implementation Year 6

Reference: CLBMON–15b

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

Survey Period: 2012

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PROGRAM NO. CLBMON-15B

MIDDLE COLUMBIA RIVER ECOLOGICAL PRODUCTIVITY MONITORING, 2007-2012

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CLBMON 15B Status of Objectives Management Questions and Hypotheses After Year 6			
Objectives	Management Questions	Management Hypotheses	Year 6 (2012) Preliminary Status
A key environmental objective of the minimum flow release is to enhance the productivity and diversity of benthic communities. The benthic community of the 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 the 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 accepted, but only under certain operating conditions. Theoretically, the spatial area of habitat should increase. The spatial area of productive habitat is determined by the BC Hydro flow operating regime and occurred in three typical growth bands that moved across the channel in relation with mean low flows and duration of high daily flows. During certain operating regimes the total productive is area is determined by factors such as high daily average flows, backwatering from Arrow Lakes Reservoir through large portions of habitat between Big Eddy and the Illicillewat River, and weather conditions for instance. To explicitly determine the spatial area of habitat due to 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 more complex spatial model will allow more specific conclusions for the hypothesis and will provide useful information for considering alternative operating regimes.
	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: The hypothesis is accepted, but only under certain operating conditions. Given no other operating constraints, we conclude that minimum flows in combination with daily, weekly, monthly, and annual operating regimes affects 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 that exceed 24 hours with high or freezing average daytime temperatures. • Repeated exposure events in excess of 12 hours Ho_{2A}: The hypothesis is accepted because the permanently wetted area occurred in the mid-channel, with the

CLBMON 15B Status of Objectives Management Questions and Hypotheses After Year 6			
Objectives	Management Questions	Management Hypotheses	Year 6 (2012) Preliminary Status
		Ho_{2A}: There are no changes in accrual rates of periphyton at channel elevations that remain permanently wetted by minimum flow releases.	highest water velocity and depth during high flows. The physical characteristics such as velocity, light, and substrate were more important determinants of periphyton accrual than minimum flows within these areas. Peak flows associated with REV 5 or high water events may reduce periphyton accrual and standing crop in permanently submerged habitats.
	Q3. 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?	Ho_{2B}: There are no changes in accrual rates of periphyton at channel elevations that are periodically dewatered by minimum flow releases.	Ho_{2B}: The hypothesis is accepted, but only under certain conditions. We conclude that minimum flows do not affect areas periodically dewatered (i.e., above minimum flow), but they have likely had an effect in areas that were regularly exposed before the minimum flow operating regime because increased accrual would have occurred. Daytime submergence, seasonal patterns, and operating cycles were also important determinants of periphyton accrual and must also be considered.

CLBMON 15B Status of Objectives Management Questions and Hypotheses After Year 6			
Objectives	Management Questions	Management Hypotheses	Year 6 (2012) Preliminary Status
	Q.4. 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_3: 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.	Ho_3: The hypothesis is accepted, but only under certain operating conditions. Permanently submerged areas were the most productive and diverse, but frequently submerged varial zone areas also had some level of productivity and diversity. The area of productive invertebrate habitat is bounded by average daily low flows and its upper limit is determined by average daily submergence. Specifically 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.
		$Ho_{3A:}$ There are no changes in abundance/biomass/diversity of benthic invertebrates at channel elevations that remain permanently wetted by minimum flow releases.	$Ho_{3A:}$ We conclude that minimum flows have not affected permanently wetted areas and this hypothesis is accepted REV 5 or high peak flows associated with high water events may also be important determinants of invertebrate production. Invertebrate abundance, biomass, and diversity in permanently submerged areas are determined by physical characteristics of the MCR, including velocity and substrate.
		$Ho_{3B:}$ There are no changes in abundance/biomass/diversity of benthic invertebrates at channel elevations that are periodically dewatered by minimum flow releases.	$Ho_{3B:}$: The hypothesis is accepted, but only under certain conditions. We conclude that minimum flows do not affect areas periodically dewatered (i.e., above minimum flow), but they have likely had an effect in areas that were regularly exposed before the minimum flow operating regime because the data suggest that benthic invertebrate abundance, diversity, and biomass are positively associated with submergence or time in the water. Daytime submergence, seasonal patterns, and operating cycles were also important determinants of benthic accrual and must also be considered.

CLBMON 15B Status of Objectives Management Questions and Hypotheses After Year 6			
Objectives	Management Questions	Management Hypotheses	Year 6 (2012) Preliminary Status
	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 m^3/s minimum flow release does not change the availability of fish food organisms in the Middle Columbia.	Ho_4: This hypothesis is accepted, but only under certain operating conditions. Food for fish was assessed using a Fish Food Index (FFI). The index 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 high or freezing average daytime temperatures. • Repeated exposure events in excess of 12 hours Substrates submerged for 450 to 500 hours (10 to 11 hours per day) during daytime hours have the greatest availability of preferred fish food items. Both periphyton, and invertebrates showed similar responses, suggesting that overall productivity and food for fish is directly affected by the BC Hydro operating regime.

ACRONYMS AND ABBREVIATIONS

ALR	Arrow Lakes Reservoir
ANOSIM	analysis of similarity
ANOVA	analysis of variance
BC Hydro	British Columbia Hydro and Power Authority
BW	backwater
BE	Big Eddy
BR	bedrock
CFU	Colony forming units (bacteria culture)
chl-a	chlorophyll-a
CLBMON 15-b	Middle Columbia River Ecological Productivity Monitoring (this study)
Cultus Lake	Department of Fisheries and Oceans Cultus Lake Laboratory
d.f.	degrees of freedom
EPT	Ephemeroptera (mayflies), Plecoptera (stoneflies) & Trichoptera (caddis flies)
F	F-Statistic
HBI	Hilsenhoff Index
HTPC	Heterotrophic plate count (non-photosynthetic bacteria)
IL	Illecillewaet River
JR	Jordan River
MCR	Middle Columbia River
m	metre
min	minimum
max	maximum
MW	megawatts
NMDS	Non metric multi-dimensional scaling
REV 5	Revelstoke 5
SD	standard deviation
WUP CC	Columbia River Water Use Plan Consultative Committee
WW	whitewater
FFG	functional feeding group
ALR	Arrow Lakes Reservoir

DEFINITIONS

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

Term	Definition
Accrual rate	A function of cell settlement, actual growth and losses (grazing, sloughing)
Autotrophic	Capable of photosynthesis
Autotrophic Index AI	Autotrophic Index is the proportion of the organic matrix which is viable algae. It is usually calculated as (AFDM / chl-a) The inverse is known as AP –autotrophic potential
Benthic	Organisms that dwell in or are associated with the sediments
Benthic production	The production within the benthos originating from both periphyton and benthic invertebrates
Bioaccumulation	Removal of metal from solution by organisms via adsorption, metabolism
Bioavailable	Available for use or uptake by plants or animals
Catastrophic flow or event	Flow events that have population level consequences of >50% mortality in areas affected by the operational flow changes, either through exposure related mortality or stress-induced mortality after exposure.
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)
Functional Feeding group	(FFG) Benthic invertebrates can be classified by mechanism by which they forage, referred to as functional feeding or foraging groups
Invertebrate Production	Benthic invertebrate biomass, abundances, and measures of diversity
Light attenuation	Reduction of sunlight strength during transmission through water
Microflora	The sum of algae, bacteria, fungi, Actinomycetes, etc., in water or biofilms
Minimum flow	The current operating regime maintaining a minimum flow of 142 m^3/s flow. Minimum flow does not refer to the addition of the REV 5 turbine, which increases maximum potential flow in the MCR
Myxotrophic	Organisms that can be photosynthetic or can absorb organic materials directly from the environment as needed
Nano plankton	Minute algae that are less than 5 microns in their largest dimension
Operations / operating regime	the day to day changes in flow associated with on- demand power generation
Pico plankton	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
Periphyton production	Periphyton productivity measures include chl-a, biovolume, and abundance.
Phytoplankton	Algae that float, drift or swim in water columns of reservoirs and lakes
REV 5 flow	REV 5 is the newest turbine added to the Revelstoke Dam. It added 500 MW to the station’s generating capacity, increasing peak discharge to 2124 m^3/s
Riparian	The interface between land and a stream or lake
Varial Zone	The maximum and minimum water elevations over a specific period of time. Varial zones can be considered in varying units of time, such as over the last 30 to 70 days or on an annual basis.
Zooplankton	Minute animals that graze algae, bacteria and detritus in water bodies

EXECUTIVE SUMMARY

Aquatic habitats in the Middle Columbia River (MCR) are heavily influenced by variable flow releases from the Revelstoke Dam. To lessen the effect of 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 to the MCR. The key 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). The goal of the ecological productivity monitoring program CLBMON-15b is to provide long-term data on benthic productivity of the MCR using artificial substrate samplers that assess how minimum flow influences benthic communities and availability of food for fish. This summary report presents data from years 1 through 6 of the study period (2007 - 2012).

Habitat conditions of the MCR include the permanently submerged zone and two varial zones of differential submergence. The permanently wetted zone showed high productivity and accrual rates despite periodic thinning by high water velocities. The next zone is the highly productive lower varial zone located in areas directly above minimum flow elevations. The final zone is the less productive upper varial zone located in areas of increased exposure above the lower varial zone. The boundaries between these three zones shifted in response to the operational flow regimes over the preceding 30 – 70 days which creates the different varial zones. Benthic productivity in all zones was directly influenced by physical factors such as velocity, light, and substrate stability. Within the varial zones, submergence times were the most important determinants of benthic productivity. 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. Minimum flows on the MCR benefit the benthic communities by ensuring that a minimal channel area remains wetted and productive at all times.

Distinguishing between the benefits of minimum flows and operating regimes observed over the study period was difficult. Daytime submergence and high average daily flows were key factors in determining benthic productivity because varial zone areas submerged for 9 hours per day were equally productive to those permanently submerged by minimum flows. Although minimum flows are considered beneficial, these operating conditions are difficult to differentiate from the specific benefits of minimum flow. Further, the benefits of minimum flows were lessened by other factors, most notably backwatering from Arrow Lakes Reservoir, which create larger, different riverine conditions. In the absence of other operating constraints, minimum flows will benefit benthic productivity in the MCR, but alternative operating regimes that have average higher daily flows without minimum flows may also create habitat conditions that are equally productive.

Overall benthic community structure was stable at the family group, with similar representation between years. However, the dominant species varied based upon prevailing conditions, typically over the last 30 to 70 days. Benthic invertebrates were more sensitive to exposure than periphyton. Exposure events of as little as 24 hours during high daytime temperatures caused substantial stresses and die-off in the benthic community, such as those observed in the spring of 2011. For periphyton, exposures exceeding 48 hours were required before similar effects were observed. Peak production in the MCR was not achieved within two months from the time of first wetting and may take longer than six months to establish if sites experience frequent dewatering, particularly in the spring when growth rates are slow.

Overall, submergence was identified as the most important determinant of benthic production in the MCR and minimum flows benefit productivity most during periods when average daytime flows over the preceding 30 to 70 days are lower, desiccating much of the channel regularly. However, many factors affect the total area of productive habitat, and need to be considered in conjunction with the effects of minimum flows, when determining the total area of productive habitat. Factors such as ALR backwatering, operational flow patterns, high peak flows and ramping, seasonal cycles and species tolerances were all important determinants of benthic productivity and should be considered when reviewing future operational guidelines to improve benthic productivity or considering the specific benefits of a minimum flow operational regime.

Keywords:

Middle Columbia River, Ecological Productivity

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APPENDICES

1.0 INTRODUCTION

Aquatic habitats in the Middle Columbia River (MCR) are heavily influenced by variable flow releases from the Revelstoke Dam, and to a lesser extent, by tributary inflows and backwatering from ALR. In December 2010, BC Hydro added a fifth generating unit, and it increased the peak discharge from 1699 to 2124 m^3/s. The Columbia River Water Use Plan supported implementation of a year-round minimum flow of 142 m^3/s at all times to mitigate the effects of variable flows released from Revelstoke Dam. The studies of minimum flow sought to understand how physical and biological variables affect fish habitat productivity in the MCR (WUP, BC Hydro 2005). One component of the WUP involved assessing how the productivity and diversity of benthic communities would change through implementation of a minimum flow operating regime. It was hypothesized that increasing the area of permanently wetted channel downstream of the Revelstoke Dam would result in increased benthic production (WUP, BC Hydro 2005). The increase in wetted habitat was thought to enhance the benthic community by increasing food availability for fish and ultimately improve fish abundance.

The CLBMON-15b Ecological Productivity Monitoring forms one component of a broader monitoring 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, and up to ten years of subsequent monitoring under the new operating regime. In the study years prior to implementation of a minimum flow (2007 – 2010), the water release from the 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. Since Rev 5 and minimum flows were initiated (2011-2012), flows have ranged from 142 m^3/s to 2124 m^3/s. The extent of submergence of river substrates was therefore determined by the variable water releases, in combination with backwatering from the downstream Arrow Lakes Reservoir (ALR) into portions of the MCR just upstream of Big Eddy, a large deep pool near Revelstoke.

Some of the predicted trends of the new operating regime include a general increase in the frequency of high flows with corresponding increases in river elevations and velocities immediately downstream of the dam, and a general increase in average daily discharge during low demand periods (BC Hydro 2006). These trends will generally result in a greater variability in flows. The operating regime or 'operations' of the dam have direct influence on both periphyton and invertebrate production downstream of Revelstoke Dam.

The results from the Ecological Productivity Monitoring will be integrated with other BC Hydro monitoring programs, including Physical Habitat Monitoring, Fish Population Indexing Surveys, Juvenile Habitat Use and Adult Habitat Use. The findings from these monitoring programs will be collectively used 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 the Revelstoke Dam.

These data 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 6 of the monitoring program. The 2012 sampling season differs from the previous years because water levels and flows observed in 2012 were extremely high compared to recent history.

1.2 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) in the MCR
- To assess the response of benthic community taxa (periphyton and invertebrates) of MCR to a minimum flow release from Revelstoke Dam and REV 5 operations
- 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). We developed a conceptual model, presented in 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. Although the relative importance and role of each parameter have yet to be fully clarified, this model identifies the many variables that can influence benthic productivity and ultimately food for fish. Further, it highlights areas for which data is being collected to address the management questions. At the forefront of the model are BC Hydro operations that determine quantity and duration of water release. Altered flows directly influence several factors such as velocity, turbulence, depth, submergence, scour, etc. and therefore have a direct effect on benthic productivity.

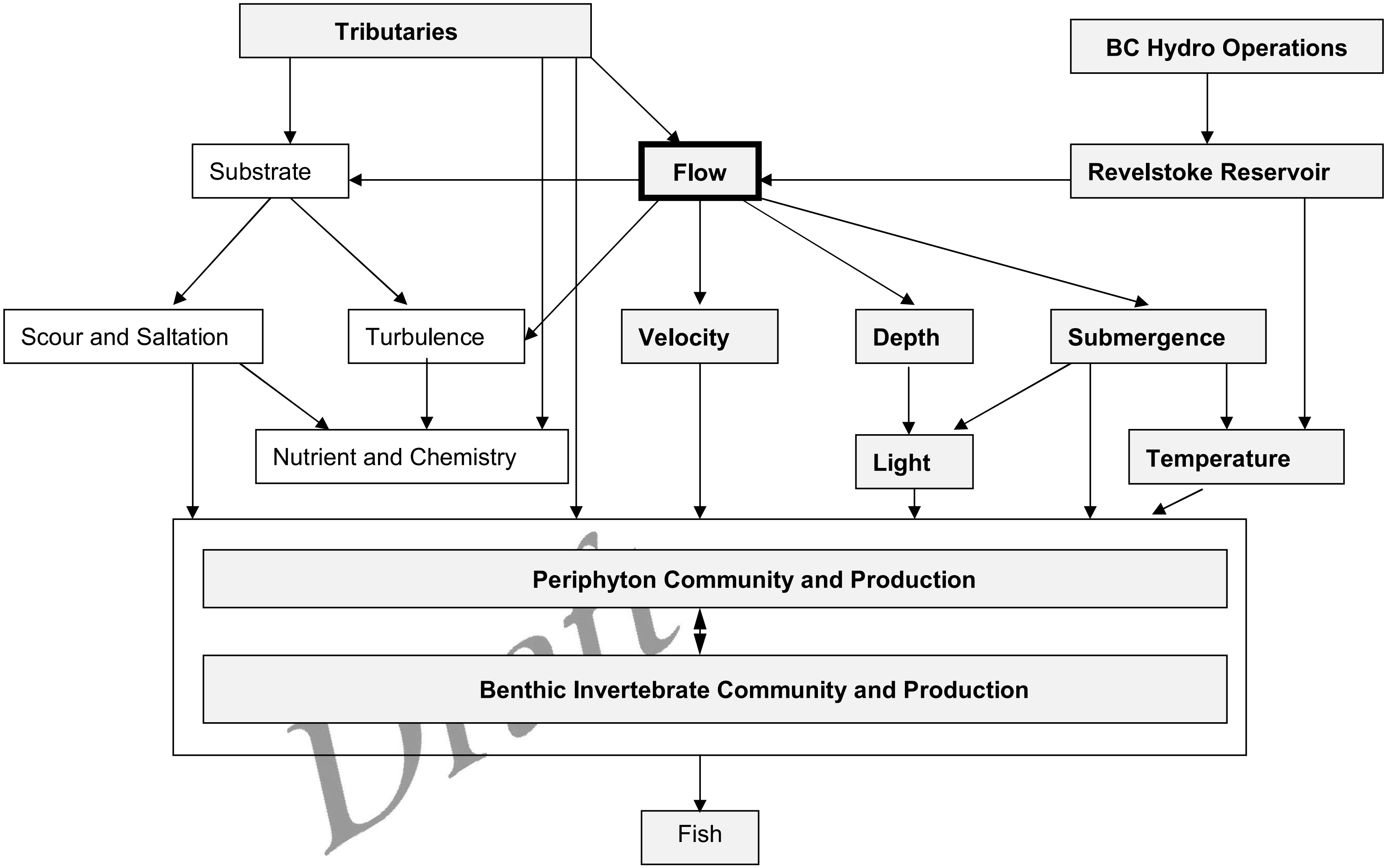


Figure 1-1: Conceptual Interactions Model of Habitat Variables and Benthic Production as they relate to Food for Fish in the MCR. Parameters shaded in grey, with bolded text represent parameters being assessed by the present study.

To comprehensively address the three main objectives, five management questions with related hypotheses were developed. Table 1.1 lists each of the management questions/hypotheses (BC Hydro 2010), and relevant components of our study that addresses them. Although several of the hypotheses/questions refer to the implementation of the minimum flow release, Ecoscape understands 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.

We used simple statistical models to understand the physical responses of periphyton and benthic productivity to flows. In a complex system like the MCR, we could not test the effects of minimum flows and REV 5 flows in isolation from each other and the larger flow regime. In lieu of this approach, we identified relationships between benthic production and spatial features that are directly influenced by flows including area of wetted habitat, and frequency and duration of submergence. From this, the effects of the operating regime, including minimum flow, is inferred. Using 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 financial aspect. 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 identify how implementation of different operational regimes may affect benthic productivity in the MCR including both a minimum flow and 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 the 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 spatial area of productive benthic habitat for periphyton or benthic invertebrates in the MCR.	Artificial sampler arrays deployed across the spectrum of flows/elevations of the MCR. Data collection includes: • Abundance –periphyton & invertebrates • Diversity – taxonomy indices for periphyton and invertebrates • Production/Biomass – chl-a, AFDW/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 the 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 spectrum 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 HTPC plate counts 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 that 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 the MCR.
Q4. 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?	Ho_3. The implementation of the 142 m3/s minimum flow release does not change the total abundance/biomass/diversity of benthic invertebrates in the 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 dewatered by minimum flow releases.	Artificial Samplers are deployed across the spectrum 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, those permanently submerged, those in varial zone areas, and those in floodplain areas of the 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.

Note: AFDW/DW = ash-free dry weight/dry weight; Chl-a = chlorophyll-a; HTPC = heterotrophic plate count

2.0 METHODS

2.1 Study Area

The MCR consists of Reaches 4 through 1; it encompasses approximately 38.5 km between the Revelstoke Dam and the Upper Arrow Lake Reservoir (ALR) near Galena Bay. This study focused on Reaches 4 and 3, which exhibit 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. It 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 2010). Big Eddy occurs at the interface of Reaches 4 and 3, immediately downstream of the Jordan River. It consists of a deep eddy bounded along the right bank by a vertical rock face. This habitat unit provides a 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 is immediately below Big Eddy, where the river turns 120 degrees and the channel thalweg occurs on the left bank with a floodplain area on the right bank. The right river bed is flat with gravel substrates and has a bankfull width of approximately 360 m. Further downstream, the thalweg occurs in the center of the channel and substrates become progressively finer and more mobile. In lower Reach 3 below the bridges, the side braided channels are exposed when ALR water elevation 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 2010). At the downstream end of Reach 3, the river channel narrows and the thalweg deepens. Substrates in Reach 3 are finer than Reach 4 with sand, gravel and cobbles predominating throughout the reach.

The key tributaries that influence the MCR are the Jordan and Illecillewaet Rivers. The Illecillewaet River accounts for nearly half of the drainage area to the MCR. The lower Illecillewaet receives treated sewage effluent from the town of Revelstoke.

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

2.3 Periphyton and Invertebrate Community Sampling Using Artificial Samplers

2.3.1 Artificial Sampler Design and Deployment

Years 5 and 6 of the CLBMON 15-b study included both spring and fall sampling sessions, where artificial samplers were placed in the river and left for a minimum of 44 days. Refer to Table 2-1 for the number of samplers that were deployed at each site in 2012. Data for previous years is available in previous CLBMON15b reports.

The sample sites used in 2012 were consistent with previous years. 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 sampled at sites S4, S5, and S6. Finally, sites at Big Eddy (BE), bedrock (BR), and Backwater areas (BW) were also sampled.

The transects (T1 through T6) were deployed in Reach 4 as shown in Figures 2-2 and 2-3. Transect position refers to the position of the sampler within the river. T1 samplers were positioned mid-channel, within or near the thalweg. T2 samplers were placed in slightly shallower areas than T1. Both T1 and T2 were permanently wetted at minimum flows. T3 through T4 were placed in the mid-channel and were wetted during moderate flow levels (e.g., 200 to 800 m^3/s). T3 and some T4 positions sampled the lower varial zone. T5 and T6 samplers were placed within the upper varial zone and were only wetted during higher flows from 1000 to 1600 m^3/s

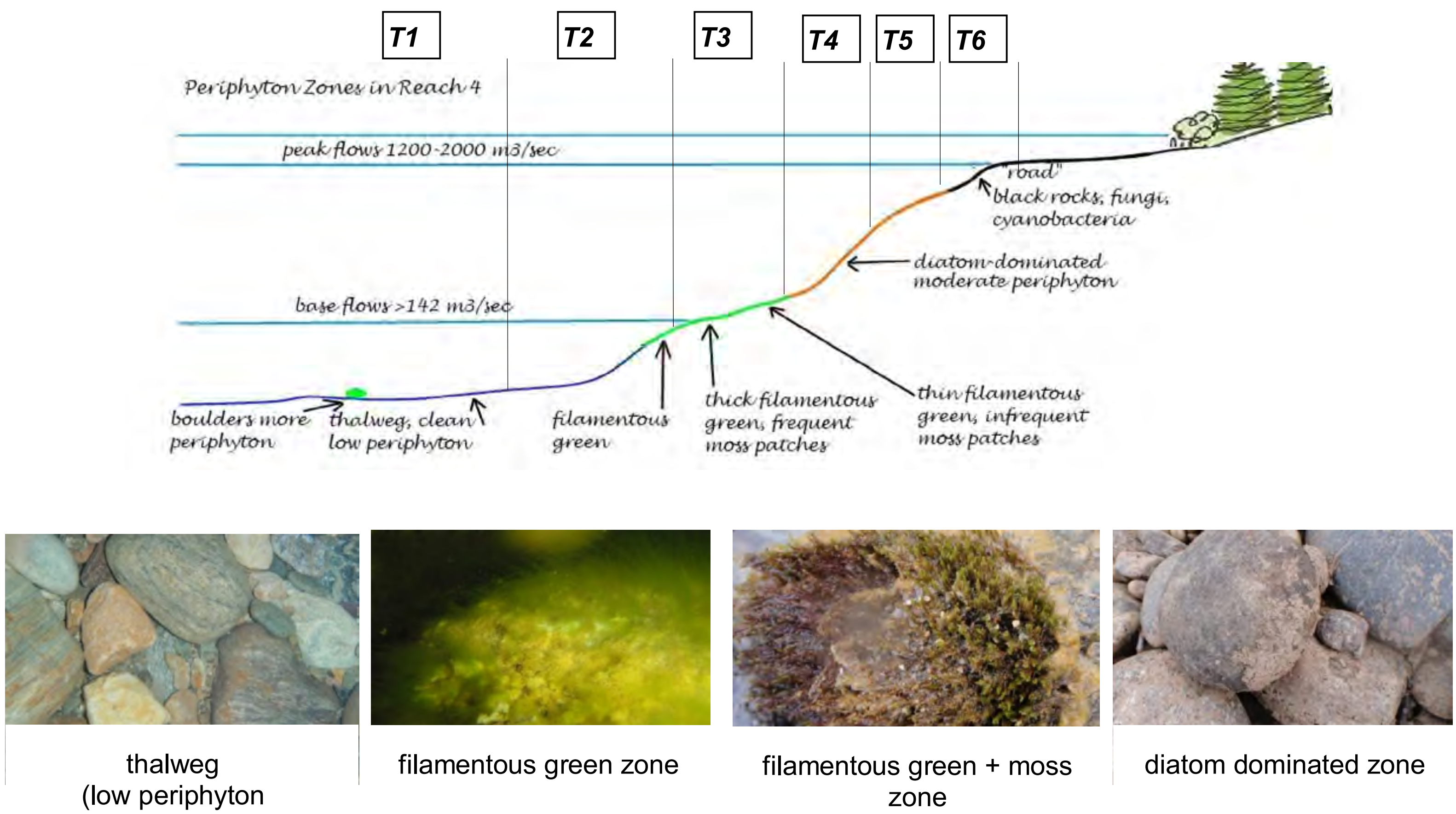
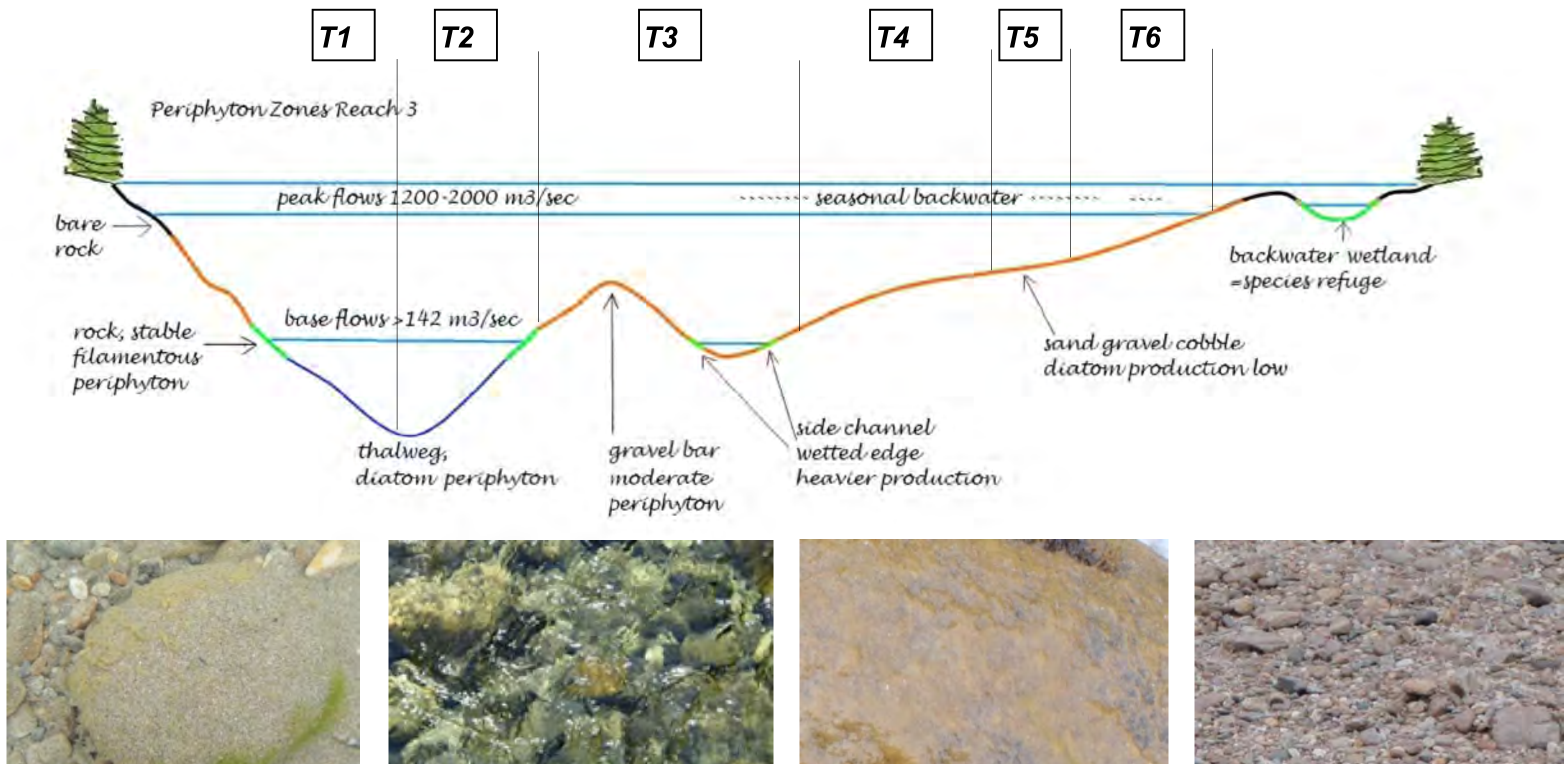


Figure 2-2: Conceptual drawing of transect positions and periphyton establishment in the MCR using data collected from fall 2010 and 2012 in Reach 4



filamentous green+, sand | thalweg, diatom periphyton | wetted edge heavy diatom zone | low diatom, bacteria zone

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

Samplers and associated rigging were assembled and deployed in the spring during April 7 – 9, and in the fall during September 3 - 5, 2012. 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.

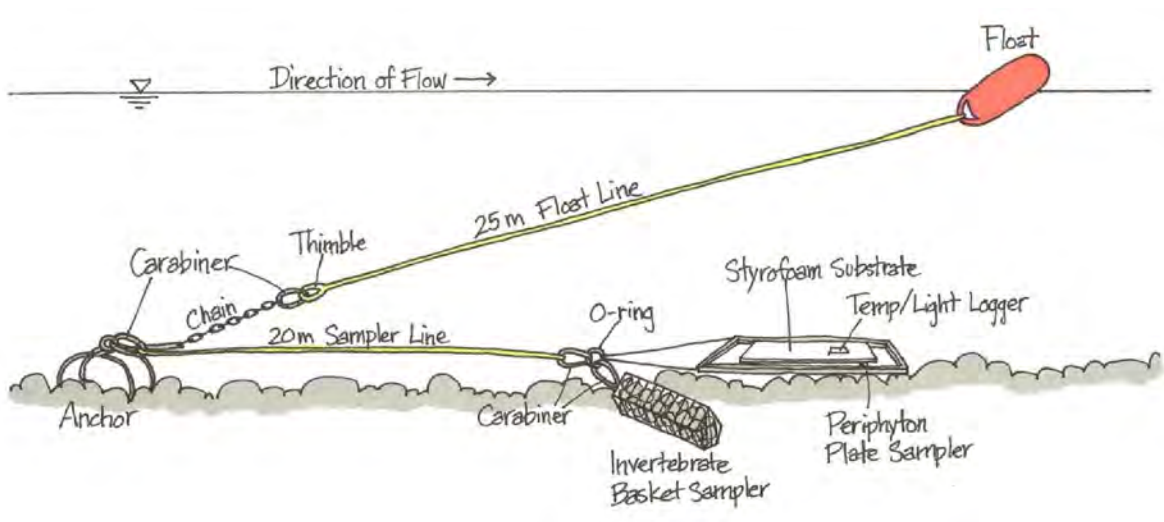


Figure 2-4: Schematic drawing of a standard artificial substrate sampler

Table 2-1: Artificial sampler deployment and retrieval in 2012

Season	Reach	Site/Habitat Type	Periphyton Samplers		Invertebrate Basket Samplers	
			# Deployed	# Retrieved (% Recovery)	# Deployed	# Retrieved (% Recovery)
Spring (Apr 10th - May 25th)	4	Site 6 (S6)	6	5 (83)	0	0 (0)
		Site 5 (S5)	6	6 (100)	6	6 (100)
		Site 4 (S4)	6	5 (83)	6	5 (83)
		Bedrock (BR)	6	6 (100)	6	6 (100)
		Time Series (TS)[1]	10	8 (80)	-	-
	3	Big Eddie (BE)	4	4 (100)	4	4 (100)
		Site 6 (S6)	6	6 (100)	6	6 (100)
		Site 5 (S5)	6	6 (100)	6	6 (100)
		Backwater (BW)[2]	2	2 (100)	2	2 (100)
		Site 3 (S3)	6	6 (100)	6	6 (100)
Spring Totals			**58**	**54 (93)**	**42**	**41 (88)**
Fall (Sept 6th - Oct 19th)	4	Site 6 (S6)	6	5 (83)	6	6 (100)
		Site 5 (S5)	6	6 (100)	6	6 (100)
		Site 4 (S4)	6	6 (100)	6	6 (100)
		Bedrock (BR)	6	6 (100)	6	6 (100)
		Time Series (TS)	10	6 (60)	-	-
	3	Big Eddie (BE)	1	1 (100)	1	1 (100)
		Site 6 (S6)	6	6 (100)	6	6 (100)
		Site 5 (S5)	6	5 (83)	6	6 (100)
		Backwater (BW)	1	1 (100)	1	1 (100)
		Site 3 (S3)	6	6 (100)	6	6 (100)
Fall Totals			**54**	**48 (88)**	**44**	**44 (100)**
2012 Totals			**112**	**102 (91)**	**86**	**90 (97)**

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. Both backwater samplers were retrieved in the spring, but one of the samplers had been compromised (i.e. vandalism resulted in the sampler pulled to shore), and thus periphyton and benthic invertebrate samples were not processed.

2.3.2 Time Series Samplers

In addition to regular samplers, 10 time series periphyton samplers were deployed in both spring and fall sessions to investigate periphyton accrual rates. To better address the management questions, the 2012 sampling configuration was modified from 2010/11 to concentrate effort in two key areas for better statistical strength; the deep area permanently wetted by minimum flows (T1) and the lower varial zone (T3/T4), located above the permanently wetted edge. Five time series samplers were deployed in Reach 4 in both transects positions. Time series samplers were retrieved once per week following deployment. During each weekly sampling, the light/temp loggers were wiped clean with a paper towel, so light measurements originating from time series periphyton samplers could be compared with undisturbed loggers left in place for the entire study duration. Although we knew that light attenuation would occur as periphyton growth covered the sensor, this simple methodology facilitated our understanding of the degree of light attenuation across the study period.

Every week, two periphyton punches were randomly collected from the Styrofoam and were immediately packed and placed in the dark, on ice. The single punch for chl-a analysis was stored at 0°C until it could be shipped overnight on dry ice to the Cultus Lake DFO laboratory, and the other punch was transported chilled to H. Larratt for taxa identification/enumeration. One Styrofoam punch was used for the analysis of chl-a, and the other for the enumeration of taxa. This methodology was followed because the chl-a concentration per cell can vary dramatically between periphyton taxonomic groups (Wehr and Sheath, 2003), therefore, having both measurements was deemed beneficial.

2.3.3 Artificial Sampler Retrieval

Artificial samplers remained in the river for a total of 44-47 days, within the previously defined incubation period of 40-50 days for attainment of peak biomass (Perrin et al. 2004). Spring and fall samplers were retrieved either by boat, wading or by foot on May 23 – 24 and Oct 17 – 19, 2012, respectively.

Four Styrofoam punches were randomly sampled from each sampler in order to assess the following metrics: 1) Chlorophyll-a to give an estimate of only 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); and 3) taxa and biovolume to give an accurate estimate of live and dead standing crop (Wetzel and Likens, 1991). At the time of collection, Styrofoam punches were placed in pre-labeled containers and stored on ice until further processing.

Benthic invertebrate baskets were retrieved similar to previous years following guideline developed by Perrin (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 any contents were rinsed into a labeled bucket with pre-filtered river water. The retrieved baskets were also placed in the labeled buckets until further field processing.

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

2.3.4 Quantitative Natural Substrate Sampling

Natural substrates were studied to provide a context for the artificial substrate results. Quantitative natural substrate samples were collected in 2012 from cobbles and sand substrates in both MCR reaches using the US EPA methods found in Barbour et al. (1999). Natural substrates were collected from the upper varial zone because flows were too high to collect samples from the mid-channel area. For cobble substrates, fifteen smooth cobbles exceeding 20 cm diameter were selected and placed on 3 plastic trays in shallow water at the river's edge to minimize drying. Each tray was sampled separately for a trio of three replicate samples from each site. A 21 cm^2 cylinder fitted with a flexible rubber gasket was held firmly on the cobble and the periphyton was loosened using modified toothbrushes. A squirt bottle filled with 100 mL of 0.54 micron filtered river water was used to remove all the periphyton within the sampler diameter into a beaker. Presence of coarser sand and predators were noted but not added to sample. This process was repeated for all 5 cobbles of a given replicate to give a final volume of 500mL per replicate. The samples were chilled on ice to 2^oC prior to shipping.

Drift Samples

MCR periphyton in depositional sites normally under > 20-40 cm of water cover was sampled quantitatively using the petri dish sampler method found in Barbour et al. (1999). Briefly, sand or silt substrate samples were collected by inverting a large 8.85 cm diameter petri dish, sliding a flat spatula under the dish, and lifting the surface sediment sample. This 55.4 cm^3 sample (surface area of 61.25 cm^2) was agitated in a plastic sample bottle with 500 mL of 0.45 micron filtered river water, shaken vigorously for one minute, and a 250 mL sample of the suspension was promptly decanted into a pre-labeled sample jar. This process was repeated three times to get three replicate samples from each site.

2.3.5 Post Processing of Periphyton Samples

Four Styrofoam punches were obtained from each artificial substrate. One 6.6 cm^2 punch was frozen and shipped on dry ice to the Department of Fisheries and Oceans (DFO) in Cultus Lake, 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 taxonomic verifications provided by Dr. J. Stockner. Fresh, chilled samples were examined within 48-hrs for protozoa and other microflora that are harder 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 undertaken. Species cell density and total biovolume were recorded for each sample. A photograph archive was compiled from the MCR samples. Detailed protocols on periphyton laboratory processing are available from Larratt Aquatic. Analogous methods were used for the natural substrate samples

Figure 2-5: Illustration of components in the natural substrate sampling process. Cobbles were selected at random, placed in a tray; the sampler was applied to each rock, and the 5 cobbles from one tray were combined into one composite sample. The process was repeated to give three replicates

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2.3.6 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. 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 keys were referenced in the identification of benthic invertebrate taxa and a partial list of references is provided in Schleppe *at al*. (2012). Species abundance and biomass were determined for each sample. Biomass estimates were completed using standard regression from Banke (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.

2.4 Variable Descriptions and Analytical Methods

2.4.1 Determination of Submergence

The water and air temperature data obtained from the HOBO light/temperature loggers was the primary dataset used to determine whether an artificial sampler (either invertebrate or periphyton) 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. However, 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.

To ensure that the determination of submergence was accurate, the entire database for both spring and fall was reviewed and professional judgment and field experience were used to assess whether a plate was submerged or exposed to the elements. 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, and time of day. Temperature data from sites of exposure had notable highs, and we speculate that localized effects (e.g., metal frame heating) may help separate similar temperature points between exposed and submersed samplers on sunny days. Manipulations were generally greatest on sites exposed to the air for longer periods.

2.4.2 Variables and Statistical Analyses

Flow varied significantly both between years and months, and within any given day. To understand how flow and operations may be influencing benthic conditions, patterns in flow were investigated. Flow data were subset to only include flows from day 1, 11, and 21 of each month because of potential autocorrelations in time series data. The days were chosen arbitrarily. For both spring and fall datasets, flow data were square root transformed and even after transformation, data still did not meet normality assumptions. A series of analyses (e.g., ANOVA's / Kruskal Wallis / Tukey's HSD) were used to group data into three periods: 1) Low Flow, 2) High Flow, and 3) Ramping (either up or down). ANOVA and Tukeys HSD tests were used to compare differences between Years in High and Low Flow Periods, noting that non parametric tests were initially used to test for differences between years and ANOVA analyses were used to facilitate post hoc tests. Only data from parametric tests were presented.

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. To interpret these data, cluster diagrams using Ward clustering of the Bray Curtis matrix were constructed. Finally, ANOSIM was used to determine if groups (either Ward's or other meaningful groupings) were significantly different in composition. NMDS was run for the species and family taxonomic levels for periphyton and only for the family level for benthic invertebrates to investigate the effects of small and large scale taxonomic community differences within the study period.

The full set of predictor data developed by Perrin and Chapman (2010) and those developed in 2010 were collected in 2011/2012. The temperature, light and submergence data were used to calculate a number of different predictor variables that could potentially test the effects of hydro operations on productivity in the MCR (see Table 2-2, Schleppe et al, 2010 and 2011). Categorical data (e.g., Reach and Tributary Code) were not considered as predictors in modelling analyses similar to 2010. Previous analyses in 2010 used PCA to reduce the number of predictors of production in MCR and to determine if general trends were present. These analyses suggested that variables related to production time (both in the water and during the day) and submergence were important predictors of benthic productivity. Similar to 2010 and 2011, production responses to predictor variables were collinear in 2012. As a result, the full set of variables predicting production were reduced to consider only those that were most biologically relevant to flow regulation and hypothesized response, in light of 2010/2011 results. Table 2-2 contains the list of predictor variables considered in analyses in 2010 and 2011.

Graphical exploratory analysis of production responses to predictors was completed for raw and transformed data. The intent of this step was to reveal any general patterns or trends across transects prior to any statistical analyses and determine the most appropriate data transformations to meet the assumptions of standard parametric tests. Appendix A contains examples of these analyses (Schleppe et al., 2011).

Four response variables for both periphyton and benthic invertebrates were modeled. Periphyton response variables included: 1) abundance, 2) biovolume, 3) chlorophyll-a, and 4) autotrophic index ((AFDW/chl-a). Similar models for invertebrate production and diversity metrics were also prepared and included: 1) abundance, 2) biomass, 3) Simpson's Index, and 4) Hilsenhoff Index. Diversity and production data were transformed using either log10 or square root in order to adhere to the assumptions of least-squares multiple regression (i.e. normal distribution of residuals and heteroscedasticity of residuals).

Hilsenhoff Biotic Index is typically used as a measure of oxygen concentration in organic loading of rivers, relating water quality conditions to the benthic biota where higher index values are indicative of low dissolved oxygen conditions (and hence poor water quality). The index factors the sensitivity of different taxonomic groups to low oxygen conditions.

To some extent, low oxygen conditions originating from poor water quality are similar to extremes associated with dewatering. The Hilsenhoff Biotic Index is calculated as follows:

$$HBI = \sum x_i t_i / n$$

where x_i is the number of individuals within a taxon, t_i is the tolerance value of the taxon (from published literature), and n is the total number of organisms in the sample (Plafkin et al. 1989).

Model averaging was used in conjunction with multiple linear regression to evaluate the relative importance of the independent variables as potential predictors of variation in the response variables. Model averaging first uses an information-criterion approach to objectively rank models. For each response variable (Table 2-2) an exhaustive analysis of least-squares multiple regression models including all possible combinations of predictor variables was conducted. Both first- and second-order terms were included, as quadratic relationships between response and predictor variables were evident in the exploratory data analyses. The small-sample Akaike Information Criterion (AIC_C) was used to rank the models (smaller values of AIC_C represent "better" models), and the difference between each model's AIC_C value and the "best" model was calculated and normalized across all models to sum to one (called the "relative evidence weight", ΔAIC_C). Each predictor variable's "importance" was quantified by summing ΔAIC_C across all models in which the predictor appears. A weight of 1 for a predictor means that there is a 100% probability that this predictor will occur in the AIC_C best model. Weights of 0.6 or higher were generally considered important during subsequent data interpretation.

A Fish Food Index (FFI) was calculated using three criteria to assess the effects of minimum flow on food for fishes. The criteria were: 1) abundance of invertebrate taxa, 2) biomass of invertebrate taxa, and 3) a ranking of preference as fish food for different Invertebrate taxa. The index is conceptually similar to the index developed by Sass et al. (2011). The Fish Food Index is calculated as follows:

$$FFI = \sum_1^I \%A \times \%B \times P$$

where:

1 through the I^{th} benthic taxon at any given sampling site
% A is the percentage abundance of any given benthic taxon;
B is the biomass of the taxon / total benthic invertebrate biomass at the site; and,
P which is a Fish Food Preference.

For each different benthic taxon encountered, a fish food preference rank was assigned. The Fish Food Preference rank was assigned using stomach contents data from MCR, literature reviews, and professional judgment of foraging behaviors. The fish food preference rankings were determined for each different fish species / life stage of importance. Finally, the fish food preference for the analysis was determined by averaging the score of all fish species / life stages. Future calibration of the fish food preference values can be completed as more data becomes available, or the FFI can be used to consider only specific fish species / life stages.

The final FFI index score for each site represents the abundance of benthic taxon as fish food, the size or biomass availability of benthic taxon as fish food, and the availability of more preferred types of benthic foods. The FFI score ranges from 0 to variable maximum (dependent upon the number of species), with higher overall scores indicating a greater presence of benthic invertebrates preferred as fish food. Future iterations of the index will attempt to standardize scores within a specified range to help aid interpretation of results and facilitate comparisons to other rivers or data collected by BC Hydro. The FFI score for each site was subsequently modeled using the same independent variables as other models for periphyton and invertebrates.

Traditional regression methods (e.g. stepwise multiple regression) consider only one model as “correct”, even if alternative models are effectively equally plausible. The model averaging approach is more objective in that it simultaneously evaluates the merits of all the different working hypotheses relating operations (including minimum flow) to invertebrate and periphyton production (see Johnson and Omland 2004). By objectively evaluating multiple alternative hypotheses, we are more likely to achieve a more accurate understanding of how operations influence benthic production.

All statistical tests were conducted using R (R Development Core Team 2006), and model averaging was completed using the R package “MuMIn” (Barton 2009). In all analyses, we assumed that each sampler is independent both within a transect and across sites. This assumption does not reflect the hierarchical sampling structure of Reach / Site / Transect previously established. In future years, and as data permit, hierarchical modeling may be used to better reflect the sampling design.

Table 2-2: 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 2012 data. Environmental predictors used in 2012 modelling are shown in bold. Variable names are in brackets after variable units and these names are used throughout the text.

Variable	Definition
Minimum Submergence (hrs/d)	The minimum number of hours per day (hrs/day) the sampler was submerged. This data was removed because it does not provide much information directly relating to Hydro Operations.
Maximum Cumulative Submergence (max_cum_sub) (hrs)	**The maximum cumulative number of hours a sampler was submerged. Every time the sampler was exposed the maximum cumulative exposure time started over. This variable was kept because it provides indication of the maximum duration any given sampler was submerged and considered producing.**
Submergence ratio (sub_ratio)	**The percentage of time the artificial sampler was submerged in water and incubated (Total Submergence Time/Total Incubation Time). A sampler in the water for the entire deployment would have a submergence ratio of 1. This variable was kept because it provided indication of time spent in the water.**
Maximum Daily Light Intensity (lux)	The maximum daily light intensity observed over the duration of deployment. This predictor was removed because it does not discriminate between submerged and exposed samplers.
Average Daily Light Intensity (lux)	Average daily light intensity observed over the duration of deployment. This predictor was removed because it does not discriminate between submerged and exposed samplers.
Cumulative Intensity Accrued During Deployment While Producing (lux)	Cumulative total of light intensity observed at the sampler location while the sampler was submerged in water and considered producing. Excludes all times when sampler was exposed to air and considered "not producing". This variable was correlated with Total Production Time and was arbitrarily removed to help reduce collinearity.
Average Daily Light Intensity While Producing (lux)	The average daily light intensity when the sampler was in the water and producing. Excludes all times when the sampler was exposed to air and considered not producing. This variable was correlated with Total Production Time and was arbitrarily removed to help reduce collinearity.
Total Incubation Time (tot_inc_time_water_light_hrs) (hrs)	**The total incubation time that the sampler was within the water and in the light producing. This is a measure of the total production time at any given sampler. This variable was chosen as the primary measure of production time.**
Mean Temperature (C)	**Average temperature over the duration of deployment (C). This variable was chosen because it gives some indication of temperature related responses. This predictor does not discriminate between time submerged and time exposed.**
Maximum Temperature (C)	The maximum temperature over the duration of deployment. This predictor was removed because it does not discriminate between time exposed and time within the water.
Minimum Temperature (C)	Minimum temperature over the duration of deployment. This predictor was removed because it does not discriminate between time exposed and time within the water.
Sampler Velocity (m/s)	**Water velocity at the sampler, measurements approximately 25 to 50 cm above the bed of the river (m/s). This variable was included because periphyton responses to velocity are well documented**
Frequency of 12 hour submergence events (Freq_Submer_.12.Hrs) (hrs)	**A count of the number of days where submergence time was greater than 12 hours. This variable is directly linked to BC Hydro operations and was included because it provides some insight regarding production responses to an operational pattern.**

2.4.3 Time Series and Artificial Sampler Assumptions

Community losses along the edges of the artificial substrate was 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.

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 along foraging on the edges of the substrata affecting productivity along the edges of artificial samplers. However, foraging intensity on samples is still considered small when compared to each sample as a whole, reducing any potential data skewing effects that may result from invertebrate grazing. Further, it is probable that invertebrate distributions around plates were clumped, reducing the potential for effects across multiple replicates.

Our analysis has assumed that artificial substrates do not bias results toward a given algal taxa nor do 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, meaning that future investigations may be required to accurately relate artificial samplers to natural substrates.

The assessment was not intended to specifically address immigration, sloughing, or any other aspects of the periphyton community. Thus, artificial substrate samples that were obviously biased due to sloughing from rock turnover, etc. were excluded from collection. This was a field decision and was easy to make because large boulders rolling over artificial substrates left distinct trails of compressed Styrofoam. This field decision slightly reduced the potential area available to sample, but we do not suspect that it biased the results. It is acknowledged that substrate mobility and sloughing are an important component of periphyton production, particularly periphyton drift, in the MCR.

3.0 RESULTS

3.1 Biophysical Characteristics of the Middle Columbia River

Water temperature from temperature/light loggers mounted on the samplers at T1 locations in R3 and R4 during the fall 2007-2012 averaged 10.1 °C to 11.0 °C (min – 2.5°C; max – 13.8°C) while 2011-2012 spring water temperatures were much cooler, averaging 3.6°C to 4.1 °C (min – 2.0; max – 7.8) (Table 3-1).

Table 3-1: Spring and fall mean (±SD), minimum, and maximum water temperatures (°C) observed across all sites permanently submerged at T1 locations (thalweg) between 2007 and 2012 in the MCR.

Year	Season	Mean	Min	Max	SD
2007	Fall	10.05	9.99	10.12	0.04
2008	Fall	10.10	9.99	10.21	0.06
2009	Fall	10.15	3.06	12.90	1.03
2010	Fall	10.52	2.52	13.85	0.82
2011	Fall	10.06	8.88	12.01	0.53
2012	Fall	10.99	7.78	12.79	0.62
2011	Spring	3.58	1.98	10.94	0.95
2012	Spring	4.11	2.84	7.78	0.93

2011-2012 fall maximum daily light availability from samplers at T1 locations averaged 11286 lux to 16248 lux and were 2.3 to 5.3 times lower and considerably less variable than those in spring of these years (Table 3-2). Differences in mean light intensity at T1 locations between Reaches 4 and 3 were minimal during the fall, but were 1.5 times higher on average in Reach 4 during the spring (Table 3-2). The loggers deployed in the fall experienced faster biofilm development that would reduce the amount of light reaching the sensors. By that logic, biofilm development was slowest in the spring and in Reach 4, both conclusions that are supported by periphyton growth metrics.

Table 3-2: Spring and fall mean (±SD), minimum, and maximum light intensities (lux) observed across all sites permanently submerged at T1 locations (thalweg) between 2007 and 2012 in the MCR.

Year	Season	Reach	Mean	Min	Max	SD
2011	Fall	R3	8668.58	2238.90	15844.50	4049.45
2012	Fall	R3	16062.69	7233.40	35822.50	5356.41
2011	Spring	R3	38061.36	10677.80	74400.50	15943.58
2012	Spring	R3	23043.48	8611.20	38578.00	7214.04
2011	Fall	R4	10253.03	1980.60	41333.60	9217.48
2012	Fall	R4	11504.52	5511.10	19977.90	3982.74
2011	Spring	R4	58854.46	15844.50	165334.40	38401.88
2012	Spring	R4	36143.94	7577.80	88178.40	18396.86

Water chemistry is covered in a different project, CLBMON-15a. The MCR tributaries showed very low conductivity and TDS while the mainstem sites were moderated by dam releases. In an effort to understand the effects of turbidity on light penetration into deep water, turbidity and TSS data were collected during the 2012 deployments. Turbidity and TSS were moderate in the MCR, with turbidity of 0.3 – 0.4 NTU in the spring and 0.7 – 0.5 NTU in the fall for R4 and R3.

At the mainstem sites, the ratios of available nitrogen to available phosphorus suggest that the MCR periphyton could be phosphorus limited. Sampling during a September storm in 2010 showed elevated nutrients above the typical MCR regime. Similarly, samples from the Illecillewaet River showed nutrient loading from the secondary-treated sewage discharge.

3.1.1 Pattern of Flow in MCR

Both 2011 and 2012 were unusually high water years. Several important features of the 2012 MCR flow regime include:

- Minimum flows of 142 m^3s were maintained
- 2012 average flows and peak daytime flows were higher from a combination of higher than normal snowpack and increased usage of REV 5 compared to 2011
- 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 2011.
- Higher than average snow melt contributed to increased tributary freshet
- The Arrow Lakes Reservoir (ALR) elevation resulted in extensive back watering of Reach 3 from early June through October, and extended into Reach 4 during the summer months

The hourly flow variations have implications for periphyton and benthic invertebrate growth. Generally, 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. (Figure 3-1). At all other times, flows were either ramping up or down from high or low flow periods. A high degree of variability in the extents of high, low, and ramping flow periods was observed and the data was grouped using both statistical tests and observations during sample collection. Multiple tests (both parametric and non-parametric), visual observations of data, and professional judgment were used to determine the specific timing of High, Low, and Ramping flows across all years.

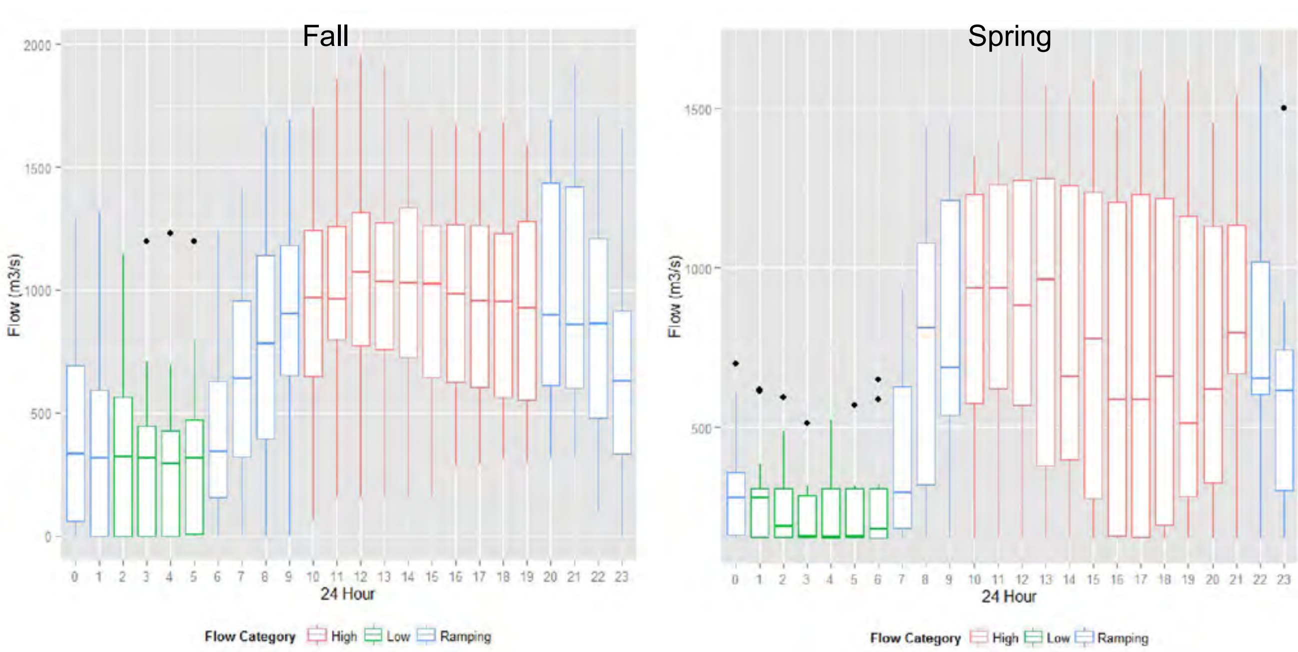

Figure 3-1: The pattern of daily flow in the MCR during the fall and spring study periods. Data are pooled for fall periods between 2007 – 2012 and for spring periods between 2011 - 2012 (± mean SD). Data are grouped between periods of low flow, high flow, and ramping.

Daytime high flows were similar in 2007 and 2012, and the remaining years were more similar (2008 through 2010) (ANOVA, $F = 25.1$, $p < 0.01$). Daytime high flows in 2008 were most similar to 2010 while flows in 2009 were similar to 2008 through 2011. 2011 was potentially unique (Figure 3.2). Daytime high flow periods (i.e., 10 a.m. to 7 p.m). resulted in similar conditions both pre and post minimum flows and are independent of minimum flows. Further analysis is required to more specifically group high flow years together due to the high variability observed between years and potential violations of parametric tests.

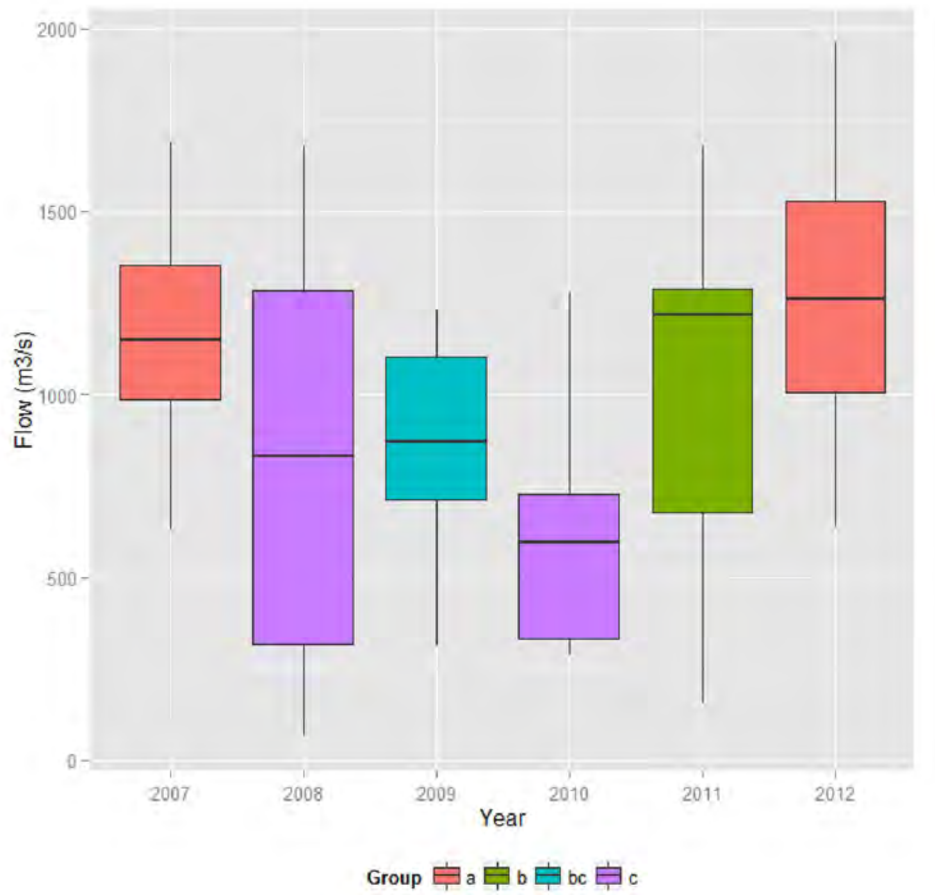

Figure 3-2: Annual flow variations during day time high flow periods occurring from 10 a.m. to 7 p.m. during the fall study period. High flow periods are grouped using ANOVA and Tukeys HSD tests and flow groupings are designated by similar lower case letters and colours.

Fall low flows were similar between 2007 and 2010, and 2011 through 2012 (ANOVA, $F = 23.1$, $p < 0.01$). There was less annual variation observed during fall low flow periods (Figure 3.3).

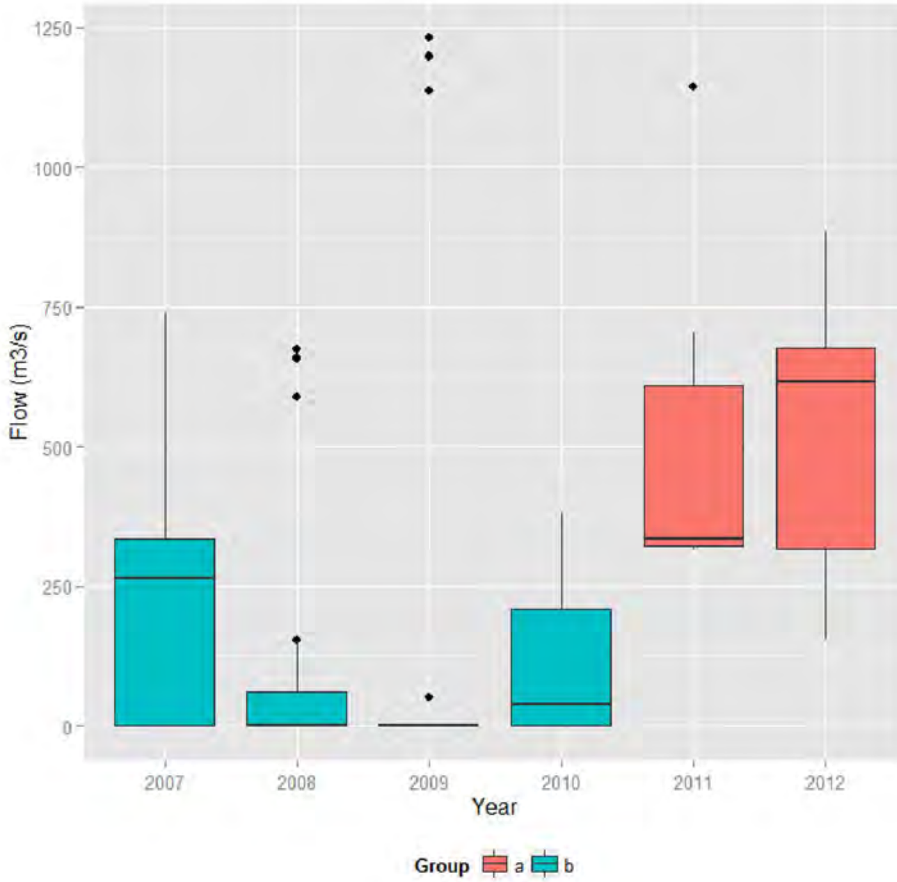

Figure 3-3: Annual fall flow variations during night time at low flow periods from 2 a.m. until 6 a.m. Data were grouped using an ANOVA and Tukeys HSD tests.

During the spring period, data was only collected during 2011 and 2012. During this period, flows during both the high (ANOVA, $F = 51.1$, $p < 0.01$) and low flow period (ANOVA, $F = 23.7$, $p < 0.01$) were different (Figure 3-4). Flows in 2012 were higher in both the low and the high flow period than the equivalent period in 2011.

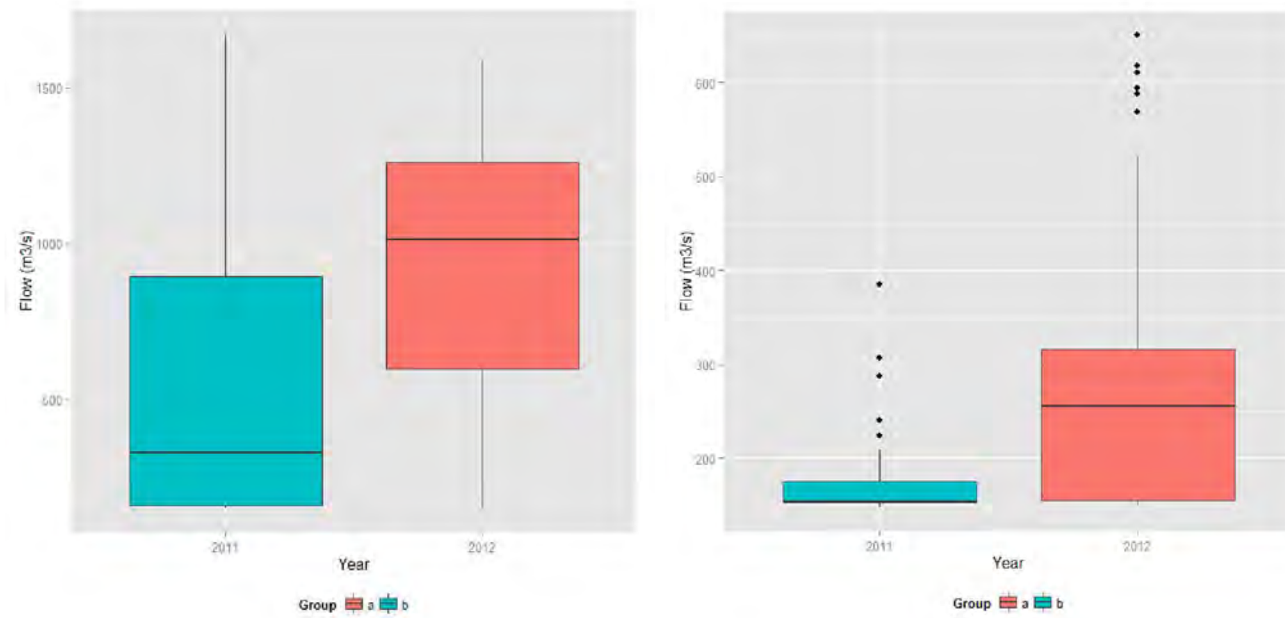

Figure 3-4: Similarities between annual flow during high (left figure) and low (right figure) flow periods. Data were grouped using ANOVA and Tukeys HSD tests.

3.2 Periphyton

Periphyton consists of two groups of micro-organisms, photosynthetic algae and bacteria, and heterotrophic (non-photosynthetic) bacteria and fungi. Algal periphyton production can only occur while substrates are submerged and in the light, while the bacterial biofilm component also grows in the dark (Lear *et al.* 2009). For both components, growth slows and mortality progressively increases during periods of desiccation.

3.2.1 Periphytic Biofilm Bacteria and Fungi Communities

Bacteria and fungi (moulds, yeasts) are pioneering organisms that can dominate the periphyton initially and again after the periphyton mat (biofilm) is well established (Fernandes and Esteves 2003). Heterotrophic bacteria counts on the artificial substrates deployed for 44-47 days in the fall were relatively low compared to other large North American rivers at 0.2 - 5 $x10^6$ colony forming unit (CFU)/cm^2, suggesting oligotrophic or stressed conditions.

Quantitative natural substrate samples were collected from R4 cobbles and suggested that the artificial substrate reduced the heterotrophic plate count (HTPC), and inflated the yeast component of the biofilm, but it accurately reflected the mould component. Given these analytical limitations, artificial substrates in Reach 3 had far more of all three biofilm components per sample than Reach 4 substrates with similar submergence times in both years (Schleppe, et al., 2012). The 2011 Reach 3 shallow yeast and heterotrophic bacteria counts were significantly higher at 1 and 5 $x10^6$ CFU/cm^2 respectively, than the other 2010 and 2011 samples. These R3 biofilm components may have benefitted from ALR backwatering.

3.2.3 Yearly Comparisons of Periphyton Algae Sampling

Like most large rivers, MCR species were dominated by diatoms representing between 85 and 98% of the biovolume in all sample sites in both natural and artificial substrates (Table 3.3; Figure 3.5). The dominant species were rapid colonizing diatoms with firm attachment strategies, along with drift species from Revelstoke Reservoir that adhered to the biofilm and remained viable. The slower growing filamentous green algae were more common in Reach 4 with its stable substrates, where they averaged 5 to 13% of the total biovolume in the fall and up to 16% in the spring. These types were under-represented in the artificial substrate sampler results because they can take longer to establish than the sampler incubation period. Filamentous greens were most numerous in the T2 samplers that had continuous inundation and experienced lower water velocities than T1 samplers. Although they were relatively abundant, the small-celled flagellates, cyanobacteria, and colonial greens rarely exceeded 1.5 – 2.8% of the biovolume in MCR samples (Figure 3.5). They formed a greater proportion of the periphyton community inhabiting the upper varial zone where frequent desiccation occurs. These rapidly reproducing types also have resting stages or protective sheaths that help them withstand desiccation. Cyanobacteria numbers were fairly consistent from T1 through T6 samplers, while flagellates were most abundant at T4/T5 sampling locations.

The relative contributions made by the algae groups were constant by transect location, while dominant taxa within those groups varied in accordance with MCR conditions in a given year (Figure 3.5). In 2011 and 2012, we expanded the range of river habitats investigated to include a backwater, Big Eddy and bedrock, but still found the same species. Algae species requiring low velocities were confined to Reach 3 side channels.

The increased frequency of high flows in 2012 impacted periphyton productivity measurements directly and indirectly. First, increased physical stresses such as shear stress (due to higher velocities) and light attenuation reduced productivity directly. Second, the Styrofoam substrate in high water velocity T1 positions was noticeably thinned, presumably with abrasion by fines. Loss of the surface layer of Styrofoam would lower production estimates. Presumably, abrasion of the Styrofoam would be similar to abrasion on natural substrates during high velocity events in the MCR, although this has not been investigated.

Periphyton community structure and production were similar when all R4 sites were compared to all R3 sites, with both reaches showing a wide range of productivity. Each year, the differences between production metrics in the two reaches were not observably different. However, the mean chl-a of R3 sites was slightly greater than R4 in some years, and a difference may exist under some conditions. For example, in spring 2012, R4 samples averaged 0.139 $\mu g/cm^2$ chl-a while R3 sites averaged 0.237 ug/cm^2 chl-a. Similarly, the fall 2011 R4 samples averaged 0.537 ug/cm^2 while the 2011 fall R3 samples averaged 1.034 ug/cm^2. However, fall 2012 production between the two reaches was very similar at 0.444 – 0.487 ug/cm^2.

There were distinct patterns of average production in MCR, despite wide variations (Figure 3-5). During the fall, most flowing water habitat units showed peak periphyton production in the T1-T3 habitat units and declined as the frequency of exposure increased within the varial zone beyond the T4 position. The fall data suggests that biovolume was greatest at the mid-channel T3 and T4 positions.

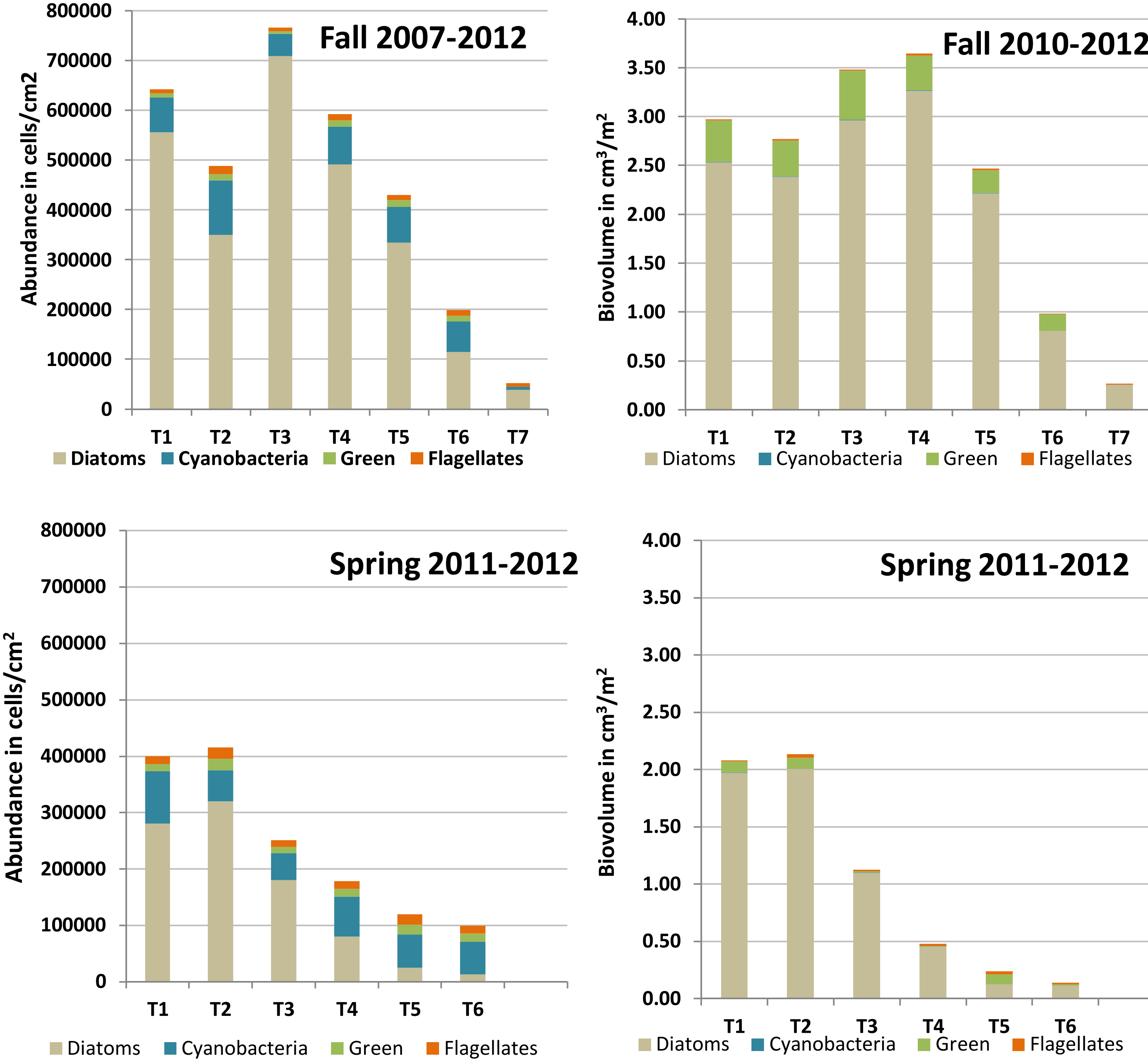

Figure 3-5: Average MCR periphyton abundance and biovolume of algal groups across transects between 2007 and 2012 from combined Reach 3 and Reach 4 data. Transect T1 represents mid-channel locations. Minimum flows river elevations occur between Transect T2 and T3. Biovolume and spring data were only collected from 2010 and 2011 onward, respectively.

Unlike the Lower Columbia River where stable spring flows support high productivity, MCR spring periphyton production was about half of fall production across all transects (Figure 3.5). The differences observed between spring and fall MCR productivity are likely dependent on the operating regime of the MCR. For instance, minimum flows were common from midnight to 6:00 am during the spring deployment and the timing and duration of this low flow period has adverse effects on some microflora species. In the spring samples, T1 and T2 were the most productive, with a progressive decline in both abundance and biovolume through the varial zone from T3 through T6.

The diatom *Didymosphenia geminata* was present in low numbers in the MCR This species is responsible for causing extensive mats in the LCR, and may have the capacity to proliferate in the MCR as well. Currently, its filament provide a small but important attachment opportunity for smaller periphytic diatoms.

Table 3-3 and Table 3-4 summarize the 10 dominant periphyton species by year for R3 and R4 combined in the spring and fall sampling seasons. Dominant species (in both abundance and biovolume) were highly variable annually. Some of this variation relates to MCR operating regime, while some is attributable to algal donations from the Revelstoke Reservoir. For example, *Asterionella formosa* is a lake diatom that was detected in drift samples, and dominated the R4 periphyton in fall 2007 - 2009 samples but was rarely encountered in 2010 – 2012 samples.

Table 3-3: Periphyton relative abundance and biovolume in the MCR in the fall from 2007 to 2012

2007

Relative abundance - dominant species	Relative Abundance (%)	Relative biovolume - dominant species	Relative Biovolume (%)
Asterionella formosa	46.6%	NA	
Achnanthidium minutissima	21.2%		
Fragilaria spp.	11.4%		
Tabellaria flocculosa	7.7%		
Achnanthidium linearis	3.4%		
Synedra ulna	3.3%		
Tabellaria fenestrata	2.3%		
Fragilaria crotonensis	1.1%		
Eucocconeis flexella	0.6%		
Cymbella cistula	0.5%		

2010

Relative abundance - dominant species	Relative Abundance (%)	Relative biovolume - dominant species	Relative Biovolume (%)
Diatoma tenue var elongatum	14.4%	*Tabellaria fenestrata*	26.1%
Tabellaria fenestrata	13.8%	*Diatoma tenue var elongatum*	15.7%
Achnanthidium minutissima	10.3%	*Synedra acus*	13.6%
Synedra acus	9.2%	*Cladophora glomerata*	9.6%
Synedra ulna sm variety	8.2%	*Tabellaria flocculosa*	8.4%
Tabellaria flocculosa	7.1%	*Synedra ulna sm variety*	4.0%
Fragilaria spp.	4.4%	*Eucocconeis flexella*	3.6%
Fragilaria intermedia	4.1%	*Synedra ulna*	2.2%
Lyngbya sp.	3.2%	*Ulothrix (zonata?)*	2.2%
Chroomonas acuta	2.7%	*Fragilaria spp.*	1.9%

2008

Relative abundance - dominant species	Relative Abundance (%)	Relative biovolume - dominant species	Relative Biovolume (%)
Achnanthidium minutissima	20.7%	NA	
Asterionella formosa	18.1%		
Staurosira construens	17.8%		
Synedra ulna	15.7%		
Tabellaria fenestrata	12.0%		
Tabellaria flocculosa	4.2%		
Eucocconeis flexella	1.9%		
Achnanthidium linearis	1.4%		
Synedra acus	1.3%		
Cymbella cistula	1.2%		

2011

Relative abundance - dominant species	Relative Abundance (%)	Relative biovolume - dominant species	Relative Biovolume (%)
Synechococcus sp.	21.7%	*Tabellaria fenestrata*	40.2%
Achnanthidium minutissima	14.5%	*Diatoma tenue var elongatum*	13.0%
Tabellaria fenestrata	9.2%	*Synedra ulna sm variety*	9.7%
Diatoma tenue var elongatum	9.0%	*Eucocconeis flexella*	4.9%
Synedra ulna sm variety	8.9%	*Didymosphenia geminata*	4.2%
Planktolyngbya limnetica	6.2%	*Synedra ulna*	4.0%
Synechocystis sp.	4.4%	*Tabellaria flocculosa*	3.5%
Achnanthidium linearis	3.2%	*Cladophora glomerata*	2.5%
Staurosira construens	2.6%	*Diatoma vulgare*	2.4%
Stichococcus minutissima	2.2%	*Synedra acus*	2.1%

2009

Relative abundance - dominant species	Relative Abundance (%)	Relative biovolume - dominant species	Relative Biovolume (%)
Synedra ulna	24.2%	NA	
Asterionella formosa	16.1%		
Staurosira construens	11.4%		
Achnanthidium minutissima	11.1%		
Achnanthidium linearis	10.0%		
Tabellaria flocculosa	7.1%		
Tabellaria fenestrata	6.0%		
Diatoma tenue var elongatum	2.3%		
Synedra acus	1.8%		
Anabaena sp.	1.8%		

2012

Relative abundance - dominant species	Relative Abundance (%)	Relative biovolume - dominant species	Relative Biovolume (%)
Achnanthidium minutissima	22.2%	*Synedra acus sm variety*	21.9%
Synechococcus sp.	14.9%	*Diatoma tenue var elongatum*	17.4%
Synedra ulna sm variety	10.5%	*Synedra ulna*	11.4%
Diatoma tenue var elongatum	8.1%	*Tabellaria fenestrata*	10.5%
Planktolyngbya limnetica	6.3%	*Synedra acus*	9.6%
Aphanothece (saxicola?)	5.8%	*Eucocconeis flexella*	4.6%
Flagellates	5.3%	*Achnanthidium minutissima*	2.7%
Achnanthidium linearis	4.3%	*Aphanothece (saxicola?)*	2.4%
Synedra acus	3.7%	*Fragilaria spp.*	1.9%
Fragilaria spp.	1.9%	*Cyclotella stelligera*	1.7%

Table 3-4: Periphyton relative abundance and biovolume in the MCR in the spring from 2011 to 2012

2011				2012			
Relative abundance - dominant species	Relative Abundance (%)	Relative biovolume - dominant species	Relative Biovolume (%)	Relative abundance - dominant species	Relative Abundance (%)	Relative biovolume - dominant species	Relative Biovolume (%)
Synechoccocus sp.	24.6%	*Diatoma tenue var elongatum*	30.6%	*Synedra ulna sm variety*	15.3%	*Diatoma tenue var elongatum*	24.3%
Synedra ulna sm variety	14.3%	*Synedra ulna sm variety*	25.1%	*Aphanothece (saxicola?)*	12.7%	*Synedra ulna sm variety*	23.0%
Diatoma tenue var elongatum	11.8%	*Synedra acus*	6.7%	*Diatoma tenue var elongatum*	12.5%	*Synedra acus*	11.3%
Achnanthidium minutissima	9.2%	*Synedra ulna*	5.9%	*Achnanthidium minutissima*	11.0%	*Tabellaria fenestrata*	6.4%
Synechocystis sp.	7.9%	*Fragilaria spp.*	5.6%	*Anacystis cyanea*	8.3%	*Chroomonas acuta*	5.5%
Lyngbya sp.	6.4%	*Diatoma vulgare*	4.7%	*Chroomonas acuta*	6.7%	*Cladophora glomerata*	5.0%
Diatoma vulgare	4.0%	*Surirella ovata*	3.4%	*Chrysochromulina sp.*	5.1%	*Synedra ulna*	3.7%
Stichococcus minutissima	3.1%	*Tabellaria fenestrata*	3.0%	*Synedra acus*	4.6%	*Chrysochromulina sp.*	3.0%
Achnanthidium linearis	2.9%	*Stichococcus minutissima*	3.0%	*Planktolyngbya limnetica*	3.7%	*Aphanothece (saxicola?)*	3.0%
Fragilaria spp.	2.7%	*Tabellaria flocculosa*	1.3%	*Synechocystis sp.*	2.4%	*Synedra nana*	1.9%

Growth metrics from the natural substrate samples are contrasted with the comparable Styrofoam artificial substrate samplers in Table 3-5. When cobble substrates are compared to adjacent artificial samplers, the inflation of growth metrics on the artificial substrates ranged from no difference to 4 times greater. Reach 3 artificial substrates had the lowest inflation at 1.1 to 2 times, while the Reach 4 samplers had a greater exaggeration of growth of 2 to 4 times. The long-term 6 month deployments of the artificial substrates were arguably closer to the incubation time of natural substrates, but the production metrics were even further apart. It is important to note that the number of natural substrate samples collected was too small for a statistical comparison with artificial substrate. The differences in production metrics between natural and artificial substrates might be smaller in the area wetted by minimum flows, but natural substrates from this area could not be sampled in 2012.

Table 3-5: Periphyton production metrics from natural substrate and artificial substrates sampled in the MCR upper varial zones of Reach 3 and Reach 4 during the fall 2012.

Upper varial zone, Fall 2012	Natural substrates				Artificial substrate MCR Styrofoam			
	R4 sand	R4 cobble	R3 sand	R3 cobble	R4 T5/T6 1.5	R3 T5/T6 1.5	R4 T5/T6 6	R3 T5/T6 6
incubation time	months	months	months	months	months	months	months	months
abundance cells/$cm^2 \times 10^5$	0.43	1.45	0.10	1.48	6.2	4.44	-	21.1
biovolume cm^3/m^2	0.024	0.148	0.024	0.21	0.57	0.24	-	1.66
chlorophyll-a ug/cm^2	0.014	0.135	0.018	0.184	0.27	0.13	0.35	0.42
Number of samples	3	3	3	3	6	6	1	3

Table 3-6: Summary statistics for periphyton in the Mid Columbia River in the fall from 2007 to 2012.

Diversity Measures	Statistics	2007	2008	2009	2010	2011	2012
Abundance cells/cm^2	Sample Size	19	24	25	37	49	42
	Mean	1.25E+06	4.98E+05	7.05E+05	4.18E+05	5.88E+05	2.73E+05
	Median	1.23E+06	4.87E+05	7.37E+05	4.17E+05	5.89E+05	2.21E+05
	Minimum	2.51E+05	1.91E+05	9.86E+04	1.92E+04	1.13E+05	1.70E+04
	Maximum	2.06E+06	8.38E+05	1.33E+06	1.20E+06	1.13E+06	8.23E+05
Species Richness # of species	Sample Size	19	24	25	37	49	42
	Mean (±SD)	9.84 ± 2.06	18.33 ± 3.55	17.72 ± 3.34	20.76 ± 7.68	22.90 ± 6.10	19.33 ± 6.83
	Median	9	18	18	23	23	19.5
	Minimum	7	13	11	3	10	4
	Maximum	15	25	25	35	37	30
Biovolume microns/cm^2	Sample Size	NA			37	49	47
	Mean				3.78E+08	3.12E+08	9.80E+07
	Median				3.31E+08	2.80E+08	6.10E+07
	Minimum				5.29E+06	1.55E+07	3.40E+05
	Maximum				9.80E+08	7.86E+08	4.20E+08
Simpson's Index	Sample Size	19	24	25	37	49	42
	Mean (±SD)	0.66 ± 0.11	0.81 ± 0.05	0.84 ± 0.02	0.82 ± 0.12	0.82 ± 0.07	0.80 ± 0.09
	Median	0.69	0.82	0.85	0.84	0.84	0.82
	Minimum	0.35	0.63	0.81	0.31	0.58	0.39
	Maximum	0.78	0.86	0.89	0.92	0.91	0.90
Chlorophyll-a ug/cm^2	Sample Size	19	26	25	37	49	42
	Mean (±SD)	1.43 ± 0.75	0.86 ± 0.43	0.93 ± 80	1.03 ± 0.85	0.76 ± 0.42	0.49 ± 0.46
	Median	1.32	0.84	0.59	0.79	0.68	0.4
	Minimum	0.79	0.02	0.05	0.04	0.09	0.003
	Maximum	4.1	1.8	2.87	2.96	1.68	2.06
Autotrophic Index	Sample Size	NA			37	49	39
	Mean (±SD)				1395.2 ± 2384.3	820.1 ± 1328.7	1569 ± 2236.8
	Median				549.0	525.0	944.5
	Minimum				135.0	214.0	250.8
	Maximum				12438.0	9605.0	1356.1
Ash-free Dry Weight mg/cm^2	Sample Size	NA			37	49	39
	Mean (±SD)				4.89 ± 3.26	2.94 ± 3.85	1.82 ± 1.26
	Median				4.47	1.64	1.36
	Minimum				1.05	0.66	0.52
	Maximum				17.14	17.74	6.25

Table 3-7: Summary statistics for periphyton in the Mid Columbia River in the spring from 2011 to 2012.

Diversity Measures	Statistics	2011	2012
Abundance cells/cm^2	Sample Size	48	47
	Mean (±SD)	2.70E+05	2.54E+05
	Median	2.03E+05	2.66E+05
	Minimum	2.68E+04	2.16E+04
	Maximum	1.23E+06	5.78E+05
Species Richness # of species	Sample Size	48	47
	Mean (±SD)	12.48 ± 4.25	16.75 ± 5.74
	Median	13	17
	Minimum	5	2
	Maximum	21	31
Biovolume microns/cm^2	Sample Size	48	47
	Mean (±SD)	1.18E+08	1.36E+08
	Median	5.49E+07	1.08E+08
	Minimum	1.22E+06	4.43E+06
	Maximum	8.97E+08	8.70E+08
Simpson's Index	Sample Size	48	47
	Mean (±SD)	0.76 ± 0.12	0.76 ± 0.14
	Median	0.817243631	0.791990225
	Minimum	0.349091144	0.036132335
	Maximum	0.876338644	0.905108631
Chlorophyll-a ug/cm^2	Sample Size	48	47
	Mean (±SD)	0.16 ± 0.22	0.19 ± 0.21
	Median	0.05	0.11
	Minimum	0.003	0.002
	Maximum	1.05	0.81
Autotrophic Index	Sample Size	48	47
	Mean (±SD)	43920 ± 74717	39861 ± 118938
	Median	10383	4390
	Minimum	691	270
	Maximum	377782	776265
Ash-free Dry Weight mg/cm^2	Sample Size	48	47
	Mean (±SD)	9.28 ± 12.11	4.70 ± 6.92
	Median	4.435	2.583333334
	Minimum	1.16	0.882352941
	Maximum	62.24	44.44444444

All metrics of periphyton production collected showed high annual variations due to flow management (Table 3-6). Differentiating the effects of minimum flows from other operational effects of flow management and were not tested statistically across reach, site or transect due to the strong effects of submergence in production models. However, observable differences were apparent. For instance, abundance for combined data across reaches ranged from a minimum of 2.73E+05 cells/cm^2 in 2012 to a maximum of 1.25E+06 cells/cm^2 in 2007. Chlorophyll-a, abundance, and biovolume all follwed similar trends and were correlated. The minimum chl-a was 0.49 ± 0.46 ug/cm^2 in 2012 and the maximum was 1.43 ± 0.75 ug/cm^2 in 2007. The decrease in abundance in 2012 corresponded with extremely high flows due to high snow pack and increased use of REV 5. Similarly, ash-free dry weight (AFDW provides an estimate of all components of the biofilm) decreased sharply from 4.47 mg/cm^2 in 2010 to 1.64 and 1.36 mg/cm^2 in 2011 and 2012, respectively. All trends observed appeared to be more associated with annual patterns and operation than specifically from pre and post implementation of minimum flows.

Species diversity and Simpson's index indicated that biodiversity in the MCR was lower than in other large rivers (Tables 3-6 and 3-7 versus Table 4-1). An oligotrophic or stressed river is expected to have <20 – 40 species (Table 4-1). Diversity was lowest at 9.84 ± 2.1 species in the fall of 2007 and was relatively stable at 17.72 ± 3.3 to 22.90 ± 6.1 species in 2008 – 2012. Some of the differences in species diversity may reflect use of a different taxonomist in the periods from 2007 - 2009 and 2010 through 2012. Overall, Simpson's index did not vary much from pre and postt implementation of REV 5 and minimum flows.

Table 3-7 provides similar summary statistics for MCR spring periphyton samples from 2011 and 2012. In all cases, estimates of spring production were lower than those from the corresponding fall, with abundance ranging from 2.54E+05 cells/cm^2 in 2012 and 2.70E+05 cells/cm^2 in 2011. Average chlorophyll-a was also much lower in the spring and ranged from 0.16 – 0.19 ug/cm^2 while the fall ranged from 0.49 – 0.76 ug/cm^2. Spring species richness was also low, ranging from 13 to 17 species, suggesting an oligotrophic or stressed river environment. The autotrophic index in the spring samples was much higher than the fall samples, indicating a greater proportion of non-photosynthetic organic matter including detritus, decomposer bacteria and fungi.

When Arrow Lakes Reservoir backwaters the MCR, substrates remain submerged even when volumes released from Revelstoke dam are low. This water cover should reduce the mortality that would have occurred if the backwatered substrates were exposed. Backwatering of R3 occurred from May through September and into R4 during the summer months of 2010, 2011 and 2012 (Figure 3-6). The spring deployments occurred at the lowest Arrow Lakes Reservoir levels and ended when backwatering was just starting, while the fall deployment commenced as backwatering declined. The time-series data demonstrated that the hydrologic regime in the preceding week is of greater importance to periphyton production than events that occurred further in the past, therefore, the fall data should give us the best insight into the effects of backwatering on R3 productivity. For example in 2011 and 2012 data, the backwatered T5 positions averaged 0.44 ug/cm^2 in R3, compared to 0.41 ug/cm^2 chl-a in R4. In the more exposed T6 positions, the difference between R3 and R4 periphyton production was greater at 0.482 ug/cm^2 in R3 and 0.154 ug/cm^2 chl-a in R4. Further, the upper varial zone did not benefit from backwatering as much in 2012 as in 2011, perhaps because of the larger and more frequent peak flows in that year. T5/T6 abundance and chl-a metrics from 2012 were both half or less of the 2011 metric. The R3 upper varial zone (T5/6) benefitted from backwatering as opposed to exposure during low flows. The effects of backwatering are accounted for by our statistical models because they consider duration and timing of submergence.

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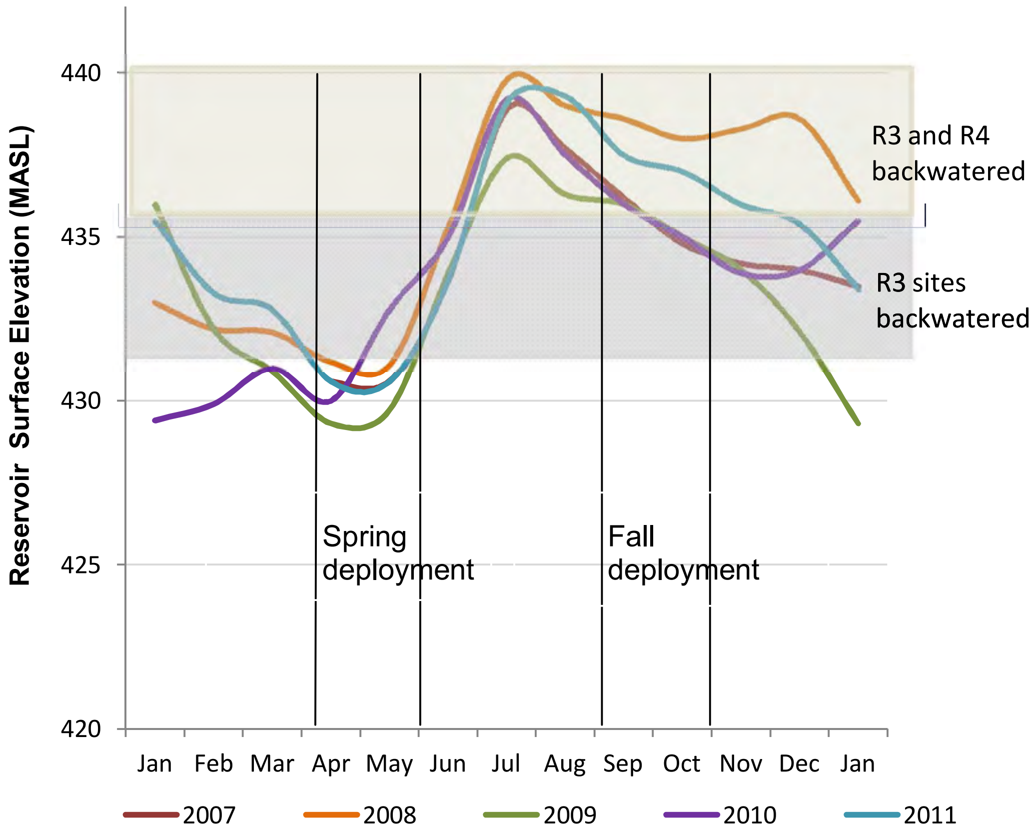

Figure 3-6: Backwatering of Arrow Lakes Reservoir (ALR) into MCR Reach 3 and Reach 4 with the spring and fall sampler deployment periods marked. The vertical axis shows elevations in the normal operating range of ALR **(Derived from Golder, 2012)**

In an effort to understand the effects of turbidity on light penetration into deep water and backwater, turbidity and TSS data were collected during the 2012 deployments. At the moderate turbidity levels found in MCR, light penetration to the varial zone substrates would not have hindered photosynthesis during backwatering (ENSR, 2001). However, light penetration through deeper water in the mid-channel permanently wetted areas would be reduced enough to influence periphyton production (Tables 3-2 and 3-6).

Both backwatering and high flow events can move benthic species to new substrate locations. The permanently wetted area can function as a source of organisms to re-colonize exposed habitat areas after catastrophic flow events.

Table 3-8: Summary statistics for periphyton in the Mid Columbia River in the fall across the river channel, 2007 - 2012. Transects start at mid channel (T1) and move to floodplain areas that are infrequently wetted (T7).

Diversity Measures	Statistics	T1	T2	T3	T4	T5	T6	T7
Abundance cells/cm^2	Sample Size	47	24	47	26	26	22	4
	Mean	6.42E+05	4.88E+05	7.66E+05	5.92E+05	4.30E+05	1.99E+05	5.23E+04
	Median	5.71E+05	5.37E+05	6.43E+05	5.25E+05	3.81E+05	1.29E+05	2.53E+04
	Minimum	1.99E+04	1.70E+04	1.66E+05	1.08E+05	7.30E+04	2.44E+04	1.92E+04
	Maximum	2.06E+06	9.43E+05	1.95E+06	1.20E+06	1.02E+06	7.10E+05	1.40E+05
Species Richness # of species	Sample Size	47	24	47	26	26	22	4
	Mean (±SD)	18.7 ± 7.21	23.5 ± 6.12	18.77 ± 6.16	22.70 ±5.17	19.04 ± 5.53	14.54 ± 5.35	9.75 ± 9.75
	Median	19	24	20	23	19	14	6
	Minimum	6	4	7	14	10	7	3
	Maximum	37	34	30	35	28	31	24
Biovolume microns/cm^2	Sample Size	21	22	18	20	20	20	4
	Mean	3.00E+08	2.77E+08	3.48E+08	3.65E+08	2.47E+08	9.83E+07	2.69E+07
	Median	2.62E+08	2.23E+08	3.14E+08	2.98E+08	1.96E+08	3.04E+07	2.50E+07
	Minimum	7.61E+05	3.40E+05	3.33E+07	2.46E+07	1.68E+07	8.31E+06	5.29E+06
	Maximum	7.86E+08	9.80E+08	9.54E+08	9.65E+08	7.32E+08	4.94E+08	5.23E+07
Simpson's Index	Sample Size	47	24	47	26	26	22	4
	Mean (±SD)	0.80 ± 0.09	0.82 ± 0.11	0.78 ± .11	0.84 ± 0.07	0.83 ± 0.04	0.79 ± 0.09	0.65 ± 0.28
	Median	0.83	0.85	0.82	0.85	0.84	0.83	0.68
	Minimum	0.54	0.39	0.35	0.63	0.74	0.58	0.31
	Maximum	0.91	0.92	0.89	0.90	0.90	0.89	0.92
Chlorophyll-a ug/cm^2	Sample Size	47	24	47	26	26	22	4
	Mean (±SD)	1.04 ± 0.59	1.12 ± 0.72	0.96 ± 0.61	0.71 ± 0.60	0.43 ±0.38	0.39 ± 0.58	0.20 ± 0.27
	Median	1.11	0.97	0.70	0.56	0.38	0.19	0.08
	Minimum	0.02	0.00	0.40	0.13	0.05	0.05	0.04
	Maximum	2.56	4.09	2.96	2.35	1.74	2.48	0.61
Autotrophic Index	Sample Size	21	22	18	20	20	20	4
	Mean (±SD)	1202 ± 2363	587 ± 995	616 ± 326	780 ± 603	1157 ± 779	2012 ± 2766	6178 ± 5239
	Median	474	452	539	532	906	1350	5993
	Minimum	135	260	178	225	251	284	291
	Maximum	9605	1988	1674	2160	2724	13057	12438
Ash-free Dry Weight mg/cm^2	Sample Size	21	22	18	20	20	20	4
	Mean (±SD)	4.81 ± 5.09	3.88 ± 3.11	2.20 ± 1.89	2.28 ± 2.13	1.92 ± 1.30	2.68 ± 2.03	8.01 ± 6.39
	Median	2.28	2.50	1.65	1.58	1.65	1.89	6.54
	Minimum	0.97	0.61	0.96	0.91	0.52	0.74	2.16
	Maximum	17.74	11.19	9.23	10.53	6.19	8.85	17.14

Table 3-9: Summary statistics for periphyton in the Mid Columbia River in the spring across the river channel 2011 - 2012. Transects start at mid channel (T1) and move to floodplain areas that are infrequently wetted (T7).

Diversity Measures	Statistics	T1	T2	T3	T4	T5	T6
Abundance cells/cm^2	Sample Size	21	16	15	15	14	14
	Mean	3.99E+05	4.17E+05	2.63E+05	1.78E+05	1.26E+05	1.07E+05
	Median	3.45E+05	3.62E+05	2.15E+05	1.65E+05	9.95E+04	7.31E+04
	Minimum	6.44E+04	9.33E+04	9.50E+04	7.11E+04	2.98E+04	2.16E+04
	Maximum	1.23E+06	9.04E+05	6.28E+05	2.89E+05	3.77E+05	3.20E+05
Species Richness # of species	Sample Size	21	16	15	15	14	14
	Mean (±SD)	16.24 ± 4.88	18.69 ± 5.18	17.27 ± 4.13	13.73 ± 4.56	10.5 ± 3.37	9 ± 2.72
	Median	17	18	18	12	10	9
	Minimum	2	11	10	6	5	5
	Maximum	26	31	23	23	16	14
Biovolume microns/cm^2	Sample Size	21	16	15	15	14	14
	Mean	2.08E+08	2.13E+08	1.13E+08	4.80E+07	1.02E+08	1.42E+07
	Median	2.E+08	2.E+08	1.E+08	4.E+07	2.E+07	1.E+07
	Minimum	2.E+07	4.E+06	1.E+07	1.E+07	6.E+06	1.E+06
	Maximum	9.E+08	8.E+08	2.E+08	2.E+08	9.E+08	5.E+07
Simpson's Index	Sample Size	21	16	15	15	14	14
	Mean (±SD)	0.79 ± 0.18	0.81 ± 0.07	0.82 ± 0.05	0.72 ± 0.14	0.72 ± 0.10	0.69 ± 0.10
	Median	0.84	0.83	0.83	0.74	0.75	0.70
	Minimum	0.04	0.61	0.70	0.35	0.52	0.45
	Maximum	0.89	0.89	0.91	0.87	0.87	0.86
Chlorophyll-a ug/cm^2	Sample Size	21	16	15	15	14	14
	Mean (±SD)	0.35 ± 0.24	0.29 ± 0.21	0.20 ± 0.18	0.07 ± 0.10	0.02 ± 0.02	0.01 ± 0.01
	Median	0.35	0.21	0.13	0.03	0.02	0.01
	Minimum	0.07	0.06	0.01	0.01	0.00	0.00
	Maximum	1.05	0.81	0.49	0.38	0.07	0.05
Autotrophic Index	Sample Size	21	16	15	15	14	14
	Mean (±SD)	3297 ± 4865	4898 ± 1676	8982 ± 3047	24911 ± 27108	65746 ± 55523	171520 ± 201603
	Median	1532	1677	3046	18027	52113	111189
	Minimum	270	291	477	921	4229	15111
	Maximum	23513	44061	56857	88543	223687	776265
Ash-free Dry Weight mg/cm^2	Sample Size	21	16	15	15	14	14
	Mean (±SD)	6.13 ± 7.91	6.16 ± 10.83	4.89 ± 9.46	5.89 ± 5.42	11.68 ± 16.43	8.13 ± 8.96
	Median	3.11	2.50	1.96	3.71	5.83	4.79
	Minimum	1.25	1.56	1.00	1.33	0.88	1.25
	Maximum	36.59	44.44	37.51	21.31	62.24	32.68

Tables 3-8 and 3-9 provide summary statistics for periphyton in the MCR across the river channel at the different transect locations for all studied years. Transects start within the thalweg at T1 sampler positions and move through the zone covered by minimum flows at T2, near the edge of the channel wetted by minimum flows. Transect sampler positions T3 through T7 experienced increasing intervals of exposure. T3 through T4 represent the frequently wetted lower varial areas, and transition to upper varial areas that were infrequently wetted at transect T5 through T7 positions. Average periphyton productivity decreased with increasing exposure as the sampler positions progress from T1/T2 through T5/T6. Interestingly, measures of productivity in lower varial zone areas (T3/T4 locations) were similar to those in permanently submerged habitat areas (T1/T2 locations). Species richness ranged from 18.7 ± 7.2 to 23.5 ± 6.1 in the permanently wetted zone to 9.75 ± 9.7 to 19.04 ± 5.5 species in the frequently dewatered zones during the fall. In both the spring and fall, the highest biodiversity was observed at T2 which was permanently wetted but typically had lower velocities and subsequently less shear than the T1 sampler positions.

Ash-free dry weight (volatile solids) samples were indicative of a moderately productive river, with the highest fall periphyton productivity occurring at T1 samplers (4.81 ± 5.1 mg/cm^2). Samplers in the floodplain T7 positions had high AFDW of 8.01 ± 6.4 mg/cm^2, because large amounts of organic detritus accumulated at these locations.

Chlorophyll-a and AFDW provide complementary information that can be combined as a ratio into the autotrophic index (Weber 1973). The autotrophic index is indicative of the proportions of the periphyton community composed of heterotrophic (fungi, yeasts, bacteria, protozoa) and autotrophic (photosynthetic bacteria and algae) organisms (Biggs and Murray 1989; APHA 1995; Biggs and Kilroy 2000; Yamada and Nakamura 2002; Runion 2011). In both reaches, samplers in the permanently wetted and lower varial zone T1 through T3 had greater autotrophic production from periphyton than frequently exposed samplers that showed increasing heterotrophic dominance (i.e., sites dominated by decomposer microflora and non-viable organic materials such as dead cells and detritus).

There were similar patterns of abundance and productivity among depths between spring and fall, but with much lower overall production (Tables 3-9 and 3-10): chl-a concentrations decreased from T1 through T6, indicating that production decreased with increasing exposure. The AFDW was higher in the spring than the fall, indicating that the biofilm had a higher percentage of non-photosynthetic organic material such as dead diatoms, decomposers and organic detritus.

3.2.6 Periphyton Accrual

Time series chlorophyll-a data has been collected since 2009, while time series species abundance and biovolume were collected since 2010 (Schleppe et al, 2010). Only chl-a accrual data was considered here because it is a standard measure of production, it is available for the longest period, and it is highly correlated with abundance and biovolume in MCR data (see Schleppe et al, 2011).

The focus of time series collections is to understand the rates of periphyton accrual and any potential differences that may exist between permanently submerged areas and those that are within the varial zone. In 2010, samplers were deployed across transects at positions from T1 through T7 and accrual rates were very complex in response to rapid flow changes, weather during dewatered periods, and varying degrees of exposure. To address the high variance, samplers were deployed at T1 and T3/T4 locations from 2011 onwards, simulating permanently submerged areas, and those just exposed at minimum flow. Time series samplers are considered to be only representative of T3/T4 locations because they cannot be accurately placed, retrieved, and re-deployed at a same location during sample collections. Time series samples collected within the varial zone area are therefore considered to be representative of accrual in the varial zone rather than a discrete sampling location such as T3.

An ANCOVA was used to analyze chl-a accrual at the T1 and T3/T4 locations within the channel for data across all years. There was a difference in periphyton chl-a accrual rates between T1 locations in the deep water and T3/T4 locations in the lower varial zone just above the area wetted by minimum flows in the fall (Figure 3-7). Accrual was much faster in the permanently wetted T1 zone than it was in the lower varial zone represented by T3.

Spring trends were similar to the fall and suggest that there were differences between T1 and T3/T4, although the differences were not as apparent as in the fall. Additionally, spring chl-a accrual was significantly slower than the fall chl-a accrual rate (Figure 3-7).

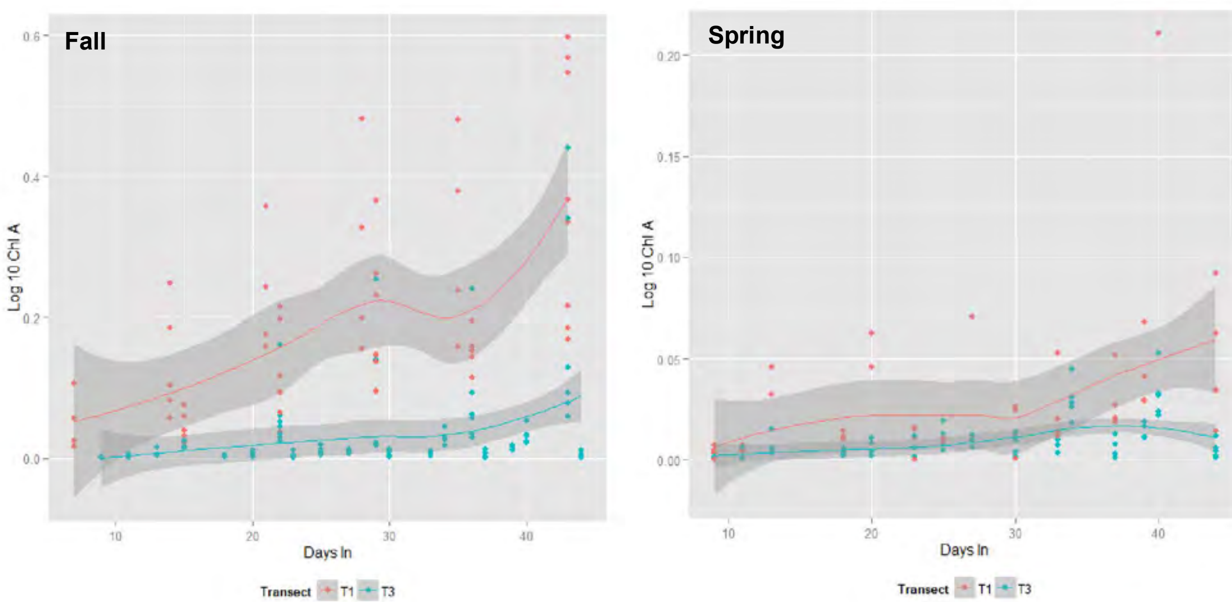

Figure 3-7: Regressions (with 95% confidence intervals (grey shade)) of days of submerged and chlorophyll-a at transect T1 and T3/T4, 2009-2012. Transect T1 and T3 are statistically different ($p<0.001$) for both spring and fall. Fitted lines were generated using a locally weighted polynomial regression method (LOWESS).

Spring and fall chl-a accrual at T1 locations did not show a plateau typical of peak biomass, but rather suggested that chl-a continued to accrue beyond the incubation time. This is supported by samplers that were incubated in the MCR for 6 months (Schleppe et al., 2011). The variable flow regime and resultant variations in submergence times between years for time series sampler data has not been accounted for in this analysis, but despite this analytical concern, the data still strongly suggests that differences in periphyton accrual exist between T1 and T3/T4 (Figure 3-7).

3.2.7 Periphyton Community Groupings

Community analyses of the full 2007 – 2011 data were completed at the species level in 2011 and indicated that communities could be grouped by year and season (see Schleppe et al, 2012, and Figure 3-8). In this summary report for 2012, the full community dataset was also analyzed, but at the family level. Using the family level (two taxonomic levels higher in the data set), reduced the potential effects of taxonomist and the effects of rare species, allowing focus on large scale trends. Ward/Bray cluster analyses of family data indicated there were potentially 4 or 5 plausible groupings of data (See Appendix A-1). No trends by year (Year (ANOSIM, R: 0.46, p = 0.56), season (Season ANOSIM, R: 0.03, p = 0.09), or transect (Transect ANOSIM, R: 0.002, p = 0.41)) were observed. NMDS analysis (stress = 0.22) of the five groups at the family level indicated high levels of overlap between sites.

NMDS results suggest that at the species level, there is high inter-annual and seasonal variation, with potential effects of either implementation of minimum flow, operational flow patterns, or taxonomist. However, at higher taxonomic levels of identification, there does not appear to be significant groupings of data by implementation of minimum flow, year, season or transect. Over the sample period, large-scale shifts in periphyton communities are not occurring but rather differences are localized to differences at lower taxonomic levels. Despite the differences in taxonomist potentially accounting for some of the difference observed between years, it is suspected that annual operational patterns affect the periphyton community because these operational patterns create specific habitat conditions that may favour different species between years.

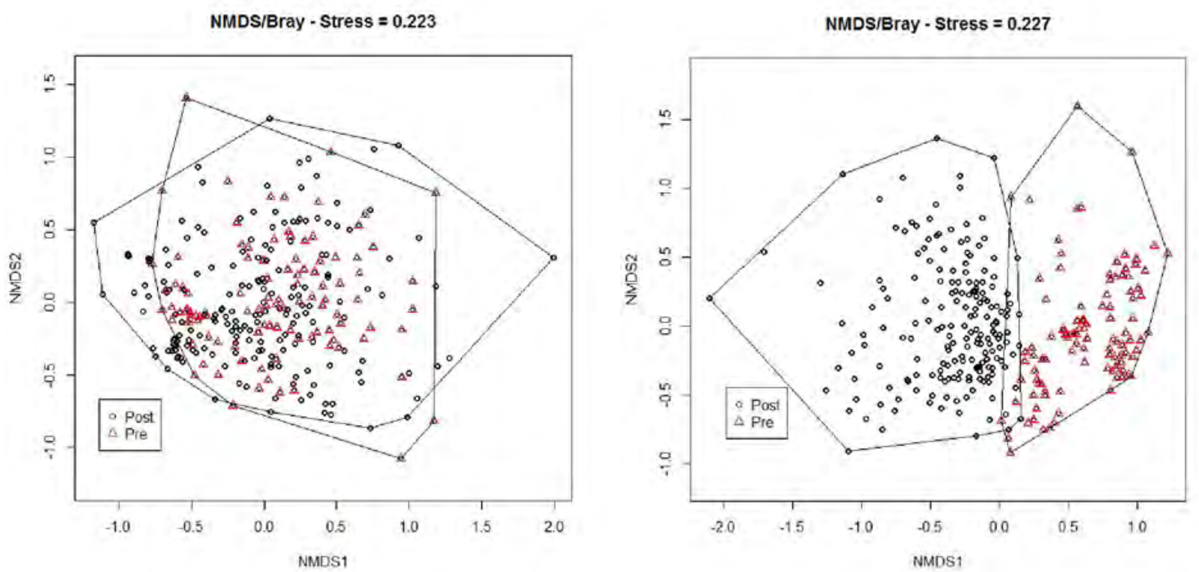

Figure 3-8: NMDS of periphyton abundance at the family level (left) and species level (right) grouped by Pre and Post implementation of minimum flow for data collected between 2007 and 2012.

3.2.8 Periphyton Production Models

Model averaging data indicated that there were numerous plausible models (those with an AICc<2.0) for abundance (13), biovolume (5), Chl-a (3), and Autotrophic Index (4) (Table 3-10). Several key and significant trends were observed across all measures of production, most notably that total incubation time in the water during daylight hours was an important predictor for abundance, biovolume, and chl-a. Other key predictors were maximum cumulative submergence, mean temperature, frequency of 12 hour submergence events, and velocity at the sampler.

Total incubation time in light and water, and mean temperature were the most important parameters predicting periphyton abundance (Table 3-10 and Figure 3-9). Periphyton abundance increased with temperature to about 10^{o}C, before decreasing at higher average temperatures that were indicative of increased exposure (Figure 3-9). The total time incubating in the light and water was positively correlated with abundance. Generally, samplers that were submerged for at least 400 hours in the light and water over the deployment time were the most productive (~9 hours per day in the light and water). Samplers in the permanently submerged T1/T2 areas and areas in the varial zone between T3 and T4 were generally the most productive because they spent more time submerged during daylight hours than the T5 –T7 positions. Other important parameters predicting periphyton abundance included water velocity over the sampler and submergence ratio. Periphyton abundance generally decreased with increasing river velocity. This all suggests that periphyton abundance is correlated with measures of submergence, physical parameters (e.g., velocity and mean temperature) or variables describing exposure (e.g., mean temperature).

Mean temperature (plus Mean Temp Squared) was the most important predictor of periphyton biovolume in 2010-2012 (Table 3-10 and Figure 3-10). Biovolume increased to about 10 $^{\circ}$C and then decreased at higher temperatures that indicated increasing exposure. Cell biovolume was also positively associated with total incubation time in the light and water (Weight = 0.96), maximum cumulative submergence and potentially frequency of 12 hour submergence events. These trends were similar to abundance data, with peaks at a minimum of 400 hours of daytime submergence over the deployment period (~9 hours per day), a period of cumulative submergence of at least 100 hours, and at least forty, 12- hour submergence events (Figure 3-10).

As expected, chl-a results were similar to both abundance and biovolume data because chl-a is correlated with both abundance and biovolume. Mean water temperature and total production time were the most important predictors of chl-a using pooled data between 2010 and 2011 (Table 3-10 and Figure 3-11). The data suggests that production benefits most from a minimum of 400 hours submerged during daytime hours, with maximum cumulative submergence events of at least 150 hours, and submergence for at least 80% of the time (Figure 3-11).

Mean temperature and sampler velocity were the most important predictors of autotrophic index, indicated by their respective weights of 1.00 and 0.98 respectively. Similar to other measures of production, autotrophic index increased with temperature, before falling at higher temperatures indicative of exposure and autotrophic index decreased with sampler velocity (Table 3-10 and Figure 3-12). Frequency of 12 hour submergence events also appeared to be important, and with lower index values occurring at sites with a minimum of forty, 12 hour submergence events over deployment (i.e., submerged for 12 hours on most days).

All of the measures of production modelled corroborate submergence time as being one of the most important overall predictors of production. During periods of lower average daily flows and without ALR backwater, minimum flows increase the area of productive habitat. However, if BC Hydro operations create conditions of increased daytime periods of submergence or ALR backwatering, then the effects of minimum flow may lessened. These data all suggest that BC Hydro operations are directly linked to periphyton production within the MCR. More modelling is required to fully determine the specific links between BC Hydro daily operations the area of productive periphyton habitats..

Table 3-10: Multi model averaging results using Akaike information criterion approach for four measures of periphyton production and diversity (abundance, biovolume, chl-a, and autotrophic index) in the MCR. The total number of plausible models with an AICc<2 is shown in brackets next to the measure of production. The weight (w) of a predictor indicates the probability the predictor will occur in the AIC Best Model and predictors with a weight of 0.6 or higher are considered important. The occurrences data indicates the total number of predictor occurrences in the most plausible models or those with AICc<2. Bold indicates whether a predictor occurred in the AIC best model.

Model Predictors	Abundance (13)		
	Estimate (CC)	Weight (w)	# Occurrences in AICc<2 Models
mean_temp	**194.61**	**1.00**	**13**
tot_inc_time_water_light_hrs	**1.37**	**1.00**	**13**
sampler.velocity	**-7.22E+01**	**0.80**	**12**
sub_ratio	**-1.44E+03**	**0.67**	**9**
max_cum_sub_hrs	**-2.75E-01**	**0.63**	**8**
sub_ratio.sq	**1503.15**	**0.58**	**9**
Freq_Submer_.12.Hrs	**12.85**	**0.43**	**3**
mean_temp.sq	-4.10E+01	0.41	5
tot_inc_time_water_light_hrs.sq	1.48E-04	0.38	3
Freq_Submer_.12.Hrs.sq	**-4.13E-01**	**0.26**	**3**
sampler.velocity.sq	33.66	0.25	2
max_cum_sub_hrs.sq	2.62E-04	0.22	1

Model Predictors	Biovolume (5)		
	Estimate (CC)	Weight (w)	# Occurrences in AICc<2 Models
mean_temp	**7.93**	**1.00**	**5**
mean_temp.sq	**-3.98E-01**	**1.00**	**5**
tot_inc_time_water_light_hrs	**1.76E-03**	**0.96**	**5**
max_cum_sub_hrs	**-4.23E-04**	**0.95**	**5**
Freq_Submer_.12.Hrs	**0.01**	**0.68**	**4**
sub_ratio	-1.14E-01	0.53	1
sampler.velocity	0.10	0.37	1
tot_inc_time_water_light_hrs.sq	5.27E-07	0.26	1
Freq_Submer_.12.Hrs.sq	3.61E-04	0.25	1
max_cum_sub_hrs.sq	1.42E-07	0.23	0
sub_ratio.sq	1.10	0.17	0
sampler.velocity.sq	-7.32E-02	0.10	0

Model Predictors	Chl-a (3)		
	Estimate (CC)	Weight (w)	# Occurrences in AICc<2 Models
mean_temp	**4.00**	**1.00**	**3**
tot_inc_time_water_light_hrs	**2.24E-03**	**1.00**	**3**
mean_temp.sq	**-2.05E-01**	**0.96**	**3**
max_cum_sub_hrs	**-1.82E-03**	**0.80**	**3**
max_cum_sub_hrs.sq	**1.42E-06**	**0.72**	**3**
sub_ratio	**-1.83E+00**	**0.72**	**3**
sub_ratio.sq	**2.57**	**0.58**	**3**
Freq_Submer_.12.Hrs	-1.56E-02	0.42	0
tot_inc_time_water_light_hrs.sq	-2.71E-06	0.37	0
sampler.velocity	0.09	0.36	1
Freq_Submer_.12.Hrs.sq	5.11E-04	0.24	0
sampler.velocity.sq	-8.50E-02	0.12	0

Model Predictors	Autotrophic Index (4)		
	Estimate (CC)	Weight (w)	# Occurrences in AICc<2 Models
mean_temp	**-5.41E-01**	**1.00**	**4**
sampler.velocity	**-1.53E-01**	**0.98**	**4**
Freq_Submer_.12.Hrs	**-1.53E-02**	**0.82**	**4**
mean_temp.sq	0.08	0.44	1
max_cum_sub_hrs	2.72E-04	0.38	1
tot_inc_time_water_light_hrs	-6.35E-04	0.38	1
sub_ratio	-1.86E-01	0.36	0
sampler.velocity.sq	-4.42E-02	0.25	0
Freq_Submer_.12.Hrs.sq	7.26E-05	0.20	0
max_cum_sub_hrs.sq	-5.15E-07	0.12	0
sub_ratio.sq	0.31	0.09	0
tot_inc_time_water_light_hrs.sq	5.65E-07	0.09	0

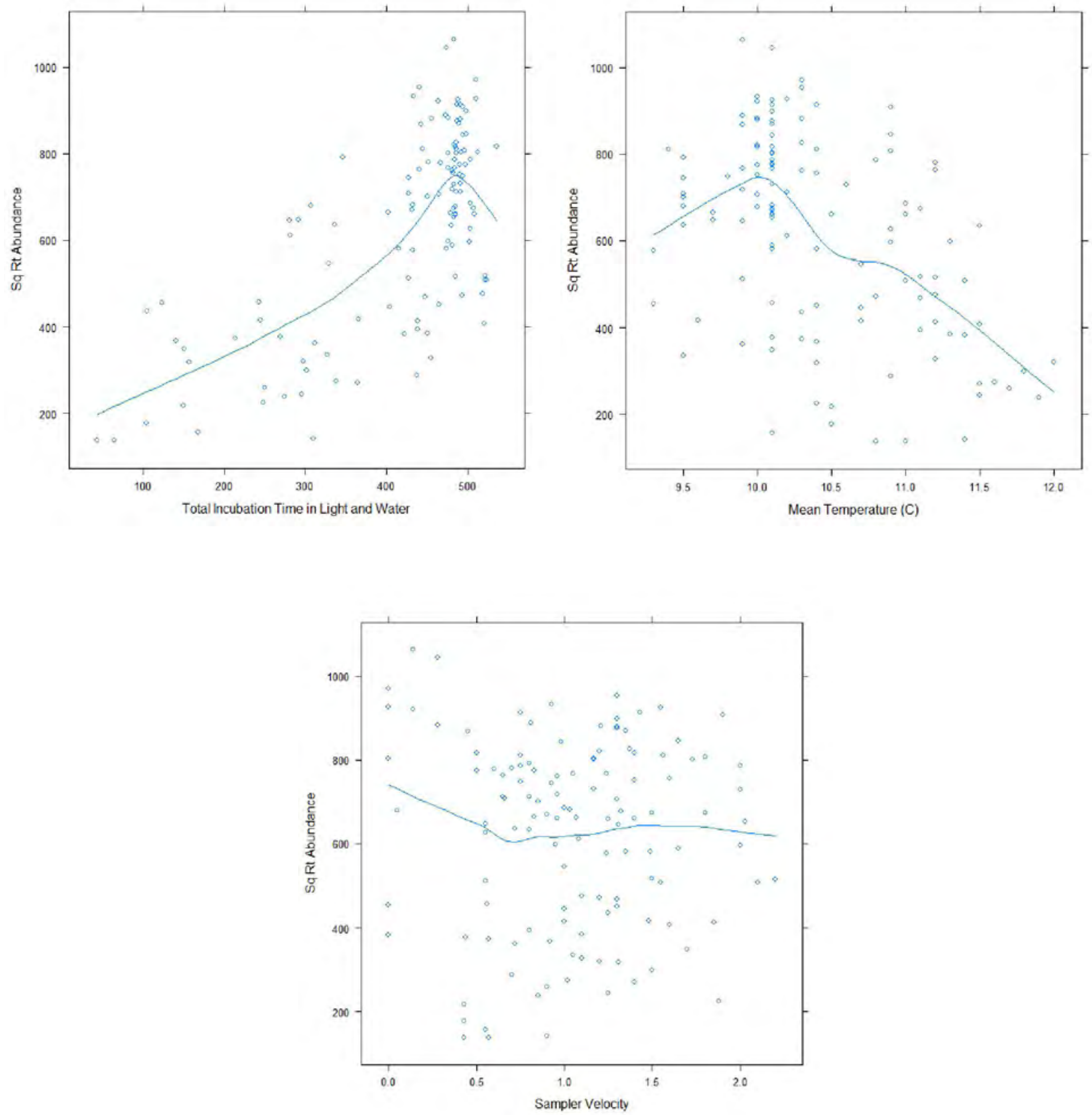

Figure 3-9: Single linear regressions of square root transformed periphyton abundance data with Total Incubation Time (Weight = 1.00), and Mean Temperature (weight = 1.00). Sampler velocity was also an important predictor of periphyton abundance (weight = 0.80). Fitted lines were significant and generated using a locally weighted polynomial regression method (LOWESS)

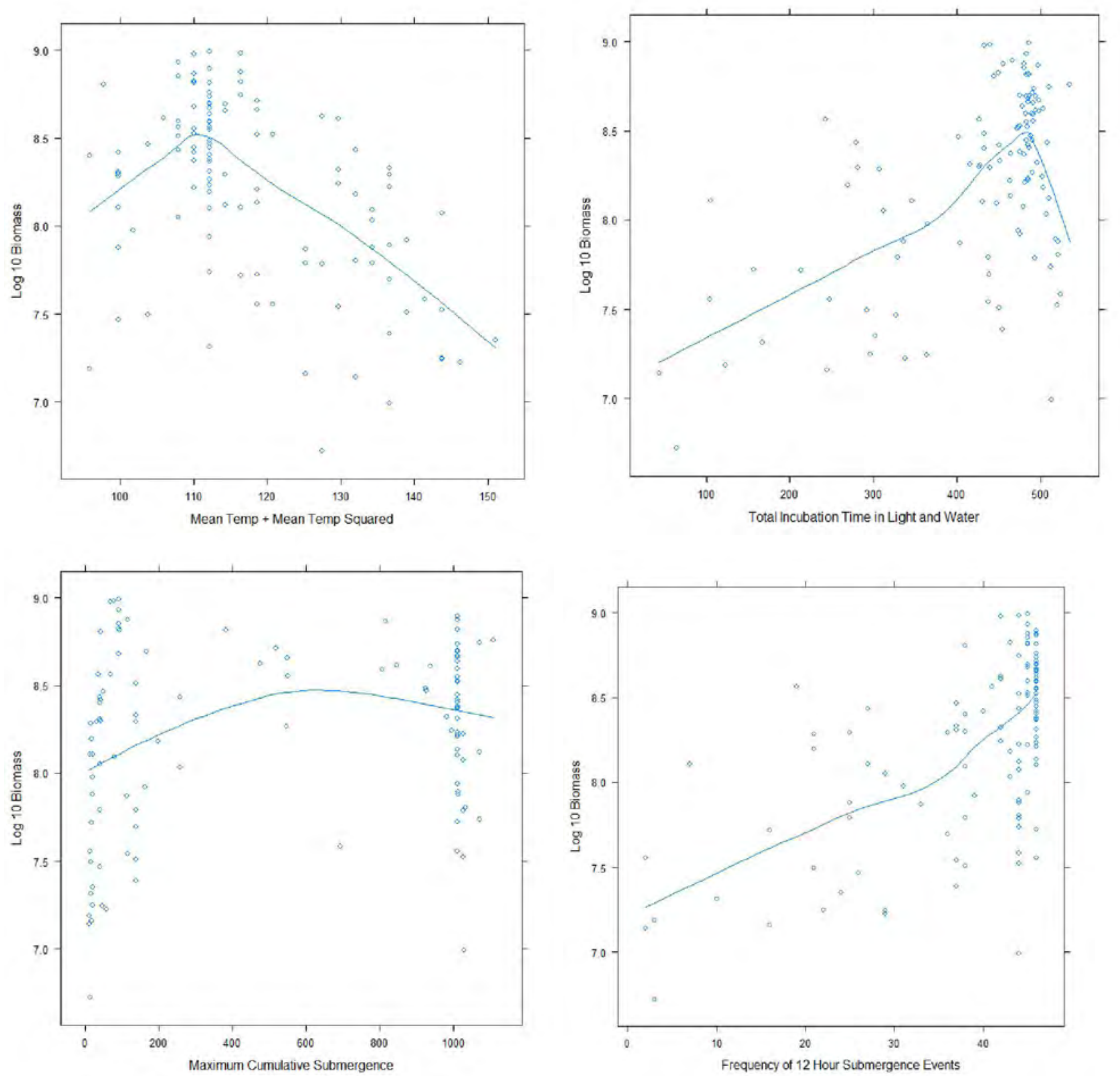

Figure 3-10: Single linear regressions of log transformed periphyton biovolume data and Mean Temperature + Mean Temperature Squared (weight =1.0), Total Incubation Time (weight = 0.96) , Maximum Cumulative Submergence (weight = 0.95 and frequency of 12-hour submergence events (weight = 0.68). Fitted lines were significant and generated using a locally-weighted polynomial regression method (LOWESS)

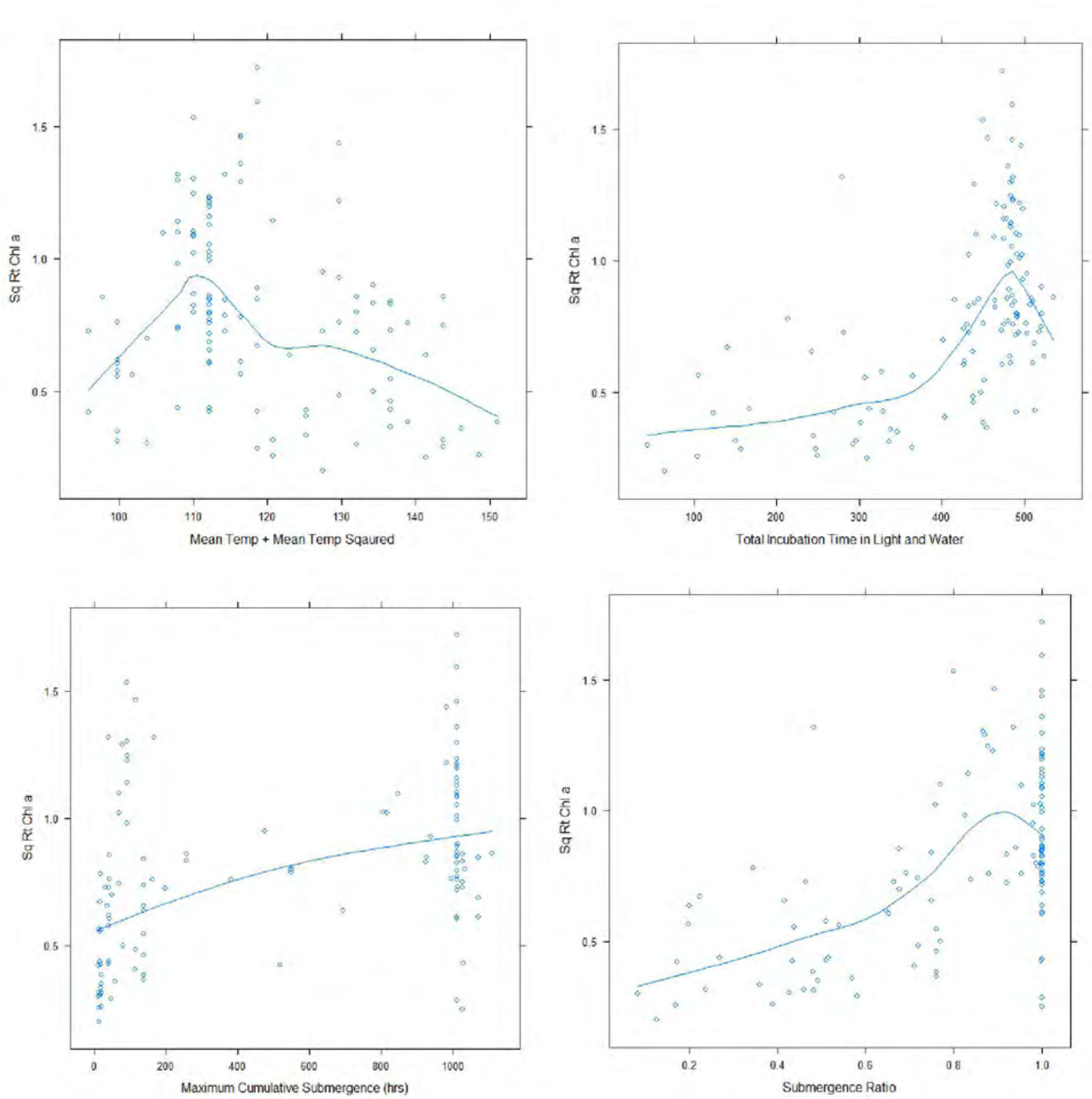

Figure 3-11: Single linear regressions of square root transformed periphyton chl-a data and total incubation time in the light and water (weight =1.00), Mean Temperature (weight = 1.00) plus Mean Temperature Squared (weight =0.96), maximum cumulative submergence time (weight = 0.8) and submergence ratio (weight = 72). Fitted lines were significant and generated using a locally weighted polynomial regression method (LOWESS)

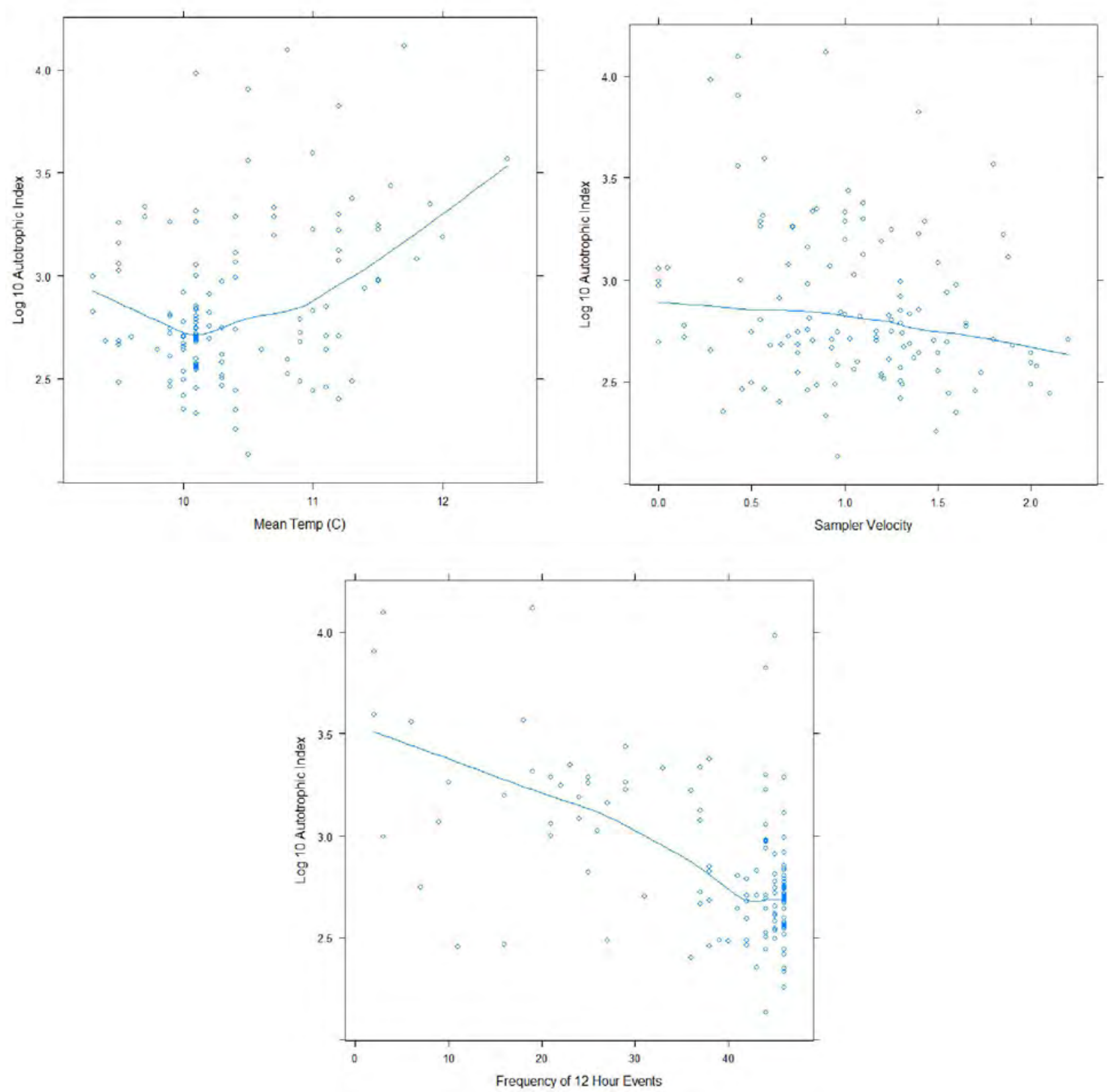

Figure 3-12: Single linear regressions log transformed periphyton autotrophic index data and Sampler Velocity (weight =0.98), Mean Temperature (weight = 1.00), and Frequency of 12 hour submergence events (weight =0.82). Lower autotrophic index values indicate a predominance of autotrophic organisms. Fitted lines were significant and generated using a locally weighted polynomial regression method (LOWESS).

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 level of identification (species). Generally, members of *Hydra* sp. and Chironomidae were the most abundant, accounting for over 65% of the total abundance in all years studied. When present, although not as numerically abundant, members of the EPT taxonomic groups typically had high relative biomass compared to their relative abundance (Table 3-12). These trends were consistently observed in both spring and fall data (Table 3-11). In most samples, less than 10 species made up over 98% of the total abundance or biomass at any sampling location.

Abundance, biomass, species richness, percent EPT, percent Chironomidae, Simpson's Index, and Hilsenhoff index were highly variable between years. Benthic invertebrates were usually more abundant in the fall than in spring. Trends with flow, season, or year were not readily apparent. Chironomidae were much more prevalent than EPT taxa, and accounted for at least 30% of the total abundance in the spring or fall at any site. EPT taxa were most prevalent in 2012, when they accounted for at least 4% of the total abundance in both the spring and fall. Greater abundance of EPT taxa corresponded with years of higher average flow and were indicative of increased submergence within varial zone areas.

Abundance, biomass and percent EPT of benthic invertebrates was greatest at mid-channel T1 through lower varial zone T3 locations (Table 3-15 and Table 3-16). Species richness, Simpson's Index, and Hilsenhoff's Index (HBI) were similar between years, but more variable across the river transect. T1 locations had the lowest HBI values, indicative of a higher prevalence of the more sensitive EPT taxa, while other diversity measures were more consistent across the highly exposed sites at T4 through T7..

Table 3-11: Relative abundance and relative biomass of benthic invertebrates in the fall of each year from 2007 to 2012.

Species	2007 Relative Abundance (%)	2007 Relative Biomass (%)	Species
Heterotrissocladius sp.	45.5%	46.5%	*Hydra sp.*
Hydra sp.	34.0%	21.7%	*Orthocladius complex*
Chaetogaster sp.	6.6%	10.1%	*Nais sp.*
Enchytraeidae	2.9%	4.5%	Torrenticolidae
Torrenticolidae	2.3%	3.5%	Chironomidae
Diamesa sp.	1.9%	3.0%	Enchytraeus
Chironomidae	1.3%	1.6%	*Ecclisomyia sp.*
Drunella sp.	1.1%	1.5%	Hymenoptera (Adults)
Procladius sp.	0.9%	1.5%	*Lymnaea sp.*
Hydrozetes sp.	0.8%	1.4%	*Simulium sp.*

Species	2008 Relative Abundance (%)	2008 Relative Biomass (%)	Species
Hydra sp.	65.0%	76.5%	*Hydra sp.*
Orthocladiinae	16.6%	5.3%	Enchytraeus
Chaetogaster sp.	4.3%	3.3%	*Lymnaea sp.*
Enchytraeidae	2.8%	3.2%	Orthocladiinae
Procladius sp.	2.5%	3.0%	Torrenticolidae
Torrenticolidae	2.2%	2.7%	*Nais sp.*
Tanytarsus sp.	1.3%	1.6%	*Drunella grandis*
Rheotanytarsus sp.	0.9%	0.7%	Pseudocaeciliidae
Cricotopus sp.	0.9%	0.6%	Thienemannimyia group
Epeorus sp.	0.6%	0.5%	*Tanytarsus sp.*

Species	2009 Relative Abundance (%)	2009 Relative Biomass (%)	Species
Hydra sp.	81.0%	78.3%	*Hydra sp.*
Orthocladiinae	5.5%	7.7%	Enchytraeus
Enchytraeidae	4.5%	3.8%	Torrenticolidae
Torrenticolidae	4.4%	3.2%	Orthocladiinae
Diptera (Adults)	1.3%	1.8%	Diamesini
Eisenella sp.	0.8%	1.2%	Mycetophilidae
Mycetophilidae	0.8%	1.0%	Tanytarsini
Torrenticola sp.	0.6%	0.8%	Diptera (Adults)
Sminthuridae	0.4%	0.7%	Sminthuridae
Hymenoptera (Adults)	0.3%	0.5%	*Torrenticola sp.*

Species	2010 Relative Abundance (%)	2010 Relative Biomass (%)	Species
Hydra sp.	35.0%	48.8%	*Hydra sp.*
Orthocladiinae	29.2%	18.2%	Enchytraeus
Enchytraeus	12.7%	13.7%	Naididae
Naididae	8.0%	5.8%	*Diamesa sp.*
Tubificidae	3.7%	2.9%	*Orthocladius complex*
Pseudosmittia sp.	2.0%	2.6%	*Pseudosmittia sp.*
Oligochaeta	1.8%	2.5%	Diamesini
Diamesa sp.	1.5%	1.9%	Tubificidae
Nemata	1.5%	1.0%	Apatania
Orthocladius complex	1.2%	0.5%	Lumbriculidae

Species	2011 Relative Abundance (%)	2011 Relative Biomass (%)	Species
Hydra sp.	38.7%	25.4%	Naididae
Orthocladiinae	33.6%	17.2%	Orthocladiinae
Naididae	6.6%	14.9%	Enchytraeus
Orthocladius complex	4.9%	9.0%	Hydra sp.
Enchytraeus	2.7%	6.2%	Lumbriculidae
Oligophlebodes sp.	1.5%	2.9%	Ephemerellidae
Ephemerellidae	1.5%	2.9%	Pagastia sp.
Harpacticoida	1.5%	2.7%	Chironomus sp.
Cyclopoida	1.3%	2.1%	Tanypodinae
Diamesa sp.	1.1%	1.9%	Suwallia sp.

Species	2012 Relative Abundance (%)	2012 Relative Biomass (%)	Species
Orthocladius complex	50.1%	50.8%	Orthocladius complex
Tanypodinae	8.3%	9.7%	Tanypodinae
Hydra sp.	6.9%	5.2%	Ephemerellidae
Chironomidae	4.4%	3.9%	Chironomidae
Enchytraeus	3.2%	3.9%	Orthocladiinae
Eukiefferiella sp.	2.8%	3.7%	*Simulium sp.*
Orthocladiinae	2.8%	3.2%	Capniidae
Ephemerellidae	2.1%	2.6%	*Hydra sp.*
Chironominae	1.7%	2.5%	*Eukiefferiella sp.*
Nais sp.	1.7%	2.4%	Nemouridae

Table 3-12: Relative abundance and relative biomass of benthic invertebrates in the spring of each year from 2011 to 2012.

2011 Species	2011 Relative Abundance (%)	2011 Relative Biomass (%)	2011 Species	2012 Species	2012 Relative Abundance (%)	2012 Relative Biomass (%)	2012 Species
Orthocladius complex	38.5%	32.5%	Diamesa sp.	*Orthocladius complex*	28.7%	31.2%	*Orthocladius complex*
Cyclopoida	17.3%	10.9%	*Micropsectra sp.*	Cyclopoida	22.3%	13.5%	Orthocladiinae
Orthocladiinae	9.7%	9.3%	*Prosimulium sp.*	Orthocladiinae	12.1%	13.0%	*Hydra sp.*
Hydra sp.	8.9%	7.5%	*Sperchon sp.*	*Hydra sp.*	10.8%	3.9%	*Pagastia sp.*
Eukiefferiella sp.	8.3%	6.1%	*Stictochironomus sp.*	*Eukiefferiella sp.*	4.0%	3.9%	Ephemerella dorotha / excrucians
Nais sp.	3.3%	3.7%	Copepoda	Chironomidae	2.9%	3.8%	*Eukiefferiella sp.*
Nemata	2.2%	3.5%	Naididae	Calanoida	1.9%	3.5%	Lumbriculidae
Enchytraeus	1.7%	3.4%	*Hydra sp.*	*Pagastia sp.*	1.5%	3.5%	Ephemerellidae
Chironomidae	1.6%	2.2%	Enchytraeus	*Daphnia*	1.4%	3.0%	Chironomidae
Micropsectra sp.	1.4%	2.1%	Cyclopoida	*Cardiocladius sp.*	1.3%	2.3%	Heptageniidae

Table 3-13: Summary statistics for benthic invertebrates in the Mid Columbia River in the fall from 2007 to 2012.

Diversity Measures	Statistics	2007	2008	2009	2010	2011	2012
Abundance (#/basket)	Sample Size	21	26	25	38	49	44
	Mean (±SD)	215.86 ± 320.71	511.85 ± 771.20	67.84 ± 81.91	206.87 ± 346.37	521.82 ± 618.75	149.91 ± 394.21
	Median	78.0	94.0	29.0	68.5	274.0	26.5
	Minimum	21.0	5.0	3.0	0.0	8.0	0.0
	Maximum	1408.0	2617.0	306.0	1615.0	2363.0	2516.0
Biomass (g/basket)	Sample Size	21	26	25	38	49	44
	Mean (±SD)	3.95 ± 5.07	30.78 ± 54.52	2.16 ± 2.37	3.95 ± 6.48	6.94 ± 26.02	16.45 ± 49.48
	Range	1.6	2.5	1.3	2.1	1.2	0.2
	Minimum	0.4	0.1	0.1	0.1	0.0	0.0
	Maximum	18.6	180.8	9.3	29.7	179.8	207.8
Species Richness (#)	Sample Size	21	26	25	38	49	44
	Mean (±SD)	9.05 ± 4.34	9.15 ± 5.74	3.44 ± 1.39	4.63 ± 2.39	10.33 ± 4.65	7.07 ± 5.85
	Range	8.0	8.5	3.0	4.0	10.0	5.0
	Minimum	4.0	2.0	2.0	0.0	2.0	0.0
	Maximum	19.0	24.0	7.0	10.0	22.0	25.0
Percent EPT (%)	Sample Size	NA			38	49	44
	Mean (±SD)				0.19 ± 0.79	2.00 ± 3.01	4.00 ± 8.59
	Range				0.00	0.90	0.00
	Minimum				0.00	0.00	0.00
	Maximum				4.80	14.00	50.00
Percent Chironomidae (%)	Sample Size	NA			38	49	44
	Mean (±SD)				33.0 ± 0.29	40.0 ± 0.22	70.0 ± 0.23
	Range				0.3	0.4	0.8
	Minimum				0.0	0.0	0.0
	Maximum				0.9	0.9	1.0
Simpson's Index	Sample Size	21	26	25	38	49	44
	Mean (±SD)	0.56 ± 0.15	0.46 ± 0.20	0.28 ± 0.19	0.52 ± 0.21	0.58 ± 0.17	0.51 ± 0.27
	Range	0.65	0.49	0.24	0.55	0.59	0.51
	Minimum	0.27	0.13	0.04	0.00	0.11	0.00
	Maximum	0.73	0.83	0.80	1.00	0.84	1.00
Hilsenhoff Biotic Index	Sample Size	NA			38	49	44
	Mean (±SD)				4.51 ± 2.50	3.71 ± 1.16	5.31 ± 1.70
	Range				4.54	3.66	5.89
	Minimum				0.00	0.51	0.00
	Maximum				9.06	6.88	8.00

Table 3-14: Summary statistics for benthic invertebrates in the Mid Columbia River in the spring from 2007 to 2012.

Diversity Measures	Statistics	2011	2012
Abundance (#/basket)	Sample Size	47	1
	Mean (±SD)	78.02 ± 104.64	52.00 ± 23.5
	Range	22.0	23.5
	Minimum	1.0	2.0
	Maximum	413.0	319.0
Biomass (g/basket)	Sample Size	47	38
	Mean (±SD)	2.99 ± 4.47	2.37 ± 6.98
	Range	0.8	0.1
	Minimum	0.0	0.0
	Maximum	17.4	41.0
Species Richness (#)	Sample Size	47	38
	Mean (±SD)	6.57 ± 5.71	7.00 ± 6.07
	Range	4.0	5.0
	Minimum	1.0	1.0
	Maximum	22.0	30.0
Percent EPT (%)	Sample Size	47	38
	Mean (±SD)	2.0 ± 0.04	4.0 ± 0.07
	Range	0.00	0.00
	Minimum	0.00	0.00
	Maximum	0.20	0.33
Percent Chironomidae (%)	Sample Size	47	38
	Mean (±SD)	60.0± 0.31	53.0± 0.32
	Range	0.71	0.57
	Minimum	0.00	0.00
	Maximum	1.00	1.00
Simpson's Index	Sample Size	47	38
	Mean (±SD)	0.52 ± 0.19	0.56 ± 0.22
	Range	0.50	0.62
	Minimum	0.00	0.00
	Maximum	0.80	0.88
Hilsenhoff Biotic Index	Sample Size	47	38
	Mean (±SD)	4.32 ± 2.33	3.65 ± 7.97
	Range	5.62	1.97
	Minimum	0.00	0.00
	Maximum	8.00	6.56

Table 3-15: Summary statistics for benthic invertebrates in the Mid Columbia River in the fall from 2007 to 2012. Sampler positions occur from the thalweg (T1) to infrequently wetted areas at T7.

Diversity Measures	Statistics	T1	T2	T3	T4	T5	T6	T7
Abundance (#/basket)	Sample Size	52	28	50	26	23	20	4
	Mean	509.46 ± 687.11	367.07 ± 481.77	283.02 ± 406.25	158.38 ± 389.47	70.35 ± 157.34	139.4 ± 525.29	29.5 ± 33.75
	Median	198.50	184.00	73.50	44.00	18.00	9.50	21.00
	Minimum	5.00	17.00	9.00	1.00	2.00	0.00	0.00
	Maximum	2617.00	2100.00	1808.00	2007.00	652.00	2363.00	76.00
Biomass (g/basket)	Sample Size	52	28	50	26	23	20	4
	Mean (±SD)	12.97 ± 31.72	25.88 ± 62.92	12.53 ± 36.68	2.53 ± 6.14	1.23 ± 2.01	1.09 ± 2.00	2.34 ± 1.99
	Median	1.8	2.1	1.7	0.8	0.5	0.4	2.4
	Minimum	0.0	0.0	0.1	0.0	0.0	0.0	0.1
	Maximum	180.8	207.8	169.2	29.7	7.5	8.7	4.5
Species Richness (#)	Sample Size	52	28	50	26	23	20	4
	Mean (±SD)	8.75 ± 5.74	8.25 ± 6.30	7.72 ± 4.29	6.65 ± 4.41	6.73 ± 4.35	4.6 ± 3.81	3.75 ± 2.88
	Median	8.0	7.0	6.5	5.0	6.0	3.0	4.0
	Minimum	1	2	2	1	2	0	0
	Maximum	24	25	21	17	22	14	7
Percent EPT (%)	Sample Size	24	23	20	20	20	20	4
	Mean	1.3 ± 0.023	1.3± 0.022	2.7± 0.044	1.4± 0.021	3.0± 0.060	4.0± 0.113	
	Median	0.1	0.4	0.7	0.000	0.000	0.000	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	8.7	8.3	14.1	6.3	2	5	0.000
Percent Chironomidae (%)	Sample Size	24	23	20	20	20	20	4
	Mean (±SD)	70.0± 0.24	55.0± 0.34	55.0± 0.32	46.0± 0.27	37.0± 0.23	27.0± 0.28	16.0± 0.30
	Median	78	53	63	47	34	18	2
	Minimum	16	4	3	0.00	3	0.00	0.00
	Maximum	100	100	95	92	86	80	60
Simpson's Index	Sample Size	24	23	20	20	20	20	4
	Mean (±SD)	0.57 ± 0.20	0.52 ± 0.28	0.48 ± 0.20	0.34 ± 0.18	0.26 ± 0.14	0.32 ± 0.23	0.40 ± 0.33
	Median	0.54	0.50	0.42	0.36	0.29	0.30	0.40
	Minimum	0.18	0.11	0.20	0.00	0.00	0.00	0.00
	Maximum	1.00	0.96	0.88	0.59	0.47	1.00	0.80
Hilsenhoff Biotic Index	Sample Size	24	23	20	20	20	20	4
	Mean (±SD)	3.65 ± 1.93	5.01 ± 1.60	4.46 ± 1.54	4.44 ± 1.94	4.76 ± 1.89	4.71 ± 2.50	4.17 ± 3.97
	Median	3.20	5.67	4.63	4.52	4.58	4.98	3.86
	Minimum	0.75	0.79	0.51	1.15	0.63	0.00	0.00
	Maximum	6.29	6.88	6.44	9.01	9.06	8.75	8.95

Table 3-16: Summary statistics for benthic invertebrates in the Mid Columbia River in the spring from 2011 to 2012. Sampler positions occur from the thalweg (T1) to infrequently wetted areas at T7.

Diversity Measures	Statistics	T1	T2	T3	T4	T5	T6
Abundance (#/basket)	Sample Size	20	14	13	13	13	12
	Mean	110.9 ± 99.10	142.64 ± 116.68	66.70 ± 89.96	20.54 ± 34.28	8.23 ± 7.30	15.58 ± 20.97
	Median	82.00	94.50	36.00	6.00	6.00	8.50
	Minimum	3.00	14.00	2.00	2.00	1.00	2.00
	Maximum	413.00	353.00	314.00	123.00	27.00	72.00
Biomass (g/basket)	Sample Size	20	14	13	13	13	12
	Mean (±SD)	4.16 ± 4.54	7.50 ± 11.25	1.28 ± 2.03	1.48 ± 2.50	0.19 ± 0.35	0.38 ± 0.89
	Median	2.8	3.6	0.1	0.1	0.0	0.1
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0
	Maximum	17.4	41.0	6.8	8.4	1.2	3.1
Species Richness (#)	Sample Size	20	14	13	13	13	12
	Mean (±SD)	9.45 ± 5.36	9.79 ± 7.96	6.23 ± 5.41	5.70 ± 5.84	2.86 ± 1.72	4.75 ± 3.82
	Median	8.0	6.0	4.0	3.0	3.0	2.5
	Minimum	2	3	1	2	1	2
	Maximum	20	30	18	20	6	12
Percent EPT (%)	Sample Size	20	14	13	13	13	12
	Mean	0.024 ± 0.042	0.026 ± 0.056	0.025 ± 0.056	0.044 ± 0.095	0.008 ± 0.022	0.018 ± 0.049
	Median	1.2	0.000	0.000	0.000	0.000	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	18	25	20	33	7.1	17
Percent Chironomidae (%)	Sample Size	20	14	13	13	13	12
	Mean (±SD)	0.72 ± 0.22	0.81 ± 0.17	0.54 ± 0.37	0.43 ± 0.26	0.39 ± 0.35	0.39 ± 0.26
	Median	75	88	56	50	36	36
	Minimum	0.00	36	0.00	0.00	0.00	0.00
	Maximum	95	96	100	75	100	75
Simpson's Index	Sample Size	20	14	13	13	13	12
	Mean (±SD)	0.41 ± 0.12	0.46 ± 0.23	0.40 ± 0.28	0.27 ± 0.16	0.39 ± 0.37	0.30 ± 0.18
	Median	0.39	0.44	0.32	0.27	0.33	0.30
	Minimum	0.22	0.12	0.00	0.00	0.00	0.00
	Maximum	0.61	0.90	1.00	0.50	1.00	0.64
Hilsenhoff Biotic Index	Sample Size	20	14	13	13	13	12
	Mean (±SD)	5.30 ± 1.39	5.32 ± 1.34	4.01 ± 2.45	2.75 ± 2.12	3.16 ± 2.34	2.71 ± 1.97
	Median	5.69	5.79	4.62	2.89	3.14	3.42
	Minimum	1.25	2.26	0.00	0.00	0.00	0.00
	Maximum	6.81	6.62	7.50	6.25	8.00	5.20

3.3.2 Benthic Invertebrate Community Groupings

Analyses of 2007-2011 benthic invertebrate community groupings data were completed at the species level using Ward/Bray cluster analyses indicated that the communities were grouped by year and season (Schleppe et al, 2011). In 2012, the data were analyzed at the family level (Figure 3-13). Using the family level reduced the potential effects of taxonomist and the effects of rare species, allowing focus to be placed on larger scale trends occurring within the MCR. Ward/Bray cluster analyses of family data indicated there were potentially 4 or 5 plausible groupings of data (See Appendix A-1). The benthic community data appeared to be grouped by Year (ANOSIM, R: 0.11, p = 0.001), Season (ANOSIM, R: 0.18, p = 0.001), flow period (ANOSIM, R:0.14, p = 0.001), and Transect (ANOSIM, R: 0.26, p = 0.001). NMDS analysis (stress = 0.25) of the five groups at the family level indicated significant overlap between sites. Interestingly, when the data were analyzed at the species level (data not reported), the benthic data was more strongly grouped by year and season, as previously reported (Schleppe et al., 2012).

Similar to periphyton, there was high inter-annual and seasonal variation when data were analyzed at the species level. At the family level of taxonomic identification, these trends were not as apparent but were still present. This infers that over the sample period, large scale shifts in benthic communities were not observed and that trends were associated with high inter-annual variation, season, and location within the river channel. Difference in taxonomist are only expected to account for some of the differences observed between years, while most of the observed inter-annual variation is associated with the BC Hydro operating regime over the sample period (i.e., see ANOVA's of groupings of flow over the study period during stable high and low flow periods).

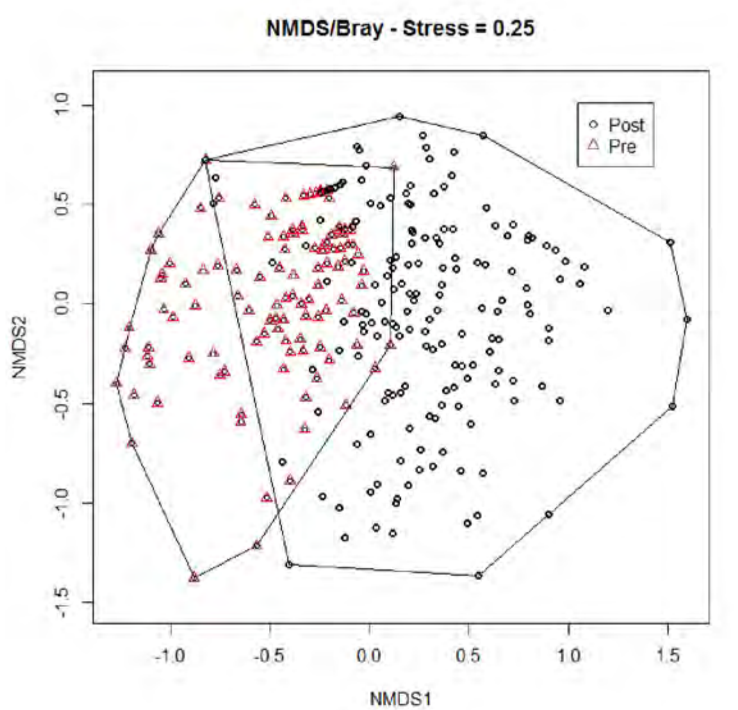

Figure 3-13. NMDS of invertebrate abundance collected between 2007 and 2012. Polygons around points were created using Ward cluster groups using a Bray Curtis dissimilarity matrix at the family taxonomic level.

3.3.3 Benthic Invertebrate Production Models

Model averaging data indicated that there were numerous plausible models (those with an AICc<2.0) for benthic abundance (6), biomass (8), Simpson's Index (15), and Hilsenhoff Biotic Index (3) (Table 3-17). Several key trends were observed across the different measures of production, most notably that frequency of 12-hour submergence events was an important predictor for all measures of production modelled. Other key predictors were total incubation time in the light and water and maximum cumulative submergence. Less notable, but potentially important predictors include water velocity over the sampler or submergence ratio. Explanatory variables of benthic production were also similar to those for periphyton, indicating that benthic production within the MCR is highly correlated with time spent in the water, exposure, operating regime (both daily, monthly, and yearly), and annual and seasonal variation.

Mean temperature, submergence ratio, frequency of 12-hour submergence events, and water velocity over the sampler were the most important predictors of benthic abundance. Benthic abundance increased with temperature to a peak before declining because higher average temperatures are indicative of increasing exposure. Benthic abundance increased with submergence ratio, frequency of 12 hour submergence events, and total incubation time in the water. Abundance appeared to increase dramatically at submergence ratios of 0.8 or 80% time in the water. Further, this corresponded with approximately forty, 12-hour submergence events and at least 450 hours of daytime submergence (submergence in the light and water) (Table 3-17 and Figure 3-14).

Water velocity over the sampler, total incubation time in the light and water (i.e., daytime submergence), frequency of 12- hour submergence events, and maximum cumulative submergence hours were the more important predictors of benthic biomass. The data suggest that after forty, 12-hour submergence events and a total of 450 daytime hours of submergence over a deployment period, there was a dramatic increase in benthic biomass. The inclusion of maximum cumulative submergence as an important predictor of benthic biomass indicates that there is a benefit to prolonged submergence (Table 3-17 and Figure 3-15).

Like abundance, frequency of 12-hour daytime submergence events and total incubation time in the light and water were the most important predictors of the Hilsenhoff Biotic Index. The data indicates that after 40, twelve hour submergence events or approximately 450 hours of daytime submergence, there was a decrease in Hilsenhoff Index value, indicative of a higher prevalence of more sensitive EPT benthic taxa (Table 3-17 and Figure 3-16). Since invertebrates are patchily distributed, some sites may have had higher prevalences of Chironomids or similar species, explaining the higher index values at sites with high submergence times.

Simpson's Index values were best predicted by water velocity over the sampler,, frequency of 12-hour submergence events, and total incubation time in the water and light (i.e., daytime submergence). Upper varial zone areas tended to have the highest Simpson's Index scores, indicating greater species diversity (Table 3-17 and Figure 3-17).

Table 3-17: Multi-model averaging results using Akaike information criterion approach for four measures of periphyton production and diversity (Abundance, Biomass, Simpson's Index, and Hilsenhoff Index) in the MCR. The total number of plausible models with an AICc<2 is shown in brackets next to the measure of production. The weight (w) of a predictor indicates the probability the predictor will occur in the AIC Best Model and predictors with a weight of 0.6 or higher are considered important. The occurrences data indicates the total number of predictor occurrences in the most plausible models or those with AICc<2. Bold indicates whether a predictor occurred in the AIC best model.

Model Predictors	Abundance (6) Estimate (CC)	Weight (w)	# Occurrences in AICc<2 Models
Freq_Submer_.12.Hrs	**0.117813372**	**0.8463746**	**6**
max_cum_sub_hrs	7.56E-04	0.7588243	3
sampler.velocity	**-2.11E-01**	**0.6572271**	**4**
sub_ratio	**-7.54E+00**	**0.6562638**	**4**
Freq_Submer_.12.Hrs.sq	**-2.09E-03**	**0.5200661**	**4**
sub_ratio.sq	**8.431559217**	**0.4385689**	**4**
mean_temp	-1.66E+00	0.3415197	1
tot_inc_time_water_light_hrs	-1.43E-03	0.2972542	1
max_cum_sub_hrs.sq	-3.18E-07	0.1790157	0
sampler.velocity.sq	0.05226432	0.1446888	**0**
mean_temp.sq	0.282711111	0.0927446	0
tot_inc_time_water_light_hrs.sq	6.28E-06	0.0816636	0

Model Predictors	Biomass (8) Estimate (CC)	Weight (w)	# Occurrences in AICc<2 Models
sampler.velocity	**-4.86E-01**	**0.9720104**	**8**
tot_inc_time_water_light_hrs	**-1.29E-02**	**0.8366475**	**8**
Freq_Submer_.12.Hrs	**0.102355848**	**0.8264601**	**8**
tot_inc_time_water_light_hrs.sq	**1.94E-05**	**0.7873619**	**8**
Freq_Submer_.12.Hrs.sq	**-2.01E-03**	**0.7541371**	**8**
max_cum_sub_hrs	**1.55E-04**	**0.7416717**	**4**
sub_ratio	-1.60E+00	0.6197118	**6**
sampler.velocity.sq	**0.207925212**	**0.5569811**	**4**
sub_ratio.sq	3.566584183	0.3650033	4
mean_temp	0.17147945	0.3629656	2
max_cum_sub_hrs.sq	6.13E-07	0.2109331	0
mean_temp.sq	-4.35E-02	0.087603	0

Model Predictors	Hilsenhoff Index (3) Estimate (CC)	Weight (w)	# Occurrences in AICc<2 Models
Freq_Submer_.12.Hrs	**0.127802517**	**0.9054737**	**3**
tot_inc_time_water_light_hrs	**-1.21E-02**	**0.8882021**	**3**
Freq_Submer_.12.Hrs.sq	**-2.42E-03**	**0.8571447**	**3**
tot_inc_time_water_light_hrs.sq	**2.10E-05**	**0.7835176**	**3**
sampler.velocity	-4.29E-01	0.5532694	2
max_cum_sub_hrs	1.97E-05	0.3842113	0
sampler.velocity.sq	0.256635407	0.3432538	1
mean_temp	-7.99E-02	0.3428899	0
sub_ratio	-8.58E-01	0.3403726	0
sub_ratio.sq	2.711356233	0.1163131	0
max_cum_sub_hrs.sq	-6.55E-07	0.1071838	0
mean_temp.sq	0.027771199	0.0736617	0

Model Predictors	Simpson's Index (15) Estimate (CC)	Weight (w)	# Occurrences in AICc<2 Models
sampler.velocity	**-1.98E-02**	**0.9491344**	**15**
Freq_Submer_.12.Hrs	**9.21E-03**	**0.8349798**	**13**
tot_inc_time_water_light_hrs	**2.79E-04**	**0.7667582**	**14**
sub_ratio	-2.48E-02	0.5703125	6
Freq_Submer_.12.Hrs.sq	**-1.47E-04**	**0.5673716**	**10**
mean_temp	-3.87E-01	0.514486	4
tot_inc_time_water_light_hrs.sq	-1.27E-06	0.4051784	6
mean_temp.sq	0.027092229	0.3487523	4
max_cum_sub_hrs	2.24E-05	0.3410935	1
sampler.velocity.sq	-1.83E-02	0.3308886	4
sub_ratio.sq	-2.07E-01	0.2138844	0
max_cum_sub_hrs.sq	-2.51E-08	0.0755432	0

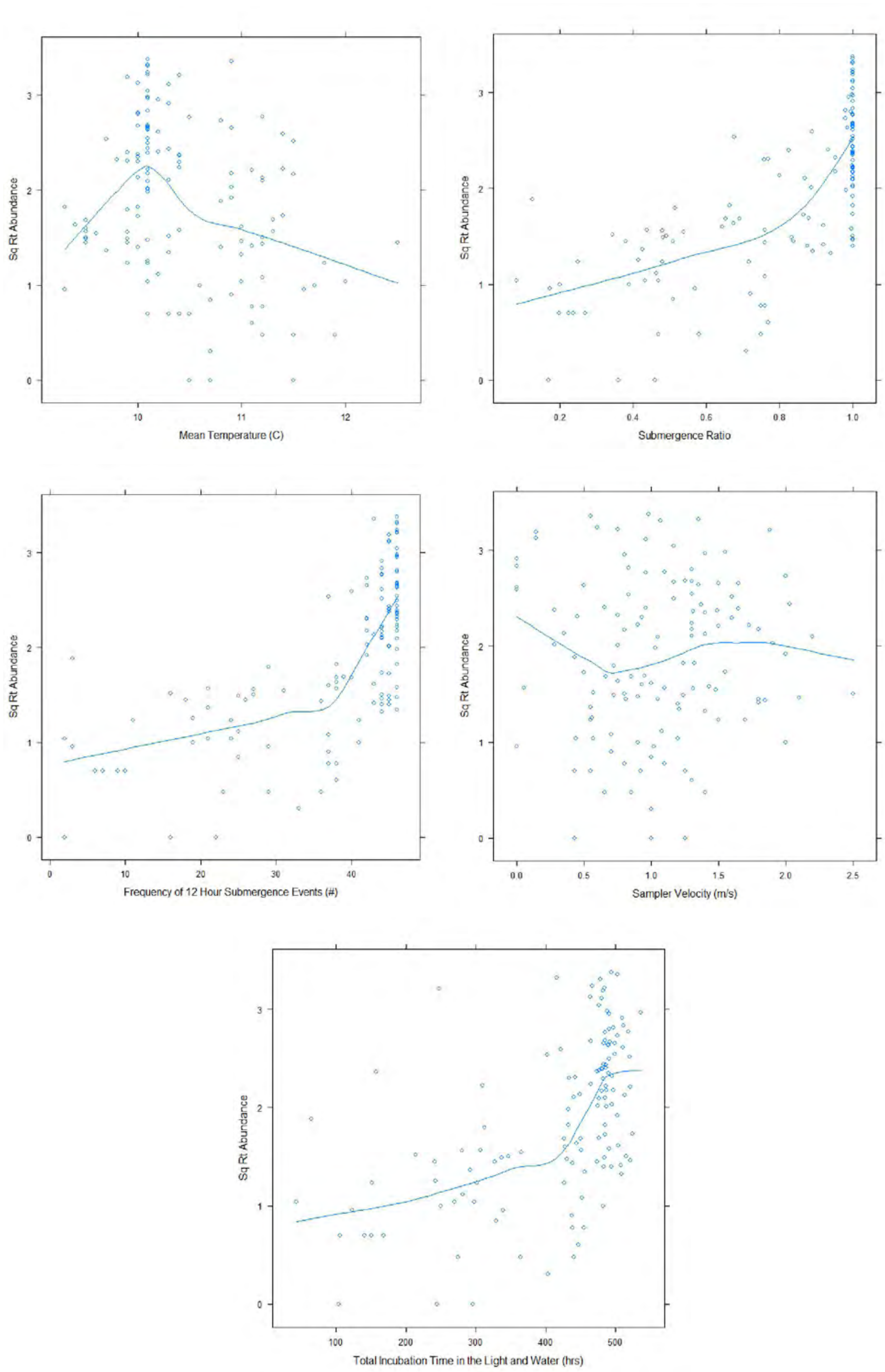

Figure 3-14 Single linear regressions of log transformed benthic abundance data and frequency of 12- hour submergence events (weight = 0.87), Maximum Cumulative Submergence (weight = 0.76), Sampler Velocity (weight = 0.0.66), and submergence ratio (weight = 0.67). Fitted lines were generated using a locally weighted polynomial regression method (LOWESS).

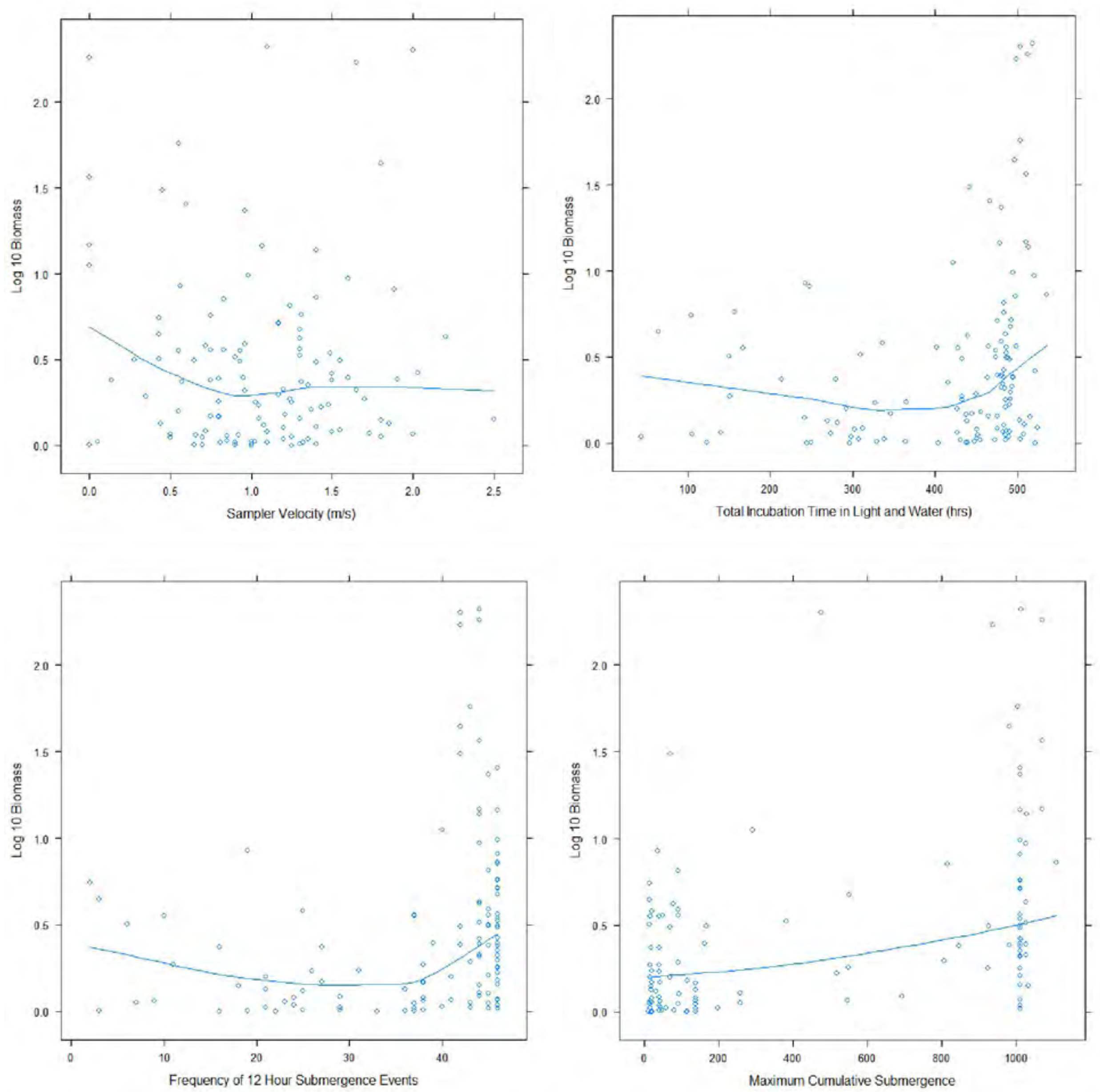

Figure 3-15: Single linear regressions of log transformed benthic biomass data and sampler velocity (m/s) (weight = 0.97), Total Incubation Time in the Light and Water (hrs) (0.84), Frequency of 12 Hour Submergence Events (#) (0.83), and Maximum Cumulative Submergence (hrs) (Weight = 0.0.74). Fitted lines were generated using a locally weighted polynomial regression method (LOWESS).

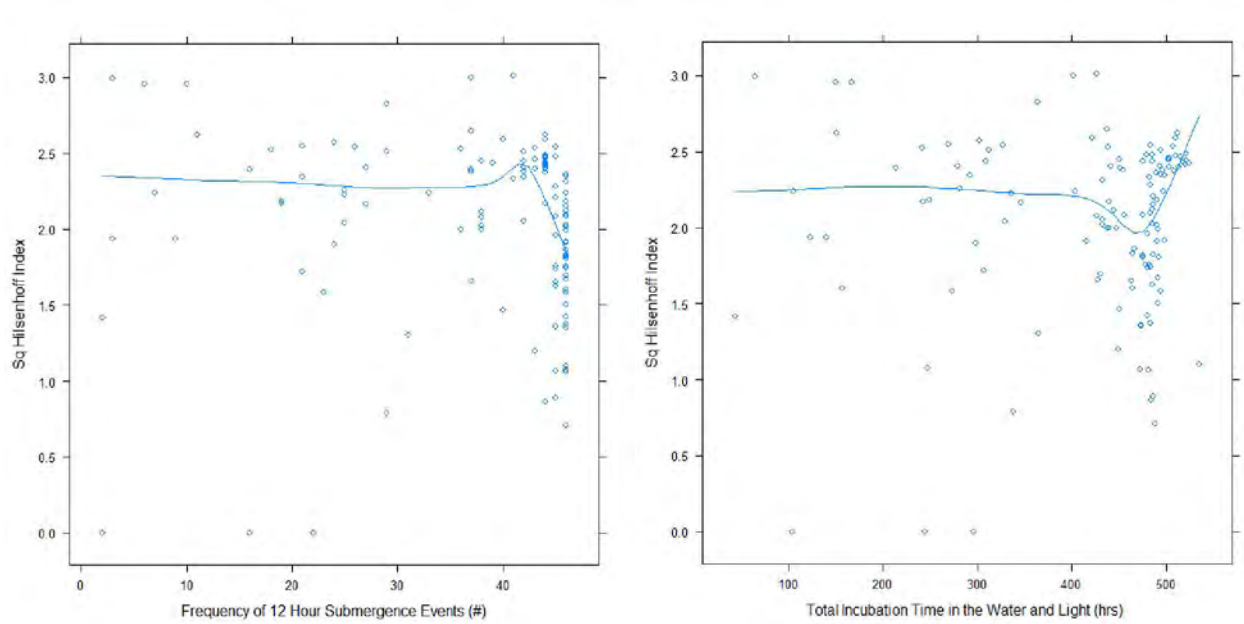

Figure 3-16 Single linear regressions of log transformed benthic Hilsenhoff Biotic Index data and Frequency of 12-hour submergence events (#) (weight = 0.91) and Total incubation time in the light and water (hrs) (weight = 0.88). Higher index values represent more exposure tolerant taxa because these species can survive in conditions with lower dissolved oxygen . Fitted lines were generated using a locally weighted polynomial regression method (LOWESS).

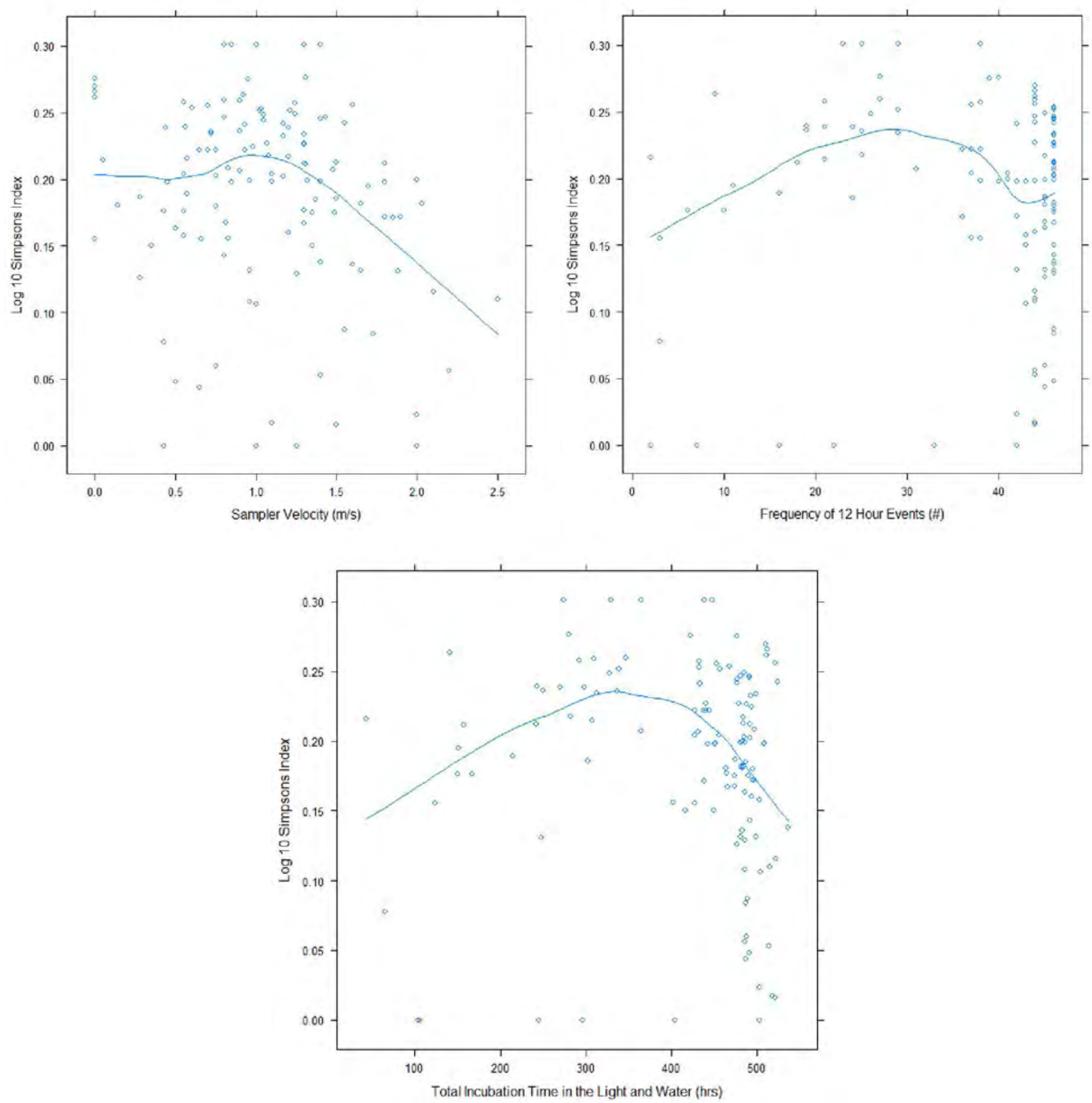

Figure 3-17 Single linear regressions of log transformed benthic Simpson's Index data and Sampler Velocity (weight = 0.95), Frequency of 12 Hour Submergence Events (weight = 0.84), and Total Incubation Time in the Light and Water (weight = 0.77). Fitted lines were generated using a locally weighted polynomial regression method (LOWESS).

3.3.4 Benthic Fish Food Index

Stomach contents data was available from 2007 to 2010. Fish food was classified into general foraging groups, and the relative abundance of fish food items within the stomachs. The analysis considered each relevant fish species separately. Stomach content data, coupled with a literature review was used to determine the food preference of different fish species / age classes for relevant benthic invertebrate taxa. The literature review supported the stomach content data well and a summary of stomach contents and the average fish food preference for each fish food group is found in Table 3-18 below.

Table 3-18: Relative abundance of Fish Food items in the MCR for fishes collected in the fall of 2007 through 2010. The average Fish Food Preference score is also shown. Fish foo preference was determined using the stomach contents data and a literature review of fish food preference for individual benthic taxon. Fish Food Preference ranges fron 0 (no preference) to 10 (high preference) and the average of all fish species / age classes is shown.

Food Group	Bull Trout	Sculpin	Sucker	Mountain Whitefish	Northern Pike Minnow	Rainbow Trout	Redside Shiner	Average Fish Food Preference Score
Aquatic Adult	0.0% ± 0.0%	0.0% ± 0.0%	0.0% ± 0.0%	3.3% ± 11.5%	0.0% ± 0.0%	3.4% ± 15.5%	0.3% ± 0.5%	3.9
Benthic	0.0% ± 0.0%	0.0% ± 0.0%	0.0% ± 0.0%	2.3% ± 13.3%	0.0% ± 0.0%	0.0% ± 0.0%	0.0% ± 0.0%	1.5 ± 0.4
Chironomidae	1.6% ± 10.9%	31.2% ± 19.9%	0.0% ± 0.0%	4.3% ± 10.0%	25.4% ± 43.0%	19.8% ± 30.1%	79.9% ± 18.7%	2.8 ± 0.9
Ephemeroptera	0.0% ± 0.0%	43.7% ± 31.2%	0.0% ± 0.0%	0.8% ± 5.4%	0.0% ± 0.0%	1.2% ± 6.0%	0.0% ± 0.0%	7.0 ± 0.0
Fish (including eggs)	74.5% ± 42.2%	4.4% ± 10.8%	25.0% ± 44.4%	9.0% ± 21.2%	0.0% ± 0.0%	12.7% ± 29.9%	5.6% ± 7.9%	7.6 ± 0.2
Other	0.0% ± 0.0%	0.0% ± 0.0%	0.0% ± 0.0%	0.0% ± 0.1%	0.0% ± 0.0%	0.5% ± 1.7%	0.0% ± 0.0%	1.5 ± 0.7
Other Aquatic	0.0% ± 0.0%	0.0% ± 0.0%	0.0% ± 0.0%	0.0% ± 0.0%	0.0% ± 0.0%	3.0% ± 10.9%	0.0% ± 0.0%	2.2 ± 0.2
Other Dipteran	0.0% ± 0.0%	0.0% ± 0.0%	0.0% ± 0.0%	0.0% ± 0.1%	0.0% ± 0.0%	0.3% ± 1.3%	0.0% ± 0.0%	6.1 ± 1.1
Plecoptera	0.0% ± 0.2%	0.0% ± 0.0%	0.0% ± 0.0%	0.0% ± 0.0%	0.0% ± 0.0%	0.0% ± 0.0%	0.0% ± 0.0%	6.0 ± 0.0
Terrestrial	0.3% ± 1.6%	0.0% ± 0.0%	0.0% ± 0.0%	3.1% ± 10.6%	0.0% ± 0.0%	19.3% ± 30.0%	14.2% ± 11.3%	2.1 ± 1.1
Trichoptera	0.2% ± 1.2%	4.8% ± 9.1%	0.0% ± 0.0%	4.5% ± 15.2%	0.0% ± 0.0%	3.5% ± 10.6%	0.0% ± 0.0%	5.7 ± 0.1
Worm	0.0% ± 0.0%	2.8% ± 9.6%	0.0% ± 0.0%	0.3% ± 1.7%	8.3% ± 14.4%	0.0% ± 0.2%	0.0% ± 0.0%	2.6 ± 0.4
Zooplankton	16.0% ± 34.4%	13.1% ± 23.8%	0.0% ± 0.0%	67.3% ± 39.3%	33.0% ± 57.1%	20.1% ± 37.5%	0.0% ± 0.0%	2.3 ± 0.1

Model averaging data of the Fish Food Index indicated that there were only two plausible models (those with an AICc<2.0) (Table 3-19 and Figure 3-18). Mean temperature, water velocity over the sampler (and its associated squared term), total incubation time in the water and light, and frequency of 12 hour submergence events were all important factors predicting available fish food in the Fish Food Index. This result follows similar trends observed for benthic invertebrate abundance and biomass.

Table 3-19: Multi model averaging results using Akaike information criterion approach for the Fish Food Index in the MCR. The total number of plausible models with an AICc<2 is shown in brackets next to the measure of production. The weight (w) of a predictor indicates the probability the predictor will occur in the AIC Best Model and predictors with a weight of 0.6 or higher are considered important. The occurrences data indicates the total number of predictor occurrences in the most plausible models or those with AICc<2. Bold indicates that a predictor occurred in the AIC best model.

Model Predictors	Fish Food Index (2)		
	Estimate (CC)	Weight (w)	# Occurrences in AICc<2 Models
mean_temp	**0.142422916**	**1**	**2**
sampler.velocity	**-6.00E-02**	**0.991894214**	**2**
tot_inc_time_water_light_hrs	**6.95E-04**	**0.892524134**	**2**
sampler.velocity.sq	**0.086730957**	**0.758788995**	**1**
Freq_Submer_.12.Hrs	**-6.84E-03**	**0.743662208**	**2**
sub_ratio	-9.07E-02	0.36578566	0
max_cum_sub_hrs	1.04E-04	0.362225064	0
mean_temp.sq	-5.88E-03	0.229497414	0
tot_inc_time_water_light_hrs.sq	3.48E-07	0.213551156	0
Freq_Submer_.12.Hrs.sq	-5.79E-05	0.180845063	0
max_cum_sub_hrs.sq	-2.93E-07	0.131316824	0
sub_ratio.sq	-1.20E-02	0.083179119	0

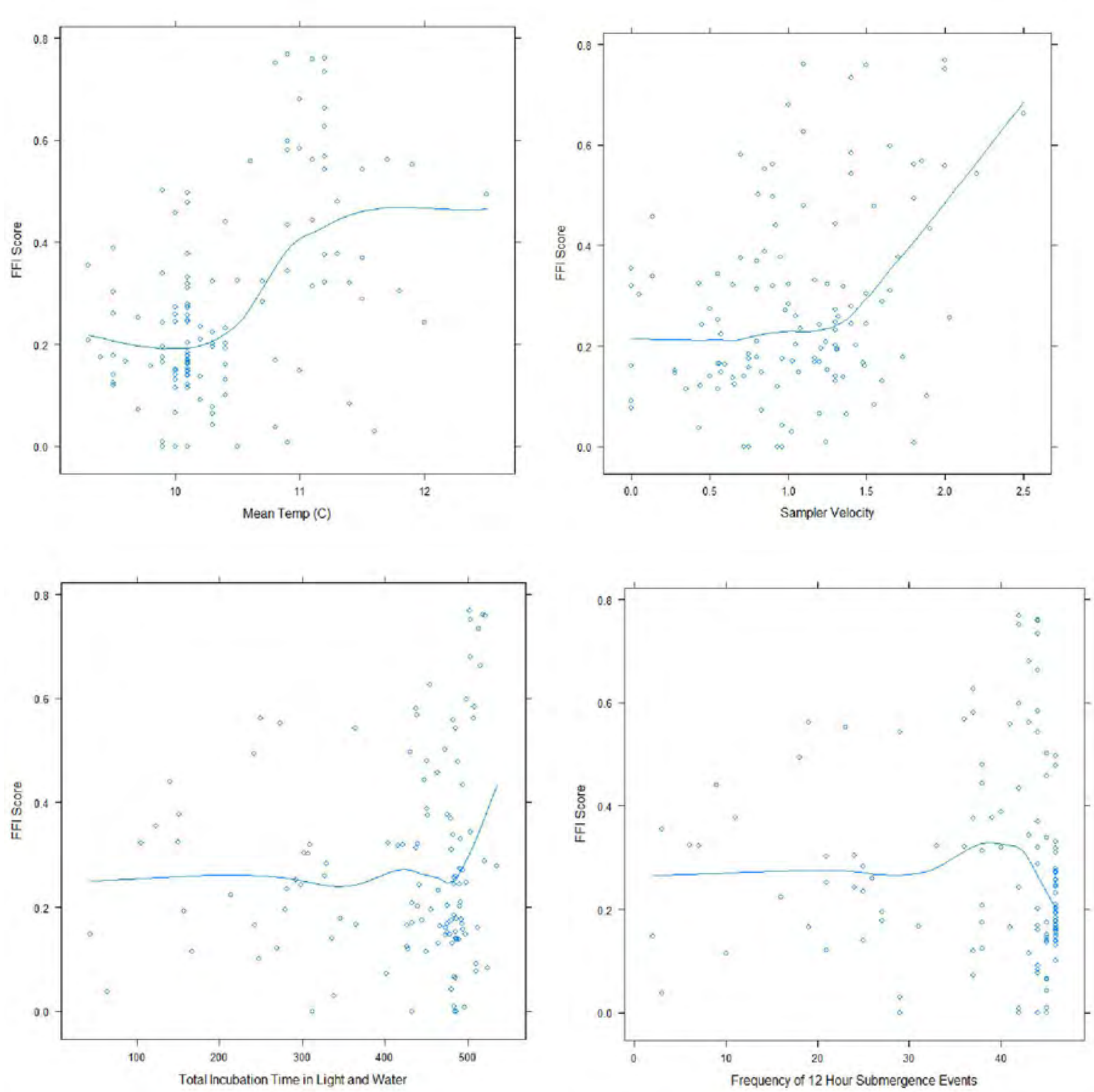

Figure 3-18 Single linear regressions of square root transformed Fish Food Index data and Mean Temperature (weight = 1.00), Sampler Velocity (weight = 0.99), Total Incubation Time in the Light and Water (weight = 0.89). Fitted lines were generated using a locally weighted polynomial regression method (LOWESS).

4.0 DISCUSSION

4.1 Overview of MCR Habitat Zones and Conditions

A long-term monitoring program of periphyton and benthic invertebrates is ongoing to determine the effect of minimum flows and REV 5 on MCR production. This discussion summarizes the findings from the 2007 to 2012 field surveys. Both the periphyton and the benthic invertebrate components of the MCR benthic community are sensitive to changes in habitat conditions, and are good indicators of hydrologic disturbance on regulated rivers (Biggs and Close 1989; Blinn et al., 1995). The typical daily pattern of flow in the MCR consists of high flows during the day and low flows at night, corresponding to peak power usage. Within this general pattern, flows are highly variable. Extreme events such as flows in excess of 1800 m^3/s, or minimum flows of 142m^3/s that extend for more than 48 hours occur regularly and can result in large scale die-off of benthic communities. Extreme events, coupled with routine BC Hydro operations, ultimately determine the aquatic communities and productivity within the MCR.

The 2007-2012 data suggest that benthic communities in the MCR occur in three large zones created by the operating regime that determines water elevations and submergence over the last 30 to 70 days. First, there are permanently submerged areas that were sampled at T1 (mid channel) and T2 (channel edge at minimum flow) transect locations. These permanently wetted habitats function like those in other large rivers, with physical habitat attributes such as velocity, light, substrate, temperature, etc. controlling periphyton and invertebrate community structure and productivity. The MCR data suggest that within these permanently wetted areas, densities and biomass of both periphyton and invertebrate communities mimic those of a more natural large river system that is oligotrophic or stressed (Table 4-1). Like most rivers, MCR periphyton production is negatively correlated with velocity. Peak production occurred near the edge of the permanently wetted channel at T2 locations where shear stress is less, light penetration is greater, substrates are most stable, and the effects of scour and saltation are typically not as pronounced as they are near the thalweg at T1 locations. Furthermore, time series data suggest 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 sufficient to cause shearing of filamentous algae (Flinders and Hart 2009), and to mobilize substrate that caused further periphyton thinning due to abrasion from saltating sands (Fisher *et al.* 1982, Gregory *et al.* 1991; Goudie 2006; Luce *et al.* 2010). Prolonged high flows in 2011 and 2012 increased water velocity in the narrower Reach 4 channel, which coincidentally had lower periphyton accrual than in Reach 3.

The second habitat condition that exists in the mid-channel MCR area is much more variable and dynamic. It occurs above the boundary of the permanently wetted habitat in what is termed the lower varial zone, typified by our T3-T4 sampler locations. The width of the productive area in the lower varial zone varied depending upon the BC Hydro operating regime and the channel morphology at any given location. The fluctuations between submergence and exposure usually occurred at night and resulted in less desiccation than the equivalent exposure period in daylight hours. Further, these areas were submerged during moderate flow events (between 600 to 800 m^3/s), which occur 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. The invertebrate community underwent periods of growth and decline depending on how the recent operating regime intersected their life cycles. Not unexpectedly, the variable hydrologic conditions of MCR tend to select for rapid colonizers and rapid reproducers, resulting in high biomass communities of diatoms and filamentous green algae where nutrient conditions allow (Biggs 2000; Biggs and Kilroy 2000). The lower varial zone is productive and an important component of the overall productivity of the MCR. However, the accrual rate at R4 T3 positions was significantly slower than R4 T1 positions in the fall. Our modelling data demonstrates that factors such as daytime incubation time (submergence during the light), exposure (as shown through mean temperature), maximum cumulative submergence, and frequency of 12 hour submergence events are all important predictors of both periphyton and benthic invertebrate community development.

The third habitat unit found in the MCR is the upper varial zone, located in the frequently de-watered area and typified by our T5 through T7 locations. It is less productive than the deeper varial zone because its productivity was curtailed by the constant 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 current operating regime and intersection of the timing of exposure and the benthic invertebrate life cycles. Although the upper varial zone periphyton community had a similar structure to deeper zones, reduced species diversity and accrual rates indicate stress, particularly to the photosynthetic microflora. Periphyton production started to dramatically increase when the substrates were wetted during daylight hours for periods in excess of 9 hours. Periphyton production halted when the substrates were dewatered during the day because normal cell processes couldn't continue and desiccation stress reduced survival. The upper varial zone became more heterotrophic as the frequency of drying events increased. This finding is also supported by the importance of frequency of 12-hour submergence events and total incubation time in the water and light identified in modelling data for the periphyton autotrophic index.

ALR backwatering of the R3 upper varial zone T6 samplers during fall 2011 and 2012 helped increase R3 T6 chlorophyll-a production by a factor of three compared to R4 T6 production over the same time. Higher peak flows in 2012 potentially reduced the apparent benefit of backwatering in the R3 upper varial zone compared to 2011. The unstable sand substrates that typify this zone are difficult for microflora to colonize, and the higher flow events occurring in 2012 would make colonization even more difficult. Coupled with this, higher velocities increased sheer stresses and sand abrasion. Clearly, physical habitat conditions play an important role in the overall productivity observed in the MCR.

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

The boundaries between these zones were dynamic, and depended upon the average flow regime during the preceding 30-70 days. After the zones were established, rapid growth occurred to at least 6 months (Table 4-1), provided conditions were appropriate for benthic community development. The width of the productive lower varial zone was expanded by stable flows in the 400 to 800 m^3/s range. 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. Further, invertebrate recovery after a catastrophic event, which was observed in the spring of 2011, could take several weeks or more to recover and that recovery was dependent upon the life-stage of the invertebrates at the time of the event. Periphyton recovery was frequently faster than invertebrate recovery because bacteria and pico-cyanobacteria pre-condition dewatered substrates with organic coatings that can accelerate periphyton recolonization (Stockner 1991; Wetzel, 2001) after a catastrophic event. Our desiccation/re-wetting experiments (2010) indicated that resumption of growth occurred faster for species capable of producing desiccation-resistant structures such as akinetes and extracellular mucilage. Periphyton species that cannot adjust to exposure would presumably be eliminated from non-permanently wetted areas of the MCR and result in the observed homogeneity of the periphyton community structure throughout the varial zone.

These pressures on the invertebrate and periphyton communities are common to all large rivers, however, BC Hydro operations create a large, and more dynamic varial zone in the MCR. Most of the artificial substrate periphyton data collected to date indicate that the MCR is moderately productive. However, the open-celled Styrofoam used in these trials may exaggerate production by 20% (Perrin et al., 2004) to as much as 400% (median = 200%) based on our preliminary natural substrate samples from the upper varial zone. 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). Further, the natural substrate samples had far higher proportions of cyanobacteria, particularly in the sand from the cobble interstices in R4. 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).

While artificial substrates are effective in controlling confounding influences, inevitably there will be some distortion of periphyton metrics, Finding a suitable correction factor for the artificial substrate is important for several reasons, First, the inflation of periphyton growth metric would cause an underestimate of the impact of operations on accrual rates and overall production, Second, the artificial substrate results could underestimate the prevalence of cyanobacteria and filamentous green species in the MCR. Finally, correction factors are required to develop estimates of the spatial area of MCR productivity as it relates to a minimum flow regime and use of REV 5. Additional natural substrate sampling would be needed to develop statically supportable "correction factors" between the natural substrates and the open-celled Styrofoam substrates used in the MCR studies.

Table 4-1: Summary of typical MCR periphyton metrics from spring and fall 2010 - 2012, with comparison to oligotrophic, typical, and productive large rivers

Metric	Oligotrophic or stressed	Typical large rivers	Eutrophic or productive	MCR (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+)	0.04 – 4.1 **(0.59-2.0)**
Algae density cells/cm^2	<0.2 x10^6	1 - 4 x10^6	>1 x10^7	<0.02 – 1.5 x10^6 **(0.9 – 13.1x10^6)**
Algae biovolume cm^3/m^2	<0.5	0.5 – 5	20 - 80	0.03 - 10 **(0.6 - 5.9)**
Diatom density frustules/cm^2	<0.15 x10^6	1 - 2 x10^6	>20 x10^6	<0.01 – 0.6 x10^6 **(0.2-1.0 x10^6)**
Biomass –AFDW mg/cm^2	<0.5	0.5 - 2	>3	0.12 – 4.8 **(0.35-3.5)**
Biomass –dry wt mg/cm^2	<1	1 – 5	>10	0.7 – 80 **(6-99)**
Organic matter (% of dry wt)		4 - 7		1 – 10 **(2-7)**
Bacteria count sediment. HTPC CFU/cm^2	<4 -10 x10^6	0.4 – 50 ×10^6	>50×10^6 – >10^{10}	0.2 – 5 x10^6
Bacteria count water CFU/mL	0.1 – 10 x10^4	0.1 – 100 x10^5	2.4 x10^7	Not sampled
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	0.001 - 0.1 shallow; 0.005 - 0.38 deep

Comparison data obtained from Flinders and Hart 2009; Biggs1996; Peterson and Porter 2000; Freese et al. 2006; Durr and Thomason 2009; Romani 2009; Biggs and Close 2006.

4.2 Overview of Benthic Communities

The physical habitat condition on the MCR creates three zones of productivity: 1) those that are permanently submerged, 2) those in the lower varial zone, and 3) those in the upper varial zone. Despite the establishment of three distinct benthic communities with variable dominant species, both periphyton and invertebrate communities were relatively stable when viewed at the family level. Benthic communities also followed annual and seasonal patterns of growth. Periphyton production metrics measured in the spring were all less than half of the fall deployments. We expect this is because night outages exposed both the upper and lower varial zone substrates to freezing temperatures, and because low water temperatures reduce enzymatic activity even in the rapidly reproducing bacterial biofilm (Wetzel 2001). The MCR benthic community structure is stable but is still subject to seasonal variation, in addition to habitat condition over the past 2 to 6 months.

MCR periphyton communities were dominated by diatoms representing between 85 and 95% of the biovolume at all sample sites. Other species, such as filamentous green algae were more prevalent in areas near the edge of permanently wetted areas (T2), and in the lower varial zone (T3/T4) where stable substrates and "ecosystem engineers" 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 "producers" to "consumers", as indicated by the Autotrophic Index at T5/T6 locations. Benthic invertebrate communities were also dominated by those that are more tolerant of disturbance, such as chironomids (Tonking *et al.* 2009) which are often overrepresented in regulated rivers (e.g., Orthoclad chironomids (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). Although the major taxonomic group contributions of periphyton and benthic taxa remained the same, the dominant species were variable with annual BC Hydro operations, weather conditions (e.g., freezing temperatures during night time low flows or hot weather and lower flows during daylight hours), and other prevailing MCR conditions such as species donations from Revelstoke Reservoir.

The modelling results identified two important factors that are determinants for both periphyton and invertebrate community development. First, time spent in the water was a consistent and vital predictor of benthic production and diversity. Submergence metrics are probably the most important predictors of the benthic community because at least 50% of the best predictors for any metric of productivity for either periphyton or benthic invertebrates were associated with some measure of submergences or analogous measure of exposure. Second, physical parameters such as temperature, light, and velocity were identified a key factors determining periphyton and invertebrate community establishment. These physical parameters are more important determinants of community in permanently submerged habitat areas. Other physical factors that may also be important to benthic abundance and diversity that are yet to be investigated include frequency and magnitude of flow events. 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).

4.3 Benthic Communities and Area of Productive Habitat (Q#2)

The intent of minimum flows is to increase the spatial area of wetted habitat and subsequently improve the benthic communities in these locations. 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 suggest that productive benthic habitat is highly influenced by submergence parameters, including duration and timing of flow events. In fact, submergence (or metrics of it) may actually be the most important determinant of benthic communities in the MCR. Further, the most productive benthic areas (T2 through T3/T4) occur at or above the edge wetted by minimum flows and that this productive zone shifts position and size depending upon the prevailing operating regime. Thus, minimum flows 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 are also important. However, our data also suggest that when the elevation of the ALR is higher, the benefit of minimum flows on the spatial area of productivity is less due to the effects of backwatering that may extend throughout the MCR 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 and 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 is difficult to determine given the highly variable flow regime, variable episodes of ALR backwatering and the timing of benthic life cycles and flow releases. Despite difficulties in determining the exact benefits in spatial area of productive habitats due to minimum flows, we conclude that minimum flow increases the spatial area of productive habitat because it provides a minimum wetted habitat area that is productive.

4.4 Effects of Minimum Flows On Periphyton Communities and Accrual (Q#1 & Q#4)

Historically, BC Hydro has tried to avoid daytime dewatering and this operating regime was implemented prior to the establishment of minimum flows. Once CLBMON15b was implemented, REV 5 also came online. This means that we do not have clear before/after periods where we can study the benefits of minimum flows in isolation of other operational changes in the MCR over the study period. We therefore contrast production in the regularly dewatered varial zones with production in the permanently wetted zones.

The benefits of minimum flows are most evident in the periphyton communities at T1/T2 and T3 locations because these locations occur directly above and below the wetted edge at minimum flows. Peak production was most apparent at T2 locations because higher velocities at T1 transect positions in the thalweg 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. The productivity of the frequently dewatered upper varial zone (T5/T6) was consistently less than half of the high productivity zones.

The 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) than the specific effects of minimum flow because this regime determines the wetted edge of the channel during daytime periods, a key explanatory variable in modelling data.

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 (e.g., less than 10 ^{o}C) are all beneficial to periphyton viability on the exposed substrates. Conversely, dry weather with air temperatures below 0 ^{o}C or exceeding 15^{o}C to 20 ^{o}C would all reduce periphyton viability on the exposed substrates.

The effects of season and peak flows are 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 winter/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 lover varial zones.

Establishment and accrual of periphyton communities in the 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 the MCR continued linearly to the end of the 46 day deployment period. Therefore, incubation periods of greater than 46 days are required to achieve peak biomass in the MCR. Since periphyton communities can take from weeks in mesotrophic and eutrophic habitats to as many as three years in oligotrophic habitats to stabilize following a change in flow regime (Wu et al. 2009; Biggs, 1988), assessing the overall effects of minimum flow in MCR will take years to fully understand. Further, the daily, weekly, and yearly patterns of operation, Arrow Reservoir backwatering, and seasonal growth cycles can all affect accrual. Therefore, although improved periphyton production stemming from the implementation of minimum flows is already occurring, it will be difficult to separate production benefits attributable to minimum flows from the effects of flows resulting from the recent and current operating regimes.

4.5 Effects of Minimum Flows on Benthic Invertebrate Communities and Accrual (Q#3)

The responses of invertebrates to minimum flows were very similar to periphyton, in that productive habitat included permanently submerged habitat and areas in the lower varial zone adjacent to the edge wetted by minimum flows. Since invertebrate communities are directly dependent upon submergence and physical conditions of the MCR for survival, the same explanation can be used to describe where and when invertebrate communities establish. Like periphyton, the area of productive invertebrate habitat is bounded by minimum flows and an upper limit determined by average daily submergence.

However, the MCR invertebrate models explained substantially less variation (i.e., lower R^2 values) than the periphyton models. This occurred for several reasons, including patchily distributed invertebrate communities, potential sampling biases associated with use of rock baskets retrieved from depths of 5 m at high velocities, and a low sample size to habitat area ratio when compared to periphyton. Further, invertebrates are more sensitive to desiccation than periphyton (Schleppe et al, 2012; Golder, 2012), and microhabitat factors could not be accounted for in our analysis. The spatial area of the lower varial zone available to invertebrates is probably smaller than that of periphyton. Further, invertebrate habitat is likely more heavily influenced by periods of daytime exposure because of their reduced tolerances to desiccation. 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 benefit the invertebrate community and that dewatering of habitat has a direct negative effect on the abundance, biomass, and community composition. Further, the permanently wetted area can function as a source of organisms to re-colonize exposed habitat areas after extensive low flow events greater than 24 hours.

4.6 Effects of Minimum Flow On the Availability of Food For Fishes in the MCR (Q#5)

The area of productive MCR habitat is directly correlated with submergence. Further our data suggest that the abundance, biomass, and overall availability of fish food (using the Fish Food Index) is also directly dependent upon time spent in the water. Thus, any increases in wetted productive habitat should cause a subsequent increase in fish food availability. 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. For these reasons, minimum flows increased fish food availability but other key influences on productivity such as frequency and duration of daytime submergence events must also be considered.

4.7 Possible Alternate Flow Regimes to Enhance MCR Productivity

We speculate that operating regimes which reduce the frequency of catastrophic drying may expand the highly productive lower varial zone. Before the December 2010 implementation of minimum flows, BC Hydro attempted to avoid zero discharge during daylight hours for ecological and social reasons, (BC Hydro, 1998).

Based on the artificial substrate results, areas experiencing daytime submergences in excess of 9 hours can maintain measures of periphyton production and diversity similar to areas permanently submerged by minimum flows. Thus, 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. It is probable that there are many operating regimes that could benefit MCR production, but more data is required to assess the merits of alternate operating regimes.

Minimum flows may not be as helpful to MCR productivity as avoiding dewatering the highly productive lower varial zone (T3/T4) in daytime outages, although more data is required to fully understand the interactions between BCH operating regimes and benthic productivity. The consequences of, and recovery from substrate exposure are explored in Table 4-2. Operating regimes that reduce the frequency and duration of catastrophic drying events could be more beneficial than always maintaining minimum flows. It may be possible to conserve minimum flow water during periods where backwatering and mounding extend through the MCR, and then use the conserved water to maintain higher releases during daytime low flow periods at a later date, thereby increasing the size of the lower varial zone.

Table 4-2: Approximate ranges of expected percent mortality of dominant periphyton in MCR Reaches 4 and 3 with substrate exposure time and corresponding recovery times Corresponding invertebrate mortality times will be shorter, and the recovery times more erratic than those for periphyton.

Expected Percent Mortality							
Substrate exposure time per event	**<2 hours**	**2-10 hours**	**10-24 hours**	**24-48 hours**	**2-4 days**	**4-6 days**	**>6 days**
Day exposure	<10	10-30	30-40	40-60	40-70	70-95	95+
Night exposure	none	0-10	10-30	30-50	50-70	70-80	80+
Corresponding Recovery Time (weeks)							
June – October	none	<1	1-2	2-3	3-5	5-8	.>8
November – May	<1	1-2	2-4	3-6	6-10	10-20	> 20

Data obtained from this study 2010 – 2012; Usher and Blinn 1990; Angradi and Kubly, 1993; and Blinn *et al.* 1995, Hodoki 2005

5.0 RECOMMENDATIONS

5.1 Review of Project Directions Proposed for 2012

Table 5.1 Review of Planned Consultant Project Directions and Actions for 2012

Recommendations from earlier CLBMON 15b Reports	Project Action in 2012
Add to water quality contract: TSS, turbidity, upwelling groundwater sampling for dissolved N and P	TSS, turbidity done, upwelling groundwater sampling not done due to record high flows
Review ADCP model data for inclusion in our benthic productivity analysis	Ongoing
Build habitat attribute data sets covering velocity and depth etc. at various flows.	Done in 2010- 2012, ongoing
Implement detailed statistical analysis of entire data set 2007 - 2012	Done, will update every year
In-stream assay for nutrient limitation	Deferred due to funding
Deploy samplers in other habitat units; Big Eddy, backwater, white water and bedrock	Done in spring and fall 2011 and 2012
Improve time series apparatus to improve retrieval efficiency and safety.	Done.
Deploy three temperature and light data loggers in continuously exposed areas	Done, ongoing
Continue to use light data to determine samplers that flipped	Done.
Use stick blender to re-distribute periphyton clumps before subsampling	Done throughout 2011 and 2012
Collect regular drift samples in 2012 during the weekly time series sampling trips	Done in Reach 3 and 4 at end of each deployment
Quantitatively sample natural substrates	Done in 2012 for R4 cobbles and sand, and for R3 cobbles and sand substrates
Trial alternate artificial substrates	Small trial completed in 2011 in Reach 4
Deploy long-term 6 month deployments, 1 transect	Done (spring to fall 2011, fall 2011 to spring 2012; spring to fall 2012)
Develop fish food index	Done

6.2 Recommended Work Program Elements for 2013

The following are recommendations are presented for incorporation into the 2013 work program.

- Chlorophyll-a should be collected and analyzed during each time series sampling event. This can vary significantly in drift samples and is important because it is a food source for filter feeders in the MCR. In 2012, these samples were collected during retrieval only.
- Four composite samples (3 replicates of each) can be collected from the area permanently wetted by minimum flows during the fall 2013 sampling session. Samples can be collected from the same selection of substrates as in 2012 (R4 sand and cobble; R3 sand and cobble).

The following are recommendations for consideration as part of the longer term CLBMON15b work program.

- A spatial model of productivity should be developed that incorporates the results of this assessment. The total area of productive spatial habitat is dependant upon more than just minimum flows. For instance, the data from this assessment suggests that daytime submergence is a key predictors of productivity and submergence can be directly related through the HEC RAS modelling to determine the spatial area of productive habitat. Future model iterations should also attempt to build in associated sampling hierarchy of Reach, Site, Transect. Development of models with these parameters would allow specific scenarios to assess the effectiveness of minimum flows or other operational regimes are planned.
- The small natural substrate project we completed in 2012 indicated that a substantial correction factor was needed to adjust the periphyton productivity predicted by the artificial substrate samplers to the production occurring on natural substrates in the varial zone. A larger sample size is required to link short term artificial substrates to natural river bed substrates that have been submerged for longer periods of time. This is important because longer term submergences and the recent operational patterns over the past 6 monthes to several years likely contribute to productivity in the river. We would recommend sampling the T6, T5, T4 and T3 locations for 2 transects in each reach for a total 16 paired samples (natural substrates adjacent to sampler and open-celled styrofoam sampler) We would recommend completing this work in spring and fall
- The initial 2010 drying/freeze-drying experiments indicated that species tolerances to drying are key to understanding the overall production in the MCR. Our initial investigations did not include replicates or drying effects on natural substrates. Further work on *in situ* desiccation and recovery of natural substrates should be considered for one year because these experiments would provide a better understanding of recruitment mechanisms in the MCR, which are believed to be important in the establishment and re-establishment of periphyton following desiccation.

- Although we speculate that nutrients are not a limiting factor in the MCR, we do not have enough data to support this. The least ambiguous approach for establishing that nutrient(s) limit growth is the in-stream assay. The value of an in-stream assay should be investigated. Improvements to our preliminary sampling apparatus are required to avoid loss of samples which were obvserved in 2011.

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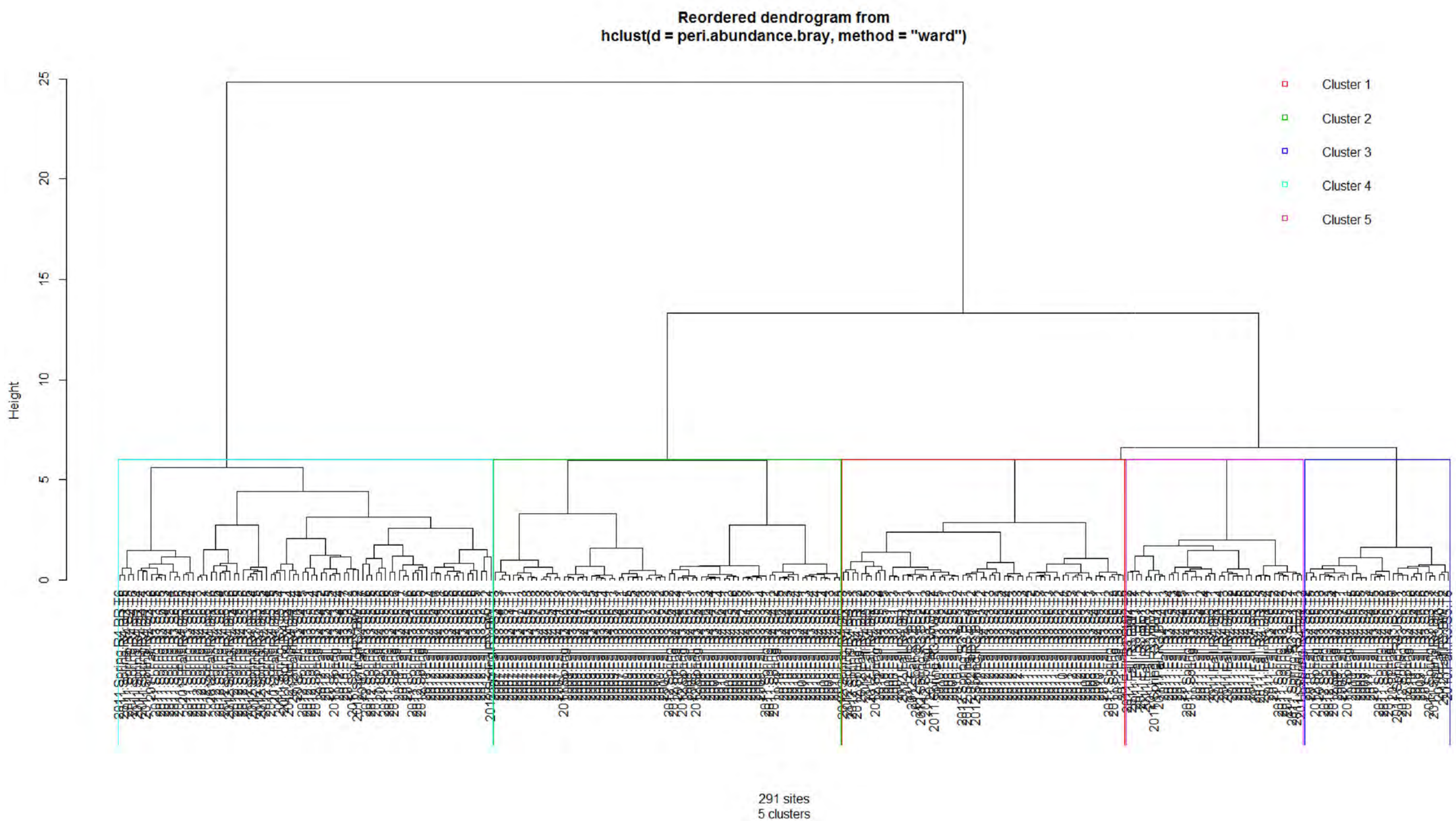
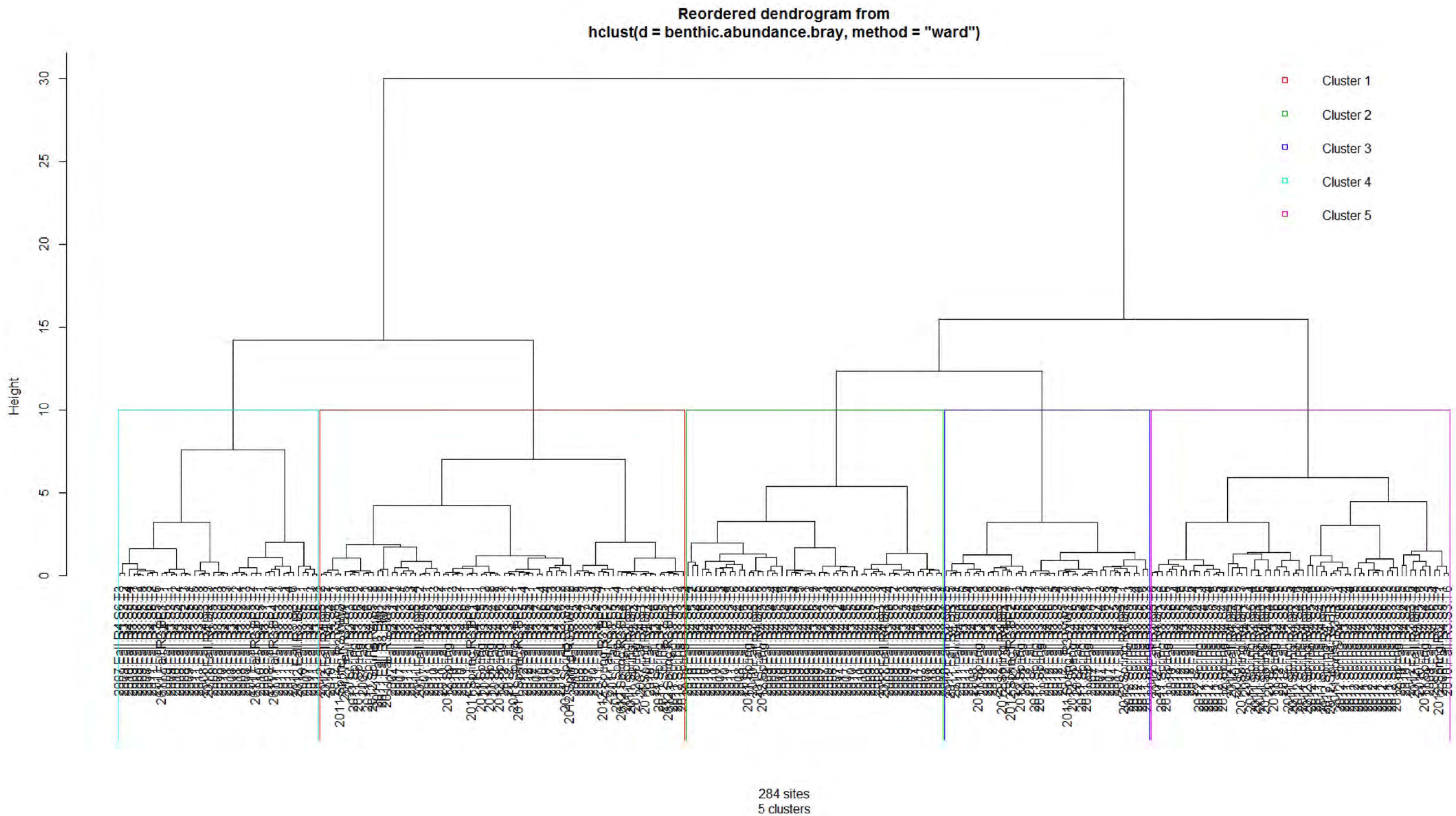
Appendix A.



Appendix A-1. Cluster analysis of periphyton data from 2007 to 2012 grouped into 5 clusters using Ward's method.



Appendix A-2. Cluster analysis of benthic data from 2007 to 2011 grouped into 5 clusters using Ward's method.