Columbia River Project Water Use Plan

MIDDLE COLUMBIA RIVER ECOLOGICAL PRODUCTIVITY MONITORING

Implementation Year 5

Reference: CLBMON–15b

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

Survey Period: 2011

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PROGRAM NO. CLBMON-15B

May 2012

MIDDLE COLUMBIA RIVER ECOLOGICAL PRODUCTIVITY MONITORING, 2011

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CLBMON 15B Status of Objectives Management Questions and Hypotheses After Year 5

Objectives	Management Questions	Management Hypotheses	Year 5 (2011) 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^3s^{-1} minimum flow release does not change the spatial area of productive benthic habitat for periphyton or benthic invertebrates in the MCR.	Ho_1: It is not yet known whether the implementation of the 142 m^3s^{-1} minimum flow release has resulted in a change in the spatial area of productive benthic habitat. This management hypothesis will be addressed in Years 6-9 of the study with the use of HEC-RAS cross sectional data (to be obtained from CLBMON-15a). Modeling will be used to determine spatial relationships between submergence and production, both before and after the implementation of minimum flow release. Theoretically, the implementation of minimum flow release should result in an increase in the permanently wetted channel area and the productivity of benthic habitat. Our preliminary work has shown that benthic invertebrates are more sensitive to exposure than periphyton; exposure events of as little as 24 hours may have a significant impact on the invertebrate community. Exposure tolerances of periphyton appear to be longer and significant losses may occur with exposures exceeding 48 hours. What remains unknown is if the dam operations before and after the implementation of minimum flow release have resulted in significant differences in wetted spatial areas of productive habitat, and the extent to which minimum flow is beneficial. We suspect there may be alternative operating regimes that are more effective at increasing productive benthic habitat. For example, ALR backwatering in 2011 could have an increased effect on productivity over the benefit of minimum flow. In short, the null hypothesis has yet to be specifically tested, but theoretically, indirect data suggests that minimum flow should result in increased area of productive benthic habitats.
	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^3s^{-1} minimum flow release does not change the total biomass accrual rate of periphyton in the MCR.	Ho_2: Preliminary time series chlorophyll-a data indicate that the null hypothesis should be rejected. Accrual rates for periphyton were very slow at shallow sites with periodic dewatering and much faster (and more typical of large rivers) in permanently wetted sites. Ignoring all other changes in the MCR flow regime, minimum flows should increase the periphyton accrual rate. The data suggest that there may be a differential response between areas of the channel permanently submerged (Ho_{2A}) and those in the frequently wetted varial zone (Ho_{2B}).

	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_{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.	Ho_{2A}: It is assumed that this sub-hypothesis refers to areas that were permanently wetted prior to the implementation of minimum flows. At this time, we do not have enough data to reject the null hypothesis, however, it should be noted that the entire channel rarely dewatered completely even with 0 m^3/s releases and as a result, the deep MCR habitat units appear to function similarly to natural river systems. Within these permanently wetted areas, periphyton biomass and accrual were influenced by biophysical habitat characteristics such as velocity, light, and sediment movement. Ho_{2B}: The null hypothesis is preliminarily rejected for the varial zone. In the varial zone biomass and accrual are apparently limited by exposure. Exposure is dependent on many factors, with MCR flows and ALR backwatering being some of the most important. The data suggest that accrual rates are higher in areas of increased submergence. Accrual rates appear linear in general; however, fluctuations in growth from exposure-related mortality were observed. The regular interruptions in production in the varial zone indicate that peak biomass varies with habitat conditions and could take six months or longer to develop.
	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^3s^{-1} 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_3: The null hypothesis is preliminarily rejected. Data for periphyton is less variable than benthic invertebrate data and responses are more easily interpreted. Minimum flows should increase the abundance/biomass/diversity of benthic invertebrates at channel elevations that remain permanently wetted by minimum flow releases. There appears to be a differential response in the channel areas that remain wetted versus those that experience varial exposure and the sub hypotheses should be considered. $Ho_{3A:}$ The null hypothesis cannot be rejected for the time being. The abundance, biomass, and diversity of benthic invertebrates within permanently wetted areas did not appear to differ substantially from a natural system within permanently wetted areas. Specific comparisons to pre and post implementation of flows have not been fully investigated. However, it is suspected that operations do have some effect and more data is required to reduce variation and fully investigate the effects of flow ramping on the MCR.

		$Ho_{3B:}$ 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 null hypothesis is rejected for areas of high channel elevation that are infrequently wetted. At high channel elevations frequently exposed benthic densities are reduced. However, at mid low channel areas that are frequently wetted, differences are more difficult to interpret. The data suggest that benthic invertebrate abundance, diversity, and biomass are positively associated with submergence or time in the water. Since minimum flows increase the area of permanently wetted habitats, benefits to benthic production should be observed.
	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^3s^{-1} minimum flow release does not change the availability of fish food organisms in the Middle Columbia.	Ho_4: The data suggest that minimum flows do increase the availability of fish food items because there is a positive relationship between time in the water and benthic abundance and biomass. Further, Hilsenhoff's index data suggest that there was increased abundance of the more palatable but sensitive EPT benthic invertebrates with increasing submergence. The extent or magnitude of the benefit or quantity of fish food as a result of minimum flows is currently unknown. Palatability of the periphyton mat for benthic invertebrates may be reduced by substrate exposure. This means that minimum flows increase the quantity of wetted substrate improving the upload of energy from the periphyton to fish food organisms in the MCR, provided that permanently wetted habitats is more palatable for energy upload. Based on this, the null hypothesis is preliminarily rejected.

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
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
IL	Illecillewaet River
JR	Jordan River
MCR	Middle Columbia River
m	metre
min	minimum
max	maximum
MW	Mega Watts
NMDS	Non metric multi dimensional scaling
REV5	Revelstoke 5
SD	Standard Deviation
WUP CC	Columbia River Water Use Plan Consultative Committee
WW	Whitewater

EXECUTIVE SUMMARY

Aquatic habitats in the Middle Columbia River (MCR) are heavily influenced by variable flow releases from the Revelstoke Dam. To lessen that effect, the Columbia River Water Use Plan supported implementation of a year-round minimum flow of 142 m^3s^{-1} from Revelstoke Dam to the MCR. Minimum flows are considered beneficial to riverine habitats, while the frequencies of extreme low or high flow events are usually considered deleterious. The key objective of the 142 m^3s^{-1}minimum flow release strategy from the Revelstoke Dam is to enhance the productivity and diversity of benthic communities in Reaches 4 and 3 of the MCR. The goal of CLBMON-15b, the ecological productivity monitoring program, is to provide long-term data on the productivity of the benthic community and to assess how minimum flow releases influence the benthic communities as they relate to the availability of food for fish. This summary report covers year 5 data (2011), and also presents trends across years.

Two habitat conditions exist on the MCR, those that are either permanently submerged or those that occur in varial zones of differential submergence. Minimum flows on the MCR appear to benefit the benthic community by ensuring that a minimal channel area remains wetted and productive at all times. This area also functions as a source of organisms to re-colonize exposed habitat areas after catastrophic events. Catastrophic events are loosely defined as events that have significant impacts on populations (e.g., >50% mortality), either through mortality or stress, related to exposure. Within permanently submerged areas, physical factors such as velocity, light, substrates, and depth determined the productivity of the benthic communities. In varial zone areas, variables related to submergence or time in the water were most important. This trend was similar for both benthic invertebrates and periphyton. For periphyton, a maximal biomass and diversity was documented at mid-channel elevations from just below the elevation of minimum flow to slightly above it.

The data for periphyton was less variable and responses were more easily interpreted than for benthic invertebrate data. In general, the responses of both periphyton and benthic invertebrate data were the same, with increased productivity in areas exposed less frequently. The adverse impact of extreme high or low flow events on benthic populations is complex and difficult to quantify. After catastrophic events, a variable period of recovery occurs, and is seemingly dependent upon the magnitude of the event, the species and the season. The MCR data suggest that benthic invertebrates are more sensitive to exposure than periphyton. Exposure events of as little as 24 hours can have a significant impact on invertebrates, while catastrophic periphyton losses may require exposures exceeding 48 hours.

Accrual rates for periphyton were very slow at shallow sites with frequent dewatering and much faster (and more typical of large rivers) in permanently wetted sites. The data suggested that six month accruals had more biomass than two month accruals, indicating that production will continue for several months on stable artificial substrates.

Theoretically, minimum flows should be beneficial to productive habitat areas. However, key factors such as ALR backwatering, peak flows and species tolerances should be considered when setting operational guidelines. Strong annual data variability indicates that factors such as specific operating regime or seasonal weather patterns are important. Alternative operating regimes without minimum flow are possible and may result in similar or higher benthic productivity.

Keywords:

Middle Columbia River, Ecological Productivity

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1.0 INTRODUCTION

Aquatic habitats in the Middle Columbia River (MCR) are heavily influenced by variable flow releases from the Revelstoke Dam. To lessen that effect, the Columbia River Water Use Plan supported implementation of a year-round minimum flow of 142 m^3s^{-1} from Revelstoke Dam to the MCR. The initiative sought to understand how physical and biological variables affect fish habitat productivity in the MCR (WUP, BC Hydro 2005). One aspect involved assessing how the productivity and diversity of benthic communities would change through implementation of the minimum flow. It was hypothesized that increasing the permanently wetted channel downstream of the Revelstoke Dam would result in increased periphyton and benthic invertebrate production (WUP, BC Hydro 2005). It was thought that an enhanced benthic community would increase food availability for fish and ultimately improves fish abundance.

Prior to implementation of a minimum flow, the water release from the Revelstoke Dam varied from 0 to 1700 m^3s^{-1}, depending on power demands and could result in sudden water fluctuations typically between 3 to 5 vertical meters. 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). The initiation of minimum flow coincided with the operation of a fifth unit (REV5) at the Revelstoke Generating Station and was initiated on November 1, 2010. With the addition of REV5, 500 MW was added to the station's generating capacity; allowing for a peak discharge of 2124 m^3s^{-1}. 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 CLBMON-15b Ecological Productivity Monitoring forms one component of a broader monitoring program designed to assess the effectiveness of minimum flows at improving habitat conditions for fish. 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 the minimum flow provides benefits for fish, and if there is an advantage to the establishment of long-term minimum operating release requirements for the Revelstoke Dam.

The Ecological Productivity Monitoring schedule consisted of four years of monitoring prior to implementation of the minimum flow / REV5 operations, and up to ten years of subsequent monitoring under the new operating regime. 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 interim status report summarizes year 5 of the monitoring program. The 2011 sampling season differs from the previous years in the following ways. First, this is the first year when both spring and fall sampling sessions were undertaken; previously only fall sampling was completed. Second, one transect was re-surveyed during each retrieval (R3S6) for the six months between sampling sessions. Third, several different habitat units were added to the sampling program including:

1. Bedrock;
2. Backwater (little to no velocity);
3. Big Eddy (deep, low velocity);
4. Tributary (upstream data only obtained, as samplers positioned downstream of tributaries were lost); and
5. Whitewater (riffles at low flow, high velocity/turbulent at high flows).
6. Benthic invertebrate sampling only was undertaken in Reach 2 at both permanently wetted sites and at recently submerged sites to understand the effects of catastrophic exposure on invertebrate biomass and abundance.

Finally, this is the first year following the implementation of minimum flows.

1.2 Objectives, Questions, and Hypothesis

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 REV5 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 REV5 operations

The first objective was satisfied by the basic study design developed by Perrin et al. (2004).

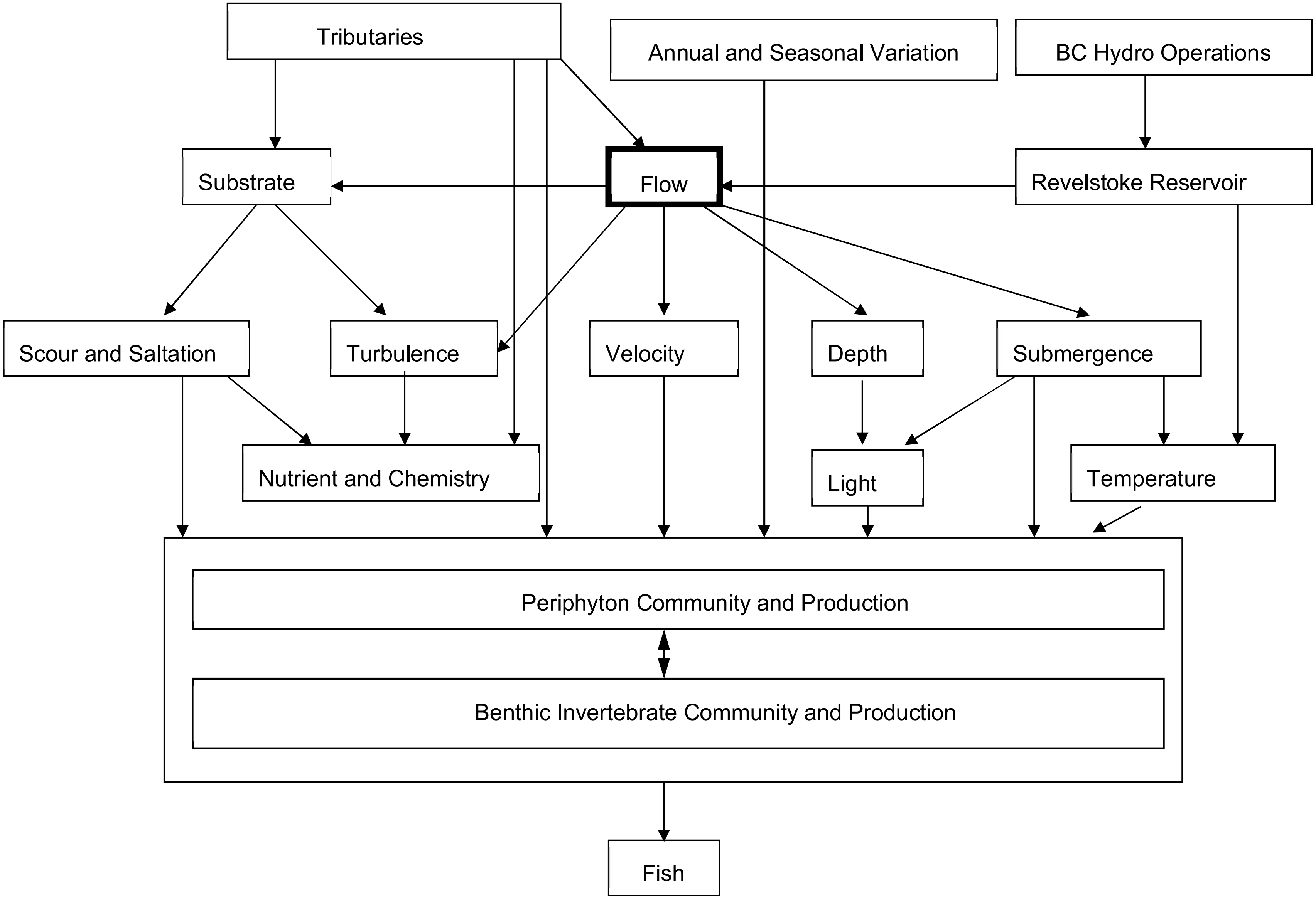


Figure 1-1: Conceptual Interactions Model of Habitat Variables and Benthic Production as they relate to Food for Fish in the MCR

We developed a preliminary conceptual model to address the second and third objectives, and to understand the potential interactions of the complex factors affected by changes in flow (Schleppe et al. 2010). Figure 1-1 depicts an updated version of that model. Although the relative importance and role of each parameter has yet to be clarified, this model identifies the many variables that may likely influence benthic productivity and ultimately food for fish. 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.

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 REV5 operations.

Although the current study design is consistent with previous years to facilitate comparisons of pre- and post- flow regime changes, additional components have been or will be added during future sampling periods to better address the questions/hypotheses posed by BC Hydro. Noteworthy additions include more rigorous natural substrate sampling of both periphyton and benthic invertebrate communities and artificial substrate sampler placement in un-sampled habitat types (e.g. bedrock, Big Eddie, etc.). Other considerations include the future mapping of benthic substrates in Reaches 4 and 3 because substrates are believed to be an important parameter affecting benthic production. Using simple statistical models, it may be easier to identify relationships between benthic production and spatial features including substrate type and area of wetted habitat or submergence than parameters such as flow or near bed velocity. The intent of these data collection additions is to facilitate the extrapolation of benthic periphyton and invertebrate sampler data to the river as a whole and enable estimation of the total benthic production of the MCR. The ultimate goal is to identify and describe what habitat attributes are most influential and identify how implementation of the new dam operation regime potentially improves benthic productivity in the MCR.

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 m^3s^{-1} 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. Data collection includes: Abundance –periphyton & invertebrates Diversity – taxonomy, indices Production/Biomass – chl-a, AFDW/DW, biovolume, benthic invertebrate biomass Comparison to natural substrates: grab and drift samples Habitat inventory and mapping that focuses on substrates, riparian condition, and spatial extents of stable periphyton communities
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 m^3s^{-1} 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.	Time series samplers to establish peak biomass chl-a and taxonomy Nano-flora HTPC plate counts Artificial sampler arrays deployed across the range of flows and loss vectors (e.g., velocity, shear, grazing) to assess production. Data collection includes: Chl-a AFDW/DW Biovolume Autotrophic Index Compare control periphyton metrics (2007-2010) with subsequent data following the establishment of minimum flows (2011-2012) Light and temperature logger data to address light attenuation and exposure Account for Revelstoke Reservoir contributions by assessing drift and existing literature Longer term plate deployment (1 year plate (R4)) and planned long term deployments between Apr-Oct and Oct-Apr Desiccation/re-wetting experiments Freeze-dry/re-wetting experiments
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 m^3s^{-1} 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 invertebrate basket sampler arrays deployed across the gradient of flows. Data collection includes: Diversity – taxonomy, indices Benthic invertebrate abundance & biomass Time series of establishment of benthic invertebrate communities across the gradient of flows Literature review of invertebrate freeze and desiccation tolerances
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^3s^{-1} minimum flow release does not change the availability of fish food organisms in the Middle Columbia.	AFDW/DW edible algal biomass Annotated taxa list of algal forage quality Functional benthic foraging groups (e.g. Predator, Collector/Gatherer, etc.) Fish food indices to classify the forage quality of benthic invertebrates Use of qualitative fish stomach contents to ascertain benthic invertebrate forage quality

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 an approximately 38.5 km stretch between the Revelstoke Dam and the Upper Arrow Lake Reservoir (ALR) near Galena Bay. This study primarily occurs in 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 generally characterized by a trapezoidal river channel with moderate to steep banks that confine the thalweg. The reach encompasses large areas of stable substrate consisting predominantly of larger gravels, cobble and boulder, while there are lesser amounts of sands, pebbles and smaller gravels that occur beneath the cobble-armoured surface. The bankfull width in Reach 4 ranges from 147 – 223 m (Perrin and Chapman 2010). The 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 present.

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 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.

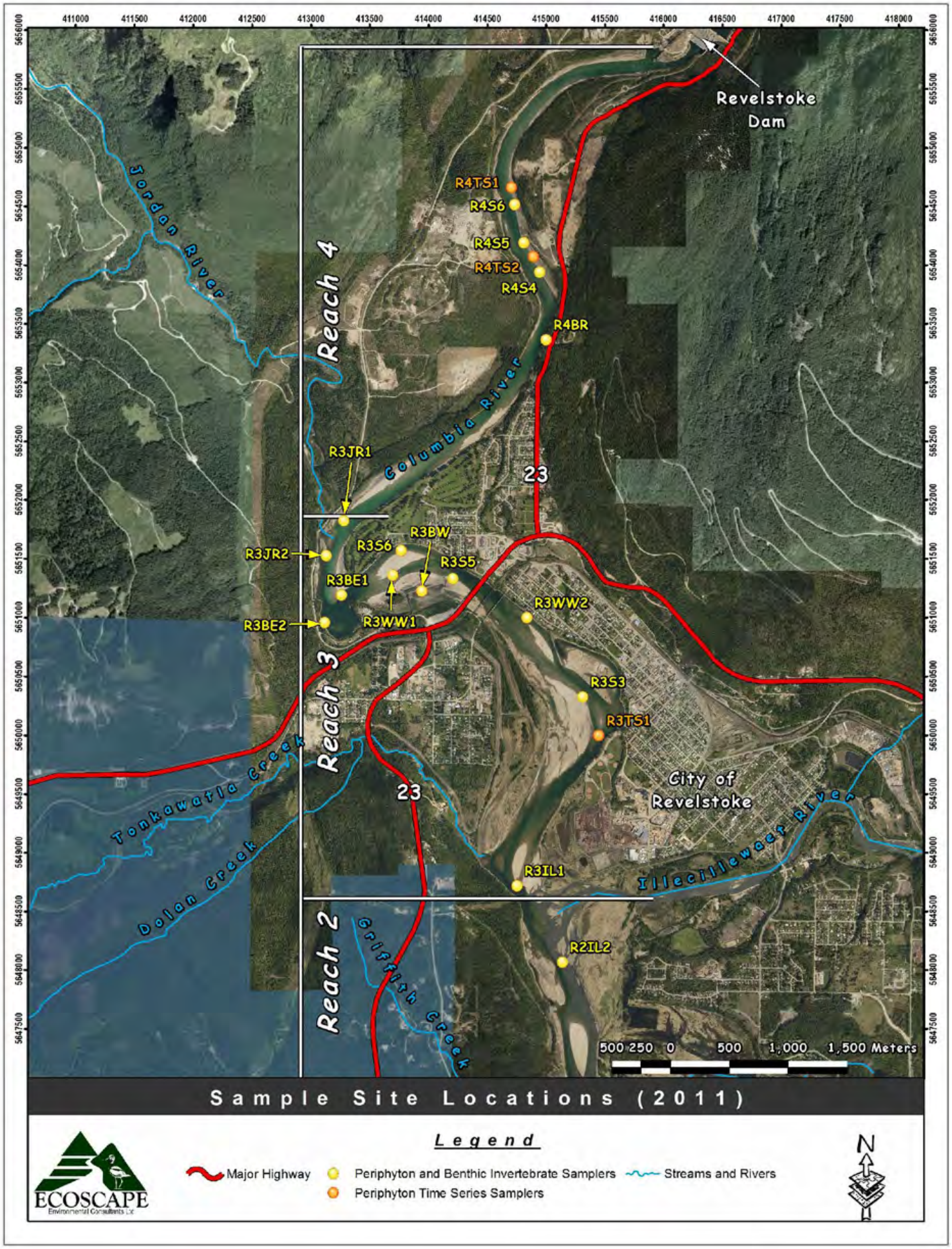


Figure 2-1: Map of the Study Area and Sampling Locations. Site names are fully defined in Table 2-1.

2.2 Natural Substrate Sampling

2.2.1 Periphyton

Semi-quantitative natural substrate and drift samples were collected from Reaches 4 and 3 in the approximate vicinity of the artificial substrate samplers. The species composition of samples were compared to those from the artificial substrate samplers to understand the extent of artificial substrate bias on species composition, if any, and to obtain a more comprehensive algal and invertebrate species list for the MCR. Transects were established for natural periphyton collection from periodically dewatered and permanently wetted elevations. The periphyton was removed from cobbles using a scalpel and nylon brush, while periphyton was removed from sand by vigorous agitation in 500 ml of filtered river water. Periphyton drift samples were collected by suspending a 80 µm mesh standard plankton net in the upper water column for one minute, and subsequently storing them chilled until processing.

2.2.2 Benthic Invertebrates

In addition to the deployment of artificial samplers, natural substrate sampling for benthic invertebrates was also conducted. Within Reaches 4 and 3, six Hess samples were obtained on April 10 and 11th, 2011, following standard procedures. Additional surveys by flipping rocks was also conducted to look for evidence of invertebrates in the channel that had been dry for over 24 hours.

In Reach 2 on May 28, 2011,an Ekman dredge was used to obtain 16 substrate grab samples from eight different random sites. At each site, substrate samples were collected from both deep (> 2 m) and shallow (1-2 m) depths. At the time of collection, the samples were screened using a 180 µm sieve and pre-filtered river water. The cleaned sample was then stored in a 500 ml container and fixed with 10% formalin until further laboratory processing. Identification and biomass determination was undertaken by Cordillera Consulting following standard procedures.

Figure 2-2: Natural benthic invertebrate samples were collected after a catastrophic event following a period of 36 hours of exposure

The rationale for the Reach 2 collections was to compare locations that were recently wetted (Shallow) with those that were permanently wetted (Deep) to determine if there was a difference in benthic invertebrate abundance and biomass. Arrow Lake Reservoir elevation data, obtained from Poisson Consulting, was used to estimate water level changes. The elevation data showed a change of approximately 2 m between May 15th and May 28th. We therefore estimated that the shallow sites had been wetted for approximately 2 to 4 weeks prior to sample collection, whereas the deep sites had been permanently wetted in 2011.

The results of this work are applicable to the upper reaches of the MCR, that experience daily fluctuations in flow, leaving portions of the stream channel dry and exposed. The resulting biomass and abundance data was assessed for normality using a Shapiro-Wilks test. The data was then log transformed to meet the normality assumptions, and a Student's t-test using depth as the predictor, was undertaken for both abundance and biomass.

2.3 Periphyton and Invertebrate Community Sampling Using Artificial Samplers

2.3.1 Artificial Sampler Design and Deployment

Year 5 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. The number of standard periphyton and invertebrate samplers was increased from 40 in 2010, to 50 and 49 in the spring and fall of 2011. The additional samplers in combination with a reduction from 7 to 6 samplers across a transect enabled the sampling of habitat units that had not be previously sampled. Refer to Table 2-1 for the number of samplers that were deployed at each site.

The original sample sites were generally consistent with previous years and the same naming system, including site numbers (Reach 4: S6-S4; and Reach 3: S6, S5 & S3) and sampler location (T1 – T6, deep to shallow) within transects was utilized. Additional sampling locations included: upstream and downstream of the two major tributaries, Jordan and Illecillewaet rivers (labeled as JR and IL), Big Eddy (BE), bedrock (BR), whitewater (WW), and backwater (BW). Figure 2-1 depicts the locations of all sampling sites. This naming convention used is inconsistent with BC Hydro's current standard, but is easier to interpret since it is more consistent with standard stream assessment terminology. Data is available in BC Hydro's standard naming system.

Samplers and associated rigging were assembled and deployed in the spring during April 8 – 11, and in the fall during September 10 - 12, 2011. One day was spent preparing gear, followed by daytime deployments in both Reaches 4 and 3, when flows were minimal to moderate. Figure 2-3 illustrates our standard artificial sampler design which did not deviate from 2010 (Schleppe et al. 2011). 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 accurately obtain the geodetic elevation of each sampler.

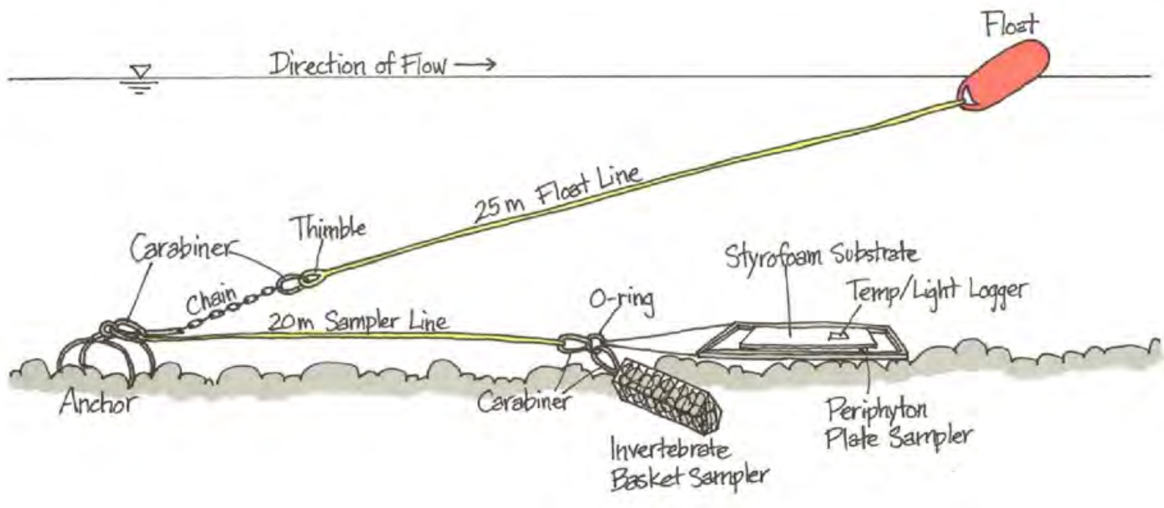


Figure 2-3: Schematic Drawing of a Standard Artificial Substrate Sampler

Table 2-1: Artificial Sampler Deployment and Retrieval in 2011

Season	Reach	Site/Habitat Type	Periphyton Samplers		Invertebrate Basket Samplers	
			# Deployed	# Retrieved (% Recovery)	# Deployed	# Retrieved (% Recovery)
Spring (Apr 9th - May 27th)	4	Site 6 (S6)	6	6 (100)	6	5 (83)
		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)	5	5 (100)	10	7 (70)
	3	Jordon River (JR)	2	1 (50)	2	1 (50)
		Big Eddie (BE)	2	2 (100)	2	2 (100)
		Whitewater (WW)	2	2 (100)	4	2 (100)
		Site 6 (S6)	6	6 (100)	6	6 (100)
		Site 5 (S5)	6	6 (100)	6	6 (100)
		Site 3 (S3)	6	6 (100)	6	6 (100)
		Illicillewaet River (IR)	2	1 (50)	2	1 (50)
		Time Series (TS)	5	5 (100)	10	5 (50)
Spring Totals			**60**	**58 (97)**	**72**	**59 (82)**
Fall (Sept 10th - Oct 28th)	4	Site 6 (S6)	6	6 (100)	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	10 (100)	10	10 (100)
	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)	3	3 (100)	3	3 (100)
		Site 3 (S3)	6	6 (100)	6	6 (100)
		Time Series (TS)	0	0	10	8 (80)
Fall Totals			**59**	**59 (100)**	**69**	**67 (97)**
2011 Totals			**119**	**117 (98)**	**141**	**126 (89)**

Note: Although time series periphyton samplers were all eventually retrieved, some weekly Styrofoam punches were not taken due to high flows, or the inability to pull plates.

2.3.2 Time Series Samplers

In addition to regular samplers, 10 time series periphyton samplers and 20 time series invertebrate basket samplers were deployed in both spring and fall to access accrual rates. In accordance with 2010 recommendations, time series periphyton and invertebrate samplers were deployed separately to reduce the weight of the samplers during retrieval.

In the spring, similar to the deployment of regular samplers, time series periphyton samplers were split between Reaches 4 and 3, and were deployed along a transect at variable elevations. Whereas in the fall, the time series periphyton sampling methodology was changed to increase the number of replicates so that time series data could be evaluated statistically. All 10 time series periphyton samplers were deployed in Reach 4 and split between two different elevations, rather than along a transect. This new sampling design resulted in 5 replicate deep and 5 replicate shallow samplers.

The 20 time series benthic invertebrate samplers were divided among 4 sites in both the spring and fall. At each site, 10 m of rope separated 5 rock baskets. This sampling design facilitated the removal of a single rock basket each week, without disturbing the other samplers further up the line. Although this sampling design was preferred due to a reduction in weight during retrieval, it also presented other problems. Even though the line of baskets was secured with a standard anchor, we still experienced difficulties with baskets drifting downstream and eventually becoming entangled. The movement of these samplers resulted in damaged baskets and the loss of rock substrate. There were also several baskets that became so entangled that we were unable to retrieve them. The difficulties with this sampling design in combination with a miniscule number of recovered invertebrates resulted in the termination of invertebrate time series sampling. In the spring, invertebrate time series samples were submitted for laboratory processing, however, by the fall it was deemed not worth pursuing from a budgetary standpoint.

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. 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.

Each week, periphyton punches were collected using a random number generator and were immediately 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. Time series rock baskets were field-processed in the same manner as regular samplers (see Section 2.3.5 below).

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 26 – 27 and Oct 27-28, 2011, respectively.

At the time of retrieval, a random number generator was used to take four Styrofoam punches 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 following a similar protocol as described in Perrin and Chapman (2010). 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, prior to being placed back in the basket and stored for re-utilization in future years. The contents from each bucket were then captured on a 100µm sieve, placed in pre-labeled containers and fixed by adding a 1:9 volume of 37% formaldehyde – 10% methanol solution to the sample. Detailed protocols on the retrieval and field processing of samples are available upon request.

2.3.4 Post Processing of Periphyton Samples

As previously mentioned, four Styrofoam punches were obtained from each artificial substrate. One 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. Another punch was chilled and transferred to Caro Labs in Kelowna, BC for analysis of dry weight and ash free dry weight. The remaining punches were used for taxonomic identification, that was completed by H. Larratt, with QA/QC and taxonomic verifications provided by Dr. Stockner. Fresh, chilled samples were examined within 48-hrs for protozoa and other microflora that cannot be reliably identified 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.

2.3.5 Post Processing of Invertebrate Samples

Following retrieval, fixed benthic invertebrate samples were transported to Cordillera Consulting in Summerland BC. Samples were sorted and identified to the genus-species level where possible. Benthic invertebrate identification and biomass calculations followed standard procedures. Briefly, field samples had organic portions removed and rough estimates of invertebrate density were calculated to determine if sub-sampling was required. After samples were sorted, all macro invertebrates were identified to species and all micro portions were identified following The Standard Taxonomic Effort lists compiled by the Xerces Society for Invertebrate Conservation for the Pacific Northwest. 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 upon request.

2.4 In Situ and Bench Experiments

In 2011 two small in-situ experiments with alternate substrates were conducted in MCR. Honed stone tile was attached with silicone adhesive to Plexiglas strips that were then mounted on the time series sampling frames. On each sampling event, one tile from each sampler was pried loose and slipped into a marked plastic bag, and transported in a cooler on ice. In the lab, the entire stone tile surface was scrubbed with the dental cleaning tool. Enumeration followed the same protocols as other periphyton samples in this program, and periphyton densities were calculated based upon the size of the tile sampled.

In the second trial, clay tile was utilized in a preliminary nutrient trial. Untreated clay pot saucers were boiled in distilled water and cooled to remove impurities. Sets of 5 saucers were then inverted over a standard petri dish containing agar with one of four treatments; nitrogen only (N), phosphorus only (P), both nitrogen and phosphorus (N+P) and control (C). These assemblies were siliconed to weighted Plexiglas sheets and placed in R4 at T5 positions for 2 weeks during the fall 2011 time series. They were spaced 20 m apart progressing downstream in the order: C control, N nitrogen only, P phosphorus only, N+P nitrogen and phosphorus combined. The nutrient-enhanced agar solutions were prepared by Caro Labs, Kelowna, following the general recipe provided by Biggs and Kilroy, 2000 and Rodriguez and Matlock, 2008. Each clay tile was pried off the sampler and slipped into a marked plastic bag, and transported in a cooler on ice. In the lab, the entire clay tile surface was scrubbed with the dental cleaning tool. Enumeration followed the same protocols as other periphyton samples in this program, and densities were calculated based upon the size of the tile sampled.

Figure 2.4: 2011 In-situ Substrate Experiments 1) Honed Stone Tile, 2) Clay Saucer-nutrient Deployed, 3) Clay Saucer Close-up with Visible Periphyton

2.5 Long-Term Plate Deployments

After the regular sampling was concluded in spring 2011, the R3-S6 transect was re-deployed for 6 months to provide information on long-term growing season accrual. Similarly, after the regular fall 2011 deployment, the entire R3-S6 transect was re-deployed for the winter and retrieved in spring 2012. The same sampling and enumeration protocols were used as other periphyton samples in this program.

2.6 Water Quality

The water quality component of this study is integrally linked with CLBMON-15a, MCR Physical Habitat Monitoring, and its intent is to provide a baseline understanding of water quality, including macronutrient concentrations that may influence biological production in the MCR. The nutrients that were assessed include NO3, NH3, soluble reactive phosphorus (SRP), total phosphorus (TP), and total dissolved phosphorus (TDP). All nutrient parameters were analyzed at the Department of Fisheries and Oceans Cultus Lake Laboratory (Cultus Lake) following their low detection protocols. In addition, parameters collected using calibrated field meters included total dissolved oxygen, water temperature, pH, conductivity and turbidity. Samples were also collected for water color and total dissolved solids and were submitted within 48 hours to Caro Environmental Laboratories (Kelowna), where they were analyzed according to Standard Methods. Water quality sampling was carried out at nine locations across the four reaches on May 18 and September 28, 2011. This data has been provided to Golder & Associates, who is currently contracted to conduct CLBMON-15a. The reader should refer to CLBMON-15a reporting for water quality results and analysis.

2.7 Variable Descriptions and Analytical Methods

2.7.1 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 ± 0.5 ºC was used to compare samplers from permanently submerged locations with samplers across a transect. A sampler was considered exposed to air in cases where the temperature was either greater or less than 0.5 C from the permanently submerged location. However, this analysis of submergence was only partially reliable as there were times during the deployment when the air temperature and water temperature 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, 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.

2.7.2 Variables and Statistical Analyses

Non metric multidimensional scaling (NMDS) using Bray-Curtis dissimilarity was used to explore variation in benthic community composition. Data were transformed using the Hellinger transformation, which is useful when considering data with large abundances. 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.

The full set of predictor data developed by Perrin and Chapman (2010) and those developed in 2010 were collected in 2011. 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). 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, production responses to predictor variables were colinear in 2011. 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 results. Table 2-2 contains the list of predictor variables considered in analyses in 2010 (for reference) and 2011.

Exploratory analysis data 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. Examples of these analyses can be found in Appendix A.

Four response variables for both periphyton and benthic invertebrate were modeled. Periphyton response variables included: 1) abundance, 2) biovolume, 3) chlorophyll-a, and 2) autotrophic index. 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 heteroscedacity 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 assemblage 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.

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 hypothesis, 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). We assumed that each sampler is independent both within a transect and across sites in all analyses. 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 was used in 2010 to predict benthic production. Environmental predictors used in 2011 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 the 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 considered producing.**
Submergence ratio (sub_ratio)	**The percentage of time the artificial sampler was submerged in water and incubated for (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 colinearity.
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 colinearity.
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 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.**

2.8.1 Time Series and Artificial Sampler Assumptions

Erosion of communities 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 supports this assumption but we do not have empirical data to support it otherwise.

The effects of grazing invertebrates was assumed to be randomly distributed over the artificial substrate within and between all sites. It is acknowledged that invertebrates may spend much more time along the edges of the substrata and that grazing effects could be greater along the edges. However, the density of invertebrate graze 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 graze. 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 is presented to describe our speculations regarding potential biases that may exist due to the artificial substrates used. The intent for this data collection was to understand how, if at all, artificial substrates may alter benthic or periphyton production from the community found on 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 is 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 the temperature/light loggers deployed during the fall 2010 sampling session averaged 10.2°C and 9.9°C. During the first spring deployment in 2011, average water temperature was much cooler at 5.4°C.

Fall light intensity data from submerged samplers was 62% higher in Reach 4 and 30% lower in Reach 3 in 2011 compared to 2010. The differences may be the result of increased flows (mainly Reach 4) or due to reduced turbidity (Reach 3). Based on observations of material from drift samples collected in the fall of both years, backwatering may also partially explain the increased light intensity observed in Reach 3. It is suspected that backwatering reduced water velocity and suspended solids in this reach, possibly allowing for increased light reaching wetted substrates.

Water chemistry is covered in CLBMON-15a The MCR tributaries showed very low conductivity and TDS while the mainstem sites were moderated by dam releases. 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

Three significant changes in the MCR flow regime occurred in 2011; minimum flows were implemented, average flow and peak flows increased with REV 5 coming online, and the ALR back-watered Reach 3 between June and October.

As in previous years, flow in the MCR followed a highly variable but predictable pattern in 2011 (Figure 3-1). The pattern of flow can generally be described as periods of highest flow during daytime from 0700 to 2100 hrs, with periods of low flow typically only occurring during the evening between 2400 and 0500 hrs. All remaining periods were ramping up or down from peak daily flows. The most notable difference in 2011 compared to previous years is a reversal in the trend from lower peak flows to higher peak flows. Each year since the study began in 2007, the peak water release (m^3/s) from Revelstoke Dam decreased each year until 2010. For example, in 2007 the maximum discharge was approximately 1100 m^3/s compared to about 620 m^3/s in 2010. In 2011, this downward trend ceased, with a maximum discharge similar to that of 2007.

While Figure 3-1 gives the averaged flow patterns by year, the hour-by-hour flow variations have implications for periphyton and benthic invertebrate growth. During the fall 2010 deployment, prior to the implementation of minimum flows, a total of 163 hours of releases below 142 m^3s occurred at night throughout the fall deployment, but were concentrated in September. Flows exceeding 1200 m^3s were infrequent (29 hours) and occurred in the evenings in late October.

During the spring 2011 deployment, peak flows occurred on April 14,15 at 1678 m^3s. High flows of 1200 – 1400 m^3s occurred regularly in the evening, while very high flows of 1400+ m^3s were rare. Minimum flows of 142 – 150 m^3s occurred regularly (100 hours approximately) and mostly at night.

During the fall 2011 deployment, peak flows occurred on Oct 3 & 4 at 1949 m^3s. High flows of 1200 – 1400 m^3s occurred in the evening on most days, while very high flows of 1400+ m^3s occurred on 10 dates. Minimum flows of 142 – 150 m^3s did not occur in the fall deployment, and low flows of 150 – 200 m^3s were rare (26 hours approximately).

Flows exceeding 2000 m^3s did not occur during the 2010 or 2011 deployments. They occurred briefly in August 2011, while the majority of these flow events occurred in the winter months, prior to the spring deployment.

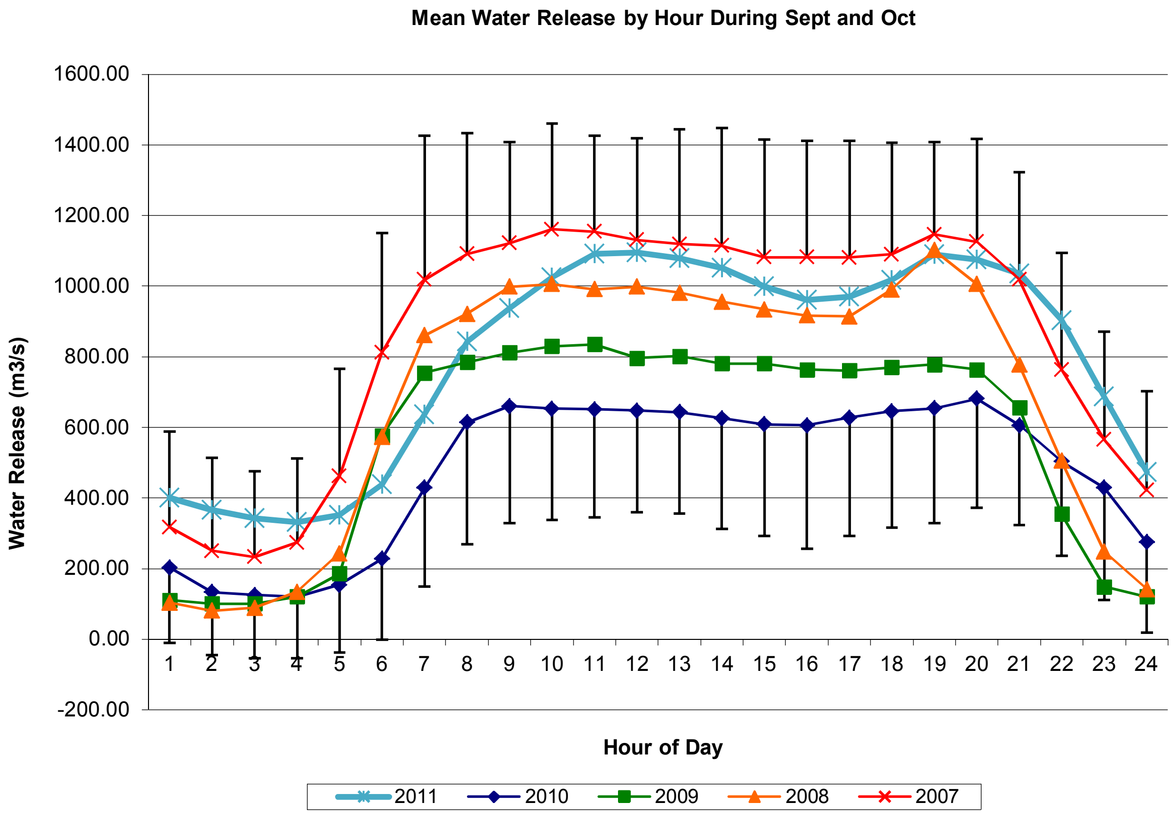


Figure 3-1: The Pattern of Daily Flow in the MCR During the Fall Study Period (September – October) for Years 2007 - 2011 (± mean SD). Standard deviations are only shown for the maximum year (2007) and minmum years (2012) to highlight data variability, which is similar across all years. 2011 had flow trend similar to 2007.

3.2 Periphyton

Two approaches were taken to analyze the large periphyton data set from 2007-2011. In the first approach, detailed, descriptive techniques and observations on flow patterns were used to assess the potential impacts of operations. In the second, statistical analyses and modeling were employed to understand how different predictors describing operations relate to periphyton and invertebrate production. Both approaches provided unique but complementary information and are presented in the following sections.

3.2.1 Natural Periphyton Community

Periphyton biofilms in rivers are complex assemblages of autotrophs (algae) and heterotrophs (bacteria, fungi, yeasts, protozoa), often embedded in a protective polysaccharide matrix. This biofilm supplies a large portion of the energy to higher trophic levels in the MCR. Periphytic algae are very sensitive to systemic modifications in water quality and hydrologic regime (Fernandes and Esteves 2003). Both Reach 4 and Reach 3 in the MCR have a variety of aquatic habitat units in addition to the typical areas covered by the main sample site transects. Many of these units were sampled in 2011. The planned sampling of spring periphyton also began in 2011. Table 3-1 summarizes our 2011 field and sampler findings.

Reach 4

Reach 4 sample sites generally have larger, more stable substrates compared to those in Reach 3. A distinct banding pattern in periphyton communities was observed on the stable substrates in Reach 4 during 2010 and had less distinct boundaries in 2011 (Figure 3-2). The boundaries of these bands are dynamic and migrate between years and probably between seasons. The banding is undoubtedly governed by the effect of operations (submergence, velocity etc.) but is also influenced by other factors not related to operations such as weather, saltating fine sediments from the channel or tributaries and groundwater infiltration.

A wide band of fungi and cyanobacteria blackened the substrate periodically inundated under 1200 - 2000 + m^3/sec flows. Inundation at R4-T6 locations increased from 30-55% in 2010 to 60-70% in 2011. Below that flow elevation, the periphyton transitioned to a beige band dominated by 21 diatom taxa. Inundation at R4-T2 locations also increased from 50-88% in fall 2010 to 71-98% in fall 2011. When this band was dewatered for multiple days, periphyton gradually died off, leaving bacteria and flagellates. Some of this loosely attached periphyton was torn away as air was displaced from dry substrate during re-inundation. A distinct green band occurred at T4 elevations covered by 400 to 600 m^3/sec flows. This band contained diatoms, moss and filamentous green algae. In areas of the green band permanently wetted by 142-150 m^3/sec flows (T3), the luxuriant filamentous algae growth was coated with diatoms while mosses were excluded. The filamentous algae ended abruptly in deeper, permanently wetted areas of higher velocity Instead, they supported a variable growth of prostrate diatom taxa on larger gravels / smaller cobbles (T2, T1) (Figure 3-2). Large boulders in the thalweg of Reach 4 supported visible periphyton while the surrounding smaller substrates did not. The smaller substrates may have reduced periphyton communities from factors such as sand abrasion (scour and saltation), while the boulders may extend above the sand transport zone.

In lower Reach 4 there are large areas of inundated bedrock with thick coatings of periphyton in the T2-T4 depth that likely took several seasons to accumulate. Samplers deployed in that area showed a high species diversity including several motile diatoms seldom seen elsewhere in the MCR. Overall productivity was moderate >1.2 X 10^6 cells/cm^2 and peaked near T-2 in both spring and fall with far lower (<1/2) species diversity, abundance, biovolume and percent dead in the spring. Similarly, chl-a averaged over all bedrock sites was 0.43 ug/cm^2 in fall and only 0.045 ug/cm^2 in spring. Bacterial concentrations were also moderate in the fall, but very low in the spring 2011 samples

Big Eddy is a large productive river unit between Reach 4 and Reach 3. Samplers deployed in fall 2011 in two subunits, one at deeper, faster sites in the thalweg (BE1 and BE 2), and one within calmer, less turbulent areas that are more prone to substrate settlement (BE3 and BE4). BE1 and BE2 occurred at the deep, thalweg sites and generally had typical periphyton. BE3 and BE4 were deployed substrate settlement areas and this inflated the sample dry weight and visibly darkened the artificial substrate (Figure 3-9). Along with the fines, BE3 and BE4 had moderately high abundance at 1.5x10^6 cells/cm^2 with much greater cyanobacteria and green algae representation the elsewhere in the MCR. Once again, spring periphyton productivity and species diversity were much lower (>1/3) than the analogous fall production in Big Eddy.

Reach 3

The channel in Reach 3 is a complex floodplain where smaller, mobile substrates are common and likely preclude a visible banding of the diverse periphyton community seen in Reach 4 (Figure 3-3). Fines were more abundant in R3 periphyton and drift samples than in R4 samples. Permanently wetted sand and gravel supported a dense community of 26-34 algae species while more frequently exposed substrates showed densities progressively decreasing to 9-12 species. Filamentous green algae were confined to protected pools, while mosses were rarely encountered in Reach 3 during 2010 or 2011. The net effect of ALR back-watering in R3 was increased periphyton production on the shallow (T5,T6) samplers, and presumably on the natural substrates as well. The inundation time on R3-T5 and R3-T6 samplers increased from 22-100% in fall 2010 to full submergence in fall 2011. The backwater effect resulted in a measurable reduction in the water velocities at many R3 sites.

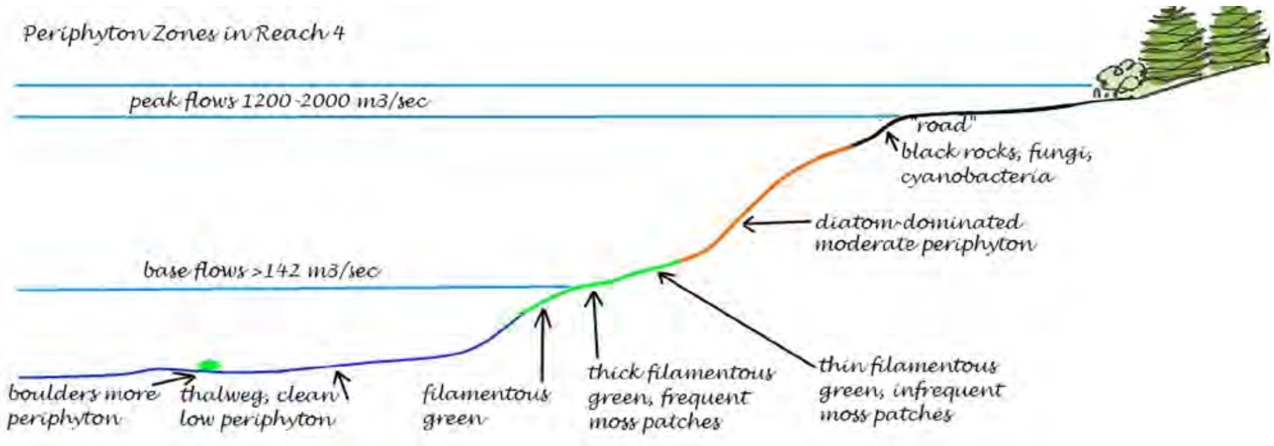
Attempts to deploy samplers upstream and downstream of whitewater in Reach 3 met with the same sampler loss problem as deploying samplers above and below the Illecillewaet River and Jordan Rivers, so was only conducted in spring 2011. As expected, species diversity was typical of thalweg samplers, but periphyton production immediately below the whitewater area was halved (0.37×10^6 cells/cm^2), with fewer dead cells than the sampler positioned immediately above the turbulence. Bacteria densities also dropped, while silt/sand was more frequently encountered in the sampler below whitewater. This observed response is considered typical of larger rivers.

The productive off-channel area upstream of the bridges was sampled in spring before backwatering and in fall during backwatering. This habitat unit supported a rich diversity of 29 diatom species, 9 cyanobacteria species and 5 non-filamentous green algae, and included species more common in ponds. Chlorophyll-a production was moderate, averaging 0.52 ug/cm^2, while the proportion of dead to live cells was high at 6-12%, as was the proportion of organic material to dry weight (9%). Stands of the macroalgae, *Nitella flexella* were more abundant in 2010 than in 2011. Although this unit has similar water quality to the mainstem MCR, the low water velocity precluded some common diatoms that benefit from riverine conditions.

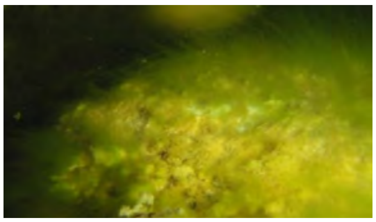
In summary, the most productive zones in the MCR during 2011 were substrates in the T2- T4 depth range in Reach 4 and the T1-T4 depth range in Reach 3. Samplers at these transects were typically covered by flows ranging from <200 to 400 to m^3/sec. Production at transect T5 and T6 increased in Reach 3 during the backwatering effects of the ALR. In areas directly proximal (T3) to low flow transects (T2), production may have benefitted from minimum flows in spring 2011. Overall chlor-a production was lower and abundance more variable in 2011 compared to 2010 and this is partially explained by a wide range of factors including BC Hydro operations during the deployment period and weather effects. At thalweg sites (T1), peak species diversity was consistent between years, with 42 periphyton species observed in the fall 2010 and 40 species in fall 2011. Production metrics and species diversity were 50 to 65% lower in spring 2011 than fall 2011. Table 3-1 summarizes our 2011 periphyton observations.

Table 3-1: Change in MCR Periphyton Zones with Adjusted BC Hydro Operations in Spring and Fall 2011, Compared to Fall 2010.

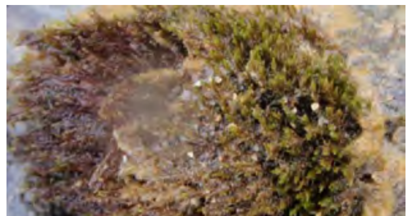
Periphyton zone	Minimum flows	Increased max flows	ALR back-watering
R4: thalweg low production (T1,2) permanently wet high shear, saltation	Minor increase in periphyton productivity; increased species diversity in spring	Expanded zone with lower production and sp richness during fall high flows (lower light)	No effect
R4: filamentous green (T3,4) + moss on outer edge Varial zone, T3 more time in water 2011	Small expansion of zone outward to extent of min. flow wetted edge	Reduced production, mat thinning along deep side, reduced species richness in fall	No effect
R4: diatom dominated (T5) often dewatered in spring	No effect; not covered by minimum flows	Small diatom increase; large cyanobacteria increase, increased. chl-a in fall high flows	No effect
R4: dark fungal/ cyanobacteria (T6) frequently dewatered	No effect; not covered by minimum flows	Large zone expansion above road; increased algae diversity, small fall increase in chl-a	No effect
Bedrock (T1-T4) immobile substrate, high shear, T1,T2 always wet	Small prod'n increase at T1,T2 in spring low flows; high sp diversity	Loss of production in fall high flows, adhering sp common	No effect
Bedrock (T5,6)	No effect; not covered by minimum flows	Very small increase in production of periphyton, bacteria	No effect
Big Eddy calmer, BE1,2 deep water; BE3,4 shallow low velocity	Minimal expansion of permanently wetted periphery of B Eddy	Increased average water depth, no measurable change	Increased water depth, small reduction in light penetration
R3: thalweg low production (T1,2) permanently wet, high shear, saltation	Minor increase in periphyton productivity; rarely exposed before minimum flows	Reduction in mid-channel biomass but increase in species diversity (higher light)	Slight reduction in light penetration
R3: deep sand, gravel (T3,4) Variable water cover, saltation	Small expansion of permanently wetted area	Biomass reduction	Consistent submergence and increased production
R3: peripheral sand, gravel, cobble (T5,6) often dewatered in spring	No effect; not covered by minimum flows	Expansion of peripheral area with small spring production increase	Significant increase in periphyton prod'n, chl-a; and higher species diversity
Back water (T1-3) side channel wetland, calm, backwatered by ALR	No effect; not covered by minimum flow	Increased water depth, high production	Consistent water cover, high prod'n , novel range of species



thalweg
(low periphyton



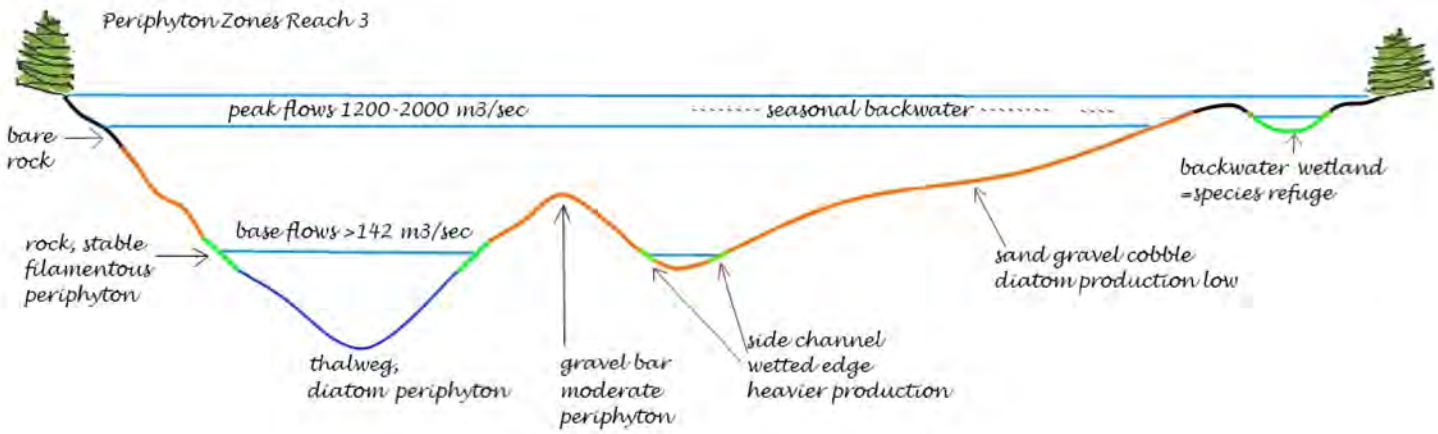
filamentous green zone



filamentous green + moss zone

diatom dominated zone

Figure 3-2: Conceptual Drawing of Periphyton Establishment in the MCR Using Data Collected from Fall 2010 and 2011 Samples in Reach 4



filamentous green+, sand

thalweg, diatom periphyton

wetted edge heavy diatom zone

low diatom, bacteria zone

Figure 3-3: Conceptual Drawing of Periphyton Establishment in the MCR Using Data Collected from Fall 2010 and 2011 Samples in Reach 3

In Reach 4, almost all diatoms found in the drift were lake types (phytoplankton) originating from Revelstoke Reservoir and not periphyton diatoms torn from the substrate. Periphyton diatoms were occasionally observed on the artificial Styrofoam periphyton samplers in Reach 4. The drift samples showed increased chl-a as the water travelled from Reach 4 to Reach 3. Periphytic diatoms torn off substrates progressively dominated the drift as the water flowed downstream. The substantial increase in chl-a on October 28, 2011 to 4.2 ug/L (more than 8 times higher than the chl-a taken on the same date in 2010) caused a light green haze in the river water (Table 3-2). It did not involve an increase in diatoms, and did involve microflora smaller than the 80 micron mesh size of the plankton net. It represented a substantial increase in the primary production of the MCR, providing organic carbon and sequestered nutrients for filter-feeding benthic invertebrates.

Table 3-2: Chlorophyll-a Content and Diversity of Microflora in the MCR Collected from Drift Samples on September 28, October 29 2010, and May 18, October 28, 2011

	Reach 4	Reach 3	Reach 1	Reach 4	Reach 3	Reach 2
Drift Parameters	28-Sep (Storm)	28-Sep (Storm)	29-Oct-10	29-Oct-10	29-Oct-10	29-Oct-10
Chl-a μg/L	0.8	1.5	0.3	0.4	0.5	0.5
# diatom taxa	10	8		11	15	
# taxa, all types	17	18		17	25	
	Reach 4	Reach 3	Reach 2	Reach 4	Reach 3	Reach 2
Drift Parameters	18-May-11	18-May-11	18-May-11	28-Oct-11	28-Oct-11	28-Oct-11
Chl-a μg/L	1.0	1.4	1.1	2.3	4.2	
# diatom taxa	5	3	5	5	9	9
# taxa, all types	6	3	7	8	12	11

3.2.2 Periphytic Biofilm Bacteria and Fungi Communities

Bacteria and fungi (moulds, yeasts) are characteristically 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 40 days in the MCR were relatively low compared to results from other large North American Rivers (Table 3-3). It is important to note that less than 0.5% of riverine heterotrophic bacteria can be cultivated on nutrient agar plates, causing significant underestimation of natural populations (Lear *et al.* 2009). Quantitative natural substrate samples were collected from R4 cobbles and suggest that the artificial substrate reduced HTPC, and inflated the yeast component of 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.

Table 3-3: Non-Photosynthetic Components of the MCR Periphyton Biofilm Sampled during the Fall of 2010 and 2011.

Parameter 2010	Units	Reach 4 Shallow	Reach 4 Deep	Reach 3 Shallow	Reach 3 Deep	R4 natural Shallow	R4 natural Deep
Heterotrophic Plate Count	CFU/cm^2	227 500	160 000	2 200 000	230 000		
Mould	CFU/cm^2	3250	1000	2500	2500		
Yeast	CFU/cm^2	1500	3250	3750	3000		
Parameter 2011							
Heterotrophic Plate Count	CFU/cm2	800 000	1 300 000	5 000 000	3 300 000	2 500 000	1 900 000
Mould	CFU/cm2	750	1750	2750	2000	750	1000
Yeast	CFU/cm2	2000	500	96 000	6000	<250	<250

CFU = colony-forming units

The moulds and yeasts found in the periphyton mats were numerous (Tables 3-3). The mould counts from 2010 and 2011 showed minimal depth effects in Reach 3 and possible depth effects in Reach 4. The Reach 3 shallow yeast sample was significantly higher than the other samples in 2011, and may be influenced by back-watering.

3.2.3 Periphyton Algae Species

Individual periphyton cell biovolumes of commonly encountered MCR periphyton species varied by reach, with a range from 15 to 19,500 $microns^3$ per cell. Table 3.4 highlights important differences in the periphyton community using dominance measures quantified by either biovolume or abundance. Biovolume may be a more accurate measurement of productivity than abundance, but this data is only available for 2010 and 2011.

Every fall, MCR species were dominated by diatoms representing between 85 and 95% of the biovolume in all sample sites (Table 3-4). When the periphyton in Reach 4 and Reach 3 were ranked numerically, the top 5-8 dominant species were rapid colonizing diatoms with firm attachment strategies. Filamentous green algae were more common in Reach 4 with its stable substrates, and averaged 9 to 13% biovolume in 2010 and 2011, respectively. Although they were numerous, the small-celled flagellates, cyanobacteria, and colonial greens rarely exceeded 1.5% of the biovolume in MCR samples. Those species requiring low flows were confined to Reach 3 side channels. Table 3-4 demonstrates these proportions and is similar to 2010, and while the relative contributions made by the algae groups are constant, the dominants vary in accordance with prevailing MCR conditions in a given year. In 2011, we expanded the range of river habitats investigated but still found many of the same species.

Table 3-4: Dominant Periphyton Algae Taxa by Biovolume from MCR Reach 4 and Reach 3 for Spring and Fall 2011. An estimate of the forage quality is also included, noting that foraging value varies with benthic foraging guilds.

2011 Rank by Biovolume	% relative Biovolume	% relative Abundance	Characteristics and Requirements	Nutrients Needed	Forage Value
Tabellaria fenestrata	30.59	4.81	Common, mat architect, high light		Fair
Diatoma tenue var elongatum	18.65	8.27	Common, mat, low-mod flows, cool		Fair
Synedra ulna (radiate)	10.90	9.01	Very Common, fluctuating flows, high nutrients	M-H	Good
Cladophora sp. glomerata?	6.91	0.08	Filamentous, mat, high light	H	Fair-lrg cells
Synedra ulna	5.93	0.50	Widespread, plankton or peri.	H	Fair
Didymosphenia geminata	4.95	0.06	Mat architect, can be aggressive		Good
Eucocconeis flexella	3.41	1.14	Common, moderate flows		Good
Diatoma vulgare	3.11	2.10	Moderate flows		Good
Tabellaria flocculosa	2.93	0.84	Common mat architect		Fair
Synedra acus	2.38	1.13	Widespread, plankton or peri.	M	Good
Stigeoclonium sp.	1.07	0.46	Filam., mat, fluctuating high flows	M-H	Fair-lrg cells
Achnanthidium minutissima	0.99	10.18	Rapid colonizer, clean water, cool		Good
Fragilariforma virescens	0.84	0.81	Widespread, moderate flows		Fair-chains
Oedogonium sp.	0.73	0.01	VC, filamentous, mat, low flows	M-H	Fair-lrg cells
Achnanthidium linearis	0.58	2.49	Colonizer, scour indicator, cool		Good
Mougeotia sp,	0.56	0.04	Filamentous, low fluctuating flows	H	Fair-lrg cells
small flagellates	0.50	3.06	Withstands drying (resting stage)		Fair
Synedra nana	0.36	0.08	Moderate conductivity, plankton		Fair-lrg cells
Diatoma hiemale	0.35	0.40	Moderate flows		Good
Cyclotella comta	0.33	0.19	Plankton or periphyton		Good
Staurosira construens v ventor	0.30	1.81	Clean, cool water		Good
Synechococcus/cystis	0.25	19.14	VC, Cyanobacteria, colonizer		Good-fair
pico-flagellates	0.23	18.66	Withstands drying (resting stage)		Poor
Stichococcus minutissima	0.18	1.50	Clean, low flow, high light		Good
(Lepto/Plankto) Lyngbya	0.03	5.87	Cyanobacteria, low light tolerant		Good-fair

3.2.4 Alternate Artificial Substrates and Nutrient Enhancement Trial

The rough open-celled Styrofoam employed in this project since 2007 has a tendency to exaggerate accrual rates and final biomass estimates by 20% when compared to adjacent natural substrates (Perrin et al. 2004). When we compared transects of natural substrates with adjacent artificial substrates in spring 2011, we found a 25% increase in overall abundance at R4 and 22% at R3. These findings are in good agreement with Perrin's original study. However, the periphyton observed on the natural substrates had an unknown accrual period that was probably much longer than the artificial sampler deployment. Our small study also suggested that species distribution could be affected by the type of artificial substrate used. For example, the 5 stone tile samples and the 20 unglazed clay tile samples had low bacteria and diatom counts, while flagellates and *Amoeba* were well represented. One trial of stone tile was conducted in fall 2010 and one of clay tile in fall 2011, both at R4 locations. In both cases, the periphyton produced was >70% lower than Styrofoam artificial substrates deployed for the same period at R4S6.

With the clay tile, we also attempted to develop methods for determining possible nutrient limitations on periphyton production in the MCR. Unfortunately, the N+P frame flipped, invalidating the nutrient assay portion of the trial.

3.2.5 Periphyton on Artificial Substrates

3.2.5.1 Artificial Sampler Submergence

The temperature and light logger data from each sampler was graphed to assess the data's quality. The light data indicated when the Styrofoam substrate sat upright and was producing periphyton and when the sampler had flipped upside down in the current. At least three different samplers had flipped at some point during the fall and spring deployments, but none of the flipped samplers were removed from further analyses since they had only flipped for a very short period of time. Because periphyton growth is limited in an absence of light, samplers that flip upside down for 50% or more of the deployment were removed from the dataset. Samplers that had flipped were assumed to be producing at all times deployed, even if it was upside down.

Submergence, or time in the water, was used as a predictor variable of production. Submergence ratio, or a ratio of time submerged to the total time deployed, was one of many metrics chosen to describe the submergence time of artificial samplers. This ratio makes data interpretation easier because submergence ratios of 1 indicate 100% submergence and ratios of 0% infer continuous exposure. Submergence ratio decreased along transects, from T1 (deepest site) to T6 (shallowest site) in both Reaches 4 and 3. Samplers at T1 were located in the thalweg of the channel and samplers at T6 were in areas of lower submergence in the floodplain.

3.2.5.2 Descriptive Statistics of Periphyton Communities and Production

Periphyton growth on artificial substrate samples showed a distinctive pattern across transects during the fall sampling periods, with more growth occurring in higher submergence areas and less growth in areas of lower submergence (Figure 3-4). This figure also portrays the possible pruning by higher peak flows in R4 T1 sites including BR (bedrock). The pattern of growth in R3 during 2011 was complex with S5 and S6 showing peak production in the varial zone while S3 showed high periphyton growth on the deepest samplers. Big Eddy sites BE3,4 showed significant growth and deposition, making these samples very dark. Similarly, R3 BW (backwater) sites showed strong growth that increased in shallower, but constantly water-covered plates during fall 2011.

The MCR is a diatom-dominated system with a significant filamentous green algae component (Table 3-4). Diatom production in Reach 4 numerically exceeded production in Reach 3, possibly because of its smaller, more mobile substrates. In both reaches, chl-a and biovolume peaked at sites that were covered by 1.5 – 2.5 m of water under moderate flows of 600 to 800 m^3/s. This typically occurred at T3 and T4 sites in both reaches. Biovolume was very low at sampler sites regularly exposed to air. Samplers from the R4 thalweg showed lower growth than samplers from shallower water. For example, in 2011, biovolumes ranged from a low of 0.052 $x10^8$ $\mu^3 cm^2$ in spring at Reach 4 S4T6 to a maximum of 104 $x10^8$ $microns^3 cm^2$ at Reach 4 S5T4, a spread of three orders of magnitude.

During fall 2010, Reach 4 samples showed peak chl-a at the deepest samplers, while Reach 3 samples showed a peak chl-a at mid-range depths. The reverse was true in 2011 when less light penetrated to deep R4 samples, (perhaps because of deeper water) and chl-a was lower, while in Reach 3, more light penetrated to the thalweg sediments (perhaps because of backwatering) and chl-a was higher.

The volatile percentage of the total algae sample dry weight is higher when other organics are present, while the percentage is lower when dead cells and/or inorganic sediments are present (Wetzel 2001). The average volatile solids (%) in the MCR were presumed not significantly different between R3 and R4 in either season because variations were highly overlapping. Volatile solids data (%) pooled between reaches were 11% in the spring and 3% in the fall. The percentage of volatile organic solids (%) in the fall 2010 and fall 2011 were both very low and indicated a significant proportion of inorganic sediment in the samples. This proportionately lower volatile solids and proportionately higher sediment content in the fall may relate to increased deposition during lower flows and/or backwatering. For example, the Big Eddy samplers with known silt deposition gave dry weight accumulations of 11 $mg/cm^2/week$.

The number of taxa present in a sample is the simplest metric of species richness. Declining richness with declining submergence was especially evident in Reach 4 samples. Species richness was greatest in the samplers that were submerged for six months at 43 species, exceeding the one year (40 periphyton species), while the routinely exposed shallow T6 samplers showed less than 10 periphyton species.

Figure 3-4: Styrofoam Punches from Reaches 4 and 3 after 45 Days of Submergence in Fall 2011. Punches are shown from T1 (deep) to T6 (Shallow) from left to right. Site labels for each punch are described in Table 2-1.

Chlorophyll-a and volatile solids 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, sampler plates in the mid-range depths showed autotrophic-dominated periphyton, while the thalweg plates showed increasing heterotrophic dominance. The plates from infrequently inundated locations were dominated by non-viable organic materials that were more prominent in areas submerged for less than 85% of the time. .

3.2.5.3 Time Series Samplers

Time series data was collected in 2010 and 2011. In the fall of 2010 and spring of 2011, data was collected across the larger depth transect (T1 through T6) to see if there were qualitative differences between different ranges of submergence or exposure. In the fall of 2011, data collection was slightly revised to increase sample size in areas of minimal exposure (i.e., those just outside the influence of minimal flow or T3) and in areas continuously submerged (i.e., T1).

All MCR time series data exhibit oscillations in growth rates that correspond to extreme flow events occurring within the deployment period. In the detailed time series sampler deployment conducted in 2010 and 2011, erratic gains in chl-a, abundance and biovolume reflected the frequent flow events. High flow events tended to improve periphyton growth on shallow substrates and reduce growth in deep substrates, while the reverse was true of low flow events when growth on shallow substrates declined and growth on deeper substrates improved (Figure 3-5, day 30). This trend is supported by regressions of abundance, chl-a, and biovolume which increase with increasing submergence or time in the water.

In 2011, spring deployment occurred for the first time. Similar to regular samplers, spring time series samplers had much lower and more variable chl-a, abundance, biovolume and species diversity throughout the deployment when compared to fall time series. During the spring 2011 deployment, abundances accrued slowly initially in both R3 and R4 (Figure 3-5). Accruals in the spring were 20-30% of the fall deployments (data not shown). The spring 2011 samplers were ultimately less diverse (26-31 species) than the fall samplers (37-38 species). The dominant fall diatoms *Tabellaria* and *Achnanthidium* were conspicuously low or absent from the spring populations. There was no difference observed between the species diversity in the R4 shallow and deep samplers, suggesting that recruitment from upstream periphyton is important.

In fall 2011, time series data collection was revised to increase sample size in areas of minimal exposure (i.e., those just outside the influence of minimal flow or T3) and in areas continuously submerged (i.e., T1). Pooled data between years highlights that during the period of sampling, accrual rates across transects appear to be linear, although the spring 2011 data was highly variable (Figures 3-6, 3-7).

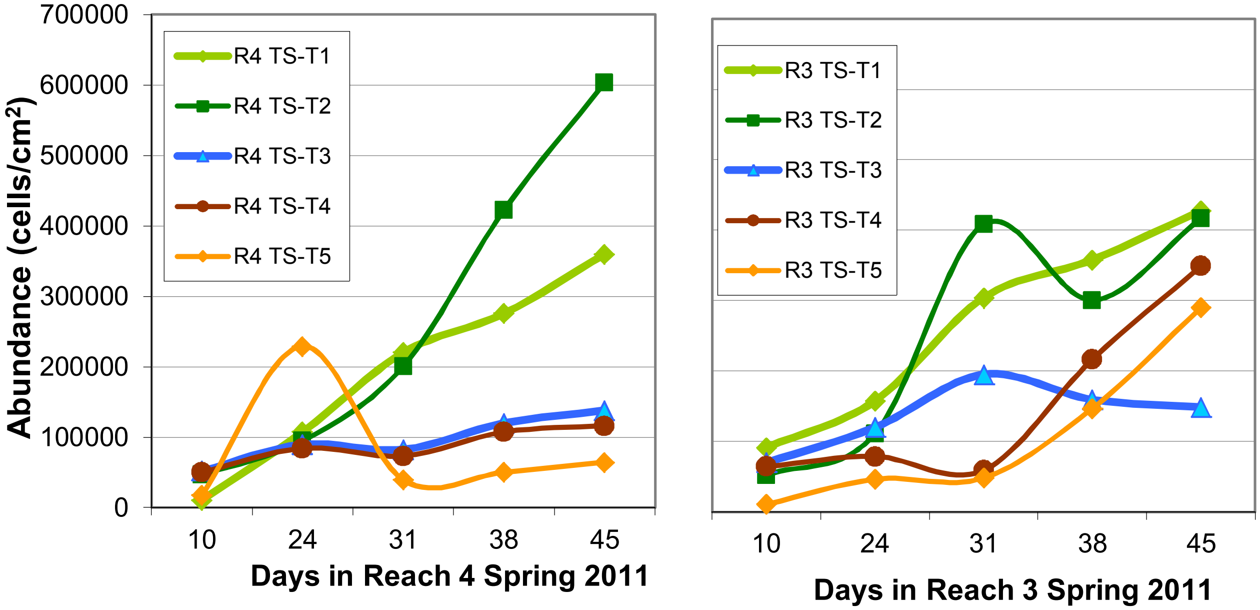


Figure 3-5: Time Series Samples of Abundance (cells/cm^2) on Artificial Styrofoam Samplers Deployed in Spring of 2011 in Reach 4 and Reach 3 of the MCR (T1 – T5; deepest to shallowest sites)

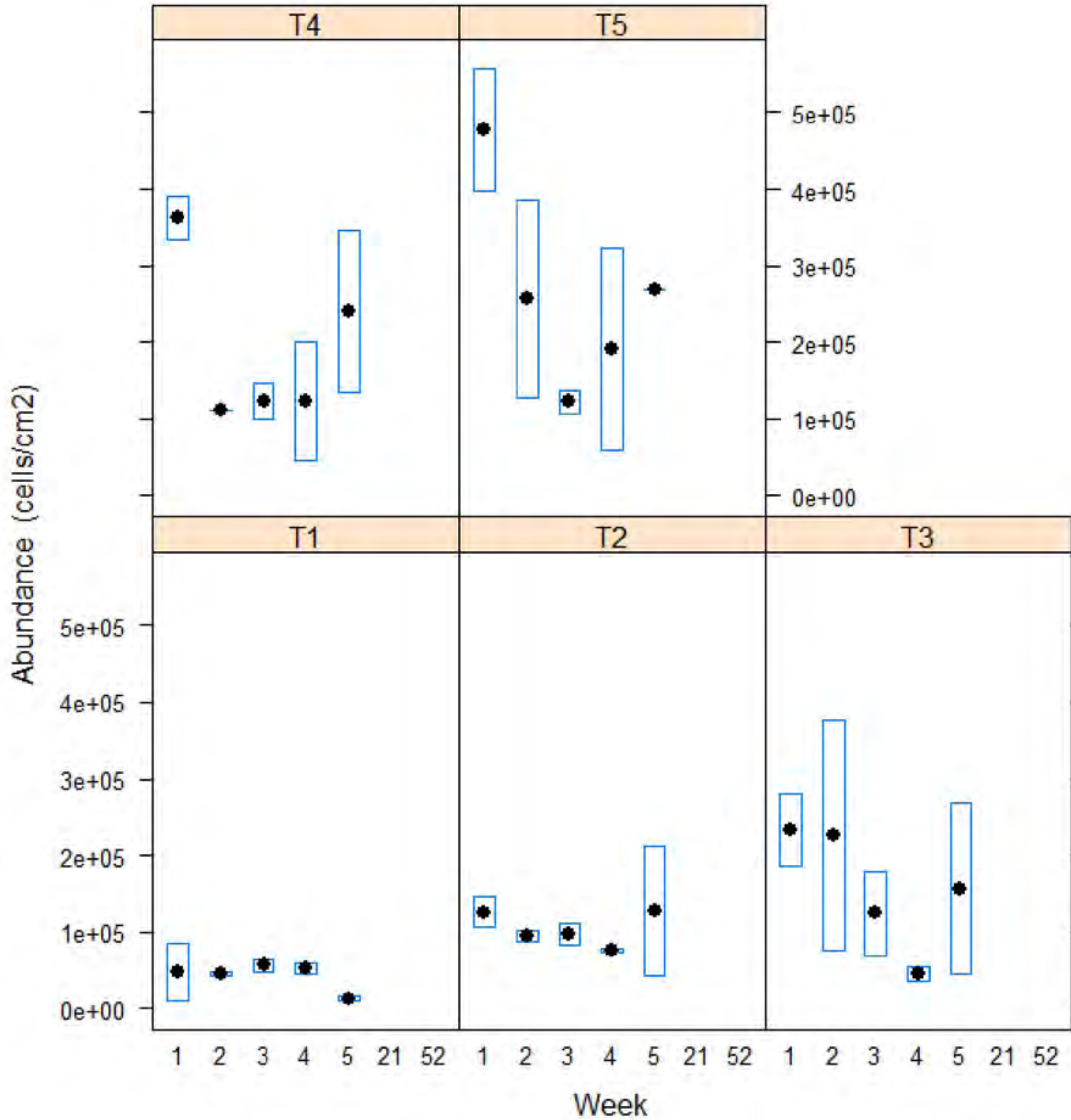


Figure 3-6. Boxplots of total periphyton abundance (cell/cm^2) collected weekly during spring 2011. Data are pooled between years, reach, site, and transect where possible.

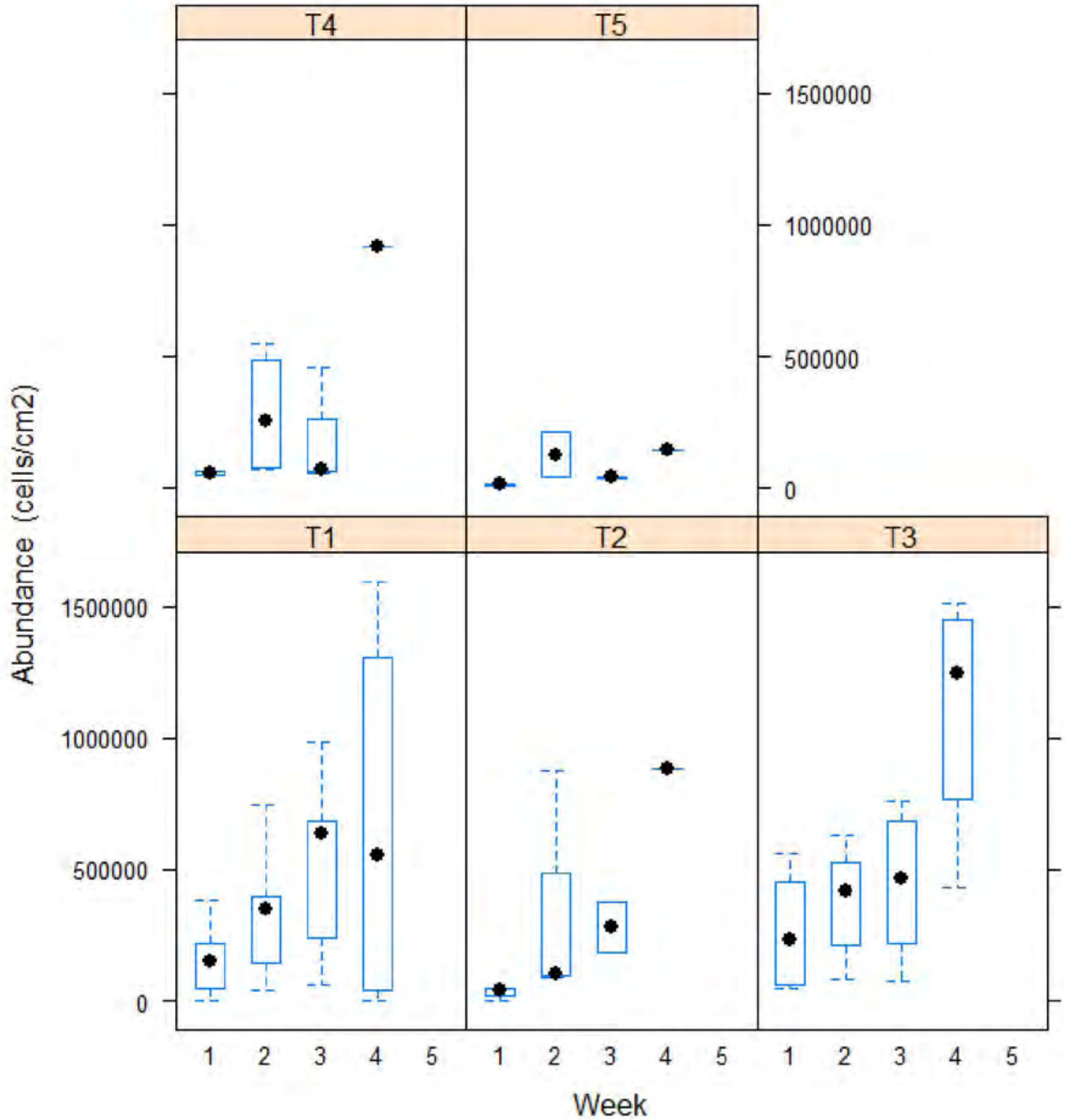


Figure 3-7. Boxplots of total periphyton abundance (cell/cm^2) collected weekly during fall of 2010 and 2011. Data are pooled between years, reach, site, and transect where possible.

In 2011, sampler plates were re-deployed for 6 months of the growing season between May – September. Species diversity on the 6 month plates reached 32 diatom taxa and 52 total taxa, more than the one-year sampler with 28 diatom and 39 total taxa, and both more than any other MCR site within the regular deployment periods. The climax species list (maximum, stable species richness) was probably attained within six months, while the peak biomass was probably not attained within one year on MCR artificial substrate samplers. As often occurs in the MCR, abundance peaked at mid-depth T3 with $1.8x10^6$ cells cm^2. Despite the six month deployment, filamentous green algae did not develop on the samplers, but it did snag on the sampler frame as it sloughed or was torn off upstream substrates. Growth on the 6 month and one year periphyton plates were noticeably greater than the 6 week deployments at the same location (Figure 3-8).

Most samplers demonstrated a positive linear relationship between time spent in the water and measures of production including abundance (see figure 3-7 and 3-8), biovolume (not shown), and chlorophyll-a (not shown). With the frequent flow change events, it would appear that the MCR is very slow to reach peak accrual and requires many months to achieve peak biomass. Data from Reach 3, Site 6 samplers left for a duration of approximately 6 months demonstrate that peak biomass does appear to continually accrue beyond samplers deployed for 6 weeks at the same site (Figure 3-8). Further, data collected from a plate lost and retrieved after one year demonstrates that accrual continues for at least this long on stable substrates.

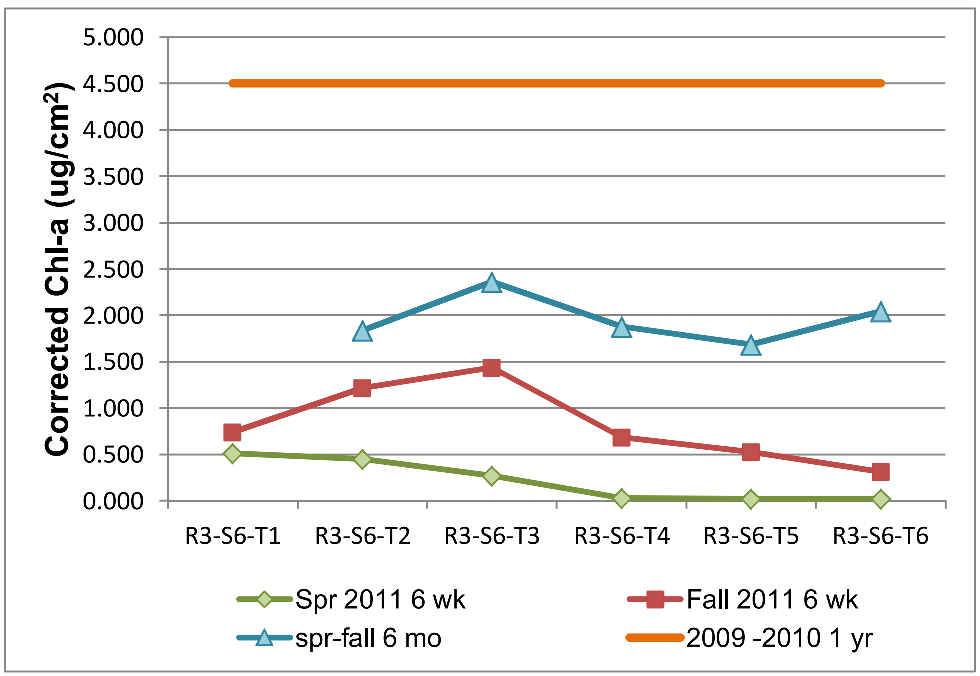


Figure 3-8: In 2011, samplers at Reach 3, Site 6 transects (T1 deep, through T6 shallow) were left for an extended period of time from the spring to the fall (~6 months). The **c**orrected chlorophyll-a (µg/cm^2) of Long-Term Time Series Samples for plates left from Spring to Fall in 2011 when compared to normal sample deployments for 6 weeks in both spring and fall at the same Reach/Site/Transect. The solid orange line represents the corrected chlorophyll from a retrieved plate deployed for year in Reach 4, Site 5 at approximately Transect 3 or 4 (mid channel).

The artificial substrate is much rougher than any natural MCR substrate and its surface texture may prevent sloughing and encourage large periphyton accumulations over periods of over one year. As the riverine periphyton mats develop, the cells at the bottom of the mat die off and encourage sloughing. This die-off accounted for only 4-12 % of the deep MCR samplers, 6-23% of the shallow samplers, 6-17% of the 6 month samplers and only 5% in the mid-river one year sampler retrieved from Reach 4. The Styrofoam may retard decay processes at the bottom of the mat relative to natural substrates, thus discouraging sloughing and causing a long accrual phase, ultimately inflating the biomass estimates.

Accrual rates can be calculated from time series samplers. Visible periphyton developed on MCR samplers in 6-9 days and this may be faster than the rate on adjacent natural substrates. In both Reach 4 and Reach 3, accrual as measured by chlorophyll-a and abundance was always faster and ultimately larger on permanently wetted samplers than on regularly dewatered samplers (Table 3-5). With more time in the water, accrual on the R4-shallow samplers in 2011 was double the 2010 accrual, while R4-deep samplers in 2011 with high flows had lower chl-a accrual than in 2010. Compared to other large North American rivers, peak fall accrual rates in the MCR were very slow at shallow sites (0.012 - 0.027 µg/cm^2/d) and more typical at deep sites (0.13 – 0.38 µg/cm^2/d) (Flinders and Hart, 2009).

The percentage of dead algae cells increased with time on all MCR samplers in fall 2010, but frequently peaked at 26-31 days in spring and fall 2011, and became more variable thereafter. Increased peak flows in 2011 may accelerate the loss of dead cells from the periphyton mat. The deepest sites usually showed the lowest percent mortality, again suggesting loss of dead cells during peak flows, while the frequently exposed sites in R4 (T5, T6) showed increasing mortality, likely through desiccation. Spring samples generally showed higher percentage dead cells than the fall samplers, suggesting more stress in the spring,

Table 3-5:Periphyton Accrual Rates Calculated from 2010 and 2011 Time Series in Reach 3 and Reach 4 of the MCR.

chl-a accrual	Fall 2010		Spring 2011		Fall 2011	
(ug/cm2/day)	R3	R4	R3	R4	R4 shallow	R4 deep
T-1 (deep)	0.0617	0.0284	0.0034	0.0007	0.0049	0.0133
T-2	0.0661	0.0723	0.0053	0.0018	0.0086	
T-3	0.0290	0.0429	0.0019	0.0002	0.0037	0.0333
T-4	0.0013	0.0250	0.0006	0.0001	0.0037	0.0162
T-5 (shallow)	0.0008	0.0024	0.0003	0.0001	0.0060	0.0120
Average	0.0318	0.0342	0.0023	0.0006	0.0054	0.0187
S. Error	0.0140	0.0120	0.0050	0.0003	0.0009	0.0049

All analyses conducted to date indicate the variable nature of the MCR. Reach 3 behaves similarly but not identically to Reach 4, and the variation between years is large (Figure 3-9).

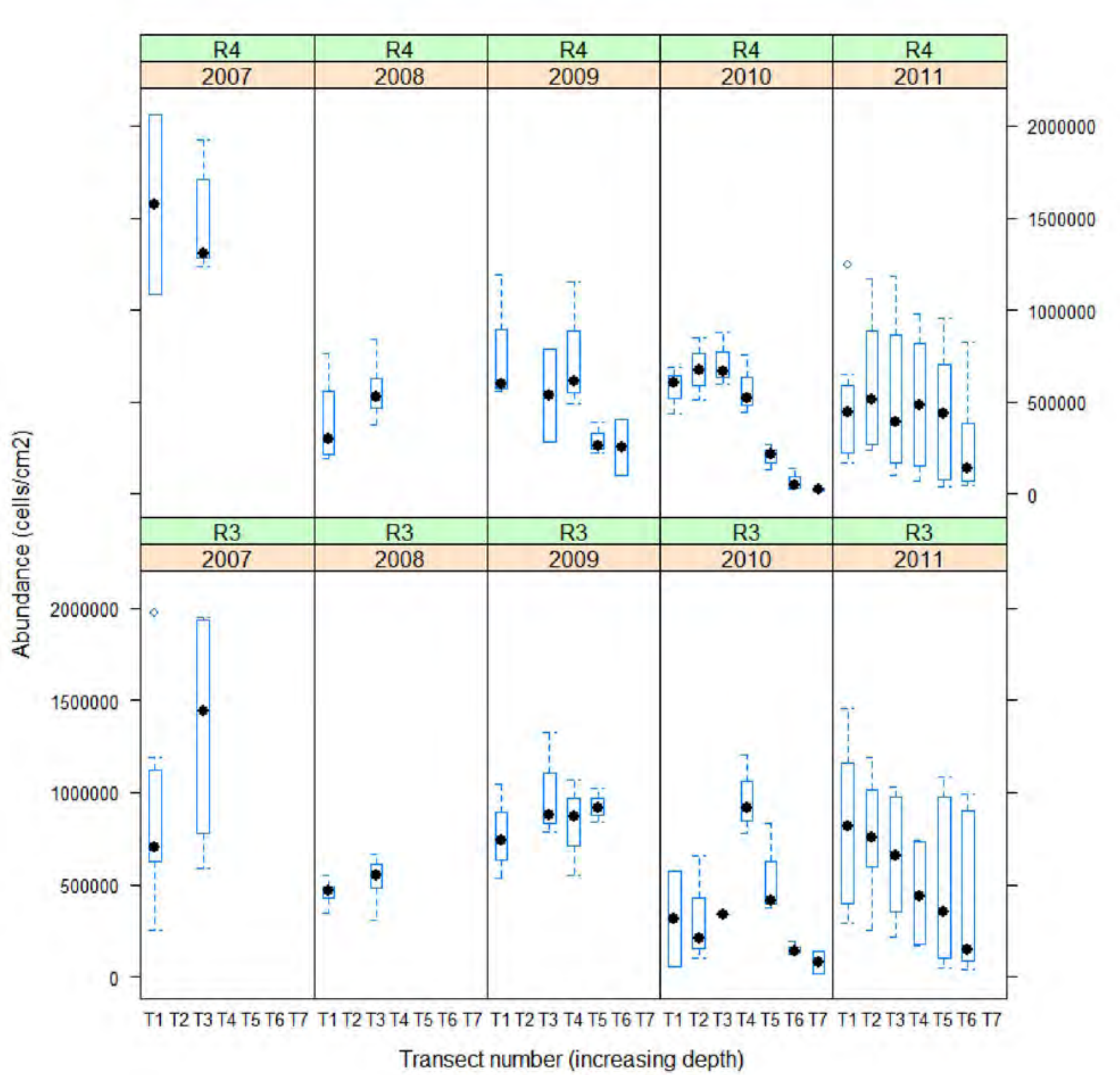


Figure 3-9: Periphyton abundance (cells/cm^2) pooled between all sites collected between 2007 and 2011 in the fall in Reaches 3 and 4 of the MCR.

3.2.6 Periphyton Community Groupings

Ward/Bray cluster analyses showed that there were potentially 4 or 5 plausible groupings of data (See Appendix A-1). NMDS analysis (stress = 0.19) of the five groups shows that there is a strong grouping by year (ANOSIM: R: 0.99, $p < 0.001$) and the Ward Bray Clusters (ANOSIM: R: 0.99, $p < 0.001$) for benthic data collected between 2007 and 2011 (Figure 3-10). This result is not surprising, given that the Ward clusters correspond exactly with year (i.e., 2007 through 2012). The differentiation between Years may be reflective of differences in taxonomy between 2007 - 2009 and 2010 and 2011. Despite the differences in taxonomy accounting for some of the difference between years, annual variation of physical predictors (e.g., temperature, velocity) and operation (e.g., submergence ratio) may partially explain the strong variation observed between years.

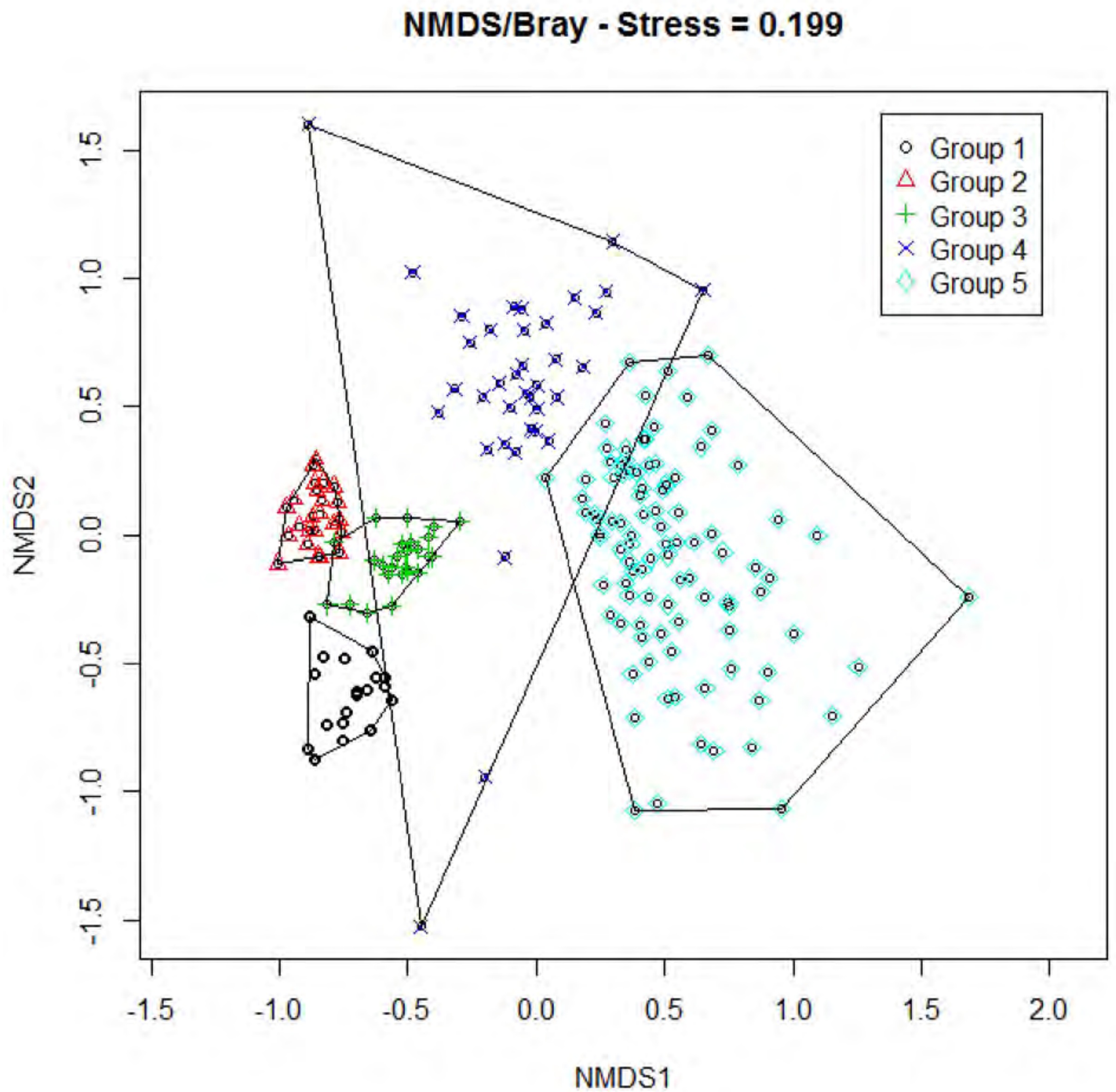


Figure 3-10: NMDS of periphyton abundance grouped using Wards clustering for data collected between 2007 and 2011. Note that the Ward clusters Group 1 through Group 5 correspond exactly to the Years 2007 through 2011, respectively.

3.2.7 Periphyton Production Models

Data from 2010 indicated that measures of production (i.e., Biovolume, Boimass, Abundance, Autotropic Index) and physical measures predicting production were positively correlated. With merged data from 2011, these relationships persisted. Generally, there were positive correlations between measures of production when data was pooled between years (Figure 3-11) indicating that variables predicting production will likely be similar in many cases.

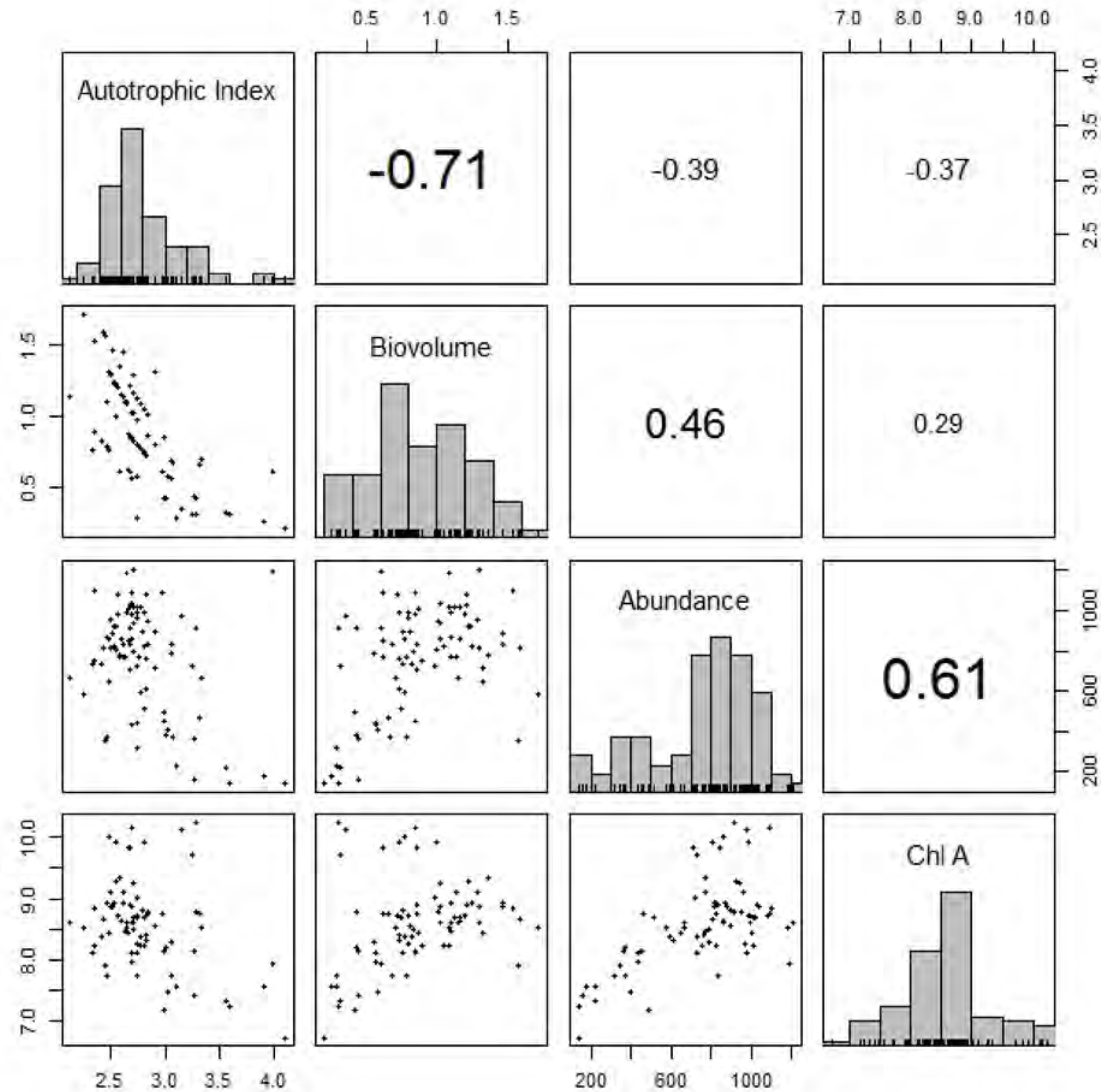


Figure 3-11: **Scatter plots / Pearson's correlation coefficients for measures of periphyton production in the MCR.** Data presented has been log or square root transformed. Stronger correlations coefficients are shown with larger font, which corresponds with the strength of the relationship.

Model averaging data indicated that there were numerous plausible models (those with an AICc<2.0) for abundance (15), biovolume (17), Chl-a (9), and Autotrophic Index (15) (Table 3-6). Several key trends were observed across the different measures of production, most notably total incubation time in the water and light which was an important predictor for abundance, biovolume, and chl-a. Other key predictors were mean temperature and sampler velocity. Less notably, but potentially important predictors include frequency of 12 hour submergence events and maximum cumulative submergence hours.

Total incubation time in light and water was the most important parameter predicting periphyton abundance (Table 3-6 and Figure 3-12). Production time was positively correlated with abundance, increasing to varial zone areas around T3 (mid channel) which is exposed at flows between 200 to 400 m^3/s (T3-T4). Production time appeared to plateau from this varial zone to samplers consistently submerged (T1 locations). Other important parameters predicting periphyton abundance included sampler velocity and mean temperature. Not surprisingly, periphyton abundance generally decreased with increasing river velocity. Abundance increased with mean temperature until a point, before decreasing, noting that higher mean temperatures were indicative of exposure. This all suggests that periphyton abundance is directly correlated with predictors describing measures of time in the water, physical parameters (e.g., velocity and mean temperature) or variables describing exposure (e.g., mean temperature).

Velocity was the most important predictor of periphyton biovolume in 2010-2011 (Table 3-6 and Figure 3-13), increasing with velocity to a point and then decreasing at high velocity sites. This humped trend was observed because highly exposed sites occurred at channel margins and had low velocities. Moderate velocities were generally present in mid to low channel areas in the productive varial zone. Total production time in the water was also important, with the most productive areas observed in permanently wetted or low channel varial zone areas. The only other important physical predictor was mean temperature. The biovolume results were similar to to abundance, with similar production levels observed between T1 (Deep and permanently submerged) and the varial zone at approximately T3 (mid channel elevation).

Mean water temperature and total production time were the most important predictors of chl-a using pooled data between 2010 and 2011 (see Table 3-6 and Figure 3-14). Production appeared to peak at an optimal temperature because high temperatures meant increased exposure (i.e., daytime highs were generally greater than average water temperature and is independent of submergence). These higher average temperatures indicated exposure has a negative effect on chl-a production resulting in the decrease from the increased production in the varial zone around T3. Similar to abundance and biovolume, chl-a increased with increasing production time in the light and water.

Sampler velocity was the most important predictor of autotrophic index, with lower index values observed at higher velocities, meaning the community had a predominance of producers in higher velocity areas (see Table 3-6 and Figure 3-15). The trend observed was the inverse of measures of production, meaning lower index values or higher predominance of autotrophic taxa were observed between T1 and T4. The frequency of 12 hour submergence events was also negatively correlated with autotrophic index, meaning that autrotrophic taxa were more prevalent at sites with an increased frequency of 12 hour submergence events. This data suggests that operations are directly linked to proportion of autrotrophic to hetertropic taxa in the MCR.

Table 3-6: 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 (15)		
	Estimate (CC)	Weight (w)	# Occurrences in AICc<2 Models
tot_inc_time_water_light_hrs	**1.34**	**1.00**	**15**
sampler.velocity	**-1.19E+02**	**1.00**	**15**
mean_temp	**901.37**	**0.88**	**14**
sub_ratio	**-1.29E+03**	**0.51**	**7**
max_cum_sub_hrs	0.10	0.38	3
Freq_Submer_.12.Hrs	10.83	0.35	3
tot_inc_time_water_light_hrs.sq	1.16E-03	0.32	4
mean_temp.sq	-1.49E+02	0.32	5
sub_ratio.sq	**1471.13**	**0.31**	**5**
sampler.velocity.sq	**-2.39E+00**	**0.22**	**7**
Freq_Submer_.12.Hrs.sq	-2.05E-01	0.12	1
max_cum_sub_hrs.sq	-2.27E-04	0.10	1

Model Predictors	Biovolume (17)		
	Estimate (CC)	Weight (w)	# Occurrences in AICc<2 Models
sampler.velocity	**1.26**	**1.00**	**17**
tot_inc_time_water_light_hrs	**6.73E-03**	**0.97**	**17**
mean_temp	**-5.00E+00**	**0.91**	**17**
sampler.velocity.sq	**-6.35E-01**	**0.81**	**17**
tot_inc_time_water_light_hrs.sq	**-9.99E-06**	**0.50**	**9**
max_cum_sub_hrs	-8.64E-04	0.48	5
sub_ratio	0.39	0.46	5
Freq_Submer_.12.Hrs	0.02	0.37	3
mean_temp.sq	**0.58**	**0.34**	**5**
max_cum_sub_hrs.sq	1.36E-06	0.18	2
sub_ratio.sq	-2.47E+00	0.18	2
Freq_Submer_.12.Hrs.sq	-8.25E-04	0.14	1

Model Predictors	Chl a (9)		
	Estimate (CC)	Weight (w)	# Occurrences in AICc<2 Models
tot_inc_time_water_light_hrs	**2.15E-03**	**0.99**	**9**
mean_temp	**8.11**	**0.96**	**9**
mean_temp.sq	**-5.21E-01**	**0.72**	**9**
max_cum_sub_hrs	**-1.07E-03**	**0.64**	**5**
sub_ratio	-2.33E+00	0.50	0
sampler.velocity	0.12	0.46	0
Freq_Submer_.12.Hrs	0.01	0.43	2
max_cum_sub_hrs.sq	**1.17E-06**	**0.42**	**3**
tot_inc_time_water_light_hrs.sq	-1.12E-06	0.27	1
sub_ratio.sq	2.59	0.22	1
Freq_Submer_.12.Hrs.sq	3.46E-04	0.14	0
sampler.velocity.sq	-7.33E-02	0.11	0

Model Predictors	Autotrophic Index (15)		
	Estimate (CC)	Weight (w)	# Occurrences in AICc<2 Models
sampler.velocity	**-1.95E-01**	**0.95**	**19**
Freq_Submer_.12.Hrs	**-2.13E-02**	**0.67**	**12**
sub_ratio	**-7.54E-02**	**0.49**	**9**
mean_temp	-3.22E+00	0.46	6
tot_inc_time_water_light_hrs	-1.20E-03	0.43	6
max_cum_sub_hrs	5.50E-04	0.42	3
mean_temp.sq	0.35	0.22	3
sampler.velocity.sq	3.51E-03	0.21	0
max_cum_sub_hrs.sq	-8.95E-07	0.20	2
Freq_Submer_.12.Hrs.sq	1.58E-04	0.17	2
sub_ratio.sq	0.73	0.16	3
tot_inc_time_water_light_hrs.sq	2.25E-06	0.12	0

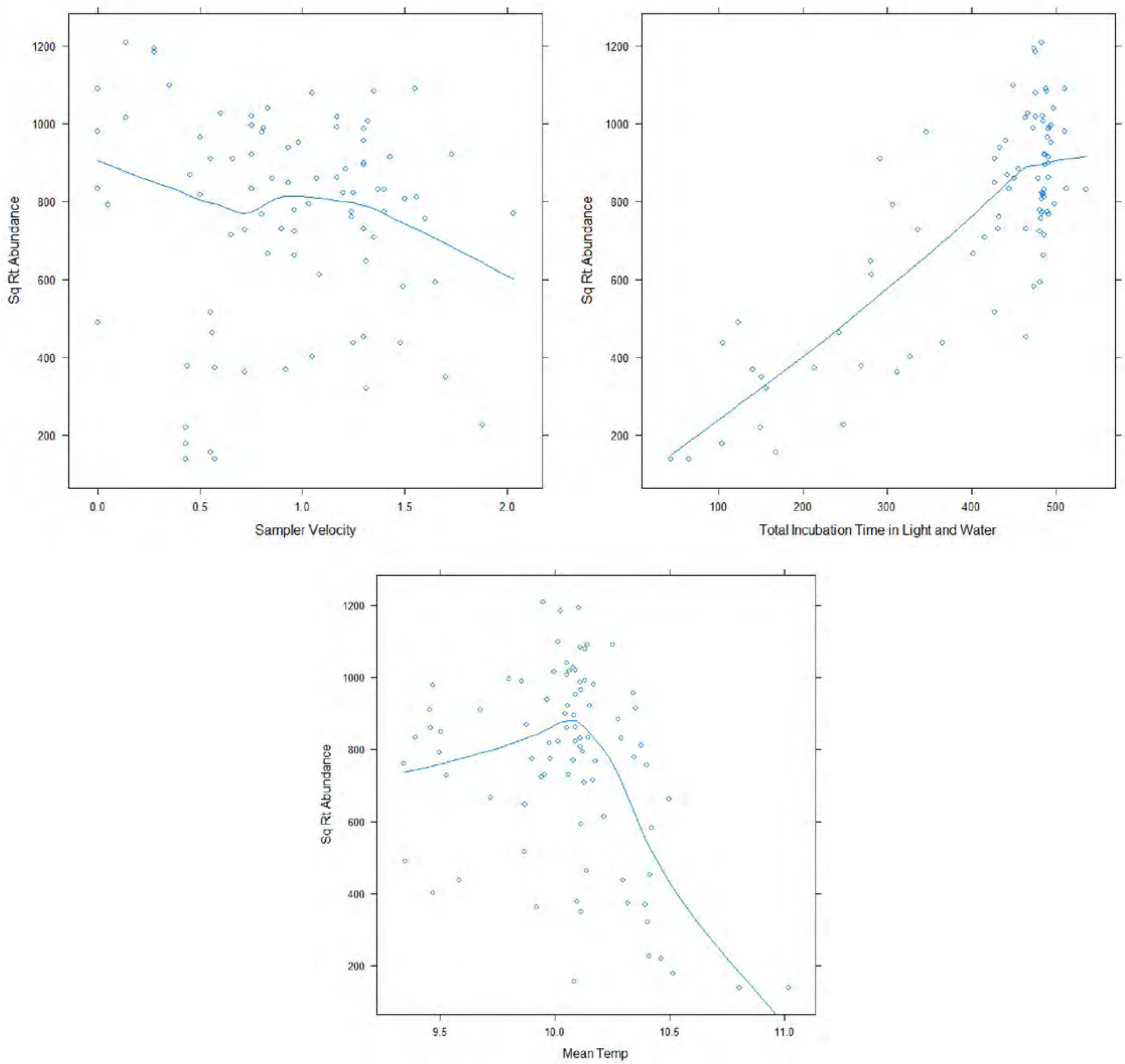


Figure 3-12: Single Linear regressions of square root transformed periphyton abundance data and Sampler Velocity (Weight = 1.00), Total Incubation Time (Weight = 1.00) , and Mean Temperature (Weight = 0.80). Fitted lines were generated using a locally weighted polynomial regression method (LOWESS)

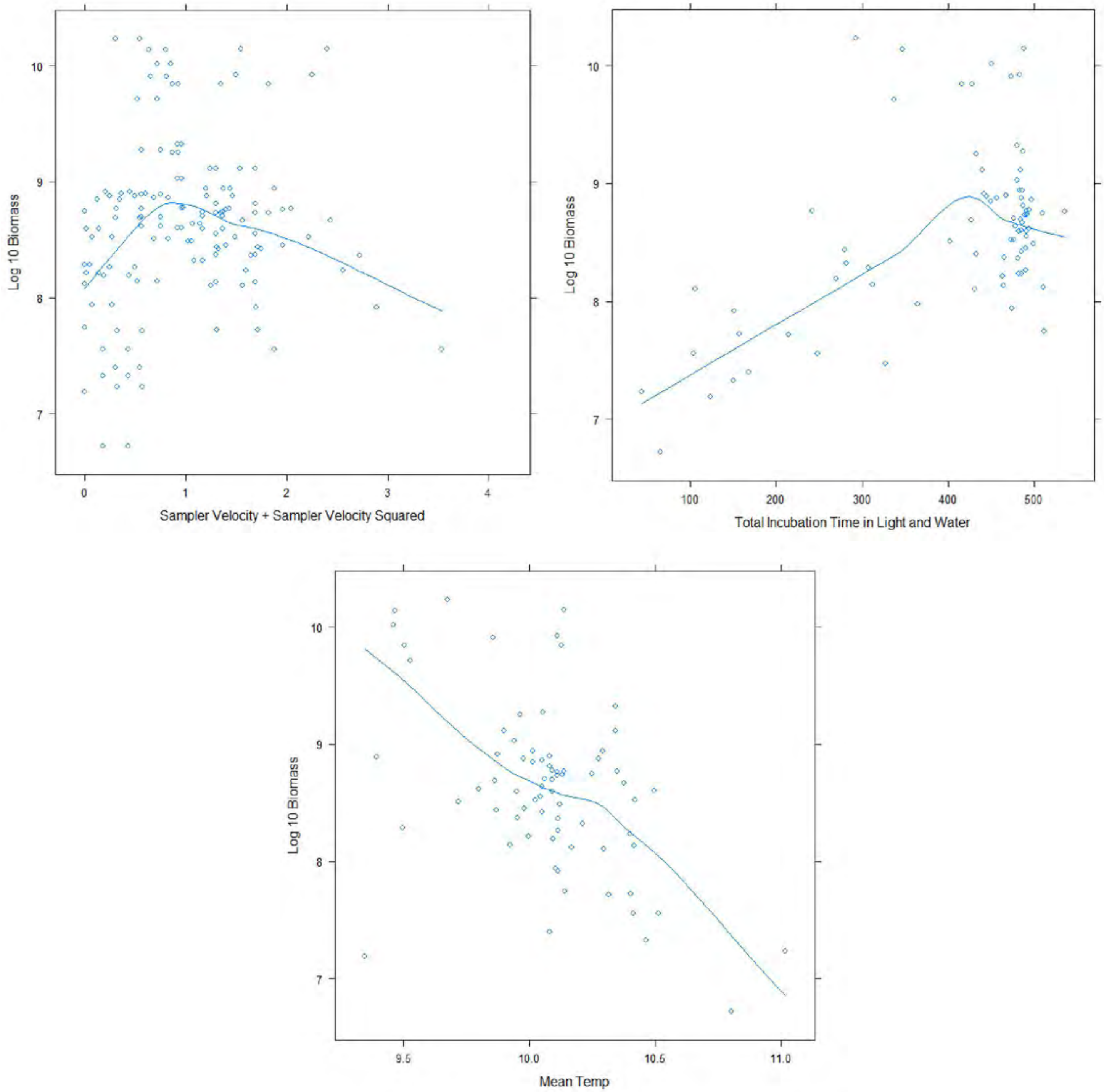


Figure 3-13: Single Linear regressions of log transformed periphyton biovolume data and Sampler Velocity + Sampler Velocity Squared (Weight =1.0), Total Incubation Time (Weight = 0.97) , and Mean Temperature (Weight = 0.94). Fitted lines were generated using a locally weighted polynomial regression method (LOWESS)

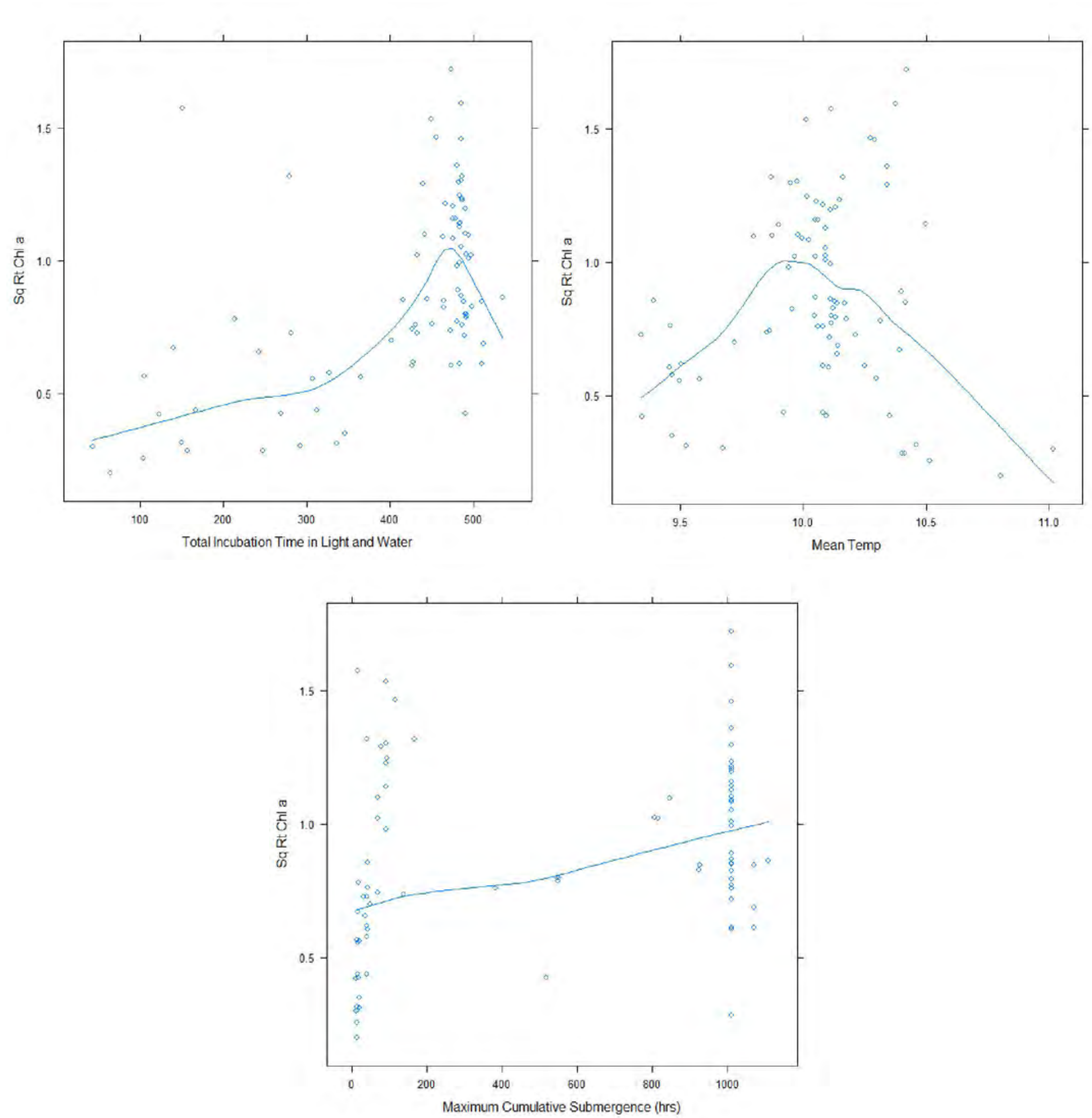
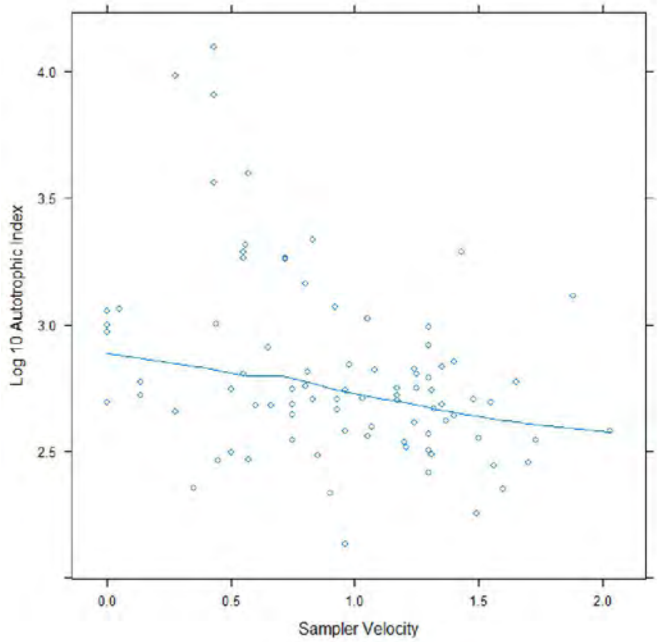


Figure 3-14: Single Linear regressions of square root transformed periphyton chlr-a data and Total incubation time in the light and water (Weight =0.99), Mean Temperature (Weight =0.96) , and maximum cumulative submergence time (Weight = 0.64). Fitted lines were generated using a locally weighted polynomial regression method (LOWESS)



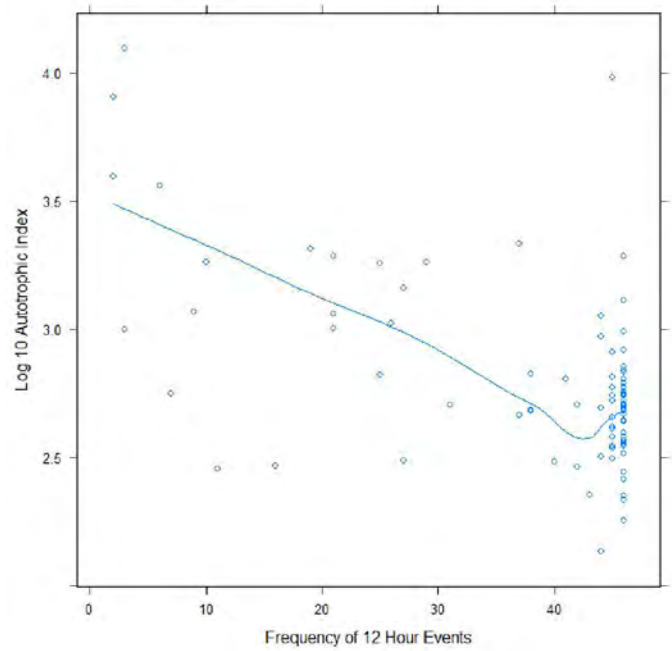


Figure 3-15: Single Linear regressions of square root transformed periphyton autotrophic index data Sampler Velocity (Weight =0.99) and Frequency of 12 hour submergence events (Weight =0.67). Lower autotrophic index values indicate a predominance of autotrophic organisms. Fitted lines were generated using a locally weighted polynomial regression method (LOWESS)

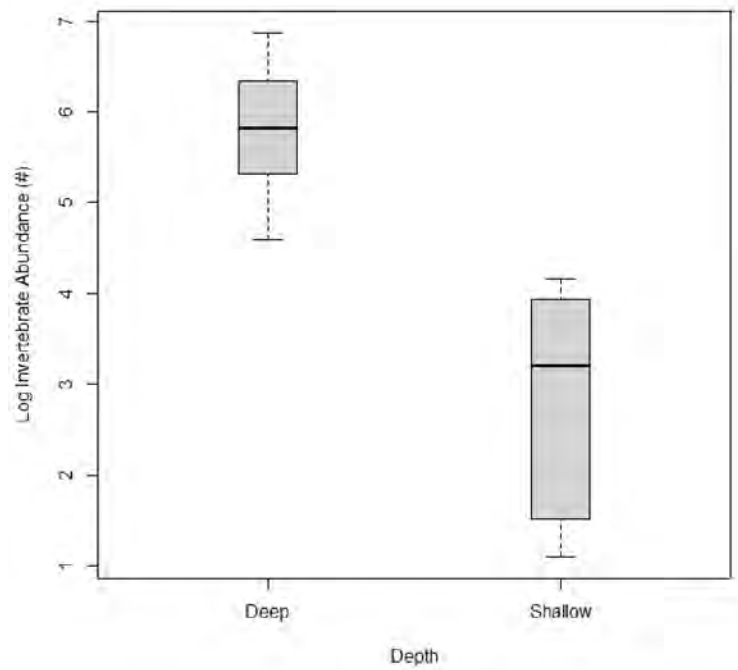
3.3 Benthic Invertebrates

3.3.1 Benthic Invertebrate Inundation Samples

Substrate samples were obtained from two depths within Reach 2, deep and shallow, to better understand how catastrophic exposure may affect benthic invertebrate abundance and biomass. Samples collected from deep sites were permanently wetted, whereas shallow sites were wetted for approximately 2-4 weeks. Prior to this re-wetting, sites were dry for an extended period and it is presumed that benthic abundance was zero. This meant that a direct comparison of the two areas would allow us to directly test potential recovery times in the MCR. The deep samples maintained a significantly greater biomass and abundance of benthic invertebrates compared to shallow samples (Table 3-7 and Figure 3-16; t-test; d.f. 10.679, $t=5.925$, $p<.001$ and d.f. 11.915, $t=5.973$, $p<.001$, respectively). Both depths' abundances were highly variable (e.g., deep samples abundance varied from 114 to 1084 invertebrates; Table 3-8). The average species richness of deep sites was 20.63 ± 5.07 (SD) compared to 4.75 ± 2.49 (SD) for shallow sites (data not shown). Benthic invertebrate families documented in the shallow samples included Chironomidae, EPT, Ephemeroptera, and Oligochaeta.

Table 3-7. Benthic Invertebrate Abundance (number/sample) in Reach 2

Depth	n	Mean	SD	Min	Max
Shallow	8	31	27	3	64
Deep	8	533	315	114	1084



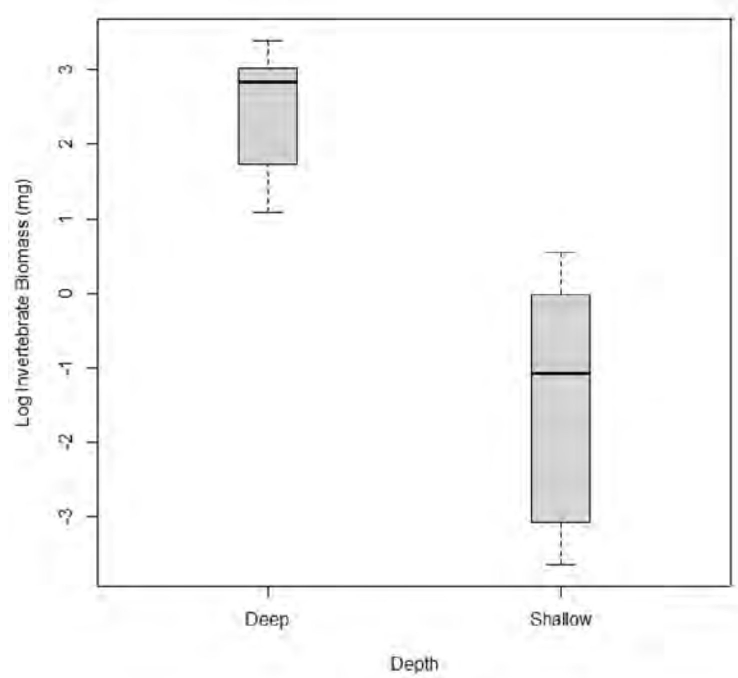


Figure 3-16: Benthic Invertebrate Biomass and Abundance of Reach 2 Samples (ANOVA; d.f. 1,14, F=35.1, p<.001 and d.f. 1,14, F=31.3, p<.001, respectively)

3.3.2 Benthic Invertebrate Natural Compared to Artificial Substrates

The loss of invertebrates from basket samplers during the retrieval process was identified as a potential concern. It has been noted that benthic organisms retrieved in baskets from the MCR are generally small and not apparent to the naked eye (Chapman et al. 2009). It is therefore possible that as the baskets are retrieved through the water column, some loss of invertebrates occurs and loss rates may be different for larger organisms than for smaller organisms. Natural substrate sample size could be increased to better quantify any differences between artificial substrates and natural substrates. Unfortunately, it is not a direct comparison due to factors such as substrate volume, community establishment times, etc. and doesn't help understand factors of loss.

To reduce the bias as much as possible, natural substrate samples were collected from Reaches 4 and 3 with a Hess sampler at low flows in the spring of 2011. Invertebrate diversity indices from these samples were then compared with T2 artificial substrate samples from Reaches 4 and 3; also collected in the spring.

Table 3-8. Comparison of Natural Substrate Sampling with Artificial Substrates (rock baskets)

Sampling Type	Diversity Indices	Mean	SD	Min	Max
Natural Substrate Reaches 3 & 4 (n=6)	**Species Richness**	13.8	4.6	7	19
	Abundance	608.3	486.2	34	1464
	Biomass	28.93	27.09	0.84	81.06
	Community Composition				
	% Ephemeroptera	4.67%	5.25%	1.30%	14.71%
	% Plecoptera	0.09%	0.23%	0.00%	0.56%
	% Trichoptera	0.00%	0.00%	0.00%	0.00%
	% EPT	4.77%	5.18%	1.66%	14.71%
	% Diptera	3.59%	6.96%	0.00%	17.65%
	% Oligochaeta	0.14%	0.22%	0.00%	0.47%
	% Baetidae	0.04%	0.10%	0.00%	0.24%
	% Chironomidae	63.93%	10.50%	49.18%	75.76%
	% Odonata	0.00%	0.00%	0.00%	0.00%
Artificial Substrate R3 & R4 - T2 baskets (n=6)	**Species Richness**	9.5	7.9	4	22
	Abundance	179.5	133.792	21	353
	Biomass	4.04	4.10	0.09	10.10
	Community Composition				
	% Ephemeroptera	0.90%	1.53%	0.00%	3.68%
	% Plecoptera	0.00%	0.00%	0.00%	0.00%
	% Trichoptera	0.36%	0.68%	0.00%	1.70%
	% EPT	1.26%	2.20%	0.00%	5.38%
	% Diptera	15.07%	33.26%	0.00%	82.86%
	% Oligochaeta	0.14%	0.35%	0.00%	0.86%
	% Baetidae	0.26%	0.52%	0.00%	1.29%
	% Chironomidae	72.55%	29.47%	18.18%	97.14%
	% Odonata	0.00%	0.00%	0.00%	0.00%

We estimate that the Hess sampler held approximately twice the volume of the artificial invertebrate baskets. Therefore, invertebrate diversity indices originating from natural substrates cannot be directly compared with those from artificial substrates without a correction factor. Given the inherent variability within the invertebrate data as a whole, in combination with the small sample size, we have not taken this additional comparative step. Rather, we looked at the data qualitatively to identify any obvious discrepancies between natural and artificial sampling.

Both sample types were highly variable (Table 3-8). Chironomidae were clearly the dominant family group in both natural and rock basket samples. Natural substrate samples appeared to have an increased prevalence of Ephemeroptera, inferring rocks baskets may potentially underestimate this important taxa.

3.3.3 Yearly Comparisons of Benthic Invertebrate Sampling

Table 3-9 shows the benthic invertebrate data from all sites for 2010 and 2011. Despite the larger sample size, the data is still highly variable and many of the broader taxonomic groups are underrepresented. For example, the mean relative abundance of EPT in the fall of 2010 was 0% and 2% in the fall of 2011 but had a mean of 20% in the spring.

The mean abundance, or organisms per sample, ranged from 209 in the fall of 2010 to 522 in the fall of 2011. Despite differences in mean abundances, the variability was so great that it is difficult to identify any trends.

Table 3-9. Relative Abundance and Diversity Indices of Benthic Invertebrates in 2010 and 2011.

			Fall 2010		Spring 2011		Fall 2011	
			n	Mean ± SD	n	Mean ± SD	n	Mean ± SD
Benthic Taxonomic Groups	Chironomidae	Mean Relative Abundance (%)	38	33 ± 29	47	60 ± 31	49	40 ± 22
	Ephemeroptera			0 ± 0		10 ± 4		2 ± 3
	EPT			0 ± 0		20 ± 4		2 ± 3
	Odonata			0 ± 0		0 ± 0		0 ± 0
	Oligochaeta			14 ± 20		0 ± 0		7 ± 7
	Plecoptera			0 ± 0		0 ± 0		0 ± 0
	Trichoptera			0 ± 0		0 ± 0		0 ± 0
Foraging Groups	Collector-Gatherers	Mean Relative Abundance (%)	34	37 ± 3	37	63 ± 21	45	20 ± 17
	Predators		35	37 ± 26	34	14 ± 12	49	40 ± 26
	Unclassified		38	33 ± 30	47	30 ± 34	49	38 ± 23
Diversity Indices	Mean Abundance	Organisms Per Sampler	38	209 ± 347	47	78 ± 105	49	522 ± 619
	Species Richness	# of Species		5 ± 2		7 ± 6		11 ± 5

3.3.5 Benthic Community Groupings

Ward/Bray cluster analyses showed that there were potentially 4 to 7 plausible groupings of data (See Ward dendogram in Appendix A). When looking at 6 groups derived from the Ward dendogram, data was grouped by Year and Season, with nearly all groups corresponding directly to a given year or year/season. NMDS analysis of the Ward groupings (stress = 0.13) using six groups confirms this grouping, which was also tested directly for Year (ANOSIM: R: 0.66, $p < 0.001$) and the Ward groups (ANOSIM: R: 0.93, $p < 0.001$) for benthic data collected between 2007 and 2011. The differentiation between Years may be reflective of differences in taxonomy between 2007 - 2009 and 2010 - 2011. Despite the differences in taxonomy accounting for some of the difference between years, annual variation of physical predictors (e.g., temperature, velocity) and operation (e.g., submergence ratio) may partially explain the strong variation observed between years (Figure 3-17) because data was still grouping by year despite different taxonomists. The final possible observation was that season may be important because one Ward Bray cluster was present for spring and fall 2011 data, although having only one season of data collection makes confirming whether this trend is actually occurring difficult.

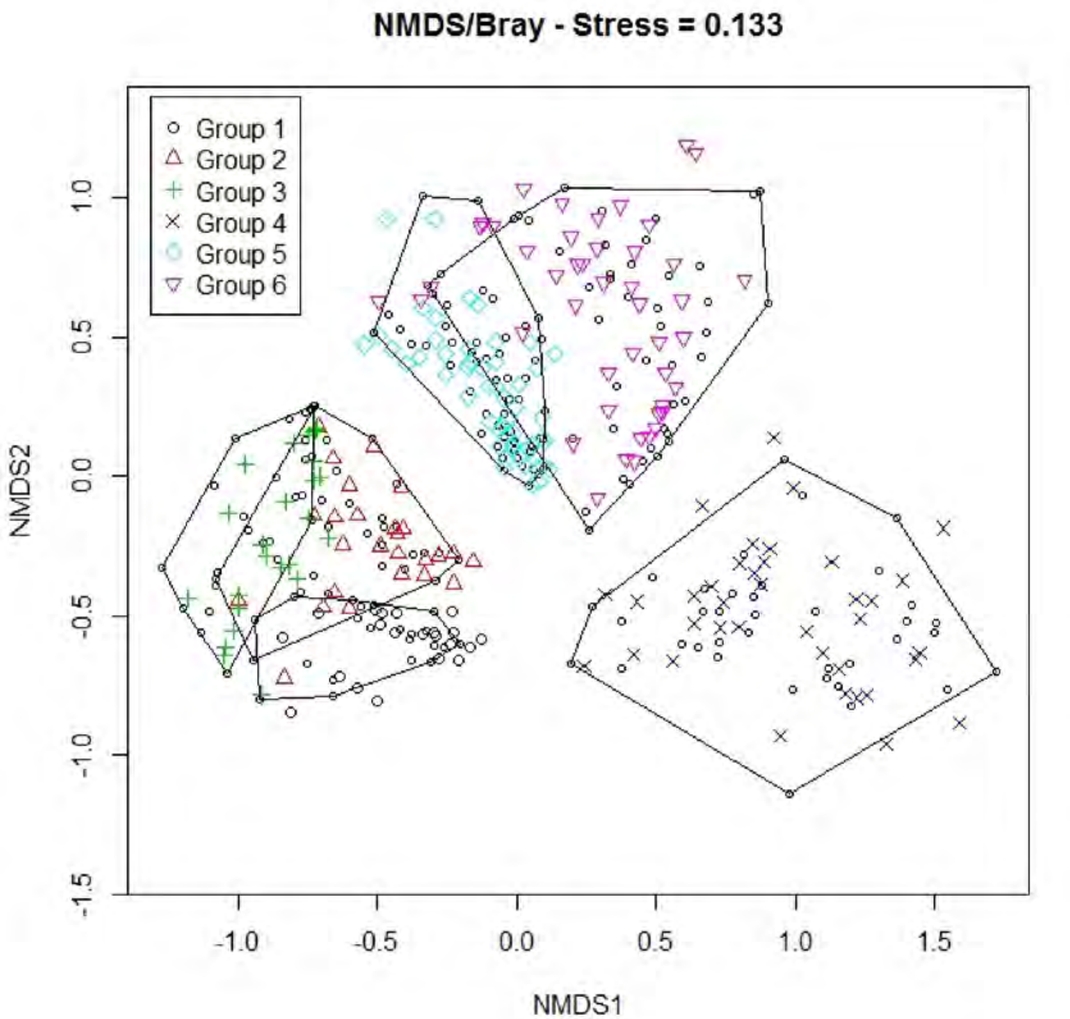


Figure 3-17. NMDS of invertebrate abundance collected between 2007 and 2011. Polygons around points were created using Ward cluster groups using a Bray Curtis dissimilarity matrix.

3.3.6 Benthic Production Models

Correlations between measures of benthic production were also similar to periphyton measures (Figure 3-18) meaning that model results should be similar between different measures of benthic invertebrate production.

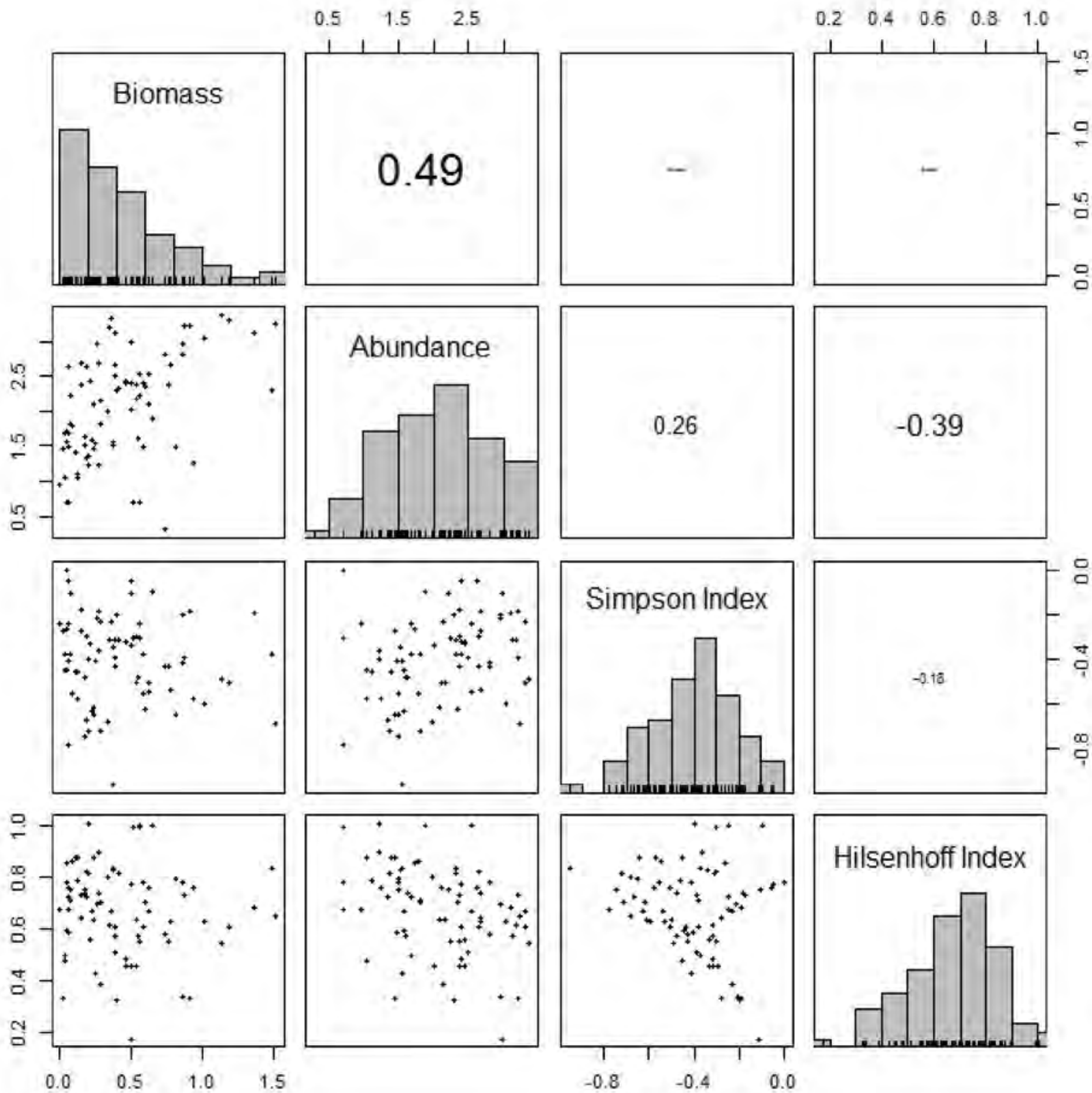


Figure 3-18: Pearson's correlation coefficients for measures of benthic production measure in the MCR. Data presented is Log10 transformed to help reduce the effects of outliers in the analysis.

Model averaging data indicated that there were numerous plausible models (those with an AICc<2.0) for benthic abundance (7), biomass (4), Simpson's Index (7), and Hilsenhoff Biotic Index (2) (Table 3-10). Several key trends were observed across the different measures of production, most notably maximum cumulative submergence which was an important predictor for abundance and biomass. Other key predictors were mean temperature, sampler velocity, and frequency of 12 hour submergence events. Less notably, but potentially important predictors include submergence ratio and total incubation time in the water and light.

Maximum cumulative submergence (hrs), frequency of 12 hours submergences, and sampler velocity were the most important predictors of benthic abundance. Maximum cumulative submergence was positively correlated with benthic abundance and was the most important predictor of benthic abundance. Both frequency of 12 hour submergence events and velocity were also important and positively associated with benthic abundance. Other important predictors of benthic biomass included submergence ratio and possibly total incubation time in the light and water (see Table 3-10 and Figure 3-19).

The variable flow conditions in the MCR may reduce invertebrate survival. Maximum cumulative submergence (hrs) was the most important parameter predicting benthic biomass and the relationship was positive (Estimate = 1.78E-05, w = 0.6). Other important predictors of benthic biomass included mean temperature, submergence ratio, and sampler velocity (Table 3-10 and Figure 3-20).

Frequency of 12 hours submergences and velocity (and their quadratic terms) were the most important predictors of benthic diversity (Simpson) (Table 3-10 and Figure 3-21). These relationships were concave in nature. Generally, diversity decreased from T1 through T4 and then increased from T5 through T7.

Mean temperature (and the quadratic), velocity (and the quadratic term) and submergence ratio were the most important predictors of benthic Hilsenhoff Diversity Index (Table 3-10 and Figure 3-22). The Hilsenhoff Index is indicative of low oxygen conditions and is therefore indicative of survival under sub optimal conditions. Less tolerant species such as EPT were more prevalent in areas of higher velocity or higher average temperature which was indicative of exposure because daily temperature highs were typically greater than water temperature. This means that sensitive EPT were most prevalent in lower velocity areas that were regularly submerged and more tolerant species were found in areas of greater exposure.

Table 3-10: Multi model averaging results using Akaike information criterion approach for four measures of benthic invertebrate production and diversity (Abundance, Biomass, Simpson's Index and and Hilsenhoff Biotic Index) in the MCR. The total number models 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 (7) Estimate (CC)	Weight (w)	# Occurences in AICc<2 Models
max_cum_sub_hrs	**7.91E-04**	**0.86**	**6**
Freq_Submer_.12.Hrs	**0.08**	**0.78**	**5**
sampler.velocity	**-2.44E-01**	**0.63**	**8**
sub_ratio	-4.03E+00	0.59	4
Freq_Submer_.12.Hrs.sq	-1.60E-03	0.36	2
mean_temp	-1.80E+00	0.31	0
sub_ratio.sq	6.53	0.30	2
tot_inc_time_water_light_hrs	-8.36E-04	0.29	1
max_cum_sub_hrs.sq	-3.41E-07	0.20	4
sampler.velocity.sq	0.09	0.15	0
mean_temp.sq	0.31	0.09	0
tot_inc_time_water_light_hrs.sq	2.91E-06	0.07	0

Model Predictors	Biomass (4) Estimate (CC)	Weight (w)	# Occurences in AICc<2 Models
max_cum_sub_hrs	**1.78E-05**	**0.61**	**3**
mean_temp	1.49	0.51	2
sub_ratio	1.71	0.50	0
Freq_Submer_.12.Hrs	-1.63E-02	0.40	0
sampler.velocity	0.16	0.37	0
tot_inc_time_water_light_hrs	-9.50E-04	0.35	0
max_cum_sub_hrs.sq	5.98E-07	0.18	1
sub_ratio.sq	-2.15E+00	0.17	0
sampler.velocity.sq	-2.41E-01	0.17	0
mean_temp.sq	-2.31E-01	0.14	0
Freq_Submer_.12.Hrs.sq	4.53E-04	0.11	0
tot_inc_time_water_light_hrs.sq	2.97E-06	0.08	0

Model Predictors	Simpsons Index (7) Estimate (CC)	Weight (w)	# Occurences in AICc<2 Models
sampler.velocity	**-4.54E-01**	**0.84**	**6**
sampler.velocity.sq	**0.23**	**0.78**	**6**
tot_inc_time_water_light_hrs	**-2.39E-03**	**0.58**	**4**
Freq_Submer_.12.Hrs	-1.89E-02	0.58	4
tot_inc_time_water_light_hrs.sq	**4.87E-06**	**0.45**	**4**
sub_ratio	0.27	0.42	1
mean_temp	0.19	0.41	2
Freq_Submer_.12.Hrs.sq	4.81E-04	0.41	3
max_cum_sub_hrs	-2.35E-04	0.34	2
sub_ratio.sq	0.12	0.17	0
max_cum_sub_hrs.sq	4.59E-07	0.11	0
mean_temp.sq	-2.07E-02	0.09	0

Model Predictors	Hilsenhoff Biotic Index (2) Estimate (CC)	Weight (w)	# Occurences in AICc<2 Models
mean_temp	**7.61**	**0.93**	**2**
mean_temp.sq	**-3.89E-01**	**0.92**	**2**
sampler.velocity	**0.24**	**0.80**	**2**
sampler.velocity.sq	**-1.81E-01**	**0.67**	**0**
sub_ratio	**-3.29E-01**	**0.61**	**1**
Freq_Submer_.12.Hrs	-6.11E-03	0.50	1
max_cum_sub_hrs	2.75E-05	0.38	0
tot_inc_time_water_light_hrs	-1.66E-04	0.31	0
sub_ratio.sq	-3.10E-02	0.14	0
Freq_Submer_.12.Hrs.sq	7.47E-05	0.12	0
max_cum_sub_hrs.sq	-2.69E-07	0.10	0
tot_inc_time_water_light_hrs.sq	-4.64E-09	0.07	0

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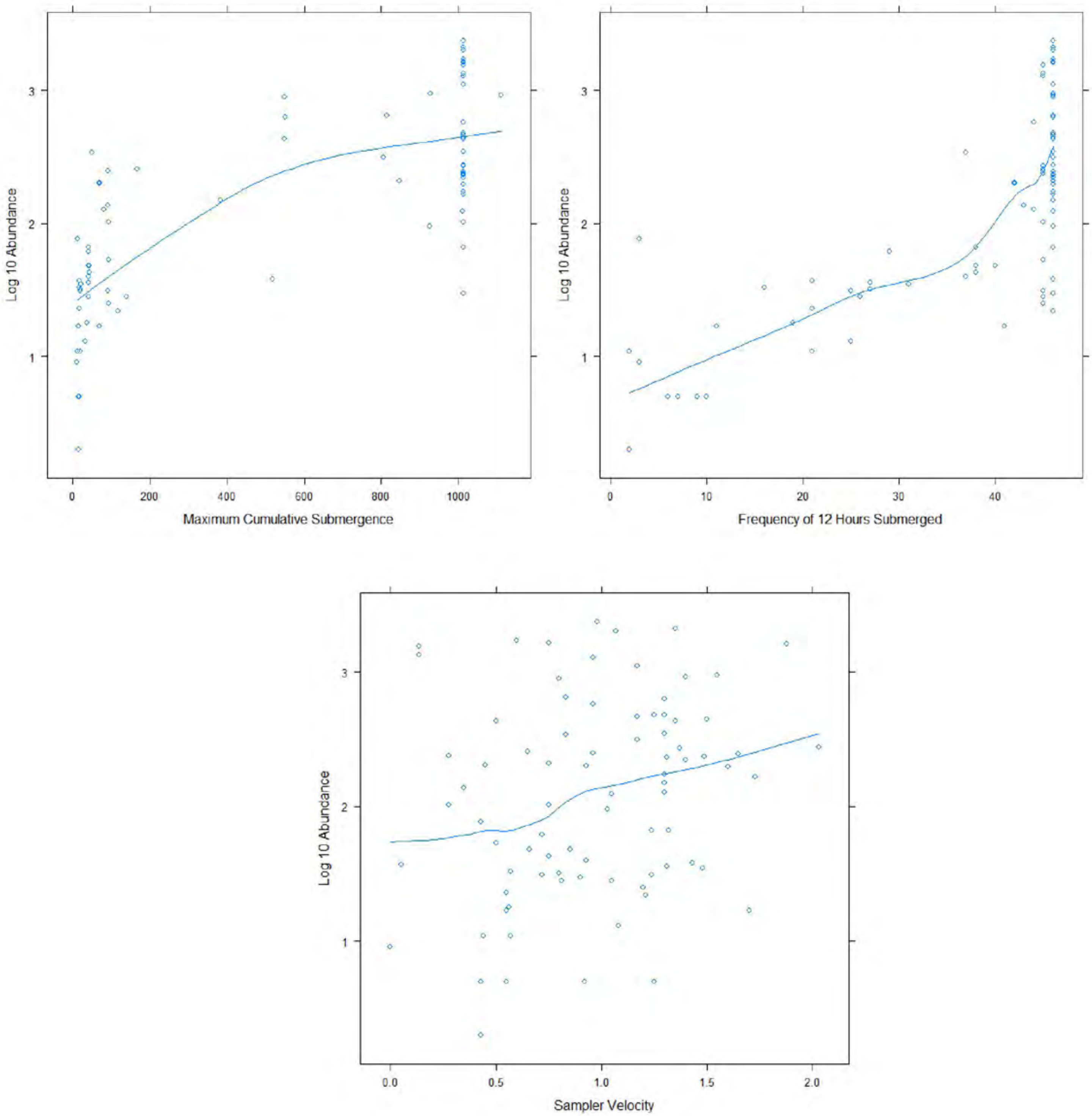

Figure 3-19 **Single Linear regressions of log transformed benthic abundance data and Maximum Cumulative Submergence (Weight = 0.86), Frequency of 12 hour submergence events (Weight = 0.78), and sampler velocity (Weight = 0.63). Fitted lines were generated using a locally weighted polynomial regression method (LOWESS)**

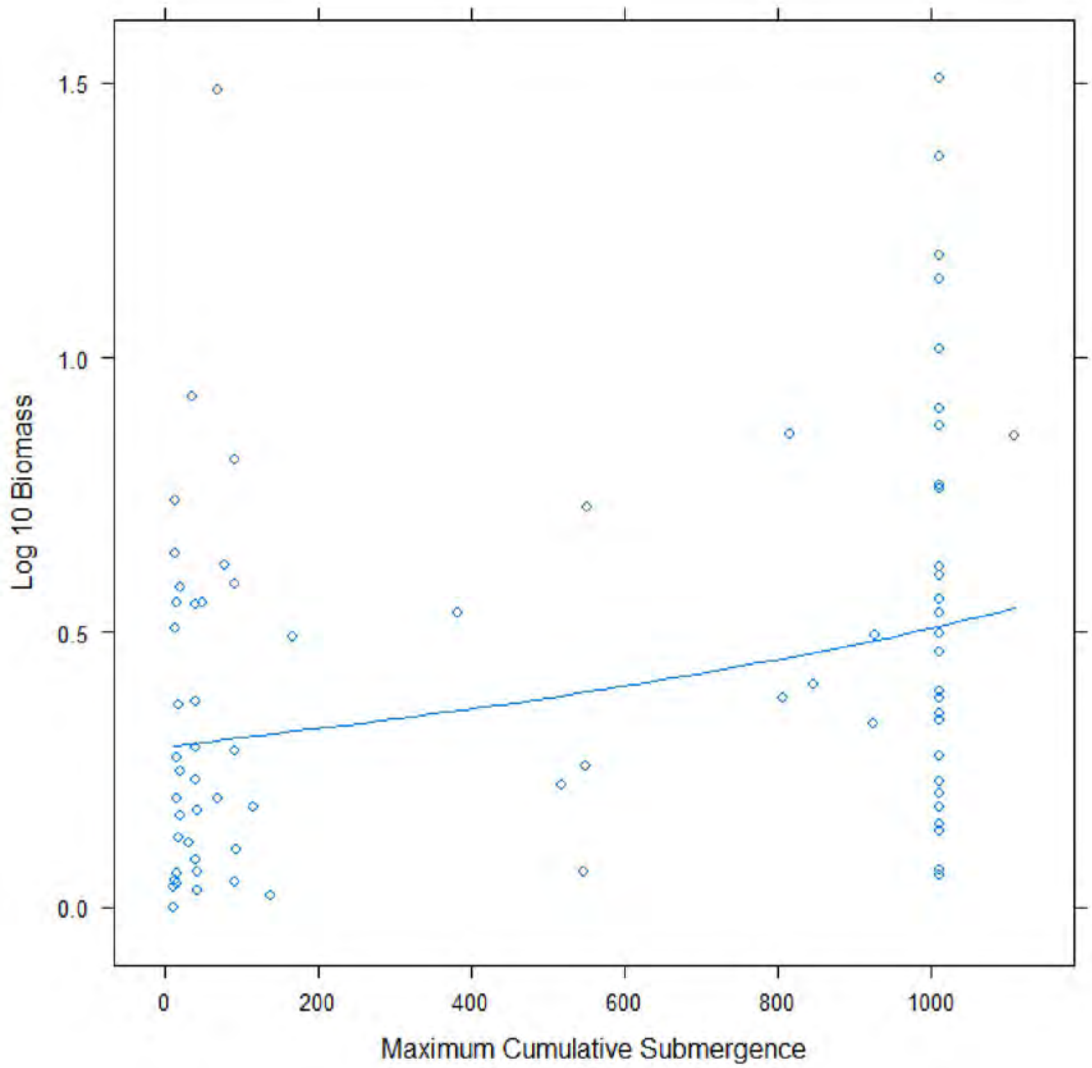

Figure 3-20 Single Linear regressions of log transformed benthic biomass data and Maximum Cumulative Submergence (Weight = 0.61). Fitted lines were generated using a locally weighted polynomial regression method (LOWESS)

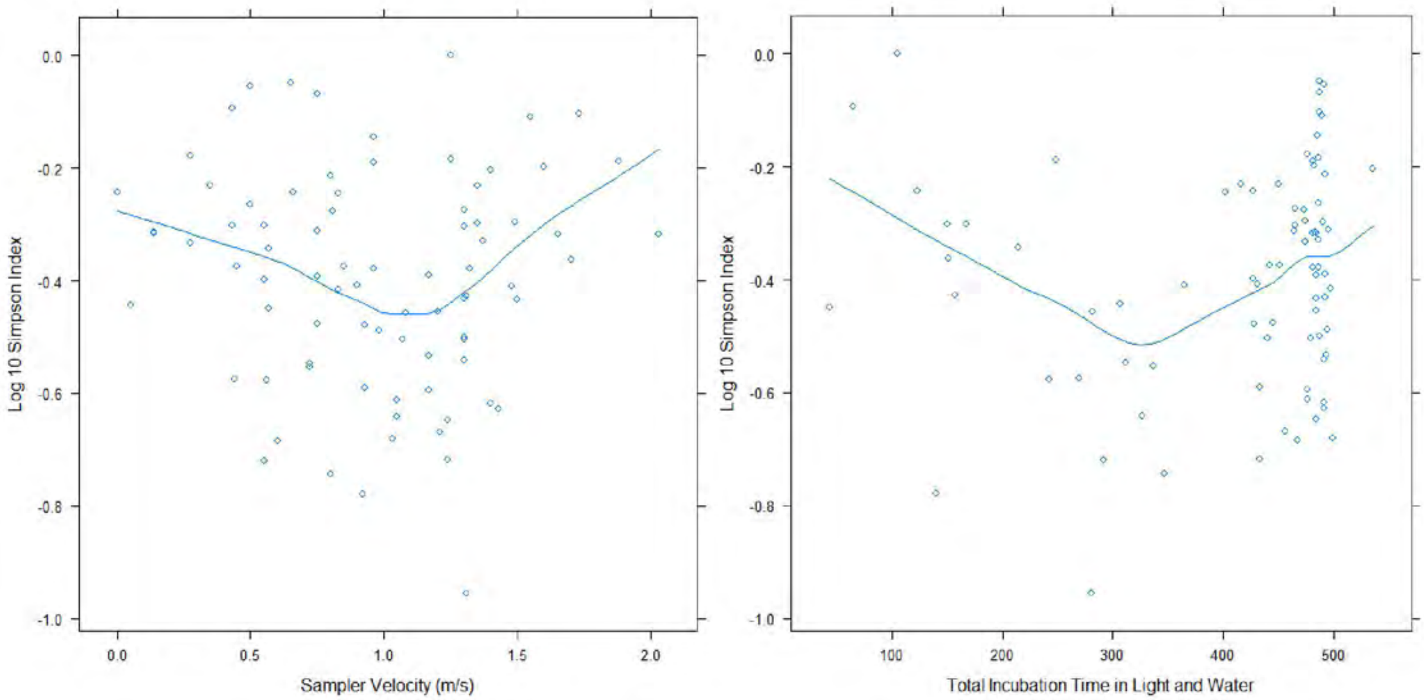

Figure 3-21 **Single Linear regressions of log transformed benthic Simpson's Index data and Sampler Velocity (Weight = 0.84) and Total incubation time in the light and water (Weight = 0.58). Fitted lines were generated using a locally weighted polynomial regression method (LOWESS)**

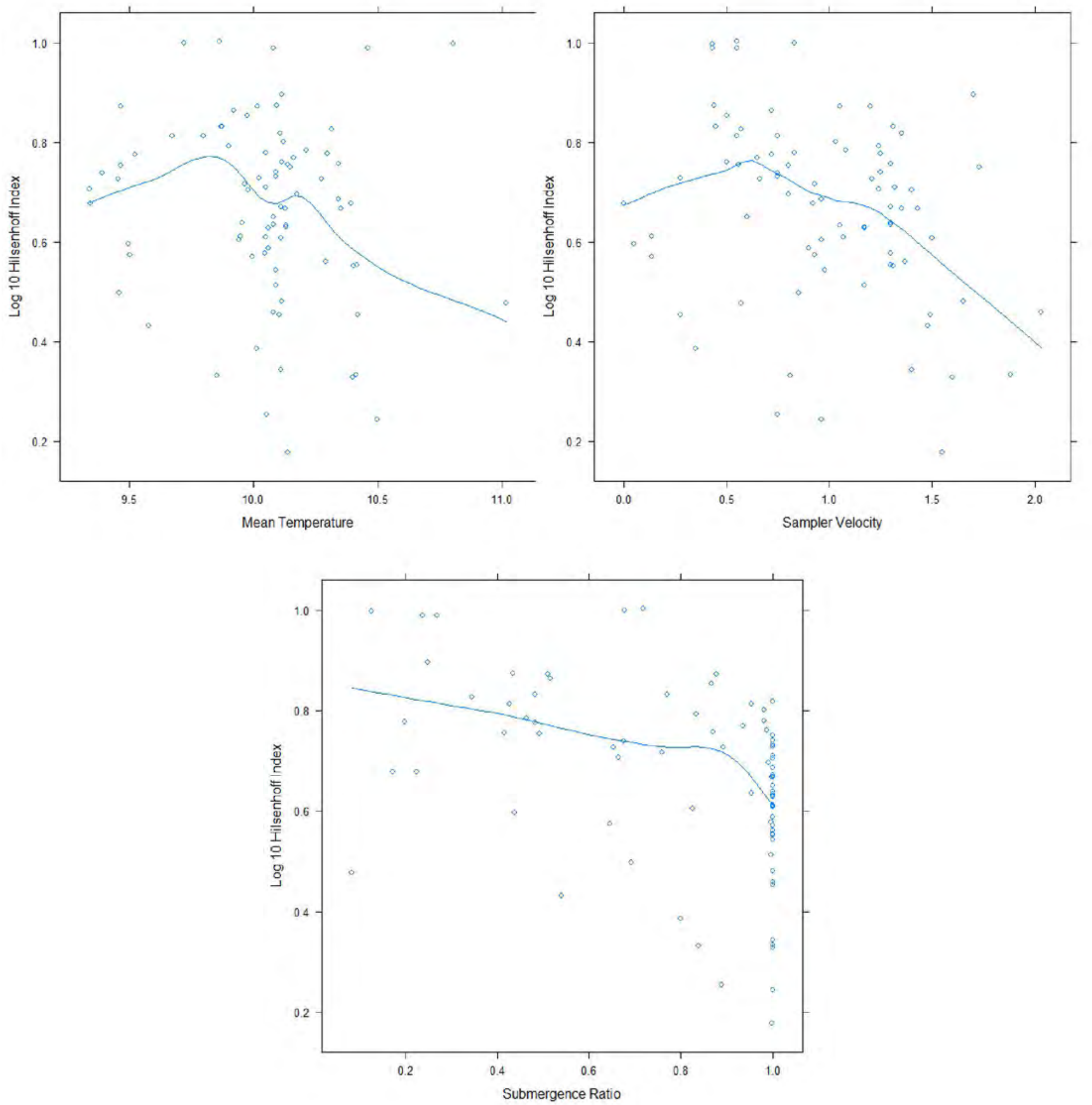

Figure 3-22 **Single Linear regressions of log transformed benthic Hilsenhoff's Biotic Index data and Mean Temperature (Weight = 0.93) Sampler Velocity (Weight = 0.92) and Submergence Ration (Weight = 0.61). Higher index values represent more exposure tolerant taxa because these species can survive in conditions with lower dissolved oxygen . Fitted lines were generated using a locally weighted polynomial regression method (LOWESS)**

4.0 DISCUSSION

4.1 Overview of Habitats and Conditions

Both periphyton and benthic invertebrates 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). A long term monitoring program of periphyton and benthic invertebrates is ongoing to determine the effectiveness of minimum flows and REV5 on MCR production. The typical daily flow pattern of MCR consists of high flows during the day and low flows at night. Within this general pattern, flows are still highly variable, with many extreme events such as flows in excess of 1800 m^3/s, or low flow periods that extend for more than 48 hours and have catastrophic implications for the benthic community. These extreme events, coupled with other routine operations ultimately determine the aquatic communities that occur within the MCR.

Two generalized habitat conditions exist in MCR Reaches 4 and 3. First, there are areas that are permanently submerged. These wetted habitats function like those in other large rivers, with physical habitat attributes such as velocity, light, substrates, temperature, etc. affecting periphyton and invertebrate communities. The MCR data suggest that within these permanently wetted areas, densities and biomass of both periphyton and invertebrates mimic those that would occur in a more natural large river system (Table 4-1). Like most rivers, MCR periphyton community data is negatively correlated with velocity. Furthermore, time series suggest that extreme high flow events coincide with a subsequent thinning of the periphyton community in the thalweg. In the MCR, velocities can exceed more than 2 m/s. These high velocities (typically as a result of high flows) are sufficient to cause shearing of filamentous algae (Flinders and Hart 2009), and to mobilize substrate that causes further community reductions due to saltating sands (Fisher *et al.* 1982, Gregory *et al.* 1991; Goudie 2006; Luce *et al.* 2010). Prolonged high flows in 2011 increased water depth in the narrower Reach 4 channel and reduced the light intensity on substrates, which coincidentally had lower periphyton accrual than Reach 3. Water velocity, saltation and light are just a few examples of the many physical habitat attributes that affect benthic community production. Further analysis and collection of physical attribute data are needed to clarify the effects of the many physical habitat attributes on benthic production in the MCR.

The second habitat condition that exists is much more variable and dynamic and occurs above the boundary of the permanently wetted habitat in what is termed the varial zone. These varial zone areas occur in the mid channel typically (approximated by our T2-T4 sites), and the size of the area varies depending upon channel morphology. The constant fluctuations between submergence and exposure result in a benthic community that undergoes periods of growth and decline depending on the specifics of the current operating regime. Not unexpectedly, the variable hydrologic conditions 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).

These ever-changing hydrologic patterns in the varial zone create a benthic invertebrate community that is in a constant state of recovery. Invertebrate data from Reach 2 compared sites 2 weeks post recovery with those that had been permanently wetted and suggests that invertebrate recovery after a catastrophic event may take several weeks. Periphyton recovery is frequently faster than invertebrate recovery because bacteria and pico-cyanobacteria condition dewatered substrates with organic coatings that can accelerate recolonization (Stockner 1991; Wetzel, 2001). Our desiccation/re-wetting experiments (2010) indicated that resumption of growth may also be faster in species that produce desiccation-resistant structures (e.g., akinetes, 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.

Table 4-1: Summary of Typical MCR Periphyton Metrics from 2010 and 2011, 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	9 - 52 **(39)**
Chlorophyll-a ug/cm^2	<2	2 - 5	>5 – 10 (30+)	0.1 – 3.0 **(2.0)**
Algae density cells/cm^2	<0.2 x10^6	1 - 4 x10^6	>1 x10^7	<0.02 – 1.5 x10^6 **(2.2 x10^6)**
Algae biovolume cm^3/m^2	<0.5	0.5 – 5	20 - 80	0.05 - 18 **(5.9)**
Diatom density frustules/cm^2	<0.15 x10^6	1 - 2 x10^6	>20 x10^6	<0.01 – 0.6 x10^6 **(0.9 x10^6)**
Biomass –AFDW mg/cm^2	<0.5	0.5 - 2	>3	0.12 – 3.5 **(3.5)**
Biomass –dry wt mg/cm^2	<1	1 – 5	>10	0.7 – 80 **(70)**
Organic matter (% of dry wt)		4 - 7		1 – 10 **(4)**
Bacteria sed. 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

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.

The MCR periphyton and invertebrate data clearly show strong groupings by both year and season (NMDS results). The grouping by season is not surprising, as benthic populations tend to vary seasonally due to differences in physical variables such as temperature and light, as well as due to specific life cycle stages. The strong grouping by year is more unusual. Although physical habitat conditions such as temperature, weather, and precipitation likely described some of the annual variation, it is presumable that some of these community groupings by year are partially explained by the specific habitat conditions that resulted from the particular operating regimes during data collection. Our data show that variables such as frequency of 12 hour submergence events, maximum cumulative submergence, and submergence ratio are important predictors of benthic communities. Thus, there is a clear connection between operations, submergence and production.

4.2 Periphyton and Benthic Invertebrate Composition and Distribution

4.2.1 Periphyton

Data from 2007 to 2011 indicate that periphyton communities follow a general pattern. Every September/October, MCR periphyton communities were dominated by diatoms representing between 85 and 95% of the biovolume at all sample sites. Filamentous green algae were more common in Reach 4, and they averaged 9 to 13% of the total biomass over 2010 and 2011. Filamentous algae require stable substrates and significant nutrient concentrations. Together with mosses, they act as ecosystem engineers, providing habitat for many other benthic species. The small-celled flagellates, cyanobacteria, and colonial greens were numerous but rarely exceeded 1.5% of the biovolume in MCR samples. While the relative contributions made by each algal group were constant from one year to the next, the dominants varied with BC Hydro operations and prevailing MCR conditions. In April/May 2011, periphyton growth metrics from the spring deployment were all less than half of the fall deployment. We suspect this is because periphyton processes are slower during winter due to lower water temperatures that retard enzymatic activity, even in the rapidly reproducing biofilm bacteria (Wetzel 2001). Our data do suggest that measures of production increase with temperature to some point, noting that declines at higher temperatures were the result of increased exposure.

Two important categories of predictors of periphyton production and diversity emerged in the periphyton modeling results. First, time spent in the water was a consistent and vital predictor of periphyton production and diversity. Second, physical parameters such as water velocity and temperature were also important. Time spent in the water is positively correlated with flow, and we therefore used it as a correlate to flow. The various predictors of time spent in the water included submergence ratio, production time (time in light and water), frequency of 12 hour submergence events, and maximum cumulative submergence. The strength of each predictor varied, but it was evident that time in the water was critical. Many of the predictors related to flow reached an optimum, or plateau, at locations outside the minimum flow boundary (i.e., T3-T4). Periphyton production still occurred in areas exposed at low flows (~200 m^3/s) but notable production only occurred at mid channel elevations immediately above those of minimum flow. It is probable that in these channel areas immediately above minimum flow that submergence occurred for sufficient time to not overly affect periphyton biomass production. It is possible that the frequency of wetting and typical exposures only occurring at night may have reduced desiccation rates in these channel areas immediately above minimum flow. Given this, the data suggest that even exposed areas directly above minimum flow are contributing to the overall productivity and that periphyton communities have some limited tolerances for exposure.

Since time in the water was positively associated with production, if minimum flow was the only operational constraint then it should ensure enhanced production. However, operations are much more complex, and exactly how beneficial minimum flows are to the overall MCR production under the current operating regime remains unclear. For example, the ALR back-watering in 2011 resulted in increased production in typically exposed substrates because Reach 3 varial zone sampling locations T3-T5 remained submerged. Minimum flow is considered most advantageous to production during prolonged low flow periods because a minimum amount of channel will remain submerged and have a higher production time (an identified predictor in MCR models). These extended drying events do occur, as witnessed during the spring 2011 deployment when the channel was at or near low flows for 44 hours on May 14 and 15th. This drying event almost certainly reduced benthic invertebrate production in exposed areas, because the channel substrates were dry and had no noticeable moisture in excess of 10 cm on highly exposed sites (~T4 through T6) that would be indicative of a productive area. Periphyton on adjacent natural substrates was also dry and readily dislodged, indicating that it would slough during the next high flow period.

The MCR submergence data suggest that any increases in submergence time could translate into increased periphyton production. Overall, minimum flow probably increased production in Reach 4 during 2011 because it reduced the frequency of exposure events in a portion of the channel, ensuring that this area was not in a constant state of recovery. It can therefore act as an extra source of viable periphyton to repopulate downstream desiccated substrates. MCR data suggest that recovery takes upwards of two to three weeks; therefore any reduction in exposure events will maintain a higher minimum production.

However, it is more difficult to predict the specific benefits of minimum flows beyond the theoretical advantages for many reasons. For instance, if BCH operations were allowed to go to zero flow for short periods at night, accompanied by a reduction in the frequency of catastrophic daytime drying events, it is possible that MCR production could increase, provided that average daily flows were maintained well above minimum flow. Key predictors such as frequency of 12 hour submergence events, submergence ratio, and production time support this hypothetical scenario. The 2010 desiccation experiments indicated that community tolerances may be exceeded in as little as 4 to 6 days for periphyton and as few as 48 hours for benthic invertebrates resulting in significant benthic community losses. These preliminary experiments were not rigorous enough to confirm results statistically, but were consistent with the literature (Usher and Blinn 1990; Angradi and Kubly 1993; and Blinn *et al.* 1995).

4.2.2 Benthic Invertebrates

Benthic invertebrate communities showed very similar responses to the periphyton communities. All measures of invertebrate production and diversity were positively associated with measures of increasing submergence, albeit the invertebrate data was less robust than the periphyton data. Trends in invertebrate data were not as strong for several reasons including a patchily distributed invertebrate community and sampling inefficiencies that resulted in taxonomic groups that were absent or underrepresented. Despite this, we conclude that minimum flows in 2011 had a positive effect on benthic invertebrates. The implementation of minimum flows increased the permanently wetted portions of the channel and thus provided a larger area of habitat not subjected to periodic desiccation. However, as with periphyton, it is possible that alternative operating regimes that reduce the frequency and duration of catastrophic drying events could be more beneficial than simply implementing minimum flows.

Invertebrate species that dominate the MCR include those that are more tolerant of disturbance, such as chironomids (Tonking *et al.* 2009). Orthoclad chironomids are often overrepresented in regulated rivers (Bunn and Arthington 2002). Presumably, benthic invertebrates from the EPT group are more sensitive to extreme conditions such as desiccation or freeze-drying compared to chironomids. This is corroborated by the Hilsenhoff Biotic Index (HBI). This index factors the sensitivity of different assemblage groups to low oxygen conditions. The HBI results suggest that more sensitive benthic invertebrates, such as EPT, were present in MCR habitats with a higher moisture regime. Sites exposed for longer periods tended to have higher HBI scores. This means that invertebrate community responses in the MCR are indicative of poor benthic invertebrate habitat conditions because species tolerant of low dissolved oxygen conditions were prevalent. Presumably, these tolerant species may also be more tolerant of desiccation. Since large invertebrate species like EPT are more susceptible to desiccation, the implementation of minimum flows should cause both abundance and biomass increases in this community.

Other factors that may also be important to invertebrate abundance and diversity are the 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). We have yet to specifically test this with the MCR data; however, as the data accumulates it may be possible to examine long-term trends of invertebrate indices from submerged sites not subjected to high flow events (e.g., the backwater in Reach 3) and compare them with submerged sites exposed to high flows.

4.3 Effects of Minimum Flows on the Area of Productive Benthic Habitat

The daily discharges from Revelstoke Dam determine the elevation of the wetted edge of the MCR. Implementation of minimum flows (142 m^3/s), as opposed to 0 m^3/s, began on November 1, 2010. Preliminary results from the HEC-RAS model showed an increase of 32% in the area of Reaches 4 and 3 that remain permanently wetted with minimum flows (K. Bray, BC Hydro, pers. comm., 2010).

The MCR data generally shows a peak in productivity near the minimum flow wetted edge (e.g. T2 - T3). In 2011, there were three notable changes in operations that affected the area of the wetted channel. BC Hydro implemented minimum flows, REV 5 became operational, and the high snowpack increased freshet flows, and resulted in the backwatering of ALR into Reach 3. Backwatering was not observed in 2010. This combination of factors, along with a single year of minimum flow data make it difficult to specifically test the effects of minimum flow on the area of benthic habitat. Despite this complication, the data suggest that production was positively associated with both physical attributes and submergence. Minimum flows increased the area of productive habitat but the extent of the areal benefit is unknown and dependent on a variety of factors beyond flow. For example, the backwatering of ALR resulted in a significant increase in the wetted channel area within Reach 3. Thus, in times of backwatering, the benefits of minimum flow are limited to Reach 4. In the absence of backwatering, operations that reduce the frequency of catastrophic drying events by wetting substrates more regularly are also of importance, as they effectively increase the area of productive habitat that occurs beyond the permanently submerged areas.

We speculate that operating regimes that reduce the frequency of catastrophic drying may actually shift the area of maximum production to a slightly higher elevation within the channel. Based on the artificial substrate results, areas experiencing minimal exposures (e.g., those with a submergence ratio of greater than 85%) may actually 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 zero flow, provided that flows of 400 to 600 m^3/s occurred every day for at least several hours. It is probable that there are many operating regimes that could benefit MCR production, but more data is required to better address the specifics any given operating regime and its potential benefit to production.

4.4 Effects of Minimum Flows on Periphyton Accrual

The combined time series data collected across year, season and river depth suggest that accrual on the MCR may be linear within the 46 day deployment period. It is likely that peak biomass is not attained within this period. The unique operating regimes on the MCR affect periphyton biomass and diversity. Periphyton communities can take from weeks to as many as three years to stabilize following a change in flow regime (Wu et al. 2009). Therefore, improved periphyton production stemming from the implementation of minimum flows may take years to fully develop in the MCR. Furthermore, habitats in some exposed areas may never actually attain peak biomass because they are insufficiently wetted to establish a climax benthic community.

The expected peak accrual is affected by both physical and BCH operating factors. For example, spring river conditions such as low water temperature and short day length resulted in lower biomass and accruals than in the fall. In varial zones, accrual declined as site exposure increased. For instance, fall 2011 accrual rates fell from a maximum of 0.067 $\mu g/cm^2/day$ at R3 T2 (constantly submerged) to a minimum of 0.0008 $\mu g/cm^2/day$ at R3 T5 (frequently exposed). The assumption of lower time series accrual at more exposed sites is further supported by regular samplers because they also had lower abundances and biovolumes at the end of the sampling season. Provided time series accrual relationships are linear, inferences about accrual can be made even though the MCR is subject to several confounding factors (Table 4-2).

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

Substrate Exposure Time	<2 hours	2-10 hours	10-24 hours	24-48 hours	2-4 days	4-6 days	>6 days
Day	<10	10-30	30-40	40-60	40-70	70-95	95+
Night	none	0-10	10-30	30-50	50-70	70-80	80+
Recovery Time (weeks)							
June – October	none	<1	1-2	2-3	3-5	5-10	.>10
November – May	<1	1-2	2-4	3-6	6-10	10-20	> 20

Data obtained from Usher and Blinn 1990; Angradi and Kubly, 1993; and Blinn *et al.* 1995, Hodoki 2005, this study 2010 and 2011 data

4.5 Effects of REV5 Peak Flows on MCR Productivity

REV5 came on-line in December 2010 and has the potential to increase the frequency of maximum flows in the MCR. The effect of the increased REV5 ramping rate will be strongest near the dam (Reach 4). Peak flows exceeding 2000 m^3s^{-1} were concentrated in the winter of 2011 but also occurred in August, and did not occur during the 2011 deployment periods. Increased flows will result in increased velocity and water depth, while winter conditions slow periphyton activity. Together these effects substantially reduced winter/spring periphyton production in 2011. The MCR may therefore require longer to regain productivity from REV5 flows in the winter compared to the summer.

4.6 Possible Implications for Fishes

The overarching concern driving this study is fish production. The WUP CC recommended establishment of a year-round 142 m^3/s minimum flow release from Revelstoke Dam to enhance fish habitats in the MCR. Variations in the forage quality of periphyton determines the availability of energy for upload to the benthic invertebrates that are both the food fish. Like most rivers, diatoms in the MCR comprise the largest algal group (Perrin and Chapman, 2010; Schleppe *et al.*, 2010), but diatoms are not considered highly nutritious to benthic invertebrates. In one study, 73% of the diatoms collected from epilithic river habitats contained intact chloroplasts while about 42% of diatoms eliminated by benthic invertebrates were still living (Peterson, 1987b). This suggests that diatoms remain viable and reproductive after passing through benthic invertebrate guts, indicative of a low nutritional value. Large algae host a variety of microflora and may provide better foraging opportunities for benthic invertebrates. The inclusion of large amounts of silt in the MCR periphyton mat may further restrict its nutritional value to benthic invertebrates.

The area of productive MCR habitat is directly correlated with time spent in the water and therefore minimum flows should increase periphyton production. Any increase in wetted productive habitat should cause a subsequent increase in fish food availability. We are currently working on the development of a fish food index, with the intent of investigating how much and where changes in important fish food items occurs across a river transect

(T1 through T6) by classifying benthic invertebrate forage quality for different fish life stages. This fish food index can be used in combination with our periphyton benthic forage data to assess forage availability and quantity across transects in future years.

5.0 RECOMMENDATIONS

5.1 Review of Consultant Project Directions Proposed for 2011

Table 5.1 Review of Planned Consultant Project Directions and Actions for 2011

Recommendations from 2010 CLBMON 15b Report	Project Consultant Action in 2011
Cross-reference species lists for periphyton and benthic invertebrates with 2007-09 data	We combined and narrowed the databases to the lowest taxonomic level possible
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 and 2011, ongoing
Implement detailed statistical analysis of entire data set 2007 - 2011	Done, will update every year
Deploy samplers above and below the Jordan and Illecillewaet River	Done in spring 2011, downstream samplers were lost to high discharges, not repeated
Deploy samplers in other habitat units; Big Eddy, backwater, white water and bedrock	Done in spring and fall 2011, with more sites added in the fall
Improve time series apparatus to improve retrieval efficiency and safety.	Done.
Deploy two temperature and light data loggers in continuously exposed areas	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
Collect weekly drift samples in 2011 during the weekly time series sampling trips	Done in Reach 3 and 4
Continue sampling the bacteria/fungi biofilm from samplers and add natural substrate samples	Done
Trial an in-stream nutrient assay	Done, but N+P sampler flipped
Trial alternate artificial substrates	Small trial completed in 2011 in Reach 4
Long-term 6 month deployments 3 samplers	Done (spring-fall 2011)

5.2 Recommended Work Program Elements for 2012

The following are recommendations for incorporation into the 2012 work program (for each item, it is indicated what we have incorporated into the 2012 spring work program within existing budgets and which items we recommend be incorporated or considered in future years):

- Light penetration to the thalweg in Reaches 4 and 3 may have been affected by flow changes in 2011. In 2012 we propose to add sampling for suspended solids and turbidity during each time series trip to better understand light scatter, particularly during in backwatering in Reach 3.

- The types of filamentous algae prevalent just below the varial zone in Reach 4 are typical in areas with moderate nutrient conditions. Since the MCR is often regarded as nutrient limited, we propose sampling upwelling groundwater for low-level nutrients during low flow conditions on the MCR during time series sample trips. The late night sample trips would provide an opportunity to collect R4 Total diss N and Total diss P – the forms of nutrients most likely to stimulate algae growth. Each sample would consist of at least three subsamples collected from Lbank, R bank and mid-river at 0.5 m above the substrates. These samples could be submitted to Cultus Lake DFO lab for low nutrient analyses. The results would be compared to the existing body of DFO lab water quality data for MCR Reach 4.

- Although we speculate that nutrients are not a limiting factor in the MCR, we do not have a large quantity of empirical data to support this. The least ambiguous approach for establishing the nutrient(s) limiting growth is the in-stream assay. The value of an in-stream assay should be investigated during 2012 with a revised support structure to avoid the flipping encountered in 2011.

- The initial 2010 drying/freeze-drying experiments were performed when field observations indicated that species tolerance to drying was a key component of production on 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.

- Six month deployment of the periphyton samplers provided useful information in 2011 and should be repeated in 2012. These would include the R3S6 transect samplers in place from spring deployment to the fall (6 months growing season) and from the fall deployment to the spring (6 month winter season). Samples of the long-term deployment would be treated the same way as the normal deployments and taxonomy, chlorophyll a and AFDW/DW data should all be collected.

- Chlorophyll-a can vary significantly in drift samples. They could be collected during time series trips to gain a better understanding of this food source for filter feeders in the MCR.

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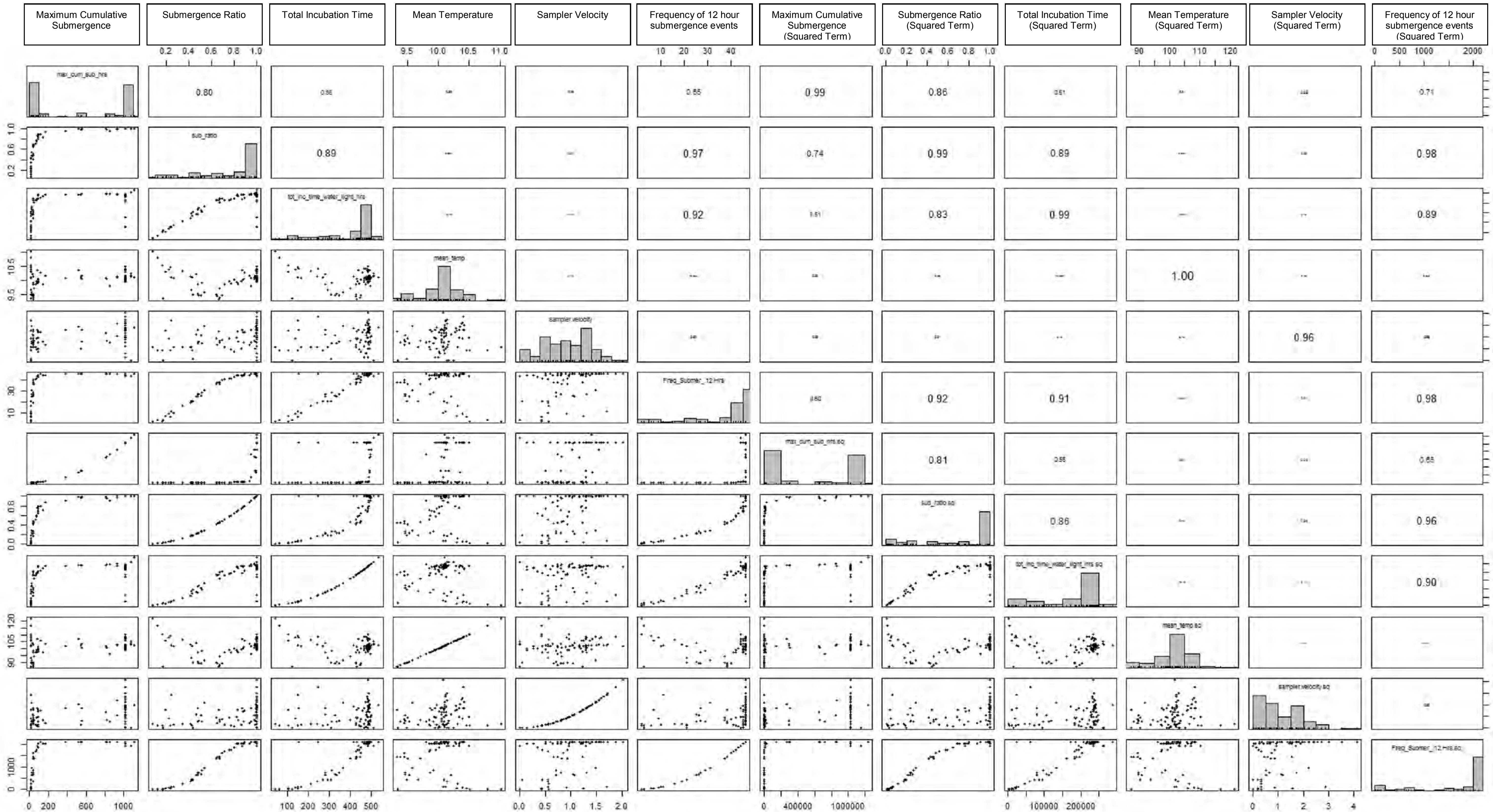
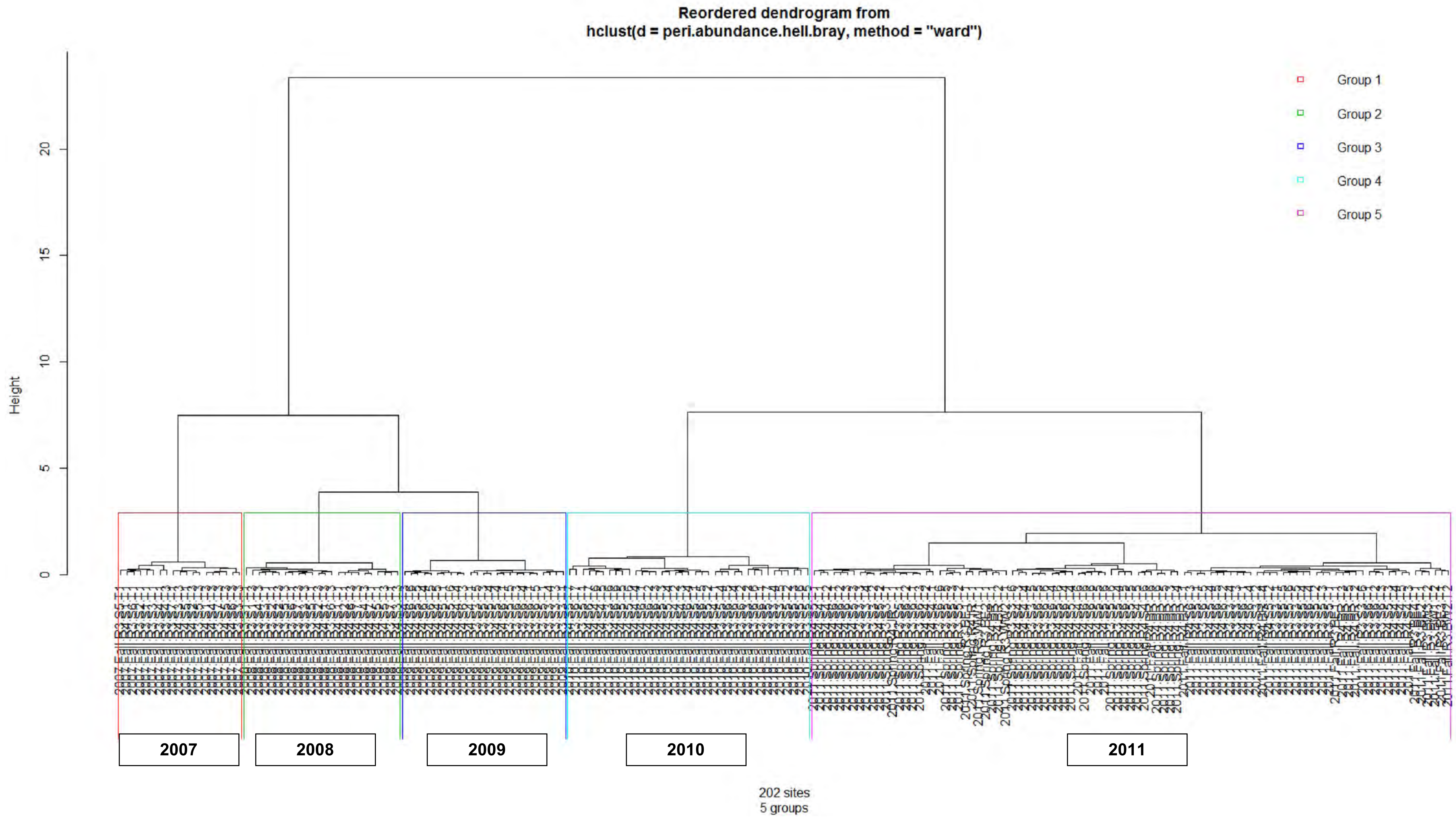
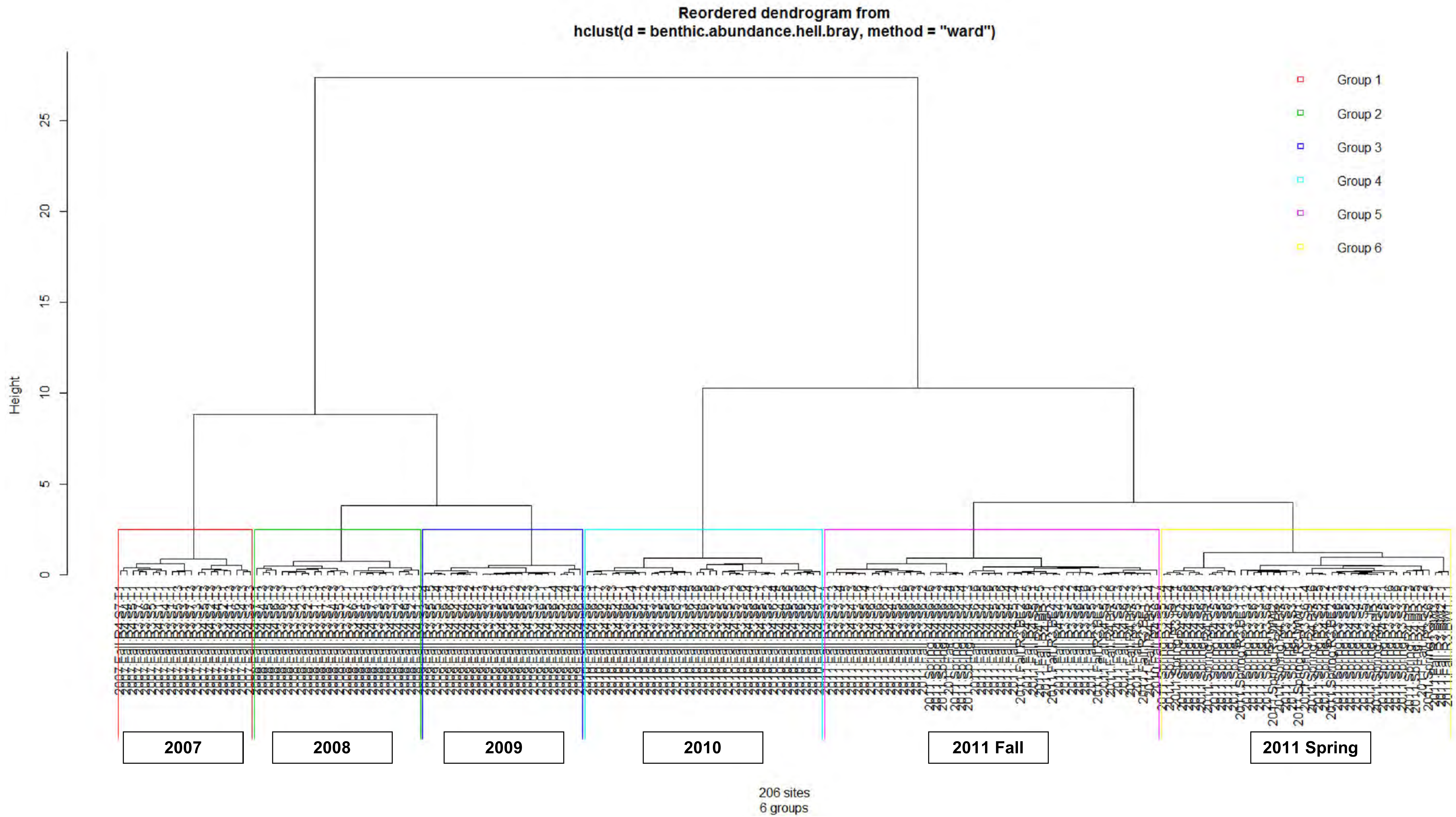
Appendix A: Exploratory data analyses.



Appendix A-1. Scatterplots and Pearson Correlation Coefficients for Production parameters and their quadratic terms considered as predictors for regression modelling on the MCR. Data are not transformed. The size of the Pearson's correlation coefficient is related to the size of the effect. Although responses shown are considered reasonable, used of Spearman's Correlations is a more valid approach because of the number of non linear associations. Spearman's correlation coefficients have not been calculated.



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



Appendix A-3. Cluster analysis of benthic data from 2007 to 2011 grouped into 6 clusters using Ward's method.