Columbia River Project Water Use Plan

REVELSTOKE FLOW MANAGEMENT PLAN

Reference: CLBMON-15b

Middle Columbia River Ecological Productivity Monitoring

Study Period: 2007 – 2019

Final Report

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Revelstoke Flow Management Plan

Monitoring Program No. CLBMON-15b

Middle Columbia River Ecological Productivity Monitoring

Final Report

Prepared for

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BC Hydro Reference #

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Cover photos:

From left to right: (1) Periphyton and macroinvertebrate sampling apparatus at Site 5 in the filamentous green/mossy zone of Reach 4 in the Columbia River on April 11 2017; (2) Scott McGill (Ecoscape) procuring a sample for fluorometric chl-a analysis on April 30 2018; (3) Reach 4 of the Columbia River taken approximately 2.7 km downstream from Revelstoke Dam on April 11 2017; (4) Deployment of periphyton and macroinvertebrate sampling apparatus at Site 4 in the diatom-dominated moderate periphyton zone of Reach 4 in the Columbia River on April 11 2017. Photo’s by Evan Smith, Okanagan Nation Alliance.

EXECUTIVE SUMMARY

This final report for the Ecological Productivity Monitoring program (CLBMON-15b) culminates 13 years of research on the ecological productivity on the Middle Columbia River (MCR), between the outflow of the Revelstoke Dam (REV) and the Illecillewaet River near Revelstoke, British Columbia. Aquatic habitats in the MCR are heavily influenced by variable flow releases from REV and to a lesser extent, backwatering from Arrow Lakes Reservoir (ALR) and by tributary inflows. In December 2010, BC Hydro and Power Authority (BC Hydro) added a fifth generating unit (REV5) that was expected to increase the peak discharge from 1,699 to 2,124 m^3/s. Under advisement from the Water Use Plan Consultative Committee, a year-round 142 m^3/s minimum flow release was established to mitigate the effects of extreme flows and to enhance the productivity and diversity of benthic communities (BC Hydro 2007). Throughout this report, the term minimum flow refers to the flow regime established after the addition of REV5.

The three main objectives of CLBMON-15b were: (1) to design and implement a long-term program for tracking the productivity and diversity of key benthic community taxa (periphyton and invertebrates) within the MCR, (2) assess the response of the MCR benthic community taxa to a minimum flow release, and, (3) to investigate and quantify the relationship between habitat attributes and benthic composition, abundance, and biomass within the section of the MCR most likely to be influenced by minimum flow and REV5 operations.

MCR benthic productivity was investigated using artificial Styrofoam samplers for periphyton and rock baskets for benthic invertebrates. Samplers were most typically placed along transects at six mainstem sites in Reaches 3 and 4 during spring and/or fall for 6-week sampling seasons to allow for the growth and establishment of periphyton and benthic invertebrates. Physical river parameters including temperature, light, and velocity were also measured.

MCR periphyton productivity was indicative of a stressed or oligotrophic system. Like many large river systems, diatoms accounted for over 90% of the biovolume in both seasons and reaches of the MCR. The dominant MCR diatom species belonged to the low-profile guild (rapid colonizing diatoms with firm attachment strategies) or to the large planktonic guild taxa imported from Revelstoke Reservoir. The MCR invertebrate community composition was dominated by chironomids that can withstand cooler water temperatures and a range of velocities associated with a hydropeaking dam. MCR invertebrate abundance was comparable to other hydropeaking dams.

A reach-wide productivity (RWP) model used daily chlorophyll-a productivity and invertebrate biomass to compare differences in benthic productive area between pre and post minimum flows. The implementation of minimum flow resulted in larger productive habitat areas in winter, spring, and fall for both periphyton and invertebrates. In summer, minimum flow caused an increased habitat area for invertebrates but not for periphyton. This is because invertebrates have a lower tolerance for substrate dewatering because of faster death rates in hot drying conditions compared to periphyton. Annual variations in ALR backwatering was a more important determinant of productive habitat area for periphyton in July, compared to minimum flow.

A variety of statistical tests were used to determine if the establishment of minimum flow resulted in changes in invertebrate productivity and diversity or changes in total periphyton accrual. The periphyton community was more dependent upon the overall operating regime (daily, monthly,

and annual patterns of flow release, ALR backwatering) than the specific effects of minimum flow. Minimum flow did not affect the invertebrate abundance and biomass; however, it resulted in an increased diversity of invertebrate taxa including EPT (Ephemeroptera, Plecoptera, Trichoptera), especially in Reach 3 sites near the thalweg. Minimum flow increased the availability of fish food organisms including Dipterans and EPT, but the increases were not substantial enough to cause changes in adult fish condition.

Our findings concur with the scientific literature, which clearly demonstrates that flow related factors including substrate submergence time, water velocity, available light, and water temperatures play interconnected roles in the growth and recovery rates of hydro regulated lotic benthic communities. However, the scale of the differences made by minimum flow in MCR, can be overshadowed by ALR backwatering and extreme flow events.

ACRONYMS AND ABBREVIATIONS

AFDW	ash free dry weight
AICc	Akaike information criterion corrected for small sample sizes
ALR	Arrow Lakes Reservoir
BC Hydro	British Columbia Hydro and Power Authority
BRX	Brilliant Expansion
Caro Labs	Caro Environmental Laboratories (Kelowna, B.C.)
CFU	colony forming unit
chl-a	Chlorophyll-a
CLBMON-15b	Middle Columbia River Ecological Productivity Monitoring Program
Didymo	*Didymosphenia geminata*
EPT	*Ephemeroptera* (mayflies), *Plecoptera* (stoneflies), *Trichoptera* (caddisflies)
FFI	Fish Food Index
HBI	Hilsenhoff Biotic Index
QA/QC	Quality assurance, quality control
km	kilometer
L	litre
LCR	Lower Columbia River
m	metre
m ASL	metres above sea level
max	maximum value
MCR	Middle Columbia River
min	minimum value
n	sample size
NMDS	Non metric multidimensional scaling
REV	Revelstoke Dam
REV5	fifth generating unit
RVI	relative variable importance
SD	standard deviation
UTM	Universal Transverse Mercator

DEFINITIONS

Term	Definition
Accrual Rate	A function of cell settlement, actual growth and losses (grazing, sloughing)
Autotrophic	An organism capable of synthesizing its own food from inorganic substances, using light or chemical energy
Benthic	Organisms that dwell in or are associated with the sediments
Benthic Production	Production originating from both periphyton and benthic invertebrates
Catastrophic Flow	Flow events that have population level consequences of >50% mortality
Cyanobacteria	Bacteria-like algae having cyanochrome as the main photosynthetic pigment
Diatoms	Algae that have hard, silica-based "shells" frustules
Death curve	The rate of death for periphyton and benthic invertebrates during exposure events (when substrates are dewatered)
Eutrophic	Nutrient-rich, biologically productive water body
Freshet	The flood of a river or stream from melted snow in the spring
Functional Feeding Group	(FFG) Benthic invertebrates can be classified by their foraging mechanisms as functional feeding or foraging groups
Heterotrophic	An organism that cannot synthesize its own food and is dependent on complex organic substances for nutrition.
Hydropeaking	The discontinuous release of turbined water due to peaks of energy demand
Hypolimnion	the lower layer of water in a stratified lake, typically cooler than the water above and relatively stagnant
Irradiance	The flux of radiant energy per unit area
Macroinvertebrate	An invertebrate that is large enough to be seen without a microscope
Mainstem Sites	Consistently sampled sites (S3, S4 and S6) in Reach 4 and (S3, S5, S6) in Reach 3
Microflora	The sum of algae, bacteria, fungi, *Actinomycetes,* etc., in water or biofilms
Morphology	The study of channel pattern and geometry at several points along a river
Oligotrophic	The trophic status of a lake having low nutrient concentrations and low plant growth, often having an abundance of dissolved oxygen
Peak biomass	The highest density, biovolume or chl-a attained in a set time on a substrate
Periphyton	Microflora that are attached to aquatic plants or solid substrates
Phytoplankton	Algae that float, drift or swim in water columns of reservoirs and lakes
Ramping of Flows	A progressive change of discharge into a stream or river channel
Reach 3 (R3)	The section of river extending from the Jordan River to the Illecillewaet River
Reach 4 (R4)	The section of river extending below Revelstoke Dam to the Jordan River
Riffle	A stretch of choppy water in a river caused by a shoal or sandbar
Riparian	The interface between land and a stream or lake

Term	Definition
Spate	A sudden flood in a river, especially one caused by heavy rains or melting snow.
Submergence ratio	The ratio of submerged to dry substrates
Substrates	The bottom material (boulder cobble sand silt clay) of a stream or lake.
Taxa Taxon	Taxonomic group(s) of any rank, including a species, family or class.
Thalweg	A line connecting the lowest points of a river, usually has the fastest flows
Unique Habitat Sites	Bedrock (BR), Big Eddy (BE), backwater areas (BW), whitewater areas (WW), upstream and downstream of Jordon River (JR), upstream and downstream of Illecillewaet River (IL)
Varial Zone	The zone of periodically inundated substrate, spanning the upper edge of the permanently wetted zone to the lower edge of the floodplain

Management Question (MQ)	Summary of Key Results
MQ-1 What is the composition, distribution, abundance, and biomass of periphyton and benthic invertebrates in the section of MCR subjected to the influence of minimum flows?	**Composition:** Like in most large rivers, the periphyton composition was dominated by diatoms throughout the MCR. Taxa donated by the Revelstoke Reservoir continuously supported MCR productivity and recovery. Annual differences in water temperature and operating conditions (ALR elevations and discharge) were important determinants of the periphyton community. There was a minor shift among dominant periphyton taxa between reaches. The MCR benthic invertebrate community composition was dominated by chironomids tolerant of a range of environmental conditions including temperature and velocity. Similar to other hydropeaking rivers, the MCR had low EPT richness and abundances due to cold-water temperatures resulting from large hypolimnetic dam release and frequent substrate dewatering. **Distribution:** Average periphyton and invertebrate productivity decreased with increasing exposure from thalweg through the lower varial zone to the upper varial zone. Changes in periphyton and invertebrate productivity within and/or between transects corresponded to changing substrate submergence time and secondarily to irradiance for periphyton (see definitions). The seasonal water cover provided by backwatering reduces desiccation on riverine substrates that would otherwise be exposed by low flow releases, particularly in Fall in R3 which receives the greatest effects from backwatering. As a result of this flow complexity, the Reach 3 upper varial zone was the most variable region for periphyton productivity in the MCR., whereas periphyton community composition in the R3 upper varial zone was less variable than productivity in both seasons. **Abundance and Biomass:** High variability in invertebrate density (mean and standard deviation of 3122±6041 individuals/m^2) was indicative of a stressed system. Invertebrate densities in the MCR varial zone ranged from 11-5122 individuals/m^2 and were comparable to other hydropeaking rivers. Periphyton abundance and biomass exhibited high annual and spatial variability in the MCR. Overall, the periphyton production metrics were indicative of an oligotrophic or stressed river system Invertebrate biomass in the MCR was highly variable with a mean and standard deviation of 0.13±0.34 g/m^2. The small invertebrate biomass was a result of the small biomasses of the dominant organisms, chironomid subfamily Orthocladiinae. Overall benthic invertebrate production metrics were higher in fall compared to spring. The higher invertebrate production in Fall could be a result of differences in wetted habitat area because Arrow Lakes Reservoir backwatering was more extensive in Fall resulting in substrates that remained wetted for longer periods. Alternately, natural seasonal variation could have resulted in higher Fall productivity as seen in other river systems

Management Question (MQ)	Summary of Key Results
MQ-2 What is the effect of implementing minimum flows on the area of productive benthic habitat?	The reach-wide productivity model for invertebrate biomass and chlorophyll-a indicated that under typical operating conditions and ALR water levels in winter, spring, and fall, minimum flows increased the spatial area of productive benthic habitat. In summer, minimum flows increased the area of invertebrate habitat but there was no statistical difference in periphyton habitat area pre and post minimum flows. The faster death rates of invertebrates in summer compared to periphyton, resulted in only the invertebrate habitat area benefiting from minimum flows. ***We therefore reject Ho$_1$,*** that minimum flows do not change the spatial area of productive benthic habitat for periphyton or benthic invertebrates in MCR.
MQ-3 What is the effect of implementing minimum flows on the accrual rate of periphyton biomass in the MCR? Is there a long term trend in accrual?	***We accept Ho$_{2A}$,*** that the implementation of the 142 m^3/s minimum flow release did not change the total biomass accrual rate of periphyton in the thalweg area that remains permanently wetted by minimum flows in the MCR. The T1 thalweg productivity was comparable pre and post minimum flows under average operations. Prior to the implementation of minimum flows the thalweg area only experienced short periods of dewatering that mostly occurred during nighttime. These short periods of dewatering were not long enough to reduce accrual rates. For this reason, minimum flows did not induce a significant improvement in MCR thalweg productivity. The overall benefits of minimum flow are greatest during: • Periods of low ALR water levels, when backwatering does not cover substrates that would otherwise be exposed; • Periods of low daily flows (400 to 600 m^3/s) that exceed 12 hours with low humidity and average daytime temperatures >10-15°C or <0°C, particularly during extreme air temperatures. ***We accept Ho$_{2B}$,*** that there is no change in the accrual rate of periphyton at channel elevations that were periodically dewatered by the implementation of 142 m^3/s minimum flow release. Estimated submergence ratios over fall and spring 2000-2019 in the periodically dewatered lower varial zone did not change before and after minimum flows because operations simultaneously decreased the frequency of low 200 – 400 m^3/s flows when the minimum flow regime commenced. With similar submergence ratios under typical operations, did not generate differences in periphyton accrual rates at T1 and T3 locations following the commencement of the minimum flow regime. Although, there was a short-term trend in periphyton accrual, there was no significant long-term trend of periphyton accrual at T1 and T3 locations.

Management Question (MQ)	**Summary of Key Results**
MQ-4 What is the effect of implementing minimum flows on **the total abundance, diversity, and biomass of benthic organisms** in the section of the MCR subjected to the influence of minimum flows? Is there a long term trend in benthic productivity?	Statistical models and estimated submergence ratios indicated that minimum flows did not affect invertebrate **abundance** or **biomass** under typical operating conditions. Only short periods of mostly nightly dewatering occurred near the thalweg prior to minimum flows, and these did not decrease invertebrate production. The amount of dewatering in the lower varial zone was similar pre and post minimum flows, resulting in **similar invertebrate production**. Minimum flows benefited invertebrate **diversity** only in Reach 3 sites near the thalweg. **Long-term trends** were not detected for either invertebrate abundance or biomass during the spring sampling sessions (2011-2019) and were not assessed for fall due to a limited number of sampling years. ***We therefore accept*** Ho_{3a} ***and*** Ho_{3b} that state the implementation of minimum flow release does not change the *total abundance / biomass* of benthic invertebrates in the area below the elevation wetted by minimum flows or at the channel elevations that are periodically dewatered by minimum flows. ***However, we reject the aspects of*** Ho_{3a} ***and*** Ho_{3b} that state the implementation of minimum flow release does not change the *diversity* of benthic invertebrates in the MCR. It is, however, acknowledged that the effect of minimum flows on invertebrate diversity is greater in Reach 3, and that operations may also play a role in the invertebrate community diversity. The specifics of dam operations may be more important than maintaining a minimum flow release.
MQ-5 If changes in the benthic community associated with minimum flow releases are detected, what **effect** can be inferred on **juvenile or adult life stages of fishes**?	***We reject Ho4*** that states the implementation of the 142 m^3/s minimum flow release does not increase the availability of fish food organisms in the MCR because it did cause an increased availability of fish food organisms including dipterans and EPT. However, the increased availability of fish food was not substantial enough to cause changes in fish condition of adult life stages. The fish indexing program in the same area, CLBMON-16, reported that body condition and growth rates of adult Rainbow Trout and Mountain Whitefish were similar before and after the implementation of minimum flows (Golder et al. 2018). Juveniles are expected to be more sensitive to changes in the availability of invertebrate fish food because they have more selective diets and primarily forage on zooplankton and chironomids; however, the effect of minimum flows on juvenile body condition and growth rates was not directly tested. Given the stressed conditions of the MCR pre and post minimum flows, we suggest that the increases in fish food associated with post minimum flows are likely insufficient to alter body condition or increase growth rates of juvenile Mountain Whitefish or Rainbow Trout.

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1.0 INTRODUCTION

This final report for the Ecological Productivity Monitoring program (CLBMON-15b) culminates 13 years of research on the ecological productivity on the Middle Columbia River (MCR), between the outflow of the Revelstoke Dam (REV) and the Illecillewaet River near Revelstoke, British Columbia. Aquatic habitats in the MCR are heavily influenced by variable flow releases from REV and, backwatering from Arrow Lakes Reservoir (ALR) and to a lesser extent tributary inflow. In December 2010, BC Hydro and Power Authority added a fifth generating unit (REV5) that was expected to increase the peak discharge from 1,699 to 2,124 m^3/s. Under advisement from the Water use Plan Consultative Committee, a year-round 142 m^3/s minimum flow release was established to mitigate the effects of extreme flows and enhance the productivity and diversity of benthic communities (BC Hydro 2007). Throughout this report we refer to minimum flow; this term encompasses the changes to the flow regime from the addition of REV5 and year-round 142 m^3/s minimum flow release.

The three main objectives of CLBMON-15b were:

- To design and implement a long-term program for tracking the productivity and diversity of key benthic community taxa (periphyton and invertebrates) within the MCR;
- To assess the response of the MCR benthic community taxa, both periphyton and invertebrates, to a minimum flow release from Revelstoke Dam and REV5 operations; and
- To investigate and quantify the relationship between habitat attributes and benthic composition, abundance, and biomass within the section of the MCR most likely to be influenced by minimum flow and REV5 operations.

1.1 Report Scope and Synopsis of Program Direction

The report includes an Executive Summary with an overview status table of the management questions. The Introduction, Study Area, and Methods sections provide a brief synopsis and context for the study. For each management question, a summary of important results is presented in *Section 4*, while additional supporting information is offered in Appendices 4 - 8. A separate appendix is provided to address each management question and is structured as a stand-alone report.

CLBMON-15b management questions covered biologically significant elements of the MCR that impact its fisheries. None of the original management questions were eliminated from the CLBMON-15b program and all management questions were statistically assessed or addressed through modelling exercises and supported with lines of evidence and findings from the scientific literature.

2.0 STUDY AREA

The MCR is a section of the Upper Columbia River adjacent to the town of Revelstoke, British Columbia, encompassing approximately 38.5 km of river between REV and the ALR near Shelter Bay. The MCR is sectioned into four reaches; this study focused on riverine reach 4 (R4) and reach 3 (R3). Reach 4 extends approximately 5 km from REV 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).

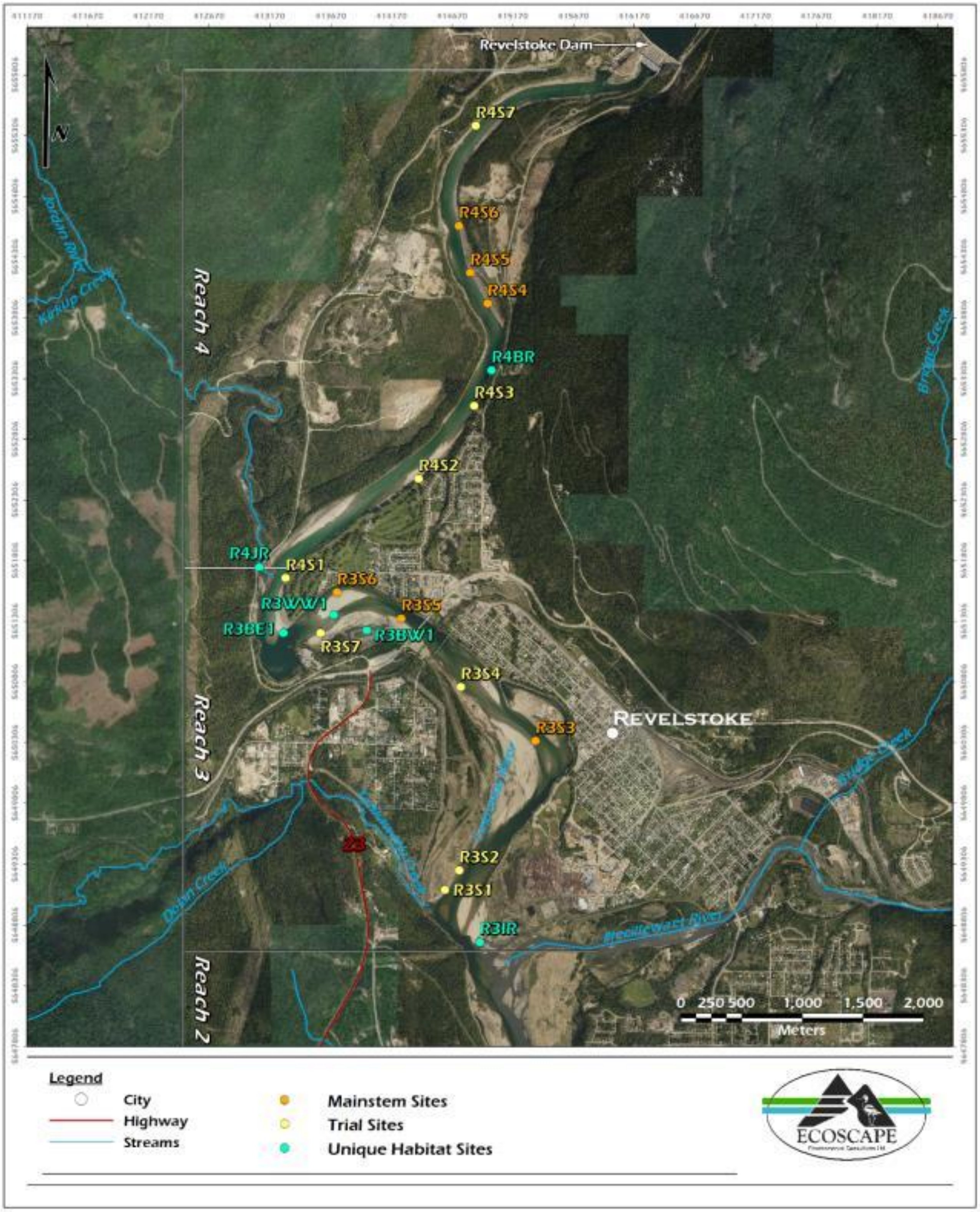

Figure 2-1: **Map of the study area including mainstem sampling sites, trial sites and unique habitat sites.**

3.0 METHODS

3.1 Overview

Benthic productivity was sampled consistently at three sites in both in R4 (S4, S5 and S6) and R3 (S3, S5, S6) between 2007 and 2019 (hereafter referred to as mainstem sites) using artificial periphyton and macroinvertebrate samplers (Figure 2-1; Table 3-1). Most data presented in this report originates from these six sites. In some cases, results are labelled as “all sites”. All sites includes the six mainstem sites and other mainstem sites that were trialed during CLBMON-15b, but not consistently sampled, as well as four other unique habitat sites including bedrock (BR), Big Eddy (BE), backwater (BW), and whitewater areas (WW) (Figure 2-1; Table 3-1). The only sites not included in the “all sites” analyses were up and downstream of the Jordan and Illecillewaet rivers (JR and IL).

Table 3-1: Benthic productivity monitoring sites and their distance downstream of Revelstoke Dam, including UTM coordinates and years sampled. A subscript (S = spring; F = fall) indicates a site was only sampled in either the spring or fall in years where both spring and fall sampling occurred (2011 – 2013).

Site Name	Sample Type	From REV (km)	UTM Coordinates (11U)		Years Sampled
			Easting	Northing	
R4S1	Reach 4 Trial Site	4.7	413299	5651663	2007, 2008
R4S2	Reach 4 Trial Site	3.3	414394	5652479	2007, 2008
R4S3	Reach 4 Trial Site	2.6	414852	5653080	2007, 2008
R4S4	Reach 4 Mainstem Site	1.7	414961	5653923	2007 – 2019
R4S5	Reach 4 Mainstem Site	1.4	414820	5654177	2007 – 2019
R4S6	Reach 4 Mainstem Site	1	414727	5654561	2007 – 2019
R4S7	Reach 4 Trial Site	0.1	414866	5655385	2007, 2008
R4BR	Reach 4 Unique Habitat Site (Bedrock)	2.3	414997	5653373	2011 – 2014
R4JR	Reach 4 Unique Habitat Site (Jordan River)	4.7	413085	5651753	2011$_S$
R3S1	Reach 3 Trial Site	10	414613	5649094	2007 – 2009
R3S2	Reach 3 Trial Site	9.9	414731	5649253	2007 – 2009

Site Name	Sample Type	From REV (km)	UTM Coordinates (11U)		Years Sampled
			Easting	Northing	
R3S3	Reach 3 Mainstem Site	8.4	415355	5650318	2007 – 2019
R3S4	Reach 3 Trial Site	7.6	414744	5650763	2007, 2008
R3S5	Reach 3 Mainstem Site	6.8	414253	5651328	2007 – 2019
R3S6	Reach 3 Mainstem Site	6.2	413724	5651543	2007 – 2019
R3S7	Reach 3 Trial Site	5.8	413586	5651210	2007, 2008
R3BE1	Reach 3 Unique Habitat Site (Big Eddy)	5.6	413281	5651210	2011 – 2015
R3BE2	Reach 3 Unique Habitat Site (Big Eddy)	5.6	413281	5651210	2011 – 2012_S, 2013, 2014
R3BE3	Reach 3 Unique Habitat Site (Big Eddy)	5.6	413281	5651210	2011_F, 2012_S, 2014, 2015
R3BE4	Reach 3 Unique Habitat Site (Big Eddy)	5.6	413281	5651210	2011_F, 2012_S, 2014, 2015
R3BW1	Reach 3 Unique Habitat Site (Backwater)	6.8	413968	5651231	2011_F, 2012_F, 2013 – 2015
R3BW2	Reach 3 Unique Habitat Site (Backwater)	6.8	413968	5651231	2011_F, 2012_S, 2013 – 2015
R3BW3	Reach 3 Unique Habitat Site (Backwater)	6.8	413968	5651231	2011_F, 2013_S, 2014, 2015
R3BW4	Reach 3 Unique Habitat Site (Backwater)	6.8	413968	5651231	2014
R3IR	Reach 3 Unique Habitat Site (Illecillewaet River)	10.5	414900	5648662	2011_S
R3WW1	Reach 3 Unique Habitat Site (Whitewater)	6	413695	5651357	2011_S
R3WW2	Reach 3 Unique Habitat Site (Whitewater)	6	413695	5651357	2011_S

During the first three years of the study (2007 – 2010), the sampling only occurred during six weeks in the fall (~mid-Sept through Oct) (Table 4-2). From 2011 to 2013, sampling took place in both the fall and spring (~mid Apr through May), followed by only fall sampling in 2014 and only spring sampling from 2015 to 2019.

At most sites, benthic productivity samplers were deployed across a depth gradient from the river's thalweg to the upper riverbank. The three mainstem sites in R4 consisted of cobble/boulder sized substrates and exhibited an increasing elevational gradient from mid-channel to the top of riverbank, similar to the top illustration in Figure 3-1. In R3, the substrates were comprised of more fines/gravels/pebbles and the elevational gradients of the river channel were more variable due to substrate mobility in response to changing flow regimes (Figure 3-1). At each site, between four and seven productivity samplers were deployed, but most commonly six samplers were placed along a depth transect (Table 3-2). Samplers T1 and T2 were placed in permanently submerged locations, where the 142 m^3/s minimum flow occurred upslope of the samplers. Samplers T3 and T4 were located within the lower varial zone, which typically experienced daily submergence and exposure, and samplers T5 and T6 were located in the upper varial zone where they were only submerged during higher flow regimes (Figure 3-1; Table 3-2).

Table 3-2: Description of transect depths sampled in Reach 3 and 4 sampled between 2007 – 2019.

Reach	Sampler	Relative depth/zone	Submergence	Years Sampled
3 and 4	T1	Mid channel / thalweg	Permanently submerged by minimum flows (142 m^3/s)	2007 – 2019
	T2			2009 – 2019
	T3	Mid channel / lower varial zone	Submerged by flows from 200 to 800 m^3/s	2007 – 2019
	T4			2009 – 2019
	T5	Upper varial zone	Submerged by flows > 1000 m^3/s	2009 – 2019
	T6			2010 – 2019
	T7	Infrequently wetted floodplain		2010

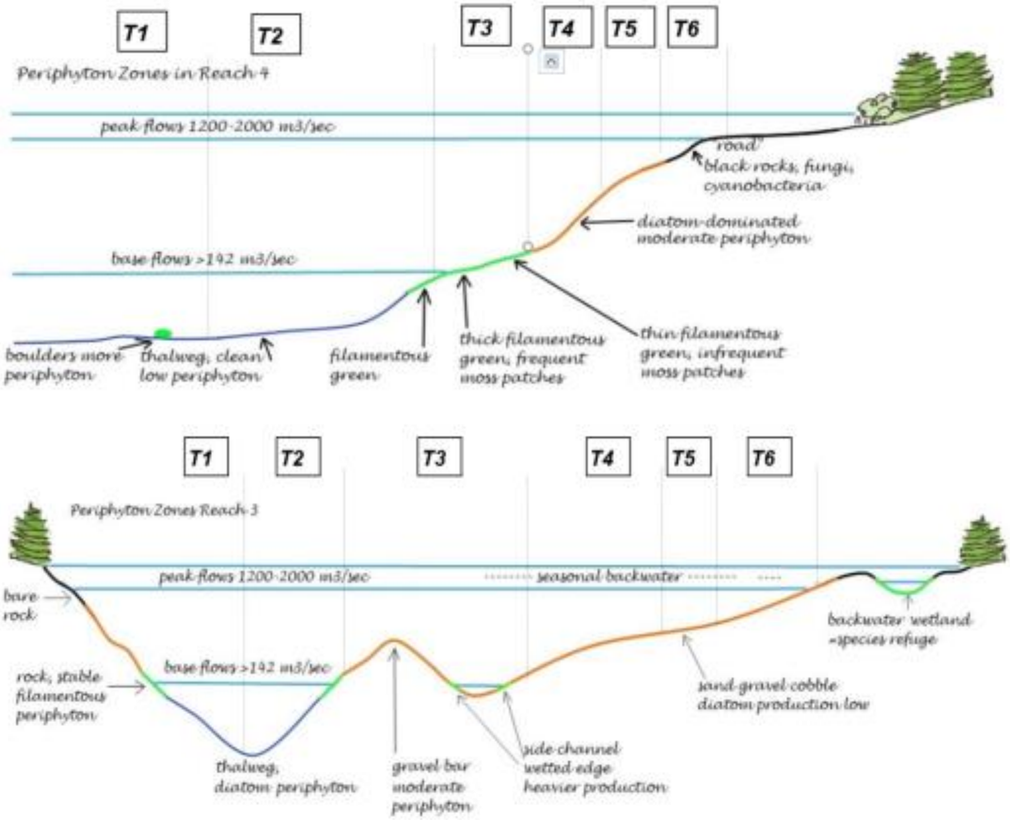

Figure 3-1: **A conceptual drawing of a typical site in reach 4 (top) and in reach 3 (bottom), with benthic productivity samplers (T1-T6) placed between the thalweg and the top of river bank.**

The location of artificial samplers was referenced as Reach (R), Site (S), and Transect number (T); therefore, a sampler deployed in Reach 4 at Site 5 in Transect location 3 would have the reference number R4S5T3. Artificial substrate samplers were deployed for 43 – 49 days annually in the spring, fall, or both spring and fall between 2007 and 2019 (Table 3-1). Only mainstem sites were sampled consistently between 2007 and 2019. Sites at Jordan River (JR), Illecillewaet River (IR), and in Whitewater (WW) were briefly sampled in the spring of 2011. Sampling during 2007 and 2008 focused on the T1 and T3 transect depths to collect data in shallow and deep habitats. In 2009, sampling expanded to cover the depths between T1 (deep) and T6 (submerged in higher flows). This provided productivity data on a gradient between shallow and deep habitats, and increased replicate samples in each habitat gradient, improving data robustness.

A typical design of the periphyton and macroinvertebrate sampling apparatus is shown in Figure 3-2, although different derivations of the apparatus were used between 2007 and 2019. Each sampler included a HOBO Pendant temperature/light data logger.

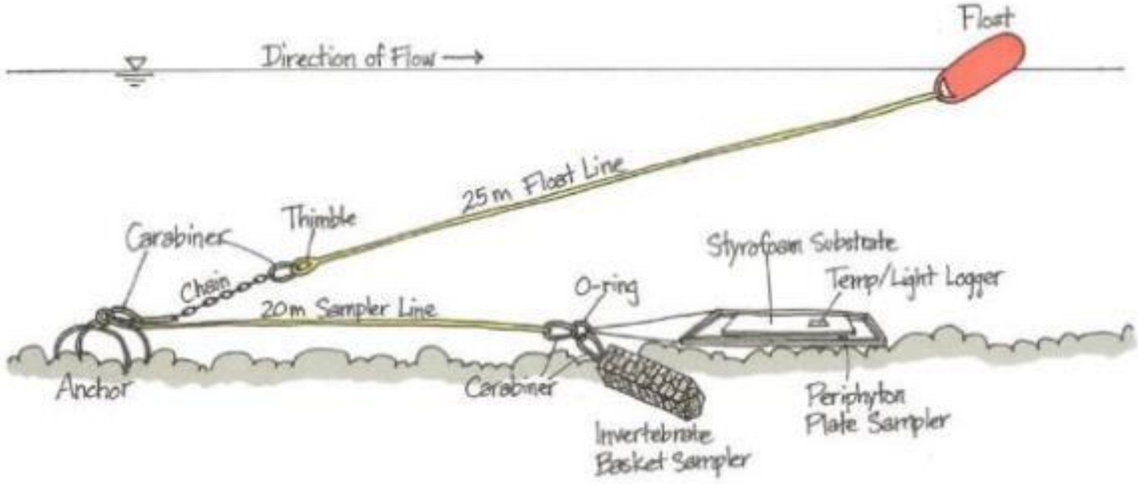

Figure 3-2 **Typical design of the periphyton and macroinvertebrate sampling apparatus.**

Periphyton accrual sampling was also undertaken to investigate chlorophyll-a biomass accrual rates. This sampling was undertaken at the same time as regular spring and fall sampling, but these samplers were collected then returned to the river at weekly or biweekly intervals over the 6-week deployment duration. Typically, ten time series samplers were deployed.

At the end of the deployment sessions, periphyton Styrofoam punches were randomly collected from each sampler to assess 1) chlorophyll-a; 2) Ash-Free Dry Weight (volatile solids) /total dry weight; and 3) taxa and biovolume. Benthic invertebrate baskets were also retrieved following standard protocols. Individual rocks from each basket were scrubbed to release clinging invertebrates. The contents from each basket were captured on a sieve and fixed with an ethanol solution prior to transport to a laboratory for taxonomic identification and determination of biomass and associated metrics. More detailed methods are available in Appendix 2.

3.2 Datasets

The primary datasets collected as part of CLBMON-15b are summarized in Table 3-3. Where additional data was used in the analyses for the various management questions, these datasets are included within each respective appendix.

Table 3-3: Predominant ecological productivity datasets.

Name/Description	Source	Years Obtained
Productivity Datasets		
Mean Daily Discharge at Revelstoke Dam	Data obtained from BC Hydro	2007 - 2019
Water Temperature and Benthic Light Penetration	Data collected at each productivity sampler during each deployment session	2007 – 2010 (fall only); 2011 – 2013 (spring and fall); 2014 (fall only); 2015 – 2019 (spring only)
Light Profile	Data collected at the following sites: R4S6, R4S5, R4S4, R3S6, R3S5, and R3S3	2019
Benthic Invertebrates	Data collected at each productivity sampler during each deployment session. Data includes abundance, biomass, taxonomy, and associated metrics	2007 – 2010 (fall only); 2011 – 2013 (spring and fall); 2014 (fall only); 2015 – 2019 (spring only)
Periphyton	Data collected at each productivity sampler during each deployment session. Data includes abundance, biovolume, taxonomy, and chlorophyll-a	2007 – 2010 (fall only); 2011 – 2013 (spring and fall); 2014 (fall only); 2015 – 2019 (spring only)
Chlorophyll-a Time Series	Data collected at a select number of productivity samplers throughout the deployment periods	2009 & 2010 (fall only); 2011 (fall and spring); 2012 (spring only); 2013 (fall and spring); 2014 (fall); 2015 – 2019 (spring)
Velocity	Data collected at each productivity sampler at least once per deployment period	2007 – 2010 (fall only); 2011 – 2013 (spring and fall); 2014 (fall only); 2015 – 2019 (spring only)

3.3 Core Challenges of the Study

The core challenges of this study included, but were not limited to:

- Physically sampling the river given the varied and often rapidly changing flow conditions;
- Achieving a sampler design that withstood ramping flows without becoming dislodged or flipped and enabled a high percent recovery of samples;
- The use of open-celled Styrofoam for periphyton sampling appeared to exaggerate production by 20 to 400%, based on the natural substrate sampling that was undertaken.
- Addressing the wide range of physical factors (i.e., light, velocity, flow, substrates, etc.) that influenced MCR productivity and were necessities in the development of a complex productivity model (Figure 3-3);
- Productivity sampling was limited to spring or fall sessions, but peak flows associated with REV5 occurred in the summer (i.e., 365 hrs/yr >1800 m^3/s, or approximately 4% of the time) and other stressors such as ice formation occurred in the winter. The lack of

summer and winter sampling resulted in limited productivity knowledge during the off-seasons and several assumptions had to be made;

- Assumptions and limitations of the productivity model, including that death curves (see definitions) were based on Trichoptera, even though Trichoptera abundances were minimal in the MCR;
- The annual variability in REV operations and backwatering of ALR due to climatic extremes complicated productivity results; and
- Several fall sampling sessions occurred in extreme years for physical parameters and productivity findings were affected.

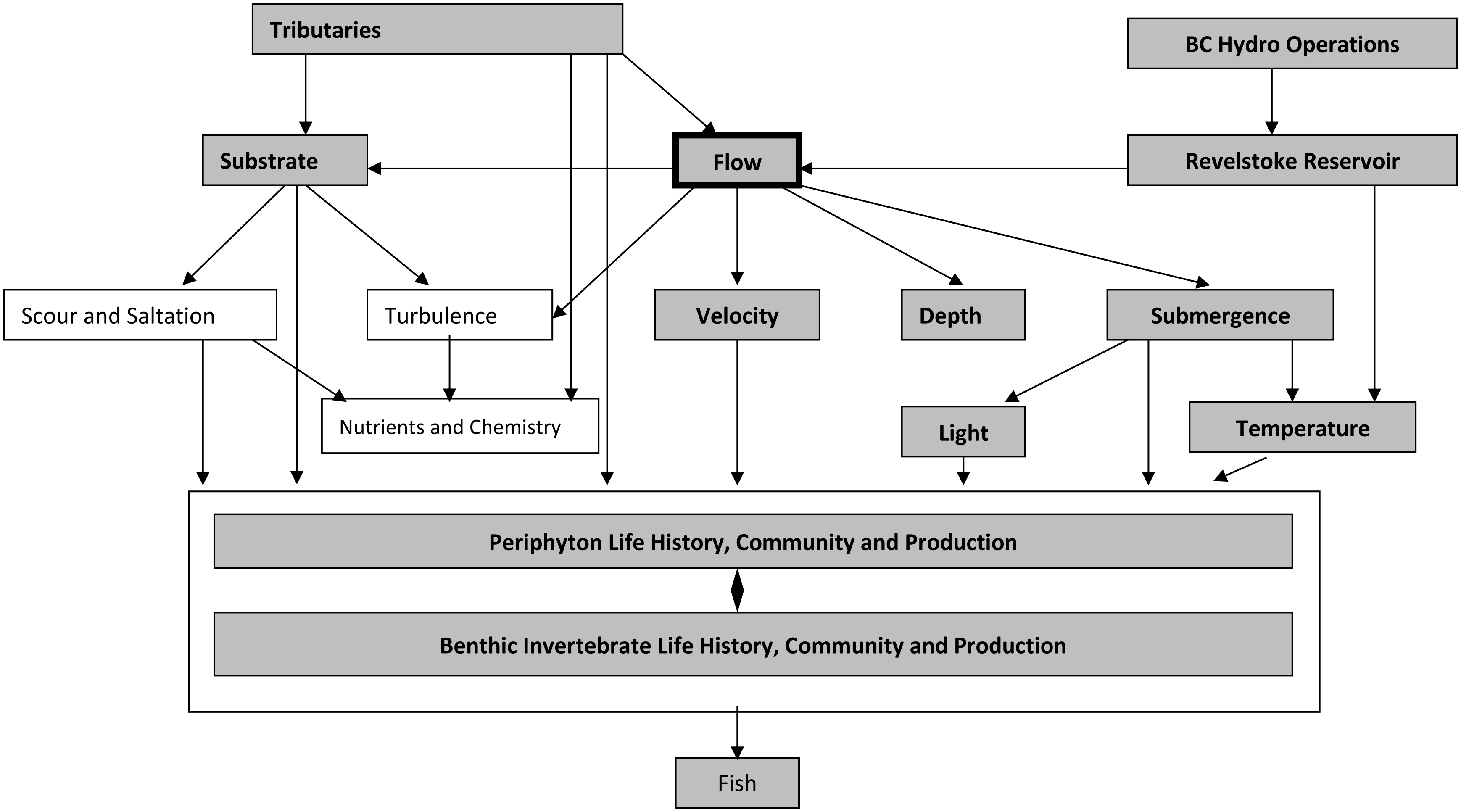

Figure 3-3: Conceptual interactions model of habitat variables and benthic production as they relate to food for fish in MCR. Parameters shaded in grey, with bolded text represent parameters under assessment in this study.

4.0 MANAGEMENT QUESTIONS

4.1 Context: River Flow and Physical Parameters

The predicted trends of the new operating regime, with minimum flow and the operation of REV5, included a general increase in the frequency of high flows with corresponding increases in river water levels and velocities, and a general increase in average daily flow during low demand periods (BC Hydro 2006). Prior to minimum flow implementation (2007 – 2010), the water release from REV ranged from 0 m^3/s to 2,114 m^3/s, with an average of 741 hours below 142 m^3/s. The post minimum flow operating regime (2011 – 2019) ranged from 0 m^3/s to 2,573 m^3/s with an average of 2 hours below 142 m^3/s (Table 4-1). Depending on hourly power demands, the variability of REV discharges could result in sudden water fluctuations ranging from 3 to 5 vertical metres in the MCR. REV5 was expected to increase the peak discharge from 1,699 to 2,124 m^3/s. However, the hourly discharge data showed that before REV5, peak discharges were just below 1,800 m^3/s (Table 4-1). The post minimum flow years had higher peak flows, with an average of 365 hours over 1,800 m^3/s, while pre minimum flow years had an average of 3.75 hours over 1800 m^3/s (Table 4-1).

Table 4-1: **Hourly flow summary table by year. Summary statistics are calculated from hourly flows.**

Year	Minimum	Median	Mean	Maximum	Hours under 142 m3/s	Hours over 1800 m3/s
2007	0.00	967.46	919.74	1,772.56	738	0
2008	0.00	664.17	715.68	1,778.92	1539	0
2009	0.00	629.65	656.23	1,765.78	1172	0
2010	0.00	631.71	684.29	2,114.85	899	15
2011	0.00	710.65	813.29	2,148.98	1	253
2012	0.00	921.03	955.86	2,573.37	2	814
2013	0.00	691.26	818.50	2,171.15	1	372
2014	0.00	640.79	758.84	2,145.13	1	305
2015	0.00	938.41	955.36	2,182.70	1	619
2016	0.00	624.92	734.08	2,149.60	1	200
2017	0.00	941.13	924.82	2,178.90	3	225
2018	0.00	651.88	789.73	2,187.97	4	243
2019	0.00	598.50	744.60	2,125.77	4	257

Productivity sampling only occurred during spring (April 10th – May 25th) and fall (September 9th – October 26th). Submergence ratios were calculated for two key areas of the river channel, the thalweg and the varial zone, for 11 years pre minimum flow (2000-2010) and 9 years post minimum flow (2011-2019) to better understand the range of operations in spring and fall. Submergence, defined as the overflow of substrates with water, is a critical determinant of benthic productivity. A submergence ratio of 0 indicates no inundation in a given period while a submergence ratio of 1 indicates that substrates were covered with water 100% of the time. It was assumed that the thalweg area experienced substrate dewatering when flows were less than 142 m^3/s and the varial zone experienced dewatering when flows were less than 400 m^3/s.

Prior to the implementation of minimum flows (2000 – 2010), the submergence ratio of the river thalweg was estimated for a 45-day period in the spring and a 47-day period in the fall (Figure 4-1). The median submergence ratios were 0.88 and 0.82 for spring and fall, respectively. The range of submergence was 0.65 (Spring 2003) to 0.94 (Fall 2007), illustrating substantial variability between years. These calculated submergence ratios do not account for possible backwatering that can occur from ALR. This complicating factor is discussed further in Appendix 3.

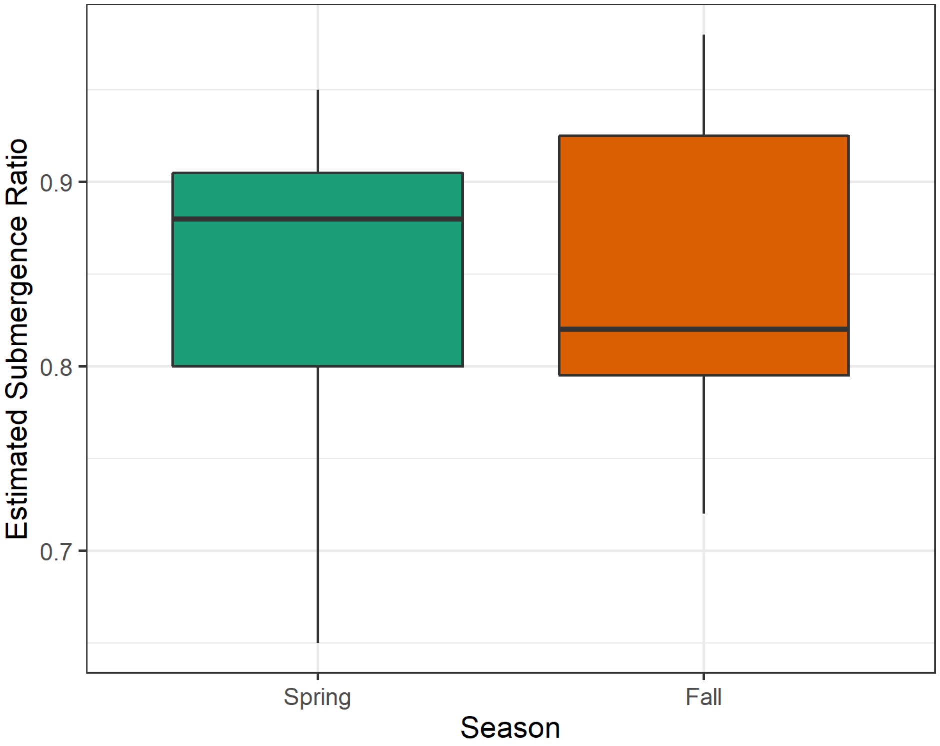

Figure 4-1: Boxplots of the estimated submergence ratio of the river thalweg in Spring and Fall (2000-2010), before implementation of minimum flows. The boxes represent the interquartile range of values (25%-75%), the median is represented by the horizontal black line within each box, and the minimum and maximum are represented by the vertical lines extending from the boxes.

Estimated submergence ratios in the periodically dewatered lower varial zone were compared before and after the implementation of minimum flows. In the spring, post minimum flows (2011 -2019) had a lower median submergence ratio (0.46) compared to pre (2000 – 2010) (0.54) (Figure

4-2). Spring 2015 had a very high submergence ratio of 0.93 compared to all other spring periods before and after the implementation of minimum flow.

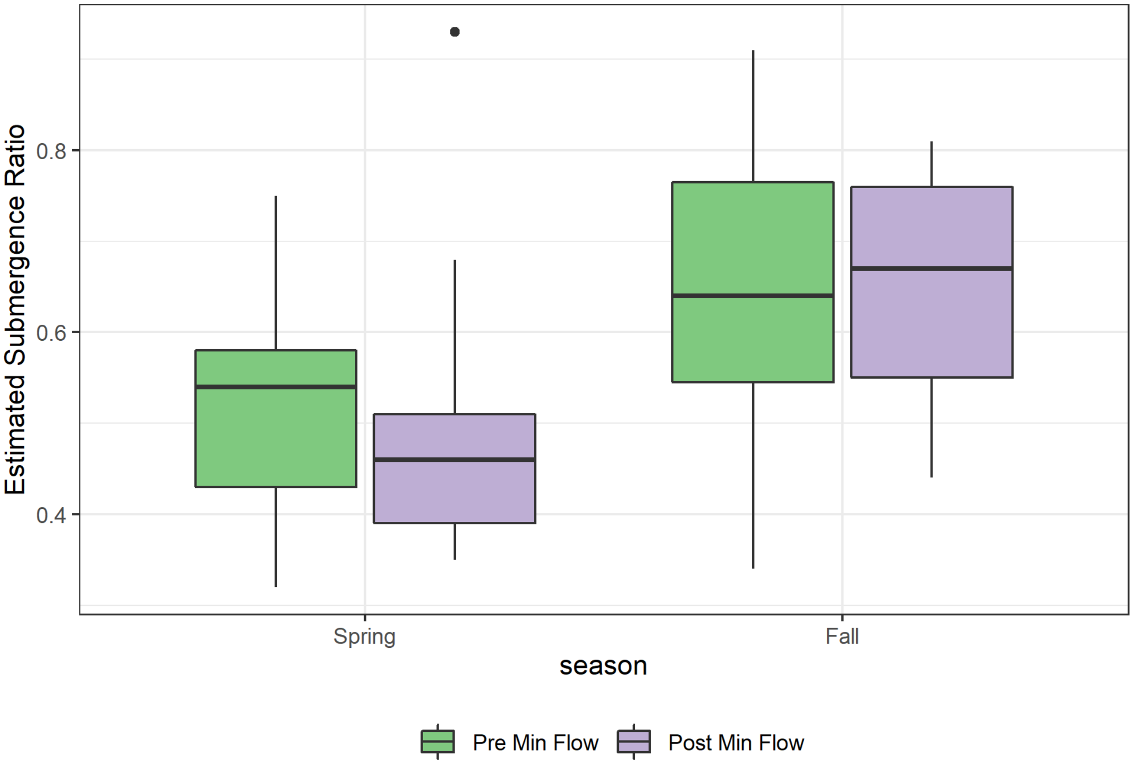

Figure 4-2: **Boxplots of estimated submergence ratio of areas that are periodically dewatered for Spring and Fall 2000-2019.**

In fall, the estimated submergence ratios in periodically dewatered lower varial zones before and after the implementation of minimum flows were comparable (Figure 4-2). The median submergence ratio was 0.64 for fall 2000-2010 and 0.67 for fall 2011-2019. The range of estimated submergence ratios was wider before the implementation of minimum flows (0.34-0.91) compared to after (0.44-0.81).

4.1.1 Patterns of Flow

Mean hourly flows in the MCR followed a highly variable but predictable pattern during the spring and fall productivity sampling sessions (Figure 4-3 and Figure 4-4). The flow was highest in daytime hours between 7:00 and 21:00, with periods of low flow typically only occurring from night to early morning between 24:00 and 5:00. The in-between periods consisted of ramping up or down from the peak daily flow.

Annual variability in the mean hourly flow during the spring and fall sampling sessions was also evident (Figure 4-3 and Figure 4-4). In the spring before establishment of minimum flows, 2008 was the only year that had mean hourly flows below 142 m^3/s (Figure 4-3), while in the fall, all years (2008-2010 except 2007) had mean hourly flows below 142 m^3/s (Figure 4-4). These low hourly flows typically occurred between 2:00 and 4:00 am. In contrast, the hourly mean flows during fall 2007 exceeded 142 m^3/s but were not as high as post minimum flow years.

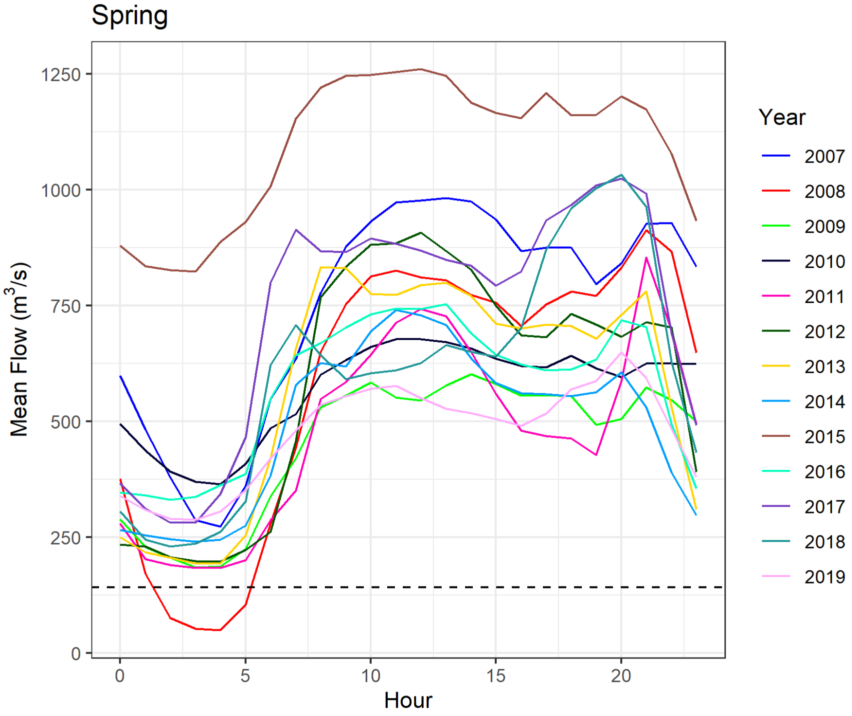

Figure 4-3: **Summary of mean hourly flows during the spring for all years of the study. The horizontal dotted line indicates the minimum flow of 142 m^3/s.**

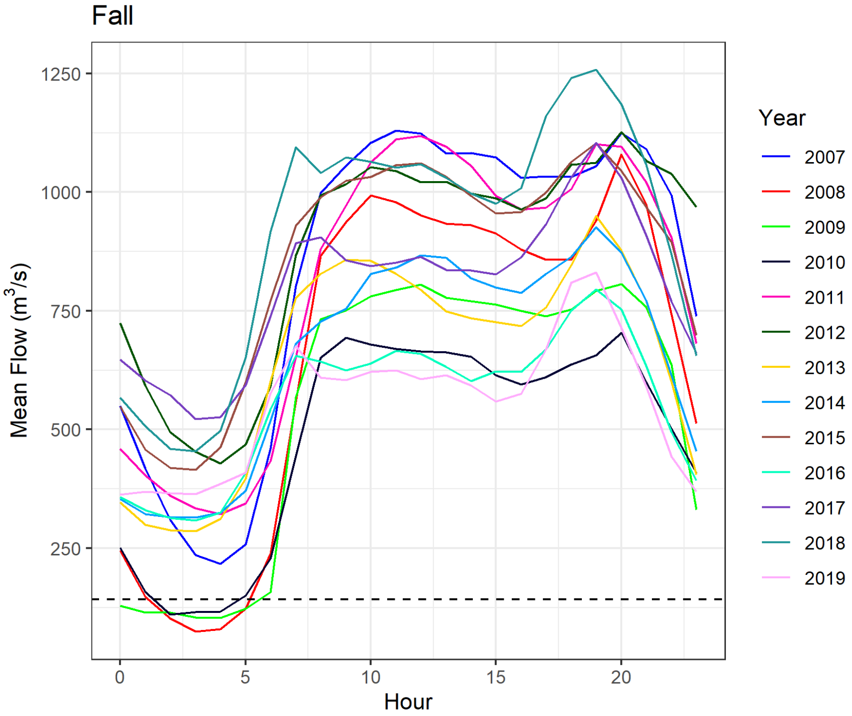

Figure 4-4: **Summary of mean hourly flows during the fall for all years of the study. The horizontal dotted line indicates the minimum flow of 142 m^3/s.**

Revelstoke Dam operations were variable in fall deployment sessions. Fall 2007, 2011, and 2012 had higher hourly mean flows from 10:00-20:00 compared to other fall deployment periods (Figure 4-4). Fall 2010 had lower hourly mean flows from 8:00-20:00 compared to other fall deployment periods. The fungal/bacterial black coloration on substrates observed in R4 was indicative of a low water year in fall 2010.

Dam operations were also variable during spring deployment sessions. Spring 2015 was unique compared to all other spring sampling sessions, as it had higher mean hourly flows (Figure 4-3). Spring 2017 and 2018 had higher mean hourly flows from 17:00-21:00 compared to spring 2011-2013, 2016, and 2019. Higher peak hourly flows in spring 2017 and 2018 were associated with above average snowpack levels. Mean hourly flows from 9:00-18:00 were lower in spring 2019 compared to other spring sampling sessions.

Despite the implementation of minimum flows, this flow data demonstrates that the annual flow variability was not always consistent or typical of the minimum flow operating regime. Therefore, annual flow variability had a substantial effect on benthic productivity and confounded the minimum flows benefits to benthic production.

Peak hourly flows can cause shearing of algae and loss of benthic invertebrates through drift, which ultimately can result in changes to the benthic community composition due to a greater loss of species that are morphologically more susceptible to high flows. Peak flows rarely exceeded 1800 m^3/s during most fall and spring sampling sessions (see Appendix 3)but did so in fall 2012 for 27 hours and in spring 2018 for 40 hours. The maximum flow in fall 2012 reached the capacity of REV5.

4.1.2 Physical Parameters

Physical parameters that influence benthic productivity in the MCR include but were not limited to submergence, water temperature, and velocity. The combination of hourly flows and ALR water levels determines the wetted history of substrates in the MCR. The MCR water temperature was more variable in spring sampling sessions compared to fall. Previous MCR findings indicated that spring water temperatures were an important determinant of periphyton productivity. Spring sampling sessions were split into two groups: warm spring sampling sessions that had mean water temperatures greater than 5°C, and; cool spring sampling sessions that had mean water temperatures less than 5°C (Table 4-2).

Spring and fall sampling sessions with atypical REV operations are summarized in Table 4-2. The ALR water levels in fall 2008 and 2011 were higher than other fall sampling sessions. Extensive backwatering caused an increase in substrate submergence and a reduction in velocities. Fall 2012 and spring 2018 experienced high hourly peak hourly flows that resulted in high maximum velocities. Higher mean hourly flows in spring 2015 compared to all other spring sampling sessions resulted in increased submergence throughout the varial zone of the river.

Table 4-2: Summary of spring and fall sampling sessions that had atypical Revelstoke dam operations and variable water temperatures.

Deployment Period	Deployment Period Spring	Deployment Period Fall	Atypical operation conditions	Water Temperature
2007		X	Low # of hours below min flow	
2008		X	Extensive ALR backwatering	
2009		X		
2010		X		
2011	X	X	Extensive ALR backwatering	<5°C (S)
2012	X	X	High peak hourly flows	<5°C (S)
2013	X	X		>5°C (S)
2014	X	X		
2015	X		High mean hourly flows	>5°C
2016	X			>5°C
2017	X			<5°C
2018	X		High peak hourly flows	<5°C
2019	X			<5°C

Appendix 3 provides an additional summary of REV operations during the spring and fall sampling sessions, pre and post minimum flow conditions, and highlights other confounding factors such as annual variability and ALR backwatering.

4.2 Management Questions

4.2.1 MQ1

MQ #1 *What is the composition, distribution, abundance and biomass of periphyton and benthic invertebrates in the section of MCR subjected to the influence of minimum flows?*

4.2.1.1 Periphyton

This study segment was designed to assess periphyton community composition and standing crop over the range of flow and habitat conditions in the MCR. The study's 13-year duration captured the inherent variability of the MCR and helped limit the impact of the increased frequency of extreme events on summary statistics and modelling. Natural substrate variability was controlled by using an artificial substrate although it is acknowledged that the rough open-celled Styrofoam employed in this project tended to exaggerate accrual rates and final biomass estimates by 20 - 25% or more compared to adjacent natural substrates.

The following section discusses the study results where the evidence was strong and offers literature context for conclusions, as well as best estimates where the evidence was weak. The level of uncertainty in the topics discussed herein is moderate and could be lowered by extending the study from fall and spring into the summer and winter seasons.

4.2.1.1.1 Community Composition, Diversity, and Distribution

Like most large rivers, diatoms accounted for over 90% of the periphyton biovolume in both seasons and both reaches in all study years. The dominant diatom species belonged to the low-profile guild, rapid colonizing diatoms with firm attachment strategies or to the large planktonic guild taxa imported from Revelstoke Reservoir that deposited on the periphyton biofilm. Smaller contributions were made by the large high-profile taxa and the motile taxa in the MCR. Selection pressure favouring low-profile guilds has also been found in other hydropeaking facilities (Passy and Larson 2011). The low-profile guild is better suited to high water velocities which may explain its prevalence in spring high flows.

The low-profile guild taxa were prevalent in both spring and fall with mean percentages of 26±15% and 30±18%, respectively. Spring sampling sessions with warmer water temperatures had higher percentages of the low-profile guild (Figure A22). The low profile guild are fast growing and can outcompete the high profile taxa at warmer water temperatures (Rimet and Bouchez 2012).

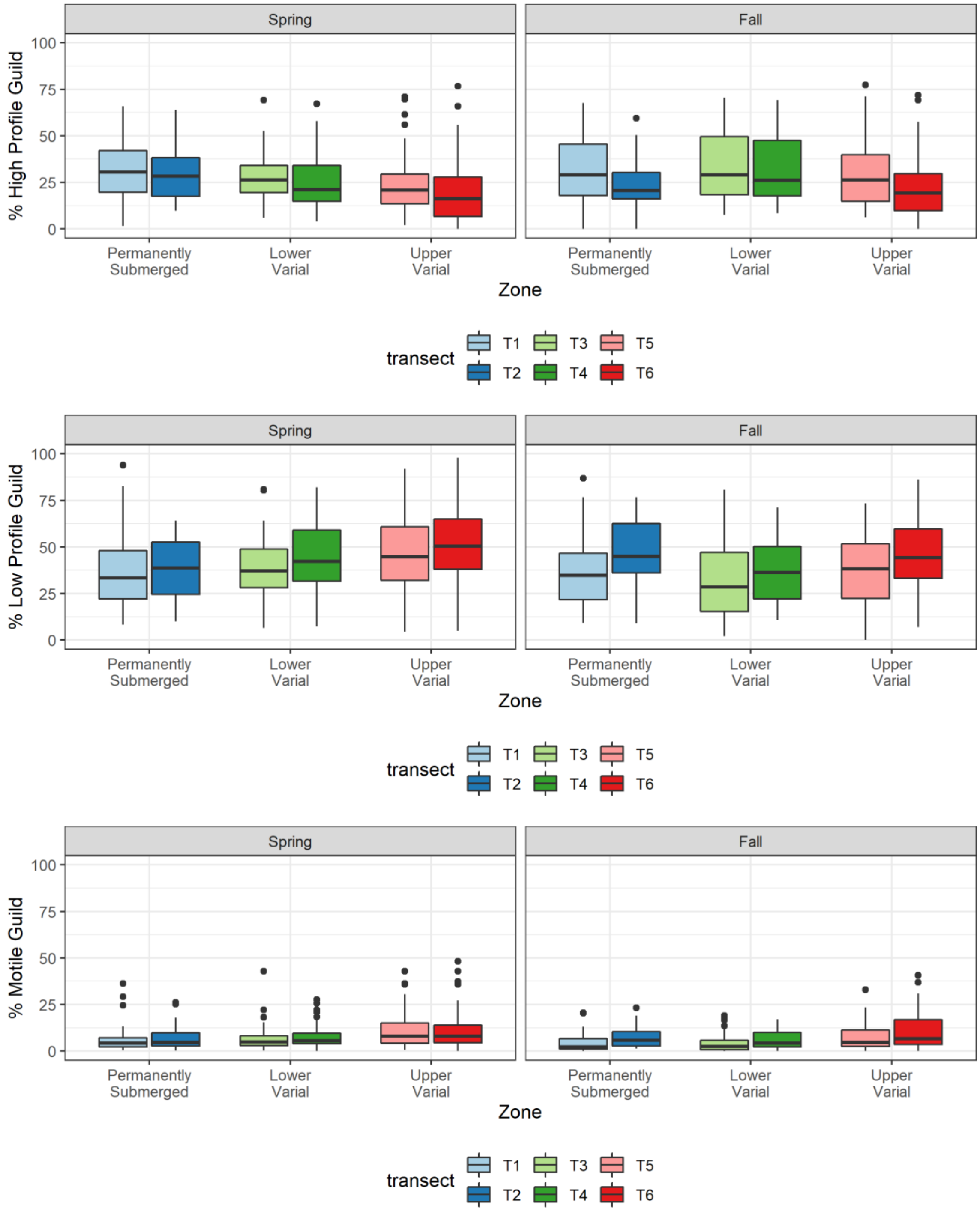

Figure 4-5: **Boxplots of periphyton composition metrics by percent abundance grouped by zone and transect for all sites sampled from 2007-2019.**

Spring periphyton composition varied across the river channel and was related to differences in substrate submergence. The planktic and high-profile guilds benefited from longer periods of submergence. The shallowest upper varial zone sampler (T6) had a much lower percent high profile guild compared to T1-T5 (Figure 4-5). Motile taxa had the highest percentages in the upper varial zone (T5-T6). Similarly, low profile taxa were more abundant in the upper varial zone during the spring sampling sessions; T4-T6 spring samplers had significantly higher percent low profile guild compared to T1-T3 samplers (Figure 4-5).

Fall periphyton composition was similar across the river channel because Fall provides more stable conditions compared to spring. Warmer air and water temperatures, protection of substrates by ALR backwatering and lower peak flows benefit the periphyton community in the lower and upper varial zones in Fall.

Although periphyton taxa are less sensitive than invertebrates to the rate of substrate de-watering as opposed to its duration, ramping down can be too rapid for spore/cyst formation and rapid ramping up can dislodge or abrade stressed taxa (Bondar-Kunze 2016; Biggs and Thomsen 1995). Periphyton mat shear/abrasion can be expected at velocities exceeding 0.30 m/s (Ahn et al. 2012) and mat removal is complete within 30 minutes of the velocity increase (Cullis, et al. 2013). For example, populations of large filamentous algae including Didymo and filamentous green algae were curtailed by filament desiccation from substrate exposure and to a lesser extent by mat removal during high flows.

There are numerous mechanisms that account for similarities **in species distribution** in large rivers like the MCR. These include flow conditions that can either shield (backwatering) or move (high flow events) benthic species to new substrate locations. Additionally, the T1/T2 thalweg area that remained wetted by minimum flows continuously receives drifting algae from Revelstoke Reservoir. The diatom taxa donated by Revelstoke Reservoir supported periphyton productivity and recovery, particularly in R4 (Plewes et al. 2019). In turn the thalweg can function as a source of organisms to re-colonize exposed habitat areas after catastrophic flow events.

Although species composition changed between reaches, overall **species diversity** was stable as was the percent contribution of each guild (Figure 4-6). R3 has greater sand concentrations, while R4 has more cobble and bedrock and these substrate differences were reflected in shifts among periphyton dominants. For example, species that were planktonic or adherent (non-motile) were more common in R4 samples (e.g. *Synedra ulna, Achnanthidium minutissima*), while species that were stalked or motile increased in R3 samples (e.g. *Didymosphenia geminata, Navicula spp.*).

The sum of these flow-related stressors limited periphyton community diversity and resulted in a species richness in MCR that was lower (~20 ± 6 taxa) than typical for unregulated large rivers of similar latitude (Table 4-3).

Table 4-3: Summary of typical MCR periphyton metrics from spring and fall 2010 - 2012, with comparison to oligotrophic, typical, and productive large rivers

Metric	Oligotrophic or stressed	Typical large rivers	Eutrophic or productive	MCR (values bolded in bracket = 6 month samples)
Number of taxa (live & dead)	<20 – 40	25 - 60	variable	5 - 52 **(39-50)**
Chlorophyll-a ug/cm^2	<2	2 - 5	>5 – 10 (30+)	0.04 – 4.1 **(0.59-2.0)**
Algae density cells/cm^2	<0.2 x10^6	1 - 4 x10^6	>1 x10^7	<0.02 – 1.5 x10^6 **(0.9 – 13.1x10^6)**
Algae biovolume cm^3/m^2	<0.5	0.5 – 5	20 - 80	0.03 - 10 **(0.6 - 5.9)**
Diatom density frustules/cm^2	<0.15 x10^6	1 - 2 x10^6	>20 x10^6	<0.01 – 0.6 x10^6 **(0.2-1.0 x10^6)**
Biomass –AFDW mg/cm^2	<0.5	0.5 - 2	>3	0.12 – 4.8 **(0.35-3.5)**
Biomass –dry wt mg/cm^2	<1	1 – 5	>10	0.7 – 80 **(6-99)**
Organic matter (% of dry wt)		4 - 7		1 – 10 **(2-7)**
Bacteria count sediment HTPC CFU/cm^2	<4 -10 x10^6	0.4 – 50 ×10^6	>50×10^6 – >10^{10}	0.2 – 5 x10^6
Bacteria count water CFU/mL	0.1 – 10 x10^4	0.1 – 100 x10^5	2.4 x10^7	Not sampled
Fungal count CFU/cm^2	<50	50 – 200	>200	<250 – 6000
Accrual chl-a ug/cm^2/d	<0.1	0.1 – 0.6	>0.6	0.0003 - 0.034 shallow; 0.001 - 0.038 deep

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

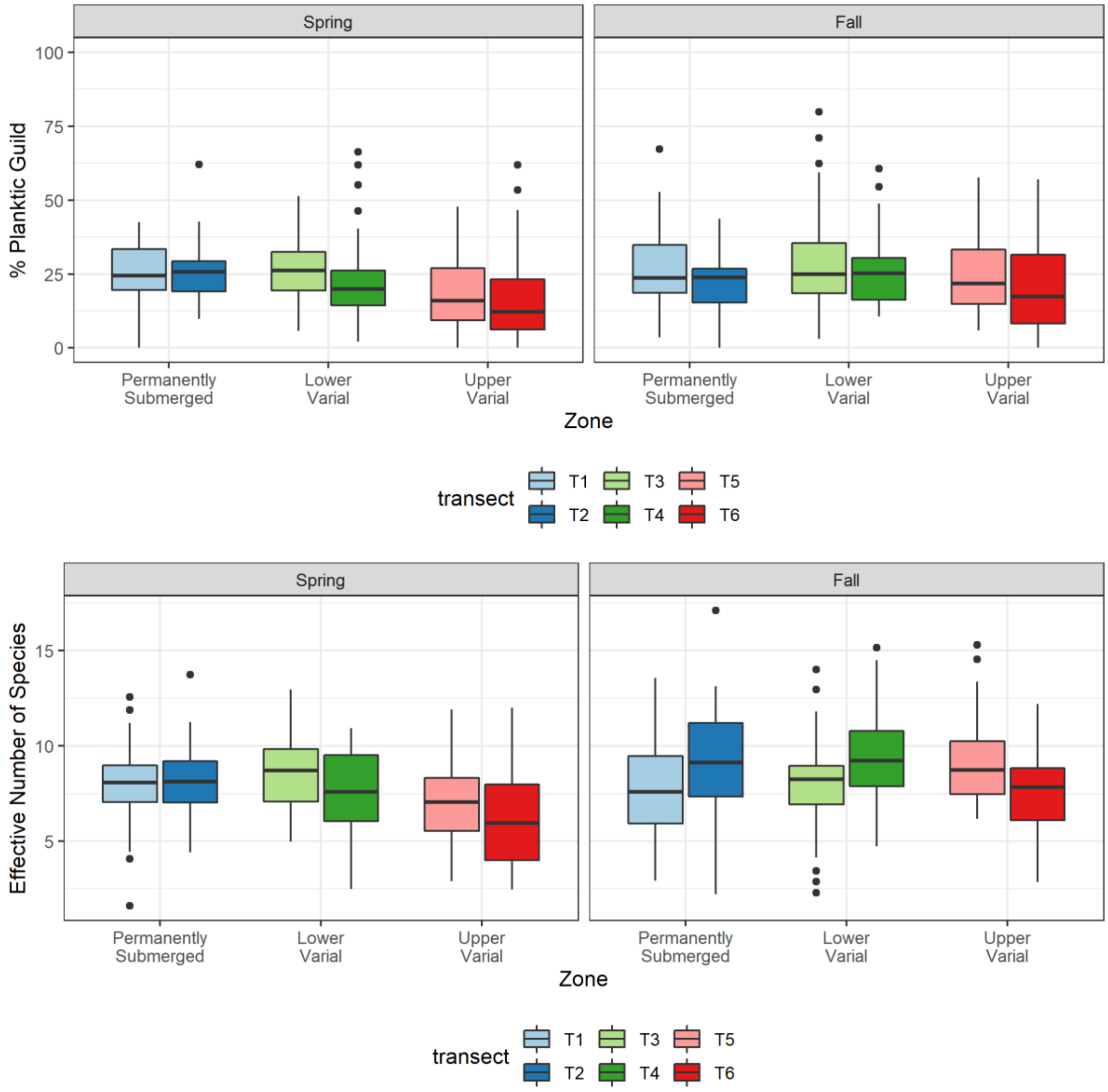

Figure 4-6: Boxplots of periphyton percent planktic guild by percent abundance and effective number of species grouped by zone and transect for all MCR sites sampled form 2007-2019.

4.2.1.1.2 Abundance and Biomass

The artificial sampler data were corrected by the median potential inflation of periphyton production, the corrected results indicated that MCR production was consistent with an oligotrophic or stressed river system (Table 4-3).

Periphyton productivity changes corresponded to substrate submergence time and secondarily to irradiance and therefore differed significantly across the river channel (T1-T6) in spring and fall (Figure A6; Figure 4-7). Average periphyton productivity decreased with increasing exposure from T1/T2 through T5/T6. The deep samplers (T1-T3) were the most productive in spring and fall, though fall productivity in the lower varial zone (T4) was similar to the deep samplers because ALR backwatering resulted in more substrate submergence. MCR substrates that were wetted for more than nine hours per day experienced rapid periphyton growth (Schleppe et al. 2012).

Overall, fall periphyton productivity metrics almost doubled the spring metrics throughout the 13-year study period. The important drivers behind the greater fall periphyton productivity and diversity were flows (lower water velocities, greater backwatering) and warmer water temperatures. Greater fall productivity occurred despite fewer hours (600-1000) of light than spring (500-1450) ; see Plewes et al. 2019 for further details).

Many growth metrics were higher in Reach 3 than Reach 4 due to flows, backwatering, and weather. The greatest difference between R3 and R4 periphyton productivity occurred in spring due to R3 variable ecological conditions. The Reach 3 upper varial zone varied the most for periphyton productivity in the MCR. With continuous backwatering, it exceeded the productivity of deeper areas but without backwatering, it had minimal productivity.

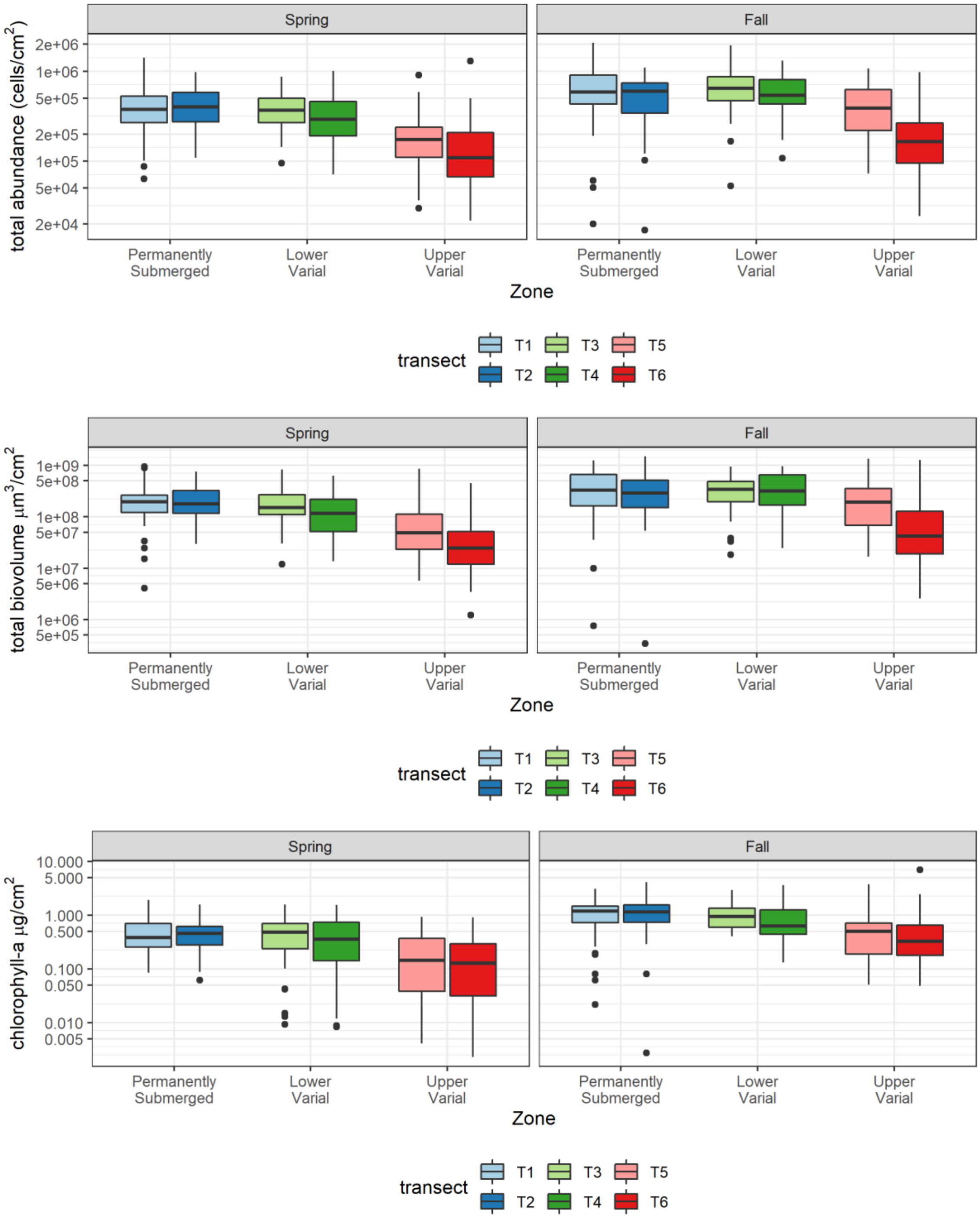

Figure 4-7: **Boxplots of periphyton productivity metrics grouped by zone and transect samples for all MCR sites sampled from 2007-2019 (includes all R3 R4 data).**

4.2.1.2 Benthic Invertebrates

4.2.1.2.1 Distribution, Density and Biomass

Invertebrate abundances for the MCR are displayed in Appendix 4 -Section 9.5.2. For comparison with other rivers, invertebrate densities are reported below. Density is defined as the abundance per unit area. Invertebrate density of the MCR was highly variable with an overall mean and standard deviation of 3122±6041 individuals/m^2. Invertebrate production in the MCR was indicative of a highly regulated, stressed system. Invertebrate communities that have low EPT richness and densities are indicative of a stressed system. Most EPT are sensitive taxa because they are intolerant of physical disturbances (Hamid and Remi 2017). Invertebrate densities were lower in the MCR compared to the Lower Columbia and Peace rivers (data not shown). Invertebrate densities in the varial zone of the MCR ranged from 11-5122 individuals/m^2 and were comparable to other hydropeaking rivers. For example, the Saskatchewan River and the Baevera River in Norway had invertebrate densities that ranged from 39-2477 individuals/m^2 and 236-1836 individuals/m^2, respectively (Mihalicz et al. 2019; Herland 2012).

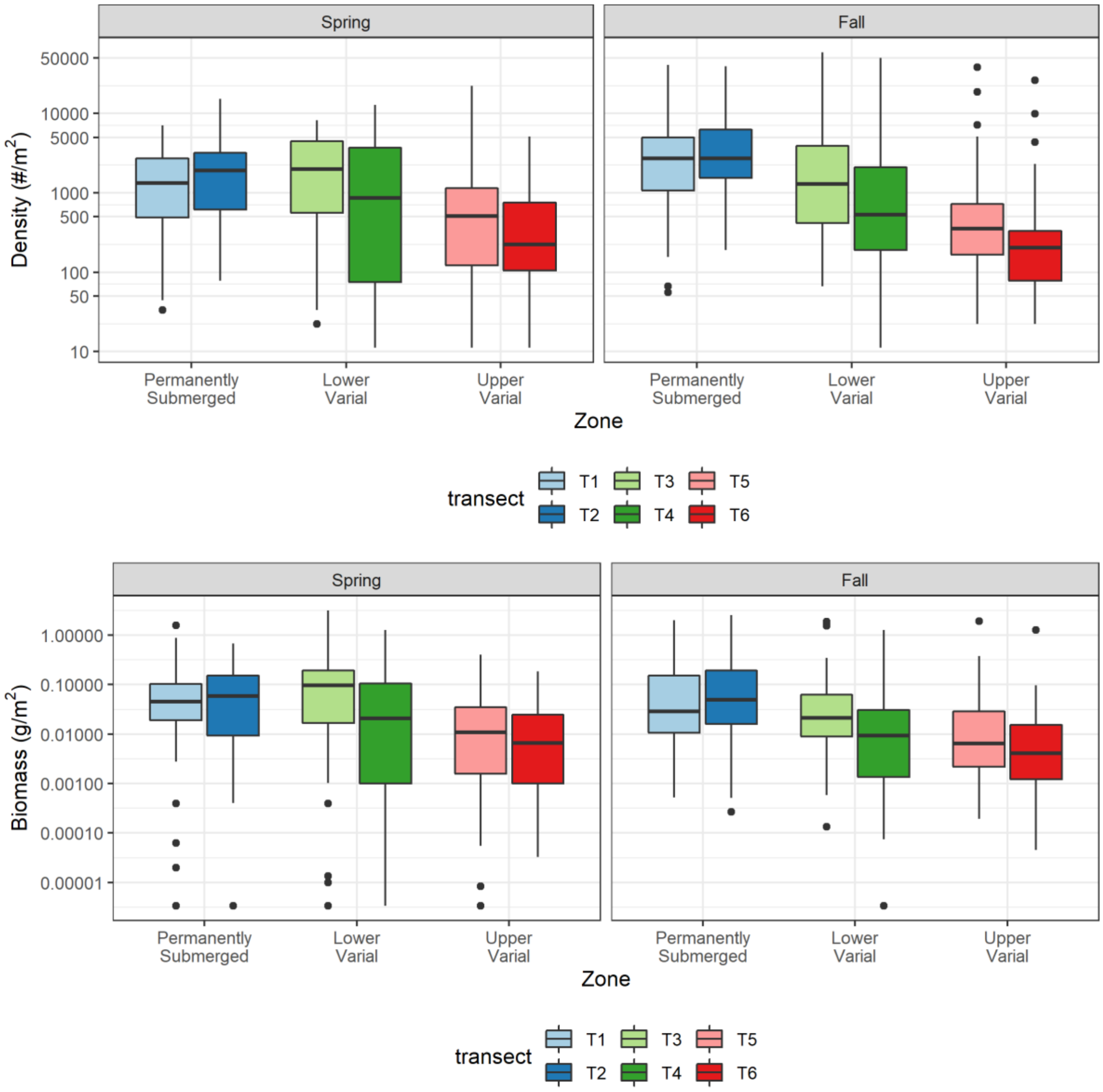

Figure 4-8: **Boxplots of invertebrate productivity metrics grouped by zone and transect for all reach 3 and reach 4 sites sampled between 2007-2019.**

The MCR invertebrate distribution varied by position across the river channel and by season (Figure 4-8). The shallowest permanently submerged sampler (T2) and both lower varial zone samplers (T3, T4) had the highest invertebrate densities in spring (Figure 4-8). In the fall, the permanently submerged zone and the lower varial zone samplers with the least amount of dewatering (T3) had the highest invertebrate densities. The reduced invertebrate densities at the deepest permanently submerged zone samplers were a result of higher spring velocities near the thalweg that exceeded the tolerance of some invertebrate taxa (Plewes et al. 2019).

Like density, invertebrate biomass in the MCR varied highly with a mean and standard deviation of 0.13±0.34 g/m^2 (Figure 4-8). The low invertebrate biomass of the MCR was expected because the dominant benthic invertebrate organisms are small. The dominant chironomid subfamily Orthocladiinae has very small biomasses that typically ranged from 0.015-0.032 mg/individual

(Niedrist et al. 2018). Orthocladiinae have small biomasses compared to other cold stenothermic chironomids such as Chironominae and Diamesinae (Anderson et al. 2012; Niedrist et al. 2018). There was limited biomass data available for rivers that had similar community compositions to the MCR.

The invertebrate biomass was highest at the lower varial zone sampler with the least amount of dewatering (T3) in spring, while in the fall, the invertebrate biomass was highest at the deepest permanently submerged zone sampler (T1). The reduced invertebrate biomass near the thalweg in the spring, was likely a result of higher velocities that dislodge invertebrates from the substrate.

The upper varial zone (T5 and T6) consistently had the lowest benthic invertebrate productivity, consistent with reduced invertebrate production in varial zones of other regulated rivers (Jones et al. 2013; Kjærstad et al. 2018). The frequent daytime and night-time dewatering in the MCR upper varial zone caused invertebrate loss due to substrate drying and potentially to predation from terrestrial biota (Jones et al. 2013). Substrates also did not remain wetted long enough to allow for complete invertebrate recovery of rapid re-colonizers such as chironomids (Kjærstad et al. 2018).

Overall benthic invertebrate production metrics were higher in fall compared to spring. It is unknown if it is a seasonal effect, or if it is due to differences in wetted habitat area. In natural river systems, invertebrate production peaks in early fall (Giller and Twomey 1993), and similar trends have been reported in the regulated Lower Columbia River (Olson-Russello et al. 2019). Longer substrate submergence in fall from ALR backwatering likely enhanced invertebrate production compared to spring.

4.2.1.2.2 Composition

The MCR benthic invertebrate community composition was similar to other flow-regulated rivers that have large dam releases from the hypolimnion. The MCR invertebrate community was consistently dominated by chironomids, hydrozoans, and oligochaetes (Figure 4-9). The dominance of tolerant invertebrate taxa such as chironomids and oligochaetes are common downstream of dams (Phillips et al. 2016; Kjærstad et al. 2018). Chironomid subfamilies found in the MCR are tolerant of a wide range of velocity conditions and cold-water temperatures (Schmedtje and Colling 1996; Szczerkowska-Majchrzak et al. 2010). High abundances of hydrozoans have been reported upstream (backwatering) and downstream (drift) of reservoirs (Hindle 2018; Schleppe et al. 2019). Similar to the Colorado River, the MCR had low EPT richness and abundances because of the cold water temperatures resulting from large hypolimnetic dam releases (Stevens et al. 1997).

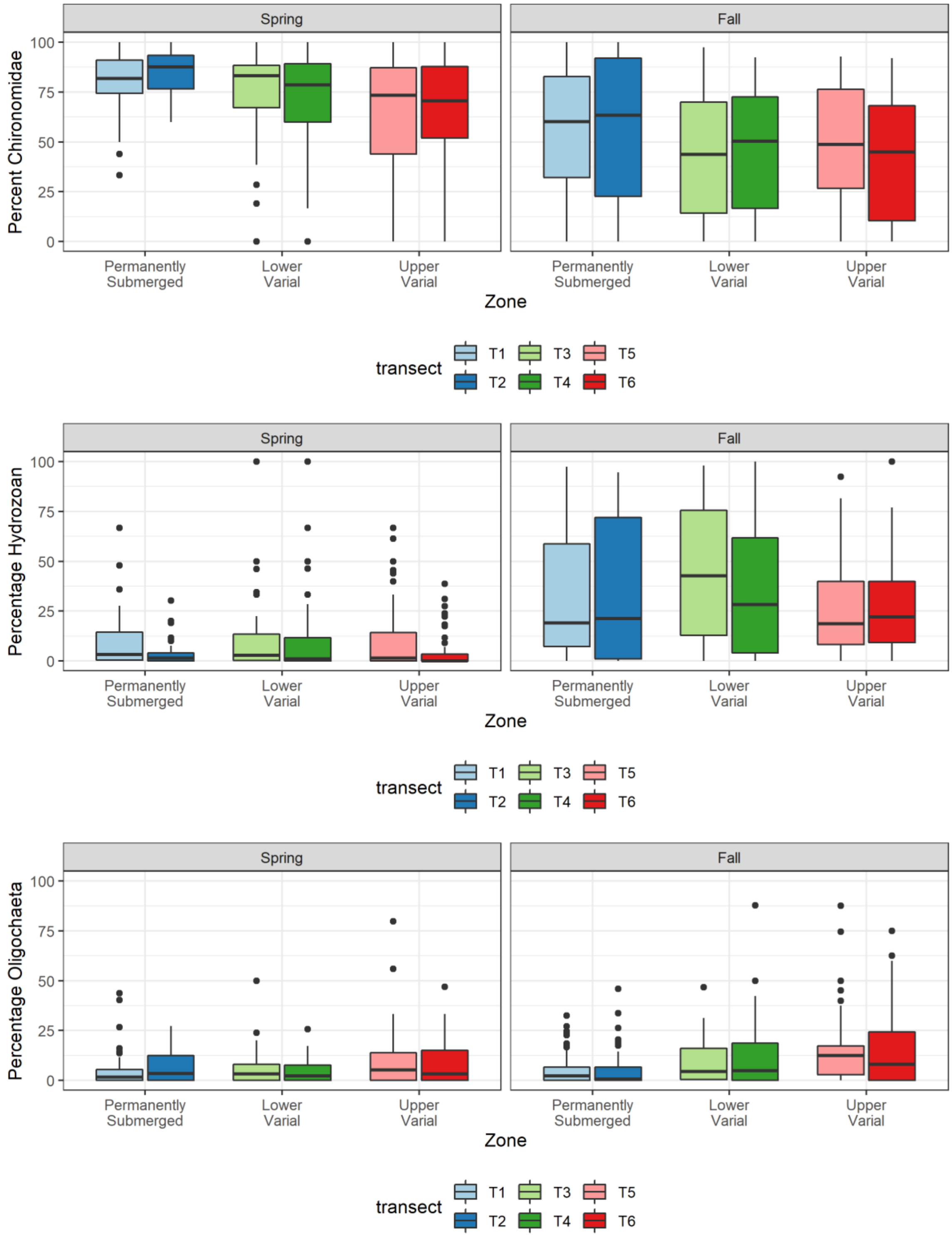

Figure 4-9: **Boxplots of invertebrate composition metrics by percent abundance grouped by zone and transect for all reach 3 and reach 4 sites sampled form 2007-2019.**

The distribution of invertebrate taxa throughout the MCR were dependent on differences in substrates, velocity, and duration of substrate exposure from dewatering (Figure 4-9). Hydrozoans and oligochaetes contributed more to the MCR invertebrate community in fall compared to spring. More extensive ALR backwatering in the fall provides favourable habitat for hydrozoans and oligochaetes because the backwatering reduces velocity. Hydrozoans and most species of the oligochaete including *Nais sp.* have preferences for slower velocities (Schmedtje and Colling 1996). Oligochaetes had higher abundances in backwater areas because of the combination of lower velocities and finer substrates (Tachet et al. 2010). In fall, chironomids were most abundant in the permanently submerged zone of the MCR and chironomid abundances were lower in the shallower zones. Chironomids frequently increase with depth in regulated river systems and have the lowest abundances in the varial zones that frequently experience dewatering (Kjærstad et al. 2018; Jones et al. 2013). For a more detailed analysis of the benthic invertebrate community and management question #1, please refer to Appendix 4.

4.2.2 MQ2

MQ#2 *What is the effect of implementing minimum flows on the area of productive benthic habitat?*

To address management question #2, a reach-wide productivity model was employed. The model used hourly submergence and exposure to predict periphyton chl-a and invertebrate dry biomass. Modelled daily productivity values were used to determine the area of productive benthic habitat. The productive habitat areas for periphyton and invertebrates compared before and after the implementation of minimum flows for R3 and R4 to determine the effect of implementing minimum flows.

4.2.2.1 Periphyton (Chlorophyll-a)

Minimum flows increased the area of productive periphyton habitat in February, May, and October (Figure 4-10). Mean periphyton productive area was significantly higher after minimum flows were implemented than it was before minimum flows in both reaches. However, the mean productive area of R3 and R4 in July was not significantly higher post minimum flows because annual variations in ALR elevations were more important determinants of periphyton productive area in July than minimum flows. High ALR elevations in the summer months increased wetted habitat area because backwatering extended through R3 and R4 in most years. Years with lower July ALR elevations such as 2015 and 2016 had smaller productive habitat areas compared to other years with minimum flow releases.

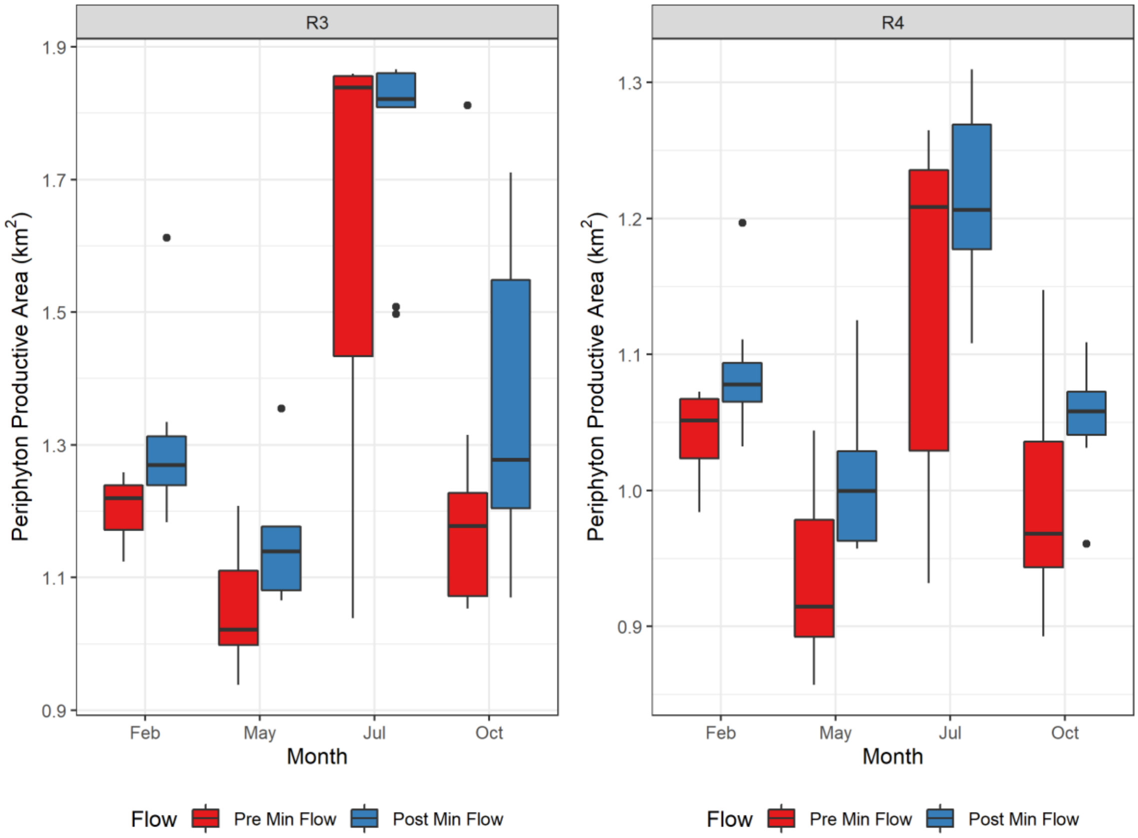

Figure 4-10: Boxplots of productive habitat area for periphyton pre (2001-2010) and post (2010-2019) minimum flows.

4.2.2.2 Benthic Invertebrates (Biomass)

Minimum flows increased the area of productive invertebrate habitat in February, May, July, and October (Figure 4-11). Mean invertebrate productive area in all seasons were significantly higher post minimum flows than it was prior to minimum flows in both reaches. We expect that minimum flows had a greater benefit on the productive invertebrate area in the winter than our reach-wide productivity has indicated because the winter colonization rates of invertebrates in the MCR are slower than what was used in the model (Doeg et al. 1989). The reach-wide productivity model for invertebrates used the same colonization curve for all seasons because there was a lack of seasonal data. The colonization curve likely overpredicts the biomass of invertebrates in winter because chironomids have slower colonization rates in winter.

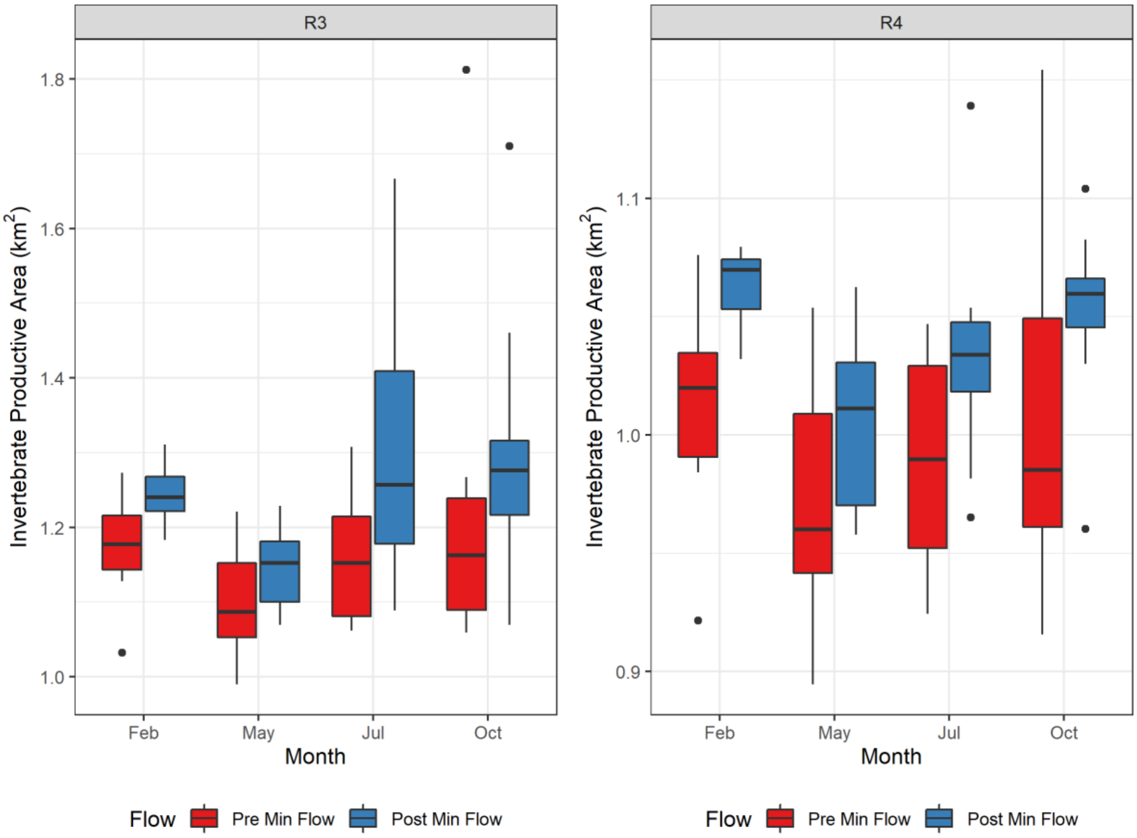

Figure 4-11: Boxplots of productive habitat area for invertebrate pre (2001-2010) and post (2010-2019) minimum flows.

For additional information pertaining to management question 2, please refer to Appendix 5.

4.2.3 MQ3

MQ#3 *What is the effect of implementing minimum flows on the accrual rate of periphyton biomass in the MCR? Is there a long- term trend in accrual?*

The MCR periphyton accrual rate depended on the sum of gains and losses over the time series sampler deployment periods. Chlorophyll-a was selected as the measure of periphyton productivity to assess accrual because it is a standard measure of production, it is available for the longest period in the MCR, and it is highly correlated with abundance and biovolume (e.g. spring 2019 abundance $R^2 = 0.85$; biovolume $R^2 = 0.78$).

Accrual samplers were deployed at two key depths to develop better statistical models: the deep area permanently wetted by minimum flows (T1) and the lower varial zone (T3), located above the permanently wetted edge, but with frequent wetting. The level of sampling effort was smaller for time series sampling aimed at developing accrual rates than it was for productivity estimates, resulting in greater uncertainty that was overcome in part by confining the sampling to the most informative T1 and T3 locations. We contrasted production in the regularly dewatered varial zones with production in the permanently wetted zones to address MQ3.

Accrual Overview

Establishment and accrual of periphyton communities in MCR occurred at slow rates, similar to other large oligotrophic rivers. Over this 13-year study period, MCR periphyton accrual demonstrated non-linear rates in response to high flow events exceeding 1800 m^3/s, gradual accrual over periods exceeding six months, and different accrual rates with depth and season. Given its variable operating regime, it is reasonable to expect the MCR periphyton communities to be in a perpetual state of recovery.

MCR periphyton communities were more dependent upon the overall operating regime (daily, monthly, and annual patterns of flow release, ALR backwatering) than on the specific effects of minimum flow because the entire flow regime determines the wetted edge of the channel during daytime periods. The frequency of high flow incidents, regardless of their duration, acted to reduce the periphyton standing crop. The effect of water velocity declined and the effect of substrate exposure increased in importance in areas shallower than the MCR thalweg.

Like other systems, MCR periphyton production was reduced immediately after the high flows of the 2012 summer and fall. Periphyton productivity recovered quickly so that productivity in the subsequent sampling season was high for MCR. However repeated flow-related pruning of the periphyton mats from high water velocities and from desiccation have contributed to a community structure consisting of low overall productivity contributed by a restricted number of rapidly reproducing taxa and taxa donated by upstream Revelstoke Reservoir. This type of periphyton community with low density and diversity is indicative of a stressed river system.

Catastrophic drying events had a far greater effect on benthic productivity than physical processes such as water velocity or light intensity. Like other researchers, we found irreversible periphyton damage certainly occurred within days and often within hours of substrate exposure (Bondar-Kunze et al. 2015).

Throughout this study and in both reaches, the spring river conditions such as higher peak flows, low water temperature, and short-day length resulted in lower biomass and accruals than were observed in the fall. Chlorophyll-a productivity was greater in mainstem R3 than in mainstem R4 in both seasons.

There were differences in spring accrual trends between T1 and T3, although the differences were not as apparent in the fall. Additionally, spring chl-a accrual was slower than in the fall in both reaches. Fall trends could not be tested statistically because there were five years of data (a minimum of six are necessary for these trend tests).

Accrual Rates Pre and Post

Due to cost constraints, physical data were not collected for the accrual (time series) sampler arrays. In lieu of this data, the mainstem sites sampled from spring 2011-2013; 2015-2019, and fall 2010-2014 were investigated for key periphyton drivers including submergence ratio, water temperature and year, reach and site. RF and CART models confirmed that substrate submergence (total time in water) was an important determinant of chl-a. CART modelling of submergence ratios for all T1 to T6 samplers indicate that chl-a productivity benefit from 83% submergence time in spring and 77% in fall (see Appendix 6 for modeling details; Figure A45).

Statistical modelling and annual comparisons of chl-a and accrual rates indicated that substrate submergence, mean water temperatures, annual variability (a composite interacting weather and ecological conditions), and maximum velocities were important drivers of periphyton productivity. Mean water temperature and annual variability became important drivers of chl-a when samplers were submerged for longer than 650 hours in spring and 860 hours in fall. Fall maximum velocities were also important in years when flows exceeded 1800 m^3/s. For example, fall 2012 had the lowest mean periphyton abundance and chl-a and it had the highest peak flows with 27 hours exceeding 1800 m^3/s (Figure 4-12).

Prior to implementation of minimum flows, the thalweg was submerged 88% of the time in fall and 82% of the time in spring; therefore a loss of periphyton productivity was not expected. The estimated submergence ratios for the thalweg before the implementation of minimum flows had medians of 0.88 in spring and 0.82 in fall; these numbers exceed the CART thresholds, thus a loss of periphyton productivity was not expected. Statistical models and estimated submergence ratios indicated differences in peak flows and water temperature are more important determinants of accrual rates than the effect of minimum flows. For the thalweg, accrual rates were not different pre and post minimum flows because periods of drying were often brief and occurred most often at night.

Estimated submergence ratios over fall and spring 2000-2019 in the periodically dewatered lower varial zone were similar before and after minimum flows because operations simultaneously decreased the frequency of low flows (200 – 400 m^3/s) when the minimum flow regime commenced.

With similar submergence ratios under typical operations, we would not expect differences in periphyton accrual rates in the periodically dewatered lower varial zone following the commencement of the minimum flow regime.

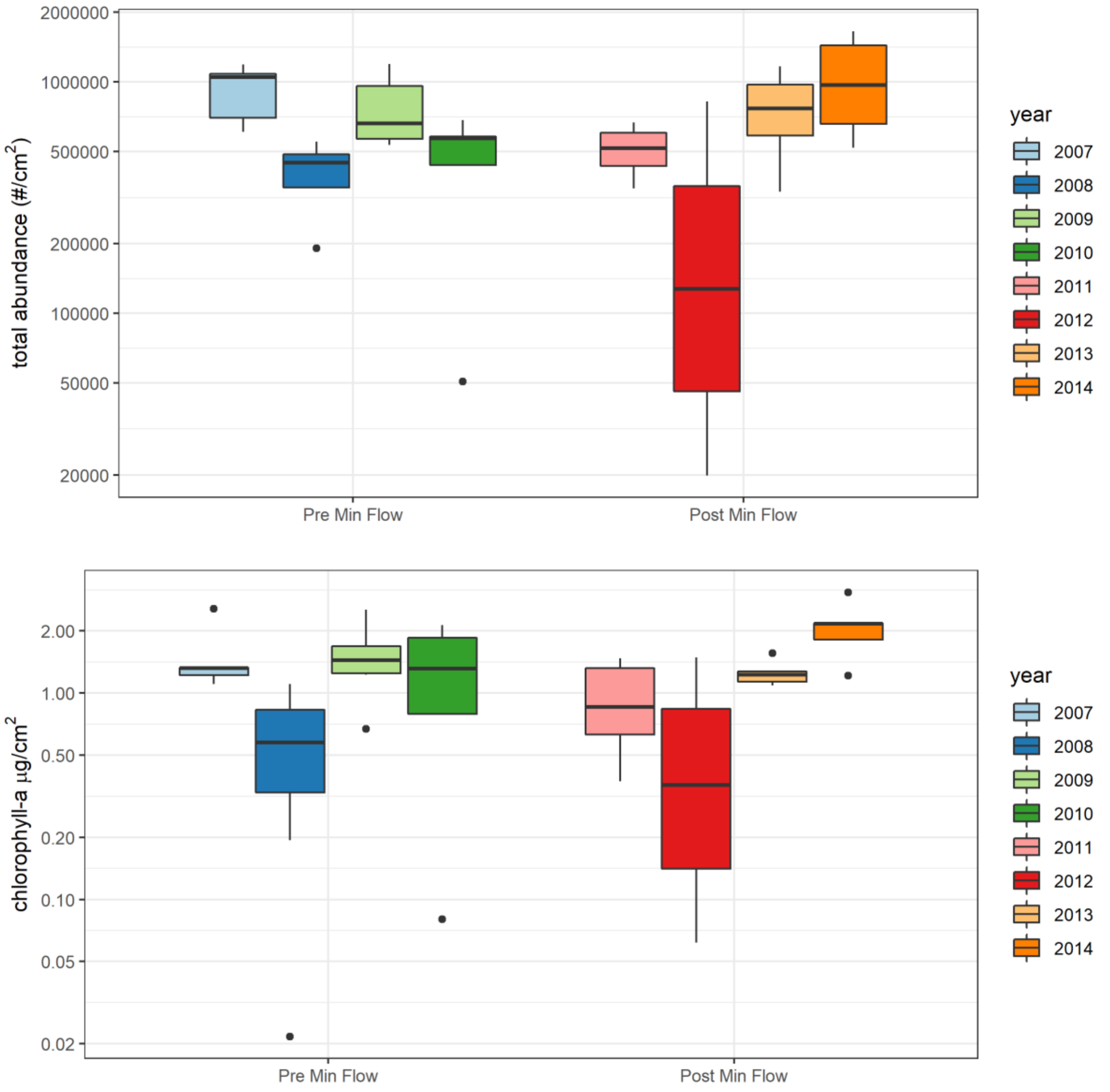

Figure 4-12: Boxplots of periphyton productivity metrics for Fall T1 samplers at mainstem sites for pre-implementation of minimum flows (Pre Min Flow) and post-implementation of minimum flows (Post Min Flow).

Trends in Periphyton Accrual Rate

Accrual rates were highly variable from year to year, particularly in the fall (Figure 4-13). For example, accrual rates were highest in fall 2013-2014 in the areas that remained permanently wetted by minimum flow releases (T1 avg 0.031±0.003 ug/cm^2/day) and in the areas periodically dewatered during minimum flow releases (T3 avg 0.022±0.0007 ug/cm^2/day). Accrual rates were lowest in spring 2011 (T1 avg 0.0009 ug/cm^2/day) and (T3 avg 0.0003 ug/cm^2/day). The difference between highest and lowest accrual rates over the years of study spans an order of magnitude. Despite this span, T1 thalweg samplers had faster periphyton accrual than T3 lower varial zone samplers in every year and season, again emphasizing the overarching importance of substrate submergence on periphyton productivity.

While there was no significant trend in long-term (2011-2019) spring accrual rates at T1 or T3 samplers, short-term trends were detected. Productivity was low from 2011-2012 but high from 2013-2015 when operating conditions were atypical. High periphyton productivity was linked to years with high average hourly flows and moderate peak flows. In spring 2015, for example, an increase submergence of the upper varial zone effectively increased the area of productive MCR habitat, resulting in higher accrual.

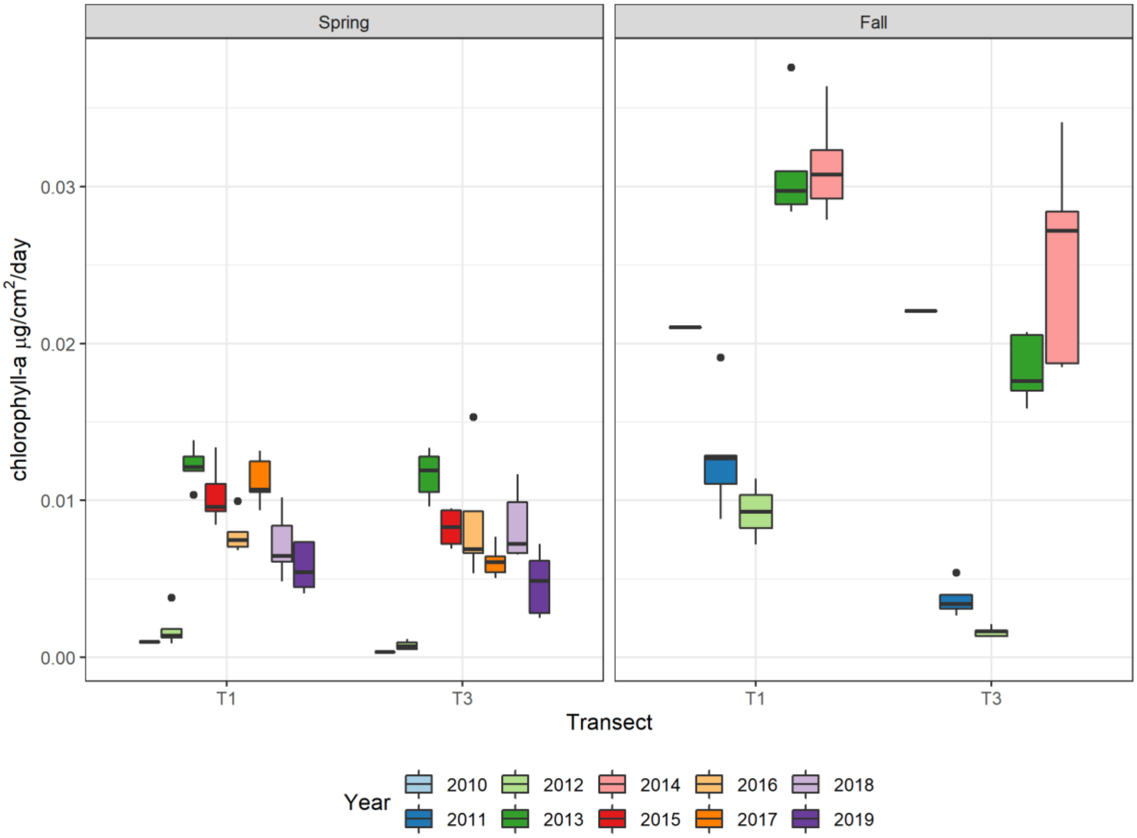

Figure 4-13: Accrual rates for R4 time series samplers for fall and spring sampling sessions.

Using field data and modelling results from this study combined with other research, we conclude that minimum flows are most beneficial to periphyton accrual by preventing catastrophic desiccation losses:

1) in the lower varial area above or adjacent to the wetted edge that would otherwise be exposed to rapid desiccation in the absence of ALR backwatering; and

2) in the thalweg substrate area below the wetted edge that would otherwise be exposed to desiccation during dry weather in summer or winter.

This 13-year study did not detect a significant benefit of minimum flows to periphyton productivity in the spring and fall sample sessions; however, benefits may have occurred in the winter and summer as a response to unique flow-driven stressors in those seasons. For additional information pertaining to management question 3 (MQ3), please refer to Appendix 6.

4.2.4 MQ4

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

The effects of minimum flow on areas that remain permanently wetted at 142 m^3/s were examined during pre (2007-2010) and post (2011-2014) implementation of minimum flow years. Invertebrate production and diversity metrics were compared at T1 samplers, which were located closest to the thalweg. Invertebrate abundance and biomass in the permanently wetted fall T1 samplers were similar before and after the implementation of minimum flows (Figure 4-14). The implementation of minimum flows benefited the diversity of the invertebrate community (measured as effective number of species), but the benefit was dependent on reach and the flow operating conditions.

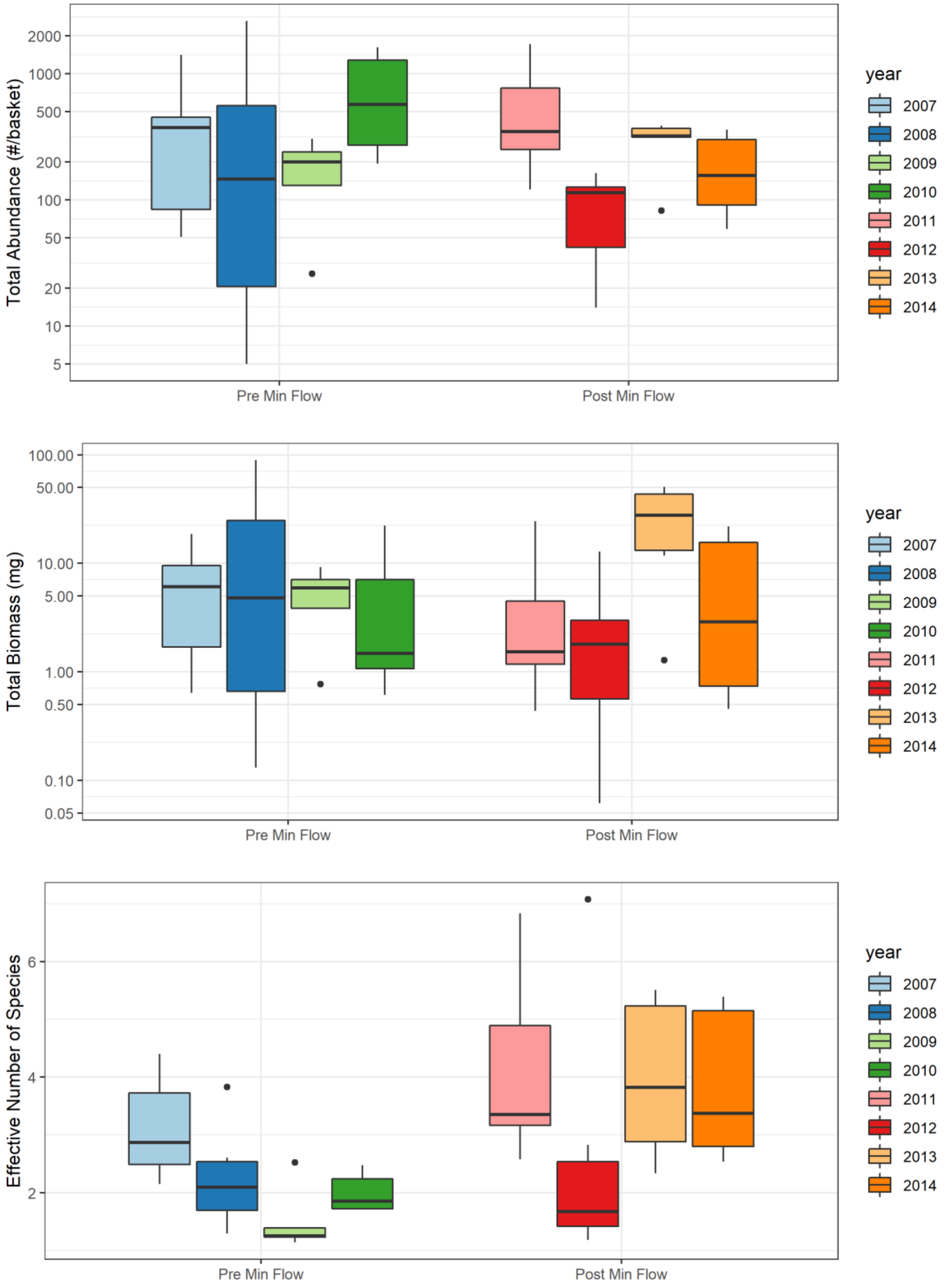

Figure 4-14: Boxplots of benthic invertebrate diversity and productivity metrics for Fall T1 samplers at main sites for pre-implementation of minimum flows (Pre Min Flow) and post-implementation of minimum flows (Post Min Flow).

Abundance

MCR fall invertebrate abundance was similar pre and post implementation of minimum flows. Annual differences in abundances were influenced more by extreme flows and high ALR water levels than minimum flows. The mean invertebrate abundance at T1 samplers pre minimum flows was 307±264 #/basket and 512±656 #/basket post. Invertebrate abundance at the T1 samplers ranged from 5-2,620 in fall 2008 and had the highest variation of all fall sampling sessions (Figure 4-14). The low invertebrate abundance at some sites in fall 2008 was a result of extensive ALR backwatering. ALR backwatering caused a reduction in current velocities and less optimal riverine habitat for invertebrates. In fall 2012, the low invertebrate abundance and biomass were a result of high flows that likely caused chironomids to be lost due to drift.

Submergence was a top predictor of invertebrate abundance. Estimated submergence ratios indicated that short periods of dewatering did not cause large decreases in invertebrate abundance and that submergence times above 64% (submergence ratio = 0.64) benefited invertebrate production (see Appendix 7; Figure A56). For the average spring sampling session, a submergence ratio of 0.64 was equal to 700 hours or 29 days of submergence. The most abundant invertebrates, chironomids and oligochaetes, appear to be able to withstand short periods of mostly night-time dewatering.

Biomass

Invertebrate biomass at fall T1 samplers were similar before and after the implementation of minimum flows (Figure 4-14). The mean invertebrate biomass pre minimum flows were 10.9±19.4 mg/basket and 11.5±15.4 mg/basket post minimum flows. The spring and fall RF invertebrate models indicated that reach differences were more important than the duration of substrate submergence in determining invertebrate biomass (Figure 4-15). Reach 3 sites had higher biomass because the Jordan River was an important source of Ephemeroptera taxa through drift (Plewes et al. 2019). Ephemeroptera taxa caused large increases in biomass because they are much larger in size than chironomids (Anderson and Lehmkul 1968).

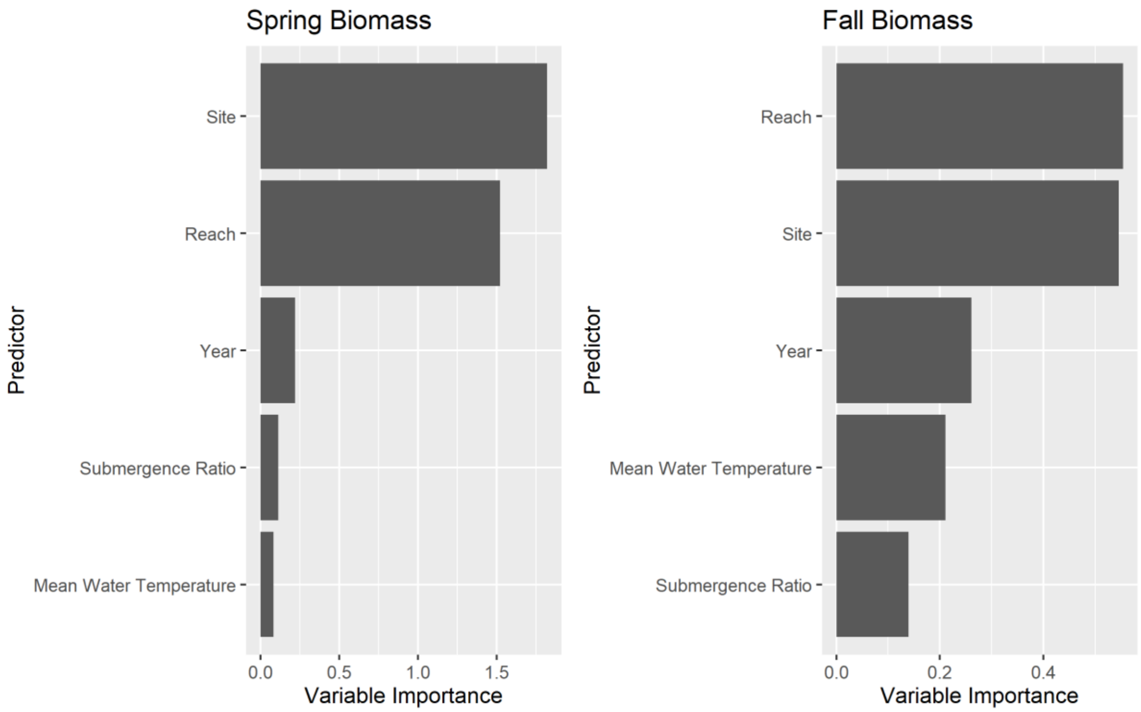

Figure 4-15: **RF variable importance plots for spring and fall biomass models.**

Diversity

The implementation of minimum flows benefited the diversity of the invertebrate community (measured as effective number of species) under typical fall operating conditions (Figure 4-14). Minimum flows provided a smaller range of environmental conditions, including temperature and velocity, which appeared to facilitate better colonization for a wider range of invertebrate taxa. The effective number of species increased from 2.26±0.90 to 3.63+1.71 in T1 samplers following the implementation of minimum flows (Figure 4-14). R4 diversity experienced only marginal benefits from minimum flow because of the high velocities near the thalweg and a limited source of invertebrates from upstream areas. The benefits of minimum flows on diversity on the T1 samplers in R3 were only evident during typical operating regimes (fall 2011 and 2013-2014), where peak hourly flows rarely exceeded 1,800 m^3/s.

Long-term trends

Long-term trends were not detected for either invertebrate abundance or biomass during the spring sampling sessions (2011-2019) (Figure 4-16). Invertebrate abundance was low in spring 2011 - 2013 compared to other spring sampling sessions. Spring 2014 was not sampled due to budget constraints and a transition to spring sampling thereafter. Abundance increased between 2013 and 2015 and remained consistent from 2016-2019 (Figure 4-16). Above average flows in spring 2015 caused an increase in invertebrate colonization in the lower and upper varial zones, which benefitted invertebrate production in 2015 and subsequently. The spring RF model predicted an increase in invertebrate biomass from spring 2013 – 2018 (data not shown), but a large increase only occurred between 2013 and 2015 at R4 sites. Invertebrate biomass was relatively similar for all years at R3 sites (Figure 4-16).

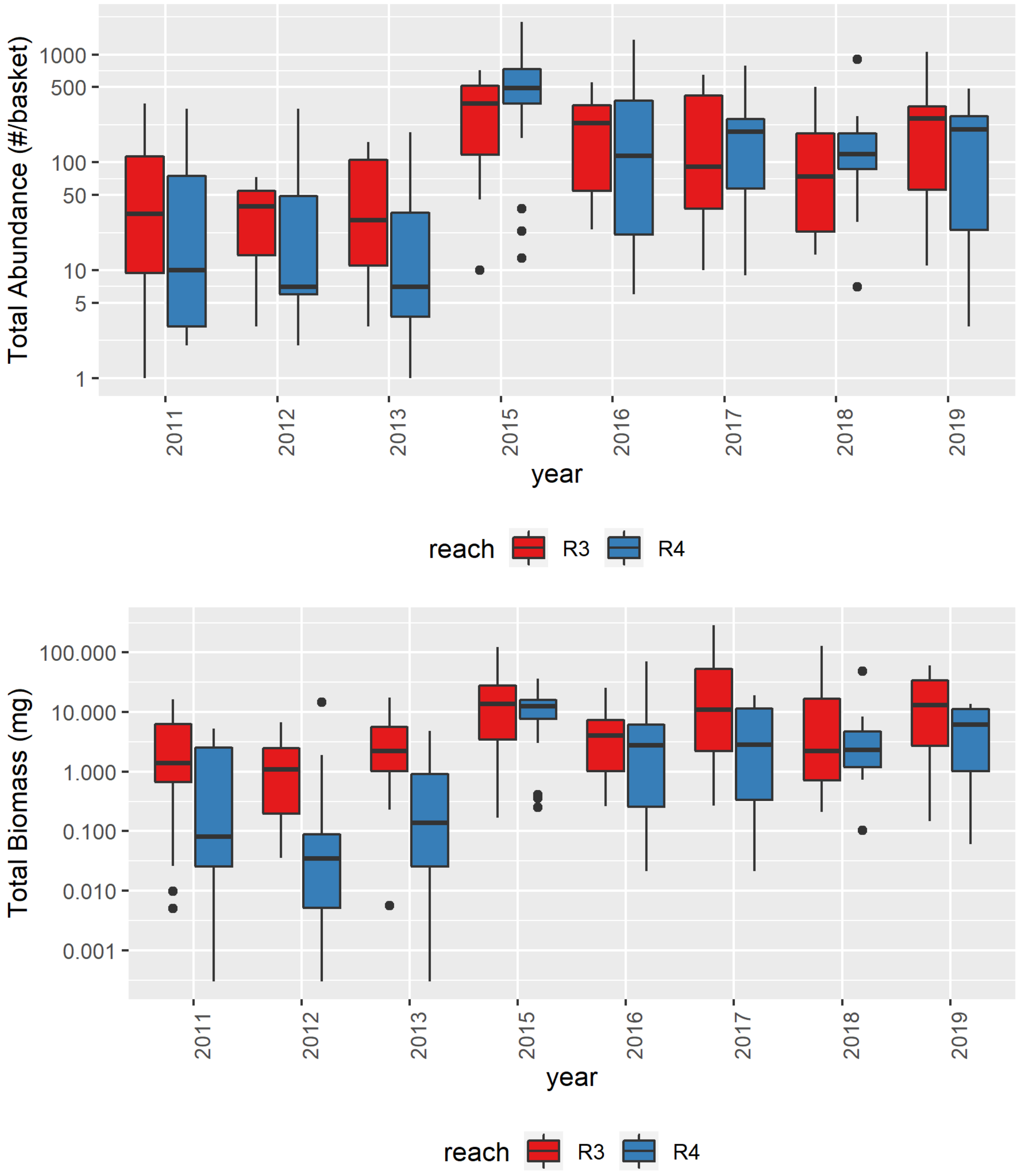

Figure 4-16: **Boxplots of invertebrate production metrics in spring for mainstem sites.**

Long-term trends (2007 -2014) were also not detected for abundance or biomass in the fall , but short-term trends occurred in response to flows (Figure 4-17). A decrease in invertebrate abundance between 2011 and 2012 was followed by an increase between 2012 and 2014. The fall RF model suggested an increase of invertebrate biomass from fall 2010 to 2011 (data not shown) which was more apparent at R3 sites. Similar to abundance, invertebrate biomass decreased between 2011 and 2012 and increased from 2012 to 2014 (Figure 4-17).

Invertebrate abundance and biomass decreased from 2011 to 2012 but increased from 2012 to 2014. Similar to other systems, the MCR invertebrate production reduced immediately after the high flows in summer and fall 2012 (Hajdukiewicz et al. 2018; Robinson et al. 2003). The invertebrate community recovered the year after because the higher flows in summer and fall 2012 increased drift and wetted habitat area, which provided higher colonization rates. The percentage of chironomids in the community was higher after the fall 2012 flood (Figure 4-17).

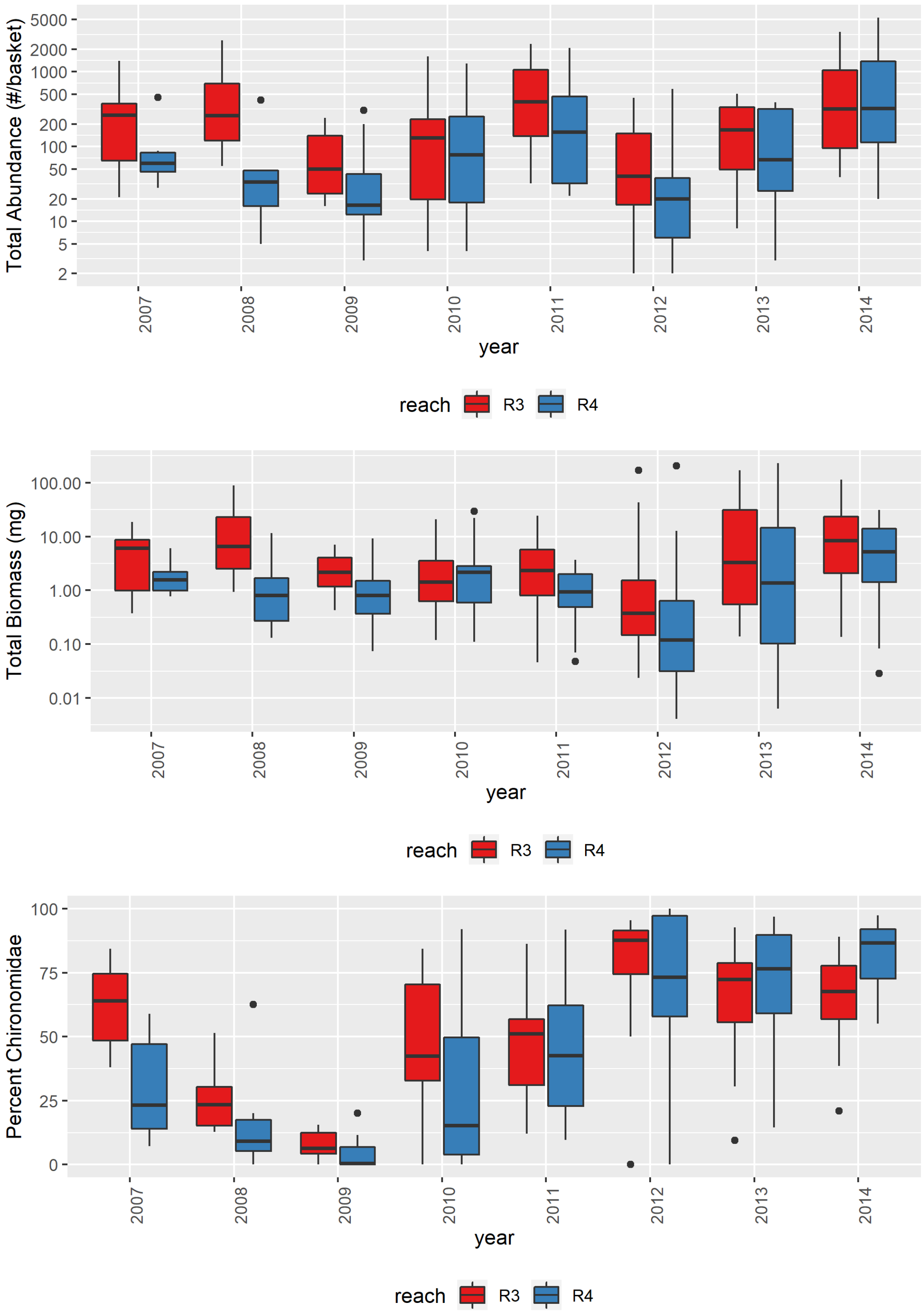

Figure 4-17: **Boxplots of invertebrate production metrics in fall for mainstem sites.**

Refer to Appendix 6 for additional results and discussion on the effects of implementing a minimum flow regime on both permanently submerged and periodically dewatered areas.

4.2.5 MQ5

MQ#5	*If changes in the benthic community associated with minimum flow releases are detected, what effect can be inferred on juvenile or adult life stages of fishes?*

Management question #5 is best addressed with Figure 4-18, which shows that the fish food index (biomass of EPT+D) at T1 and T3 for fall invertebrate samples was higher post minimum flows. After the implementation of minimum flows, R3 had a mean fish food index of 12.4±35.3 mg/basket, compared to 1.55±2.74 mg/basket before the implementation of minimum flows. In Reach 4, the mean fish food index was 0.26±0.48 mg/basket before and 7.20±13.0 mg/basket after the implementation of minimum flows.

The higher fish food index after the implementation of minimum flows was a result of an invertebrate community that had more chironomids in both reaches and more EPT in Reach 3. The mean percent biomass of the chironomids was higher in both reaches after the implementation of minimum flows (Figure 4-18).

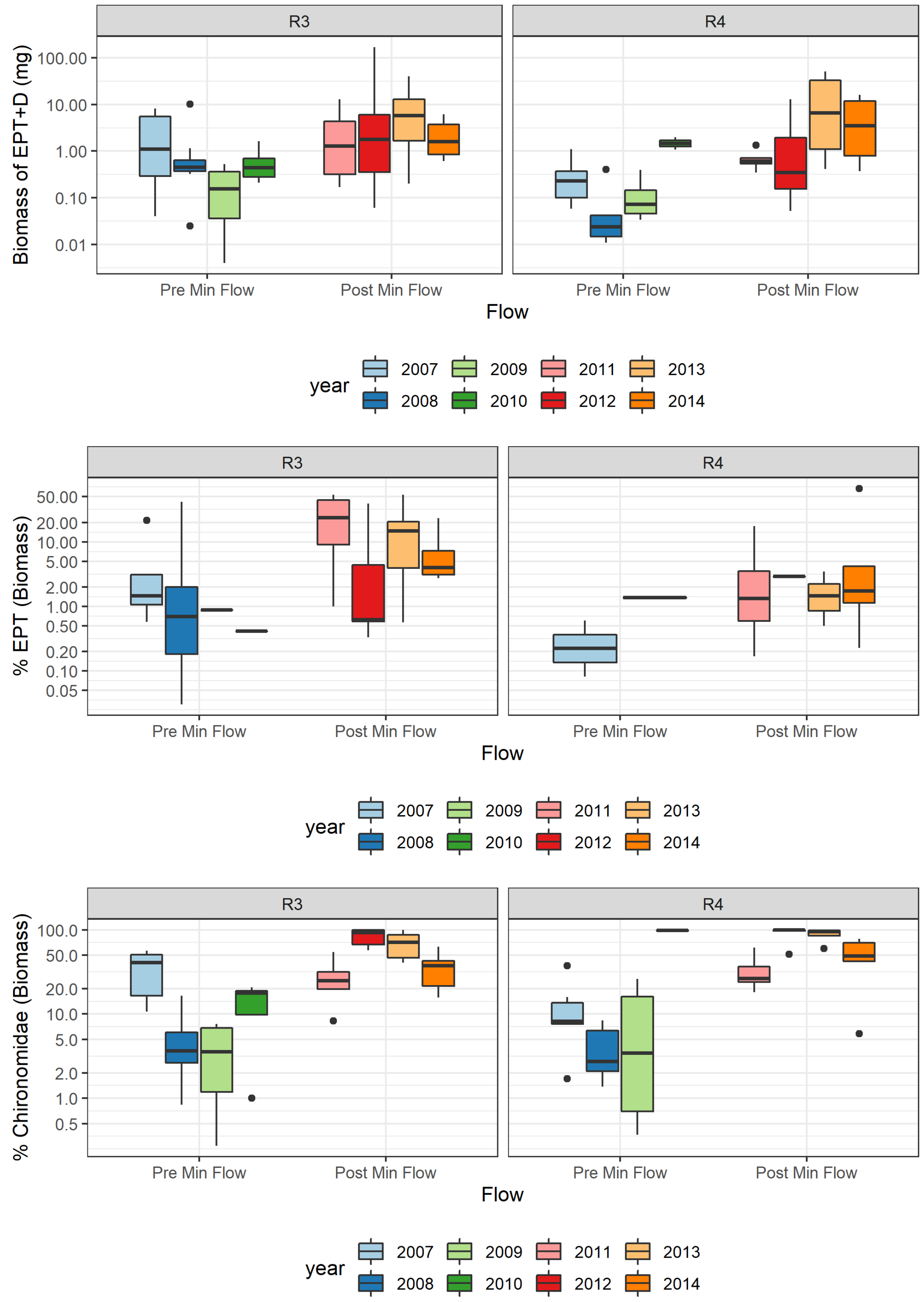

Figure 4-18: **Boxplots of fish food metrics for fall T1 and T3 samples pre-implementation of minimum flows (Pre Min Flow) and post-implementation of minimum flows (Post Min Flow).**

Despite the shifts in the benthic invertebrate community after the implementation of minimum flows the Fish Indexing Program (CLBMON-16) which specifically assessed the body condition and growth rates of adult and juvenile Mountain Whitefish (MW) and Rainbow Trout (RT) before and after the implementation of minimum flows, did not detect an effect of minimum flows in those parameters (Golder et al. 2018). Juveniles were expected to be more sensitive to changes in the availability of invertebrate fish food because they have more selective diets and primarily forage on zooplankton and chironomids (Brown 1972; Oscoz et al. 2005). However, the increases in fish food availability were likely not large enough to cause increases in body condition or growth rates. Therefore, we infer the growth rates of juvenile or adult RB and MW will not be affected by an increased availability of EPT+D. Please refer to Appendix 7 for a more detailed analysis of how the implementation of a minimum flow release affects the availability of fish food organisms in the MCR.

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6.0 APPENDIX 1. TIMELINE OF CLBMON-15B

Table A1 Timeline and Milestones of CLBMON-15b 2007 - 2019.

Year	Conducted by	Milestones
2007	Golder Associates	Start of Project. Productivity sampling occurred in R3 and R4 during fall (Sep – Oct). Sites included 1 – 7 at transect positions T1 and T3 in both reaches for 42 – 45 days. Samples included periphyton productivity, benthic invertebrates, and temperature/light data collection. Transect locations T1 and T3 were sampled to obtain data from permanently submerged and varial zone habitats. Sampler retrieval ranged from 29 - 100% due to line abrasion and flows. Vandalism also occurred at sites R3S2 and R3S1.
2008	Golder Associates	Productivity sampling occurred in R3 and R4 during fall (Sep – Oct). Sites included 1 – 7 at transect positions T1 and T3 in both reaches for 42 – 45 days. Samples included periphyton productivity, benthic invertebrate sampling, and temperature/light data collection. Fish stomach sampling and habitat measurements also occurred. Transect locations T1 and T3 were sampled to obtain data from permanently submerged and varial zone habitats. Sites R3S1 and R3S2 were re-located farther upstream due to vandalism in 2007. Sampler retrieval was 43 - 100% primarily due to anchor migration. The increase in sampler retrieval success over 2007 was attributed to stronger rope and placement of sites in lower-risk locations. No vandalism occurred.
2009	Golder Associates	Productivity sampling occurred in R3 and R4 during fall (Sep – Oct). Samplers were deployed for 46-49 days at sites 3, 5 and 6 in R3 and sites 4, 5 and 6 in R4 at transect positions T1-5. Samples included periphyton productivity, benthic invertebrate sampling, and temperature/light data collection. Ten invertebrate sampling sites were also established in R1 and R2. Fish stomach sampling and habitat measurements also occurred. Sampling expanded from transect locations T1 & T3 to include positions T1 – T5 to capture productivity on a gradient between permanently submerged and regularly exposed habitats and to increase replicate samples. Sampler retrieval was 60% - 100% primarily due tampering. Anchor migration was reduced in 2009 compared to 2008.
2010	Ecoscape	Productivity sampling occurred in R3 and R4 during the fall (Sep – Oct). Sites included 3, 5, & 6 in R3 and Sites 4, 5 & 6 in R4 at transect positions T1 – T6/7 for a minimum of 46 days. Samples included periphyton productivity, benthic invertebrate sampling, and temperature/light data collection. Ten separate time series samplers were also deployed. Natural substrate sampling for periphyton and benthic invertebrates was undertaken and drift samples were collected in R3 and R4 near artificial substrate samplers. Bench experiments on periphyton desiccation were also undertaken. Water quality data was collected in Sep 2010. Sampler retrieval was 97% - 100%.

2011	Ecoscape	Productivity sampling occurred in R3 and R4 during the fall (Sep – Oct) and spring (Apr-May). Sites included 3, 5, & 6 in R3 and Sites 4, 5 & 6 in R4 at transect positions T1 – T6 for a minimum of 44 days. Additional sampling locations included upstream and downstream of Jordan and Illecillewaet rivers (JR and IL), Big Eddy (BE), bedrock (BR), whitewater (WW), and backwater (BW). Samples included periphyton productivity, benthic invertebrate sampling, and temperature/light data collection. Ten separate time series samplers were also deployed during each season. Natural substrate sampling and drift samples were collected in R3 and R4 near artificial substrate samplers, and bench experiments on periphyton desiccation were also undertaken. Water quality data was collected in May and Sep and provided to CLBMON-15a for analysis. Sampler retrieval was 82% - 100%.
2012	Ecoscape	Productivity sampling occurred in R3 and R4 during the fall (Sep – Oct) and spring (Apr-May). Sites included 3, 5, & 6 in R3 and Sites 4, 5 & 6 in R4 at transect positions T1 – T6 for a minimum of 44 days. Additional sampling locations included Big Eddy (BE), bedrock (BR), and backwater (BW). Samples included periphyton productivity, benthic invertebrate sampling, and temperature/light data collection. Ten separate time series samplers were also deployed during each season. Natural substrate sampling and drift samples were collected and compared with data from artificial samplers. Water quality data was collected in May and Sep and provided to CLBMON-15a for analysis. Sampler retrieval was 88% - 100%.
2013	ONA & Ecoscape	Productivity sampling occurred in R3 and R4 during the spring (Apr – May) and fall (Sept – Oct). Sites included 3, 5, & 6 in R3 and Sites 4, 5 & 6 in R4 at transect positions T1 – T6 for a minimum of 46 days. Additional sampling locations included Big Eddy (BE), bedrock (BR), and backwater (BW). Samples included periphyton productivity, benthic invertebrate sampling, and temperature/light data collection. Ten separate time series samplers were also deployed during each season. Sampler retrieval ranged from 96 - 98%.
2014	ONA & Ecoscape	Productivity sampling occurred in R3 and R4 during the fall (Sep – Oct). Sites included 3, 5, & 6 in R3 and Sites 4, 5 & 6 in R4 at transect positions T1 – T6 for a minimum of 46 days. Additional sampling locations included Big Eddy (BE), bedrock (BR), and backwater (BW). Samples included periphyton productivity, benthic invertebrate sampling, and temperature/light data collection. Ten separate time series samplers were also deployed during each season. Sampler retrieval was 96%.
2015	ONA & Ecoscape	Productivity sampling occurred in R3 and R4 during the spring (Apr– May). Sites included 3, 5, & 6 in R3 and Sites 4, 5 & 6 in R4 at transect positions T1 – T6 for a minimum of 46 days. Additional sampling locations included Big Eddy (BE), bedrock (BR), and backwater (BW). Samples included periphyton productivity, benthic invertebrate sampling, and temperature/light data collection. Ten separate time

		series samplers were also deployed during each season. Sampler retrieval was 92 - 100%.
2016	ONA & Ecoscape	Productivity sampling occurred in R3 and R4 during the spring (Apr–May). Sites included 3, 5, & 6 in R3 and Sites 4, 5 & 6 in R4 at transect positions T1 – T6 for a minimum of 44 days. Samples included periphyton productivity, benthic invertebrate sampling, and temperature/light data collection. Ten separate time series samplers were also deployed during each season. Sampler retrieval was 94%.
2017	ONA & Ecoscape	Productivity sampling occurred in R3 and R4 during the spring (Apr–May). Sites included 3, 5, & 6 in R3 and Sites 4, 5 & 6 in R4 at transect positions T1 – T6 for a minimum of 44 days. Samples included periphyton productivity, benthic invertebrate sampling, and temperature/light data collection. Ten separate time series samplers were also deployed during each season. Sampler retrieval was 94 100%.
2018	ONA & Ecoscape	Productivity sampling occurred in R3 and R4 during the spring (Apr–May). Sites included 3, 5, & 6 in R3 and Sites 4, 5 & 6 in R4 at transect positions T1 – T6 for a minimum of 44 days. Samples included periphyton productivity, benthic invertebrate sampling, and temperature/light data collection. Ten separate time series samplers were also deployed during each season. Sampler retrieval was 86 - 94%.
2019	ONA & Ecoscape	Productivity sampling occurred in R3 and R4 during the spring (Apr–May). Sites included 3, 5, & 6 in R3 and Sites 4, 5 & 6 in R4 at transect positions T1 – T6 for a minimum of 44 days. Samples included periphyton productivity, benthic invertebrate sampling, and temperature/light data collection. Ten separate time series samplers were also deployed during each season. Sampler retrieval was 97 - 100%.

7.0 APPENDIX 2. PERIPHYTON AND INVERTEBRATE SAMPLING METHODS

This section provides a detailed description of the sampling methodology used to collect and analyze periphyton and benthic invertebrate data. Additional methods, specific to addressing each management question, are presented in the respective management question appendices.

7.1 Artificial Substrate Sampler Construction and Retrieval

The artificial substrate sampler design remained relatively consistent between 2007 – 2019 with few minor alterations to address site conditions. Each substrate sampler consisted of a periphyton plate and an invertebrate sampler (see Figure 3-2 in Methods). The periphyton plate assembly consisted of a 30 cm x 60 cm sheet of open celled Styrofoam attached to a waterproofed plywood surface of the same dimensions using duct tape. That plate was bolted to a 76 cm x 91 cm angle iron frame that remained stable when laid on the river bottom. The bottom of the plywood was painted bright orange so field crews could identify if the plate flipped upside-down during deployment in deeper water. The invertebrate samplers consisted of a wire “chicken barbeque” basket measuring 30 cm x 14 cm x 14 cm (planar surface area = 0.042 m^2), similar to that described by Merritt *et al.* (1996). The baskets were filled with gravel (size range of 2.5 to 3.5 cm) and closed shut with cable ties. Typically, a single artificial substrate sampler consisted of an assembled periphyton plate attached to a 30 lb 4-pronged claw anchor (with ~ 1 m of chain) connected to a 20 m, 3/8” diameter rope. A separate 25 m 3/8” diameter rope connected the anchor to an A0 or A1 float (in high velocity sites), or an LD2 or LD3 in float (in lower velocity sites). The invertebrate sampler was connected to the periphyton plate by a carabineer.

Artificial substrate samplers were deployed seasonally within the incubation period (40 days) required for attainment of peak biomass (Perrin *et al.,* 2004) and retrieved either by boat, truck, or on foot depending on site and water level. Some periphyton and benthic samples were lost due to equipment failure, anchor mobilization, scour of periphyton plates due to flow or retrieval, or breaking of invertebrate samplers. A summary of deployment and retrieval of spring 2019 samplers is provided in Table A2 , as this data has not been previously reported. The following describes the basic procedure used to retrieve the artificial substrate samplers and collect biological samples between 2007 and 2019. This procedure was based on testing by Perrin *et al.* (2004):

1. The float line was captured with a boat hook and the float was brought on-board the vessel,

2. The boat moved into position over the anchor while the rope was gathered and coiled neatly in a bucket next to the gunnel (float still attached),

3. The anchor was gently pulled free allowing the basket and plate array to rise into the water column,

4. Once the sampler array was off the bottom, the boat was allowed to drift and the samplers were slowly retrieved through the water column to a point where the basket and plate were suspended just below the water surface alongside the boat,

5. A scoop net equipped with 250 µm mesh net was placed under the basket; the basket was unclipped from the sampler line, lifted on board, and placed into a large plastic bucket pre-filled with river water containing a waterproof site label.
6. The plate, float line, and float were lifted on board and periphyton samples were taken.

Table A2 Summary of artificial substrate sampler deployment and retrieval in 2019.

Season	Reach	Site	Periphyton Samplers		Invertebrate Basket Samplers	
			# Deployed	# Retrieved (% Recovery)	# Deployed	# Retrieved (% Recovery)
Spring (April 8 – May 23 2019)	Reach 4 (R4)	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)
	Reach 3 (R3)	Site 6 (S6)	6	6 (100)	6	5 (83)
		Site 5 (S5)	6	6 (100)	6	6 (100)
		Site 3 (S3)	6	6 (100)	6	6 (100)
2019 Totals			**36**	**36 (100)**	**36**	**35 (97)**

7.2 Post Processing of Periphyton Samples

Four Styrofoam punches (2010 – 2019; two in 2007 - 2009) were randomly collected from each sampler to assess the following metrics:

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

At the time of collection, Styrofoam punches were placed in pre-labeled containers and stored on ice in the dark until further processing. One 6.6 cm^2 punch was frozen and delivered to the Cultus Lake DFO Lab (2007 – 2012) or Caro Analytical Labs in Kelowna, BC (2013 – 2019) for the processing of low-detection limit fluorometric chl-a analysis (Nusch, 1980; Holm-Hansen *et al*. 1965). A 56.7 cm^2 punch was chilled and transferred to Caro Labs in Kelowna BC for analysis of dry weight and ash free dry weight (2010 – 2019). The remaining 6.6 cm^2 punches were used for taxonomic identification that was completed by H. Larratt, with initial QA/QC and taxonomic verifications provided by Dr. J. Stockner between 2010 – 2019, and by D. Dolecki of Invertebrates

Unlimited, Vancouver BC between 2007 - 2009. Chilled samples were examined within 48-hrs for protozoa and other microflora that are difficult to identify from preserved samples. The final punch was preserved using Lugol's solution and was stored until taxonomic identification and biovolume measurements could be taken. Species cell density and total biovolume were recorded for each sample. A photograph archive was compiled from MCR samples. Detailed protocols on periphyton laboratory processing are available from Larratt Aquatic.

7.3 Post Processing of Invertebrate Samples

The invertebrate basket was opened in a large bucket by clipping the closure ties. Individual rocks from each basket were scrubbed with a soft brush to release clinging invertebrates. Washed rocks were then rinsed in the sample water before being placed back in the basket and stored for re-use in future years. The contents from each bucket were then captured on a 250 µm sieve, rinsed into pre-labeled containers, preserved in 97% Ethyl Alcohol (2010 – 2019) or 10% formalin (2007 – 2009), and labeled for delivery to the lab (Cordillera Consulting, Summerland BC 2010 – 2019 and Invertebrates Unlimited, Vancouver BC 2007 – 2009). At the lab, contents were passed through a 250 µm sieve to yield a macrobenthos fraction (>1 mm) and a microbenthos fraction (<1 mm and >250 µm). In this process, all animals were picked from twigs, grasses, clumps of algae, and other debris and were returned to a 1 mm sieve. Microbenthos was split into 4 to 16 parts using a large plankton splitter. Sub-samples of microbenthos were enumerated until 200 animals were counted. If there were 200 animals or less part way through the sorting of a sub-sample, that sub-sample was sorted in its entirety. If the estimated abundance of animals in the macrobenthos fraction was less than 200 animals, that fraction was enumerated in its entirety. If there were more than 200 animals, the subsample was partitioned in a level tray into four equal parts. Animals were enumerated from successive sub-samples until 200 animals were counted. Sub-sample counts were extrapolated to the total sample. The sample count was the sum of microbenthos and macrobenthos in the complete sample. The animals were identified to genus or lowest reliable taxonomic level using keys from Edmondson (1959), Merritt and Cummins (1996), and Pennak (1978) from 2007 – 2009 and The Standard Taxonomic Effort lists compiled by the Xerces Society for Invertebrate Conservation for the Pacific Northwest (Richards and Rogers, 2011) in 2010 - 2019. A reference sample was kept for each unique taxon found. A sampling efficiency of 90% was used for benthic invertebrate identification and was determined through independent sampling. Numerous other identification keys were referenced in the identification of benthic invertebrate taxa and a partial list of references is provided in Schleppe *et al.* (2012). Species abundance and biomass were determined for each sample. Biomass estimates were completed using standard regression from Benke *et al.* (1999) for invertebrates and Smock (1980) for Oligochaetes.

7.4 Artificial Substrate Sampler Assumptions

Assumptions made in the preparation of this assessment:

1. Erosion of communities along the edges of the artificial substrate were 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. Visual observations of periphyton growth on the samplers support this assumption but we do not have empirical data to support it otherwise.

2. Grazing invertebrates were 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 grazing 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.

3. Artificial substrates do not bias results toward a given algal taxa, nor do they bias towards taxa which are actively immigrating. However, data is presented in 2011 report to address potential biases of the artificial substrates, as compared to natural substrates. The intent is to understand how, if at all, periphyton production is altered on artificial substrates compared to natural substrates.

4. 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 that 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.

7.5 References

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8.0 APPENDIX 3. CONTEXT: RIVER FLOW AND PHYSICAL PARAMETERS

8.1 *Introduction*

This appendix provides a more detailed summary of REV discharges during the spring and fall sampling sessions, pre and post minimum flow conditions, and highlights other confounding factors such as annual variability and ALR backwatering.

8.2 *Methods*

Submergence ratios were estimated to examine the effect of minimum flows on areas that remained permanently wetted by minimum flow and areas that became periodically dewatered by minimum flow releases. Hourly discharge data from the REV during hypothetical spring (April 10th to May 25th) and fall (September 9th to October 25th) deployments were used to estimate submergence ratios between 2000-2010 for the permanently wetted zone and between 2000-2019 for the periodically dewatered zone. Substrate exposure was assumed for flows under 142 m^3/s in areas permanently wetted by minimum flows and 400 m^3/s in areas periodically dewatered during releases.

8.3 *Results and Discussion*

Productivity sampling occurred during spring (~April 10th – May 25th) and fall (~September 9th – October 26th). Hourly flows during these time periods were compared for 11 years pre minimum flow (2000-2010) and 9 years post minimum flow (2011-2019) to better understand the range of spring and fall operations. Several pre-minimum flow years had spring median hourly flows that were higher than most post-years (Figure A1). In the fall, the median flow did not exhibit a discernible pattern between pre- and post-years (Figure A2). This indicates that although the predicted trends of an increase in frequency of high flows and an increase in average daily discharge during low demand periods may have occurred, they were not substantial enough to result in distinct differences between pre and post median hourly flows.

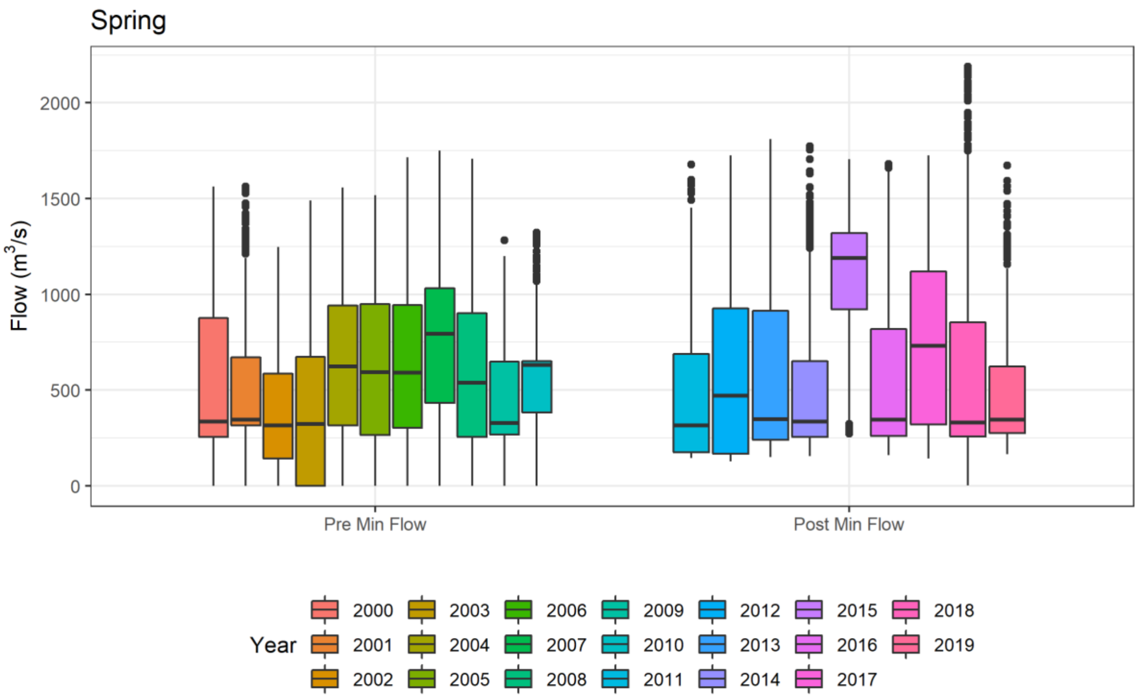

Figure A1 Boxplots of hourly flows from Revelstoke Dam from Spring (April 10th- May 25th), pre-implementation of minimum flows (Pre Min Flow) and post-implementation of minimum flows (Post Min Flow).

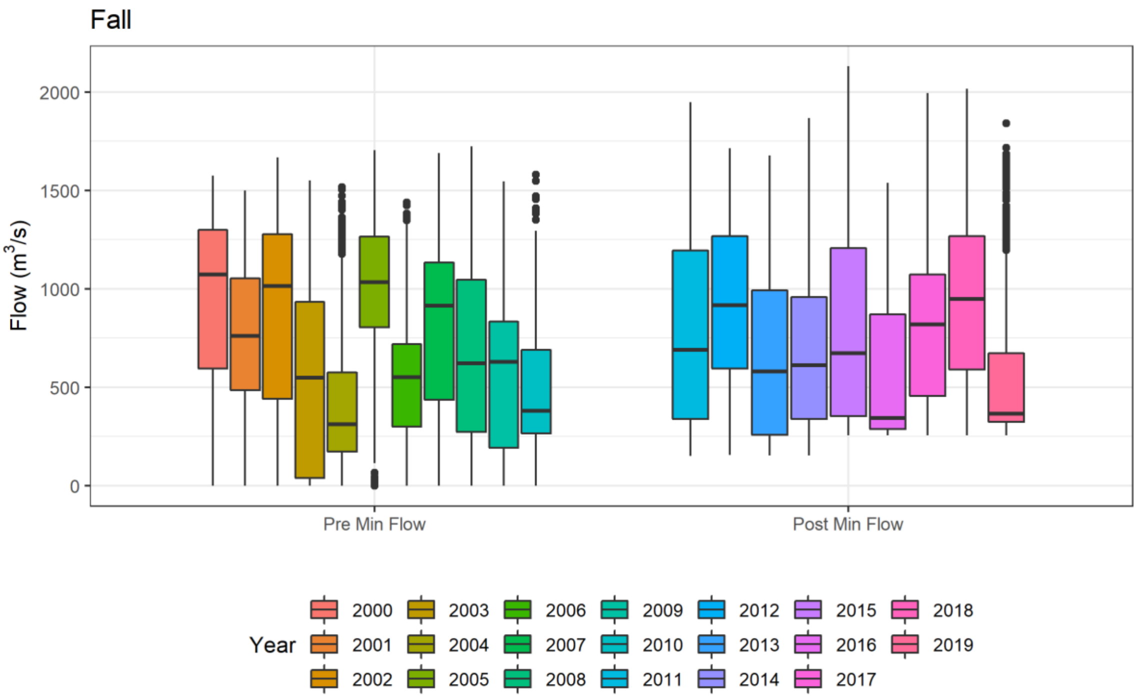

Figure A2 Boxplots of hourly flows from Revelstoke Dam from Fall (September 9th- October 26th), pre-implementation of minimum flows (Pre Min Flow) and post-implementation of minimum flows (Post Min Flow).

Hourly flows and ALR water levels determine the wetted history of substrates in the MCR. Submergence – the overflow of substrates with water – is a critical component in benthic productivity. A submergence ratio of 0 indicates no inundation of water and a submergence ratio of 1 indicates that substrates were covered with water throughout the entire deployment period. The submergence of substrates for two key areas of the river channel, the thalweg and the varial zone, were determined for both pre and post minimum flow years during the spring and fall productivity sampling sessions. It was assumed that substrate dewatering occurred in the thalweg and varial zone for flows less than 142 m^3/s and 400 m^3/s, respectively.

Before the implementation of minimum flows (2000 – 2010), the submergence ratio of the river thalweg was estimated for a 45-day period in the spring and a 47-day period in the fall (Figure A3). The median submergence ratios were 0.88 and 0.82 for spring and fall, respectively. The range of submergence was 0.65 (Spring 2003) to 0.94 (Fall 2007), illustrating substantial variability between years. These estimated submergence ratios do not account for possible backwatering that can occur from ALR. This complicating factor is discussed further in subsequent sections.

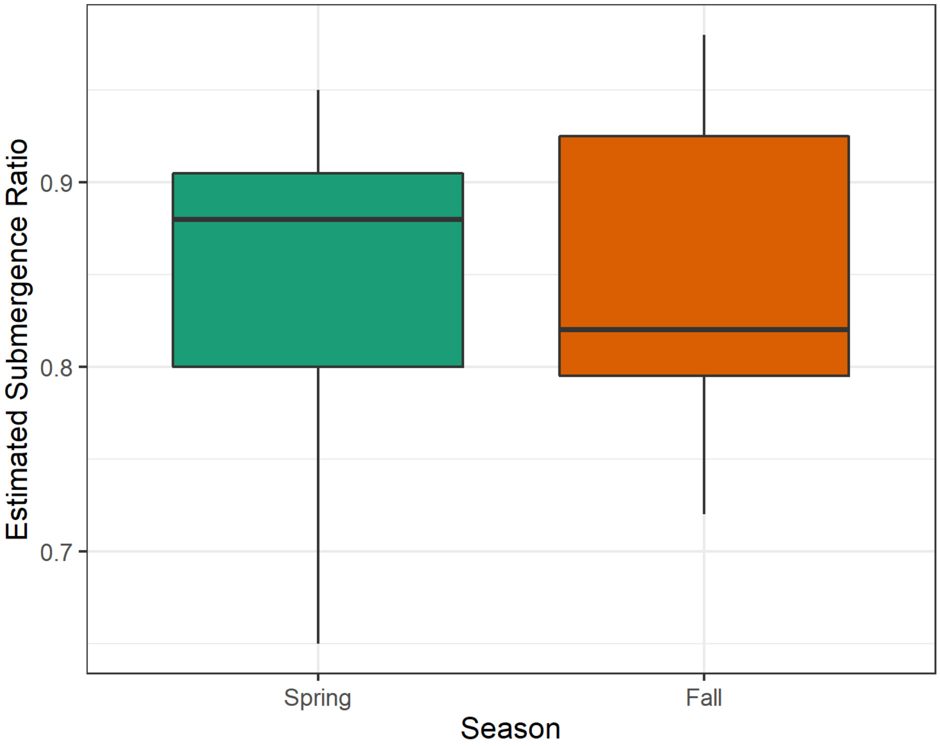

Figure A3 Boxplots of the estimated submergence ratio of the river thalweg in Spring and Fall (2000-2010) for reaches 3 and 4, before implementation of minimum flows.

Estimated submergence ratios in periodically dewatered areas were compared before and after the implementation of minimum flows. For spring, the median submergence ratio after the implementation of minimum flows (0.46; 2011-2019) was lower compared to before (0.54; 2000-2011). Spring 2015 had a very high submergence ratio of 0.93 compared to all other spring periods before and after the implementation of minimum flow.

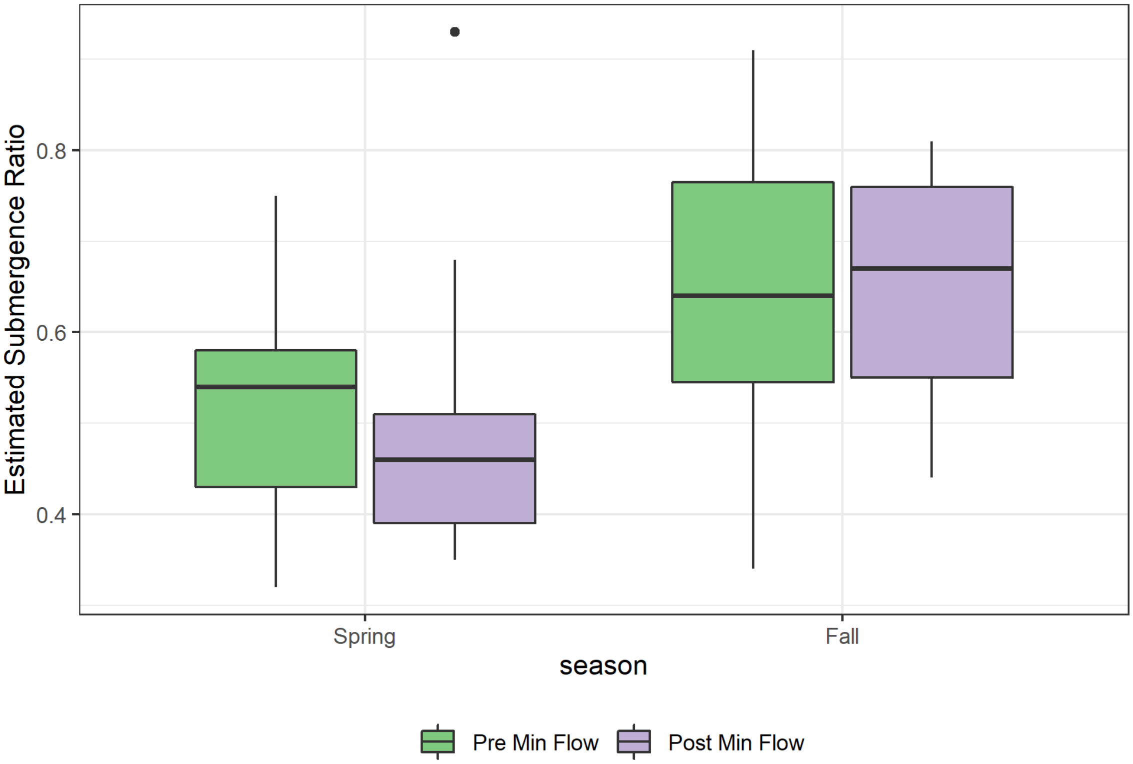

Figure A4 Boxplots of estimated submergence ratio of areas that are periodically dewatered for Spring and Fall 2000-2019.

In fall, the estimated submergence ratios in periodically dewatered areas before and after the implementation of minimum flows were comparable (Figure A4). The median submergence ratio for fall 2000-2010 was 0.64, whereas the median submergence ratio for fall 2011-2019 was 0.67. The range of estimated submergence ratios was wider before (0.34-0.91) the implementation of minimum flows than after (0.44-0.81).

8.3.1 Fall and Spring Sampling Session Flows

Mean hourly flows in the MCR followed a highly variable but predictable pattern during the spring (~April 10th – May 25th) and fall (~September 9th – October 26th) productivity sampling sessions (Figure A5 and Figure A6). Flows were highest between 7:00 and 21:00, with periods of low flow typically only occurring between 24:00 and 5:00. The in-between periods consisted of ramping up or down from the peak daily flow.

Annual variability in the mean hourly flow during the spring and fall sampling sessions was also evident (Figure A5 and Figure A6). In the spring before establishment of minimum flows, 2008 was the only year with mean hourly flows below 142 m^3/s (Figure A5). In the fall, all years (2008-2010) had mean hourly flows below 142 m^3/s (Figure A6). During fall 2007, the hourly mean flows were well above 142 m^3/s, but not as high as post minimum flow years.

Dam operations were variable in fall deployment sessions. Fall 2007, 2011, and 2012 had higher hourly mean flows from 10:00-20:00 compared to other fall deployment periods (Figure A6). Fall 2010 had lower hourly mean flows from 8:00-20:00 compared to other fall deployment periods.

The fungal/bacterial black coloration on substrates observed in Reach 4 was indicative of a low water year in fall 2010.

Dam operations were also variable in spring deployment sessions. Spring 2015 had higher average hourly flows compared to all other spring sampling sessions (Figure A5). Spring 2017 and 2018 had higher mean hourly flows compared to spring 2011-2013, 2016, and 2019. Higher peak hourly flows in spring 2017 and 2018 were associated with above average snowpack levels. Mean hourly flows were lower in spring 2019 compared to other spring sampling sessions.

The annual variability in flows was not always consistent or typical of the minimum flow-operating regime; it had a substantial effect on benthic productivity and confounded whether or not minimum flows benefited benthic production.

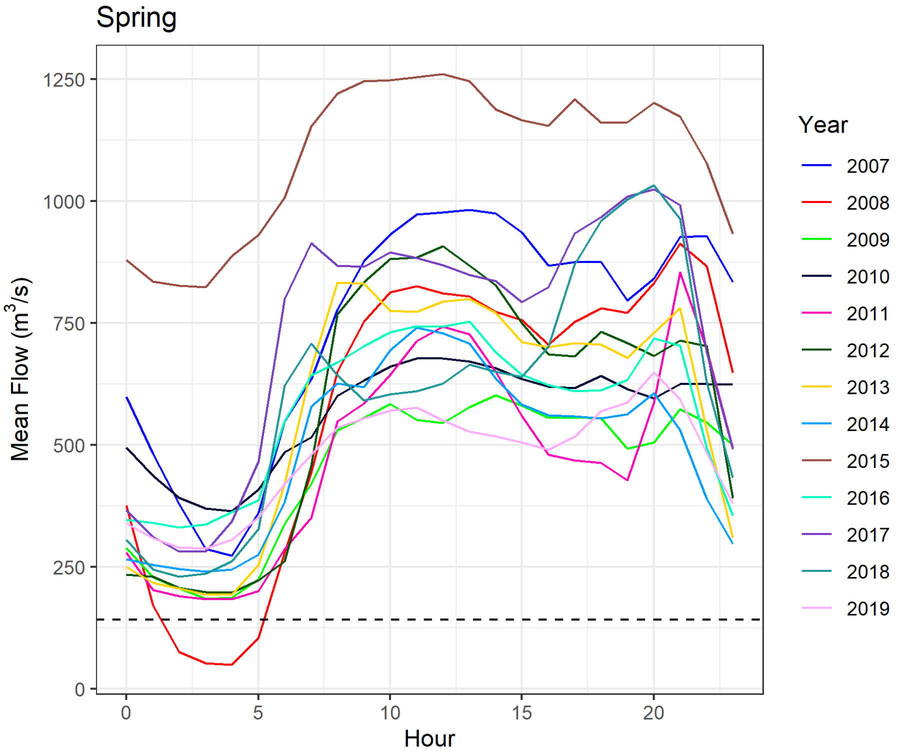

Figure A5 **Summary of mean hourly flows during the spring sampling period for all years of the study. The horizontal dotted line indicates the minimum flow of 142 m3/s.**

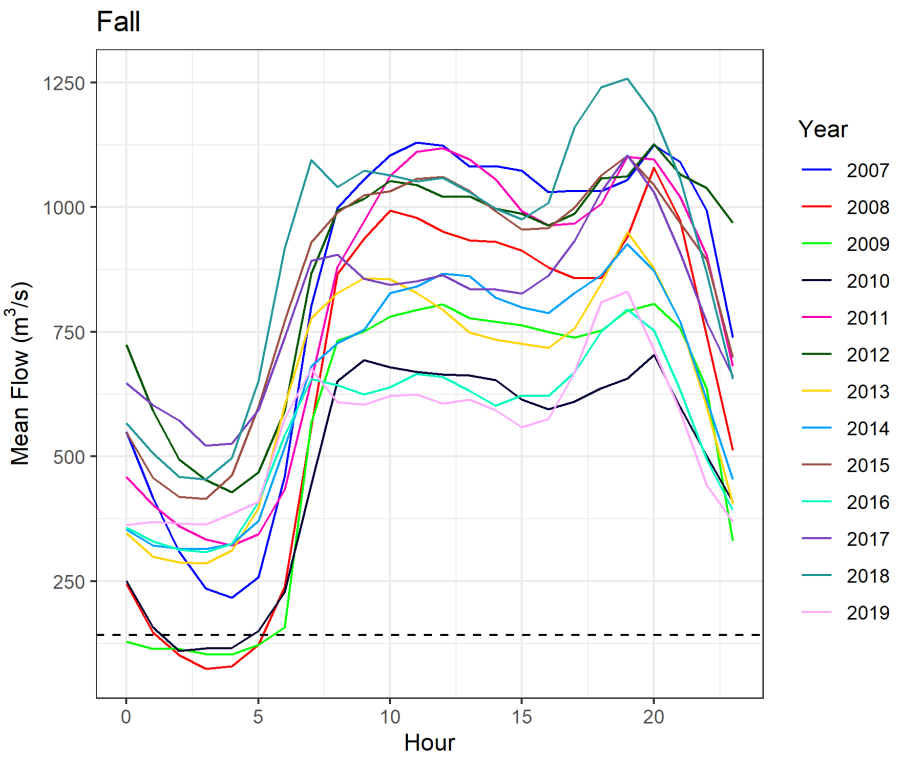

Figure A6 Summary of mean hourly flows during the fall sampling period for all years of the study. The horizontal dotted line indicates the minimum flow of 142 m3/s.

Peak hourly flows can cause shearing of algae and loss of benthic invertebrates through drift, which ultimately can change the benthic community composition due to a greater loss of species that are morphologically more susceptible to high flows. The number of hours over 1800 m^3/s was calculated for each deployment period. Peak flows rarely exceeded 1800 m^3/s during most fall and spring sampling sessions (Table A3), but did so in fall 2012 for 27 hours and spring 2018 for 40 hours. The maximum flow in fall 2012 reached the capacity of REV5.

Table A3 Summary of minimum and maximum hourly flows for spring and fall deployment periods.

Year	Season	Minimum	Maximum	Hours under 142 m^3/s	Hours over 1800 m^3/s
2007	Fall	0.00	1,689.04	119	0
2008	Fall	0.00	1,724.17	218	0
2009	Fall	0.00	1,588.36	280	0
2010	Fall	0.00	1,591.74	201	0
2011	Fall	150.56	1,948.57	0	2
2012	Fall	154.46	2,160.58	0	27
2013	Fall	153.68	1,677.80	0	0
2014	Fall	152.38	1,866.69	0	4
2011	Spring	145.38	1,677.77	0	0
2012	Spring	127.72	1,725.88	1	0
2013	Spring	150.07	1,810.06	0	1
2015	Spring	156.91	1,705.20	0	0
2016	Spring	159.84	1,680.20	0	0
2017	Spring	141.64	1,529.40	2	0
2018	Spring	1.79	2,187.97	3	40
2019	Spring	163.95	1,673.39	0	0

8.3.2 Velocities

The maximum velocities were predicted for each spring deployment period in Plewes et al. (2019) and are displayed in Figure A7. Maximum velocities of R3 samplers were lower than R4 maximum velocities of samplers. In R4, the maximum velocities were highest near the thalweg at T1 (Plewes et al. 2019). Spring 2018 had the highest maximum velocities in both reaches and was the only spring deployment period that had flows at the capacity of REV5 (Table A3).

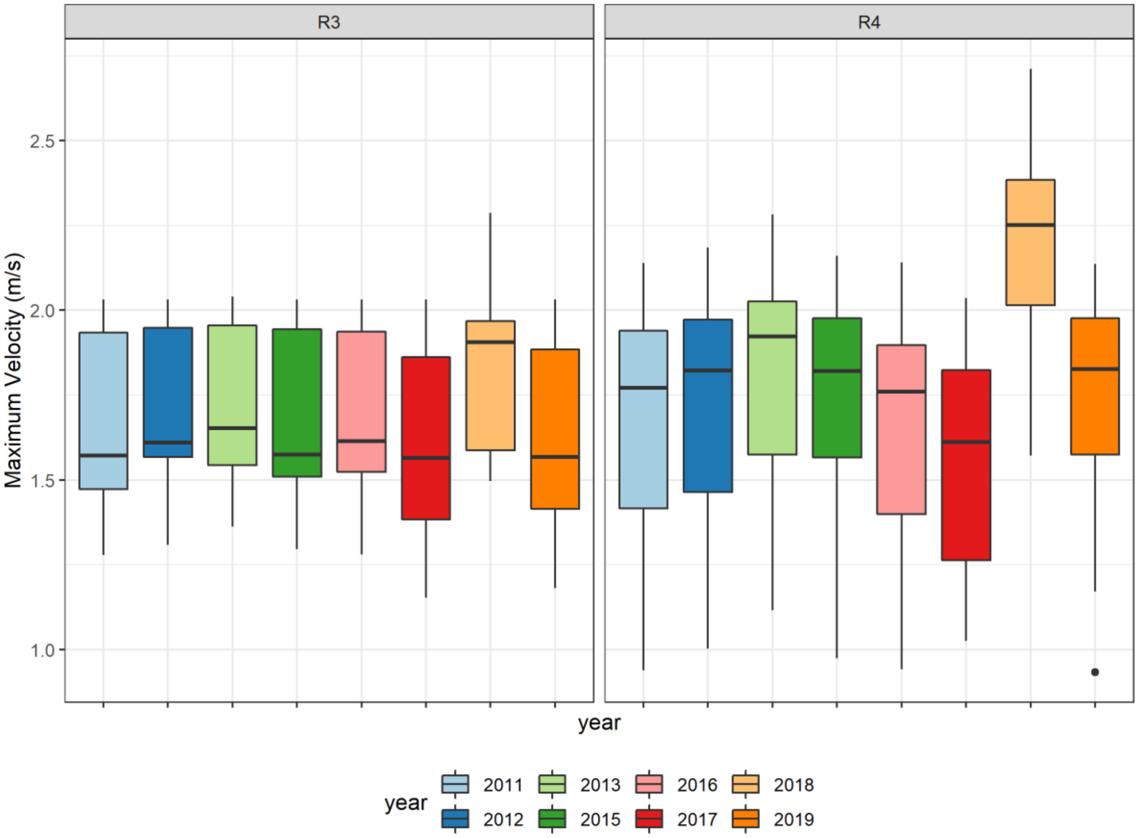

Figure A7 **Predicted maximum velocities for spring samplers from 2011-2019.**

8.3.3 Arrow Lakes Reservoir Elevations

The Arrow Lakes Reservoir (ALR) is situated between the Revelstoke (REV) and Hugh Keenleyside (HLK) Dams. ALR water levels are controlled by the HLK near Castlegar, British Columbia. When flows are held back at HLK, ALR water levels increase and backwater into the MCR study area. Water levels greater than 432 m.a.s.l., resulted in the backwatering of R3, and those than 436 m.a.s.l. backwatered into both R3 and R4. During spring, lower water levels in ALR resulted in less backwatering in the MCR (Figure A8). HLK Dam operations produced variable water levels in the ALR during the fall deployment sessions. High ALR water levels in fall 2008 and 2011 resulted in backwatering through all of R3 and parts of R4 (Figure A8).

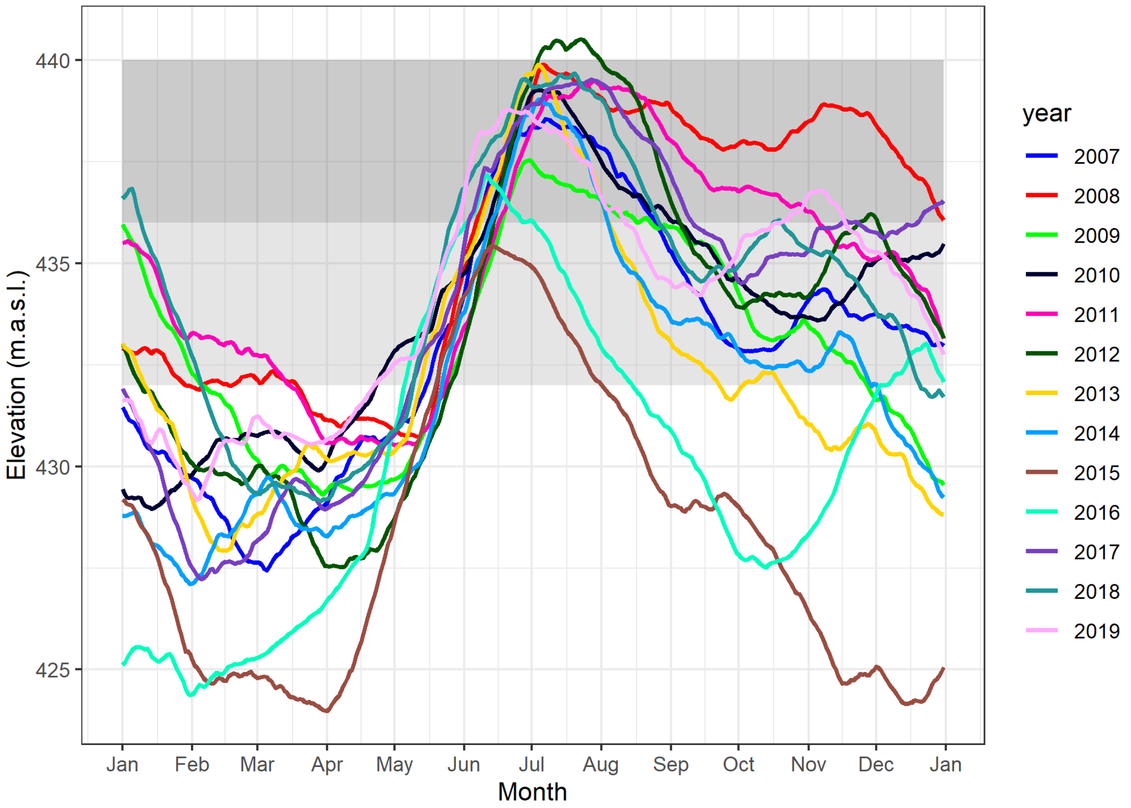

Figure A8 Backwatering of Arrow Lakes Reservoir (ALR) into the MCR Reach 3 (R3) and Reach 4 (R4). The vertical axis shows elevations in the normal operating range of ALR. Light grey shading denotes when R3 was backwatered; dark grey shading denotes when R3 and R4 were backwatered.

8.3.4 Water Temperature

Daily variations in MCR water temperature are most affected by the temperature/flow of tributaries and by Revelstoke Reservoir conditions upstream (Larratt et al. 2013; Olson-Russello et al. 2019). Mean water temperatures in spring deployment periods varied more than those during fall deployment periods. Mean water temperatures in fall 2010-2014 ranged from 10.1°C to 11.1°C (Figure A9) and spring mean water temperatures in the same years ranged from 3.7°C to 6.7°C (Figure A10). Spring water temperatures exceeded 5°C in 2013, 2015 and 2016 but were closer to 4°C in 2011, 2012, and 2017-2019.

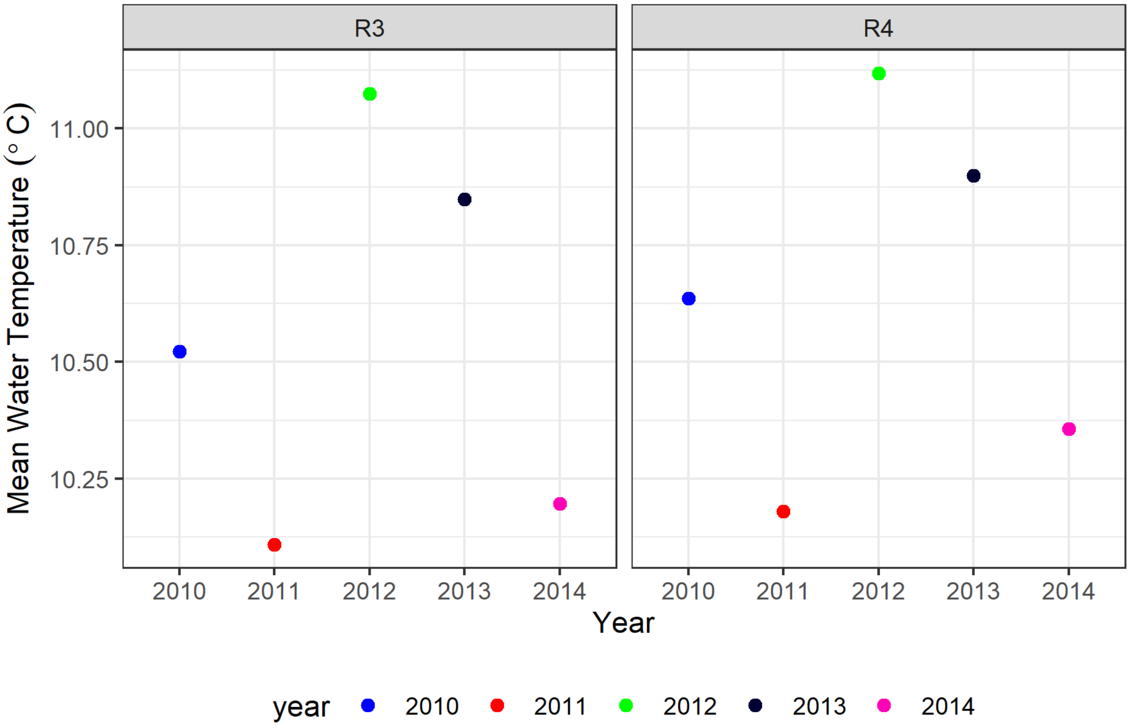

Figure A9 Mean water temperatures for R3 and R4 mainstem samples for fall 2010-2014.

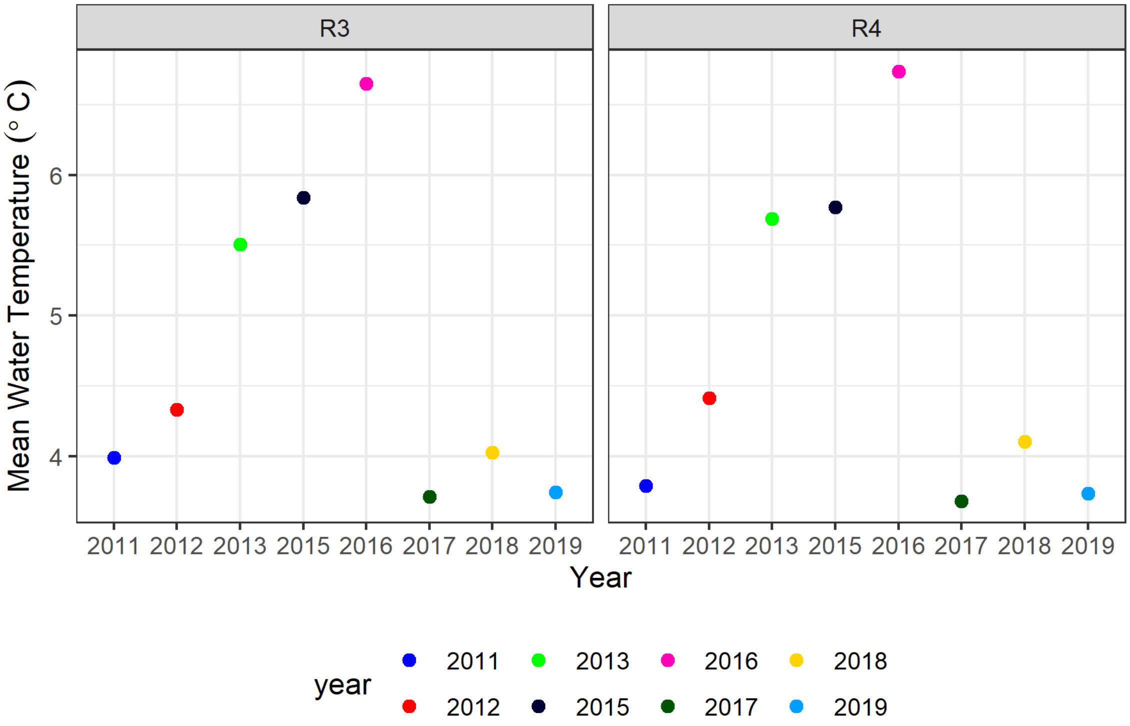

Figure A10 Mean water temperatures for R3 and R4 mainstem samples for spring 2011-2019.

8.3.5 Summary

Annual variation in operations resulted in large differences in submergence and maximum velocities for some spring and fall sampling sessions. Table A4 summarizes operating conditions that were atypical for the MCR in fall and spring. The ALR water levels in fall 2008 and 2011 were higher than other fall sampling sessions. Extensive backwatering caused an increase in substrate submergence and a reduction in velocities. More submergence near the thalweg occurred in fall 2007 compared to other fall pre minimum flow years because fall 2007 had the lowest number of hours under flows of 142 m^3/s. Fall 2012 and spring 2018 experienced high hourly peak hourly flows that resulted in high maximum velocities. Higher mean hourly flows in spring 2015 compared to all other spring sampling sessions resulted in increased submergence throughout the varial zone of the river.

Table A4 Summary of spring and fall sampling sessions that had atypical operating conditions.

Deployment Period	Season		Atypical Operations
	Spring	Fall	
2007		X	Low # of hours below min flow
2008		X	Extensive ALR backwatering
2009		X	
2010		X	
2011	X	X	Extensive ALR backwatering (F)
2012	X	X	High peak hourly flows (F)
2013	X	X	
2014		X	
2015	X		High mean hourly flows
2016	X		
2017	X		
2018	X		High peak hourly flows
2019	X		

8.4 *References*

Larratt, H., J., Schleppe, M.A., Olson-Russello, and N., Swain. 2013. Monitoring Study No. CLBMON-44 (Year 5) Lower Columbia River Physical Habitat and Ecological Productivity, Study Period: 2012. Report Prepared for BC Hydro, Castlegar, British Columbia. 97 p. Report Prepared by: Ecoscape Environmental Consultants Ltd.

Olson-Russello, M.A., H. Larratt, R. Plewes. (2019). CLBMON-44 Lower Columbia River Physical Habitat and Ecological Productivity Monitoring Final Report – 2008 – 2019. Ecoscape Environmental Consultants Ltd. Unpublished report by Ecoscape Environmental

Consultants Ltd. And Larratt Aquatic Consulting Ltd., BC for BC Hydro Generations, Water License Requirements, Burnaby, B.C. 28 pp + Appendices 1-8.

R. Plewes, H. Larratt, J. Schleppe , A. Duncan. (2019). CLBMON-15b Middle Columbia River Ecological Productivity Monitoring, Annual Report 2018. Okanagan Nation Alliance with Ecoscape Environmental Consultants Ltd. & Larratt Aquatic Consulting Ltd. 80 pp.

9.0 APPENDIX 4. MQ #1

9.1 Introduction

This appendix further addresses management question # 1. There are no specific hypotheses associated with this question.

> *MQ#1:* *What is the composition, distribution, abundance, and biomass of periphyton and benthic invertebrates in the section of MCR subjected to the influence of minimum flows?*

9.2 Methods

Periphyton and benthic invertebrate samples were collected using methods described in *Appendix 2*. The composition and abundance of the periphyton community was determined from algal cell counts by species from periphyton that was removed from a Styrofoam punch taken at each site and transect depth using a fine spray from a dental cleaning instrument. Spraying was done within an enclosed chamber to avoid loss of cells. The removed biomass was washed and concentrated into a Utermohl chamber. Contents were allowed to settle in the chamber over 24 hours. For each transect, cells were counted using a Carl Zeiss inverted microscope at 500x mag. Only intact cells containing cytoplasm were counted. A minimum of 100 individuals of the most abundant species and a minimum of 300 cells total were counted per sample. Cells of filamentous taxa were separated from counts of unicellular taxa.

Biomass of benthic invertebrate genera was determined using Zoobbiom Version 1.3 (Hopcroft 1991). The digitizing system included a dissecting microscope, drawing tube, digitizing SummaSketch III tablet with a cross-hair mouse equipped with a diode, and the digitizing program used to process the data. The software was customized for select genera and consequently specific measurements were required for each taxon. Biomass was determined from single measurements of individuals with straight-shaped bodies whereas multiple measurements were made along a curve for organisms with bent bodies. The drawing tube transferred a point of light emitted by a diode on the mouse and made it appear on the image viewed through the microscope. When the images of the diode and the organism overlapped, the cursor button on the mouse was clicked. The coordinates from the digitizing tablet were converted to length by the program. Individuals' biomasses were estimated through length-to-weight regressions (Benke *et al.* 1999, Smock 1980). Up to 25 random length measurements per taxon were taken per sample and the final biomass was expressed in mg/sample.

9.3 Dataset

Table A5 Datasets used in the analysis of management question #1.

Name	Data Source/Description	Years Obtained
Light / Water Temp	Data collected at each productivity sampler during each deployment session	Fall 2007-2014, Spring 2011-2013, 2015-2019 (Temp) Fall 2010-2014, Spring 2011-2013, 2015-2019 (Light)
Periphyton	Data collected at each productivity sampler during each deployment session. Data included abundance, chlorophyll-a, biovolume and associated taxonomy metrics. Additional metrics described in Table A8 were calculated.	Fall 2007-2014, Spring 2011-2013, 2015-2019
Benthic Invertebrates	Data collected at each productivity sampler during each deployment session. Data included abundance, biomass, and associated taxonomy metrics. Additional metrics described in Table A7 were calculated.	Fall 2007-2014, Spring 2011-2013, 2015-2019
Hourly Discharge at Revelstoke Dam (REV)	Data obtained from Poisson Consulting	2000-2019
Hourly Air Temperatures from Revelstoke Airport	Data obtained from Environment Canada	Fall 2010-2014, Spring 2011-2013, 2015-2019

Table A6 Metrics derived from datasets in Table A5.

Variable	Definition
Submergence Ratio	Total time submerged divided by duration of deployment
Mean Water Temperature While Submerged	Average temperature of the water for the duration of deployment

9.4 Analyses

The metrics in Table A7 and Table A8 were calculated to better understand invertebrate and periphyton productivity and community composition. Descriptive summary statistics that summarized the distribution of each invertebrate and periphyton metric were calculated to better understand the range of productivity in MCR. The data were grouped by season, dominant habitat type, and reach. Graphs were created to summarize invertebrate and periphyton growth metrics and community composition within these groups. Additional metrics to better understand benthic invertebrate community composition included EPT, chironomid and Oligochaeta taxa richness.

To better understand factors that influence the periphyton community composition in the MCR, Classification and Regression Tree (CART) models were run for percent planktic and low profile guilds. The explanatory variables used for CART models included reach, mean water temperature, submergence ratio, and year. The CART models used R package rpart version 4.1-15 (Therneau and Atkinson 2019), while ggparty version 1.0.0 was used to visualize the CART models (Borkovec and Madin 2019).

CART models do not make assumptions about data distribution and can handle nonparametric data and interactions between explanatory variables (De'ath and Fabricius, 2000). CART initially partitions the data into two groups based on a split point and splitting variable that minimizes the sum of squares of the response variable of each group (De'ath and Fabricius 2000; Hastie et al. 2001). A recursive algorithm is used to search through every possible combination of explanatory variables and values to determine the best splitting variable and split point (Hastie et al. 2001). The CART algorithm continues to make binary splits at each tree node until a stopping criterion is reached (June 2013).

Table A7 Responses for Benthic Invertebrates.

Variable	Description
Total Abundance	Total Abundance across all species
Total Biomass	Total Biomass across all species
Percent EPT	The percentage of Ephemeroptera, Plecoptera, and Trichoptera based on abundance
Species Richness	Number of unique species
Percent Chironomidae	The percentage of Chironomids based on abundance
Percent Oligochaeta	The percentage of Oligochaetes based on abundance
Percent Hydrozoan	The percentage of Hydrozoan based on abundance

Table A8 Responses for Periphyton.

Variable	Description
Total Abundance	Total Abundance across all species
Total Biovolume	Total Biovolume across all species
Chlorophyll-a	Density of Chlorophyll-a
Species Richness	Number of unique species
Effective Number of Species	A measure of community diversity that is the e^s. S= Shannon-Wiener index.
Percent High Profile Guild	The percentage of high profile guild based on abundance
Percent Low Profile Guild	The percentage of low profile guild based on abundance
Percent Motile Guild	The percentage of motile guild based on abundance
Percent Planktic Guild	The percentage of planktic guild based on abundance

The benthic invertebrate and periphyton sampling design did not include true replicates. There was pseudo-replication among benthic invertebrate and periphyton samples. The level of pseudo-replication was difficult to determine but expected to occur at the sample level between sampling sessions and could occur at the site level. The statistical tests used assumed that samples were not independent of one another at a site within a given year. It was assumed that because of different REV operating conditions, samples were not pseudo-replicated in different years.

Spring and fall invertebrate and periphyton metrics were compared to determine seasonal differences in abundance, biomass, and community composition of invertebrate and periphyton. A Wilcoxon signed rank test was performed because the invertebrate metrics could not be transformed to meet the normality assumptions of a paired t-test. The paired Wilcoxon signed rank test was performed with sample pairs from fall and spring 2011-2013 for the invertebrate metrics of abundance, biomass, percent Chironomidae, percent Oligochaeta, and percent Hydrozoan. Likewise, the sample pairs from fall and spring 2011-2013 for the periphyton metrics of abundance, biovolume, chlorophyll-a, percent low profile, percent high profile and percent motile guild were compared using the paired Wilcoxon signed rank test.

Differences in the distribution of invertebrates and periphyton across the river channel were explored statistically and visually through graphs. The non-parametric Friedman rank sum test for un-replicated block data was used because the invertebrate and periphyton community composition and productivity metrics did not meet the assumptions for a one- way ANOVA with repeated measures test. The invertebrate and periphyton metrics were compared between transects (T1-T6) using the combination of season, year, and site as the blocking variable. Only season, year, and site combinations with complete datasets could be included in this analysis. For invertebrate and periphyton metrics that had significant differences across transects, the Conover post-hoc test was used to determine pairwise differences.

9.5 Results

9.5.1 Periphyton

In considering all 13 years of this study, diatoms accounted for over 90% of the biovolume in both seasons and both reaches. The dominant MCR diatom species were either the low profile guild - rapid colonizing diatoms with firm attachment strategies, or large planktonic guild taxa imported from Revelstoke Reservoir that adhered to the periphyton biofilms. Green algae accounted for <10% overall, flagellates for <3% and cyanobacteria for <1%. With a mean taxa richness of ~20 ± 6 over all years, species richness in the MCR was lower than is typical for unregulated large rivers of similar latitude.

Increased fall filamentous green algae growth was observed in R4 and R3 after 2010 under the new flow regime. Filamentous growth in the Reach 4 at the edge of the permanently wetted and lower varial zone (T2-T4) may continue to gradually increase over the years since minimum flows were implemented. Filamentous green algae were also prevalent in the spring 2012/2013 samples but uncommon (>4% abundance and biovolume) during all subsequent spring sampling sessions (Figure A11).

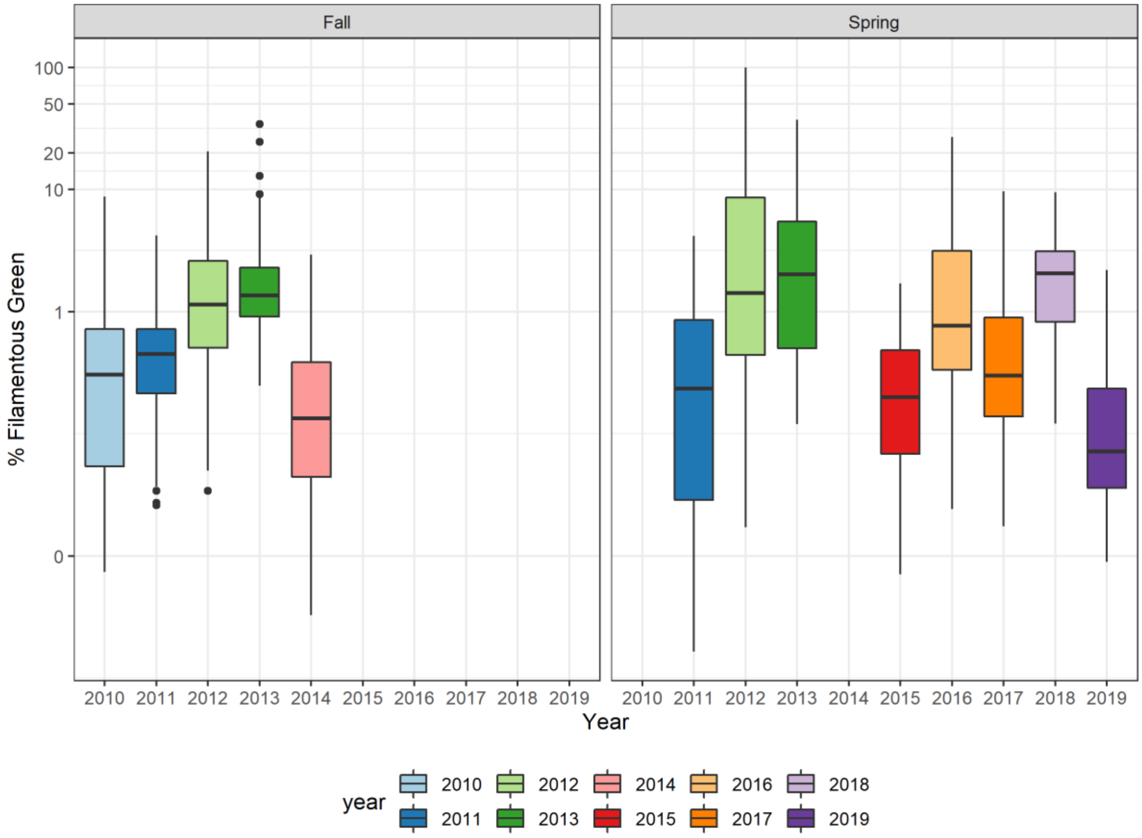

Figure A11 **Percent Filamentous Green algae by biovolume for all sites fall 2010-2014 and spring 2011-2013, 2015-2019.**

A key aspect of MCR flow regime affected by both BC Hydro releases and by watershed hydrology is backwatering of Arrow Lakes Reservoir (ALR). This seasonal water cover reduces desiccation on riverine substrates that would otherwise be exposed by low flow releases, particularly in fall and in R3. The Reach 3 upper varial zone is the most variable region for periphyton productivity in the MCR. With continuous backwatering, it can exceed the productivity of deeper areas but in seasons without backwatering, it can have minimal productivity. For example, with backwatering, upper varial zone biovolume increased by ~192% from fall 2011 to fall 2013, resulting in far greater periphyton growth throughout the R3 upper varial zone (Figure A12).

Periphyton community composition in the R3 upper varial zone was less variable than productivity in both seasons. Differences in the percent guild metrics in the R3 upper varial were likely a result of different extents in ALR backwatering in Fall. ALR backwatering in R3 was minimal in Fall 2013 compared to other fall sampling sessions. Minimal backwatering in Fall 2013 likely contributed to a higher percent motile guild in the R3 upper varial zone compared to other fall sampling sessions (Figure A13).

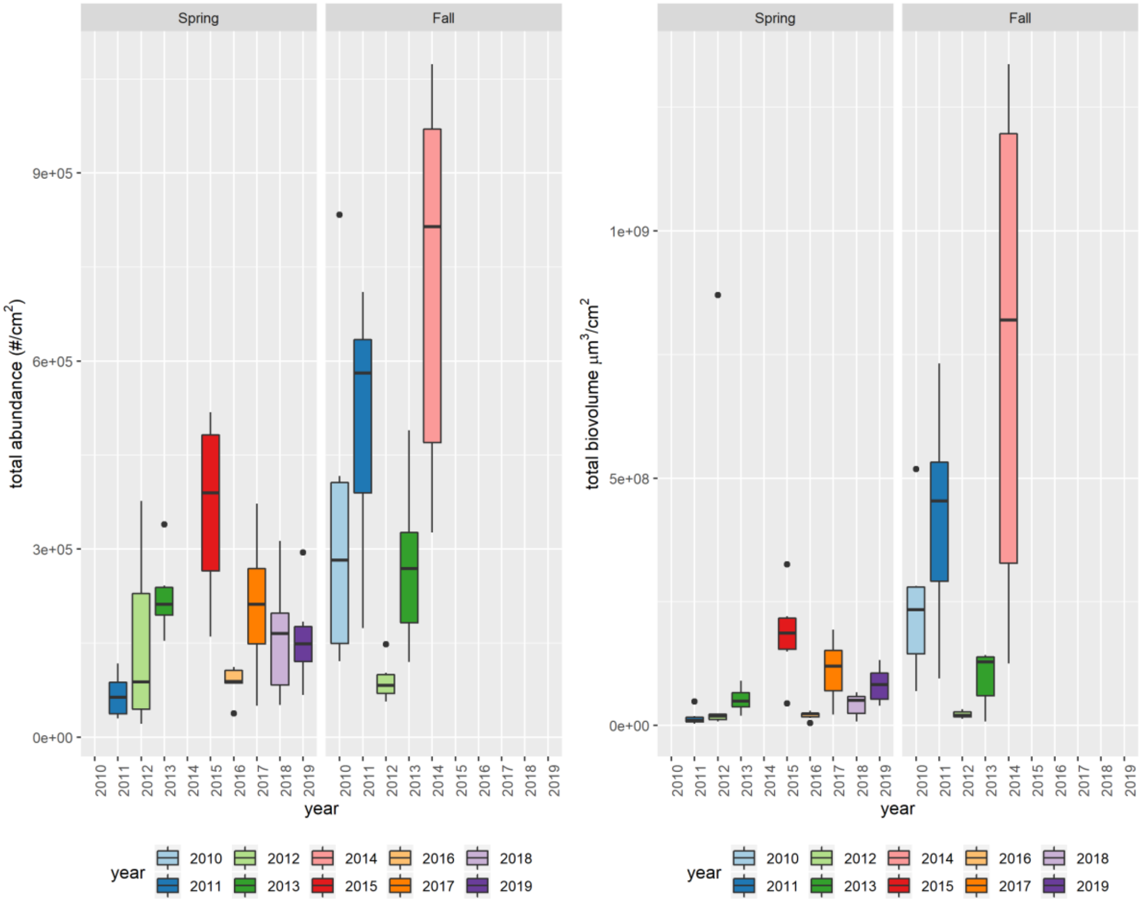

Figure A12 Upper varial zone (T5,T6) periphyton productivity in R3, 2010 – 2019 by year and season. All sampling periods were affected by some backwatering except Spring and Fall 2013.

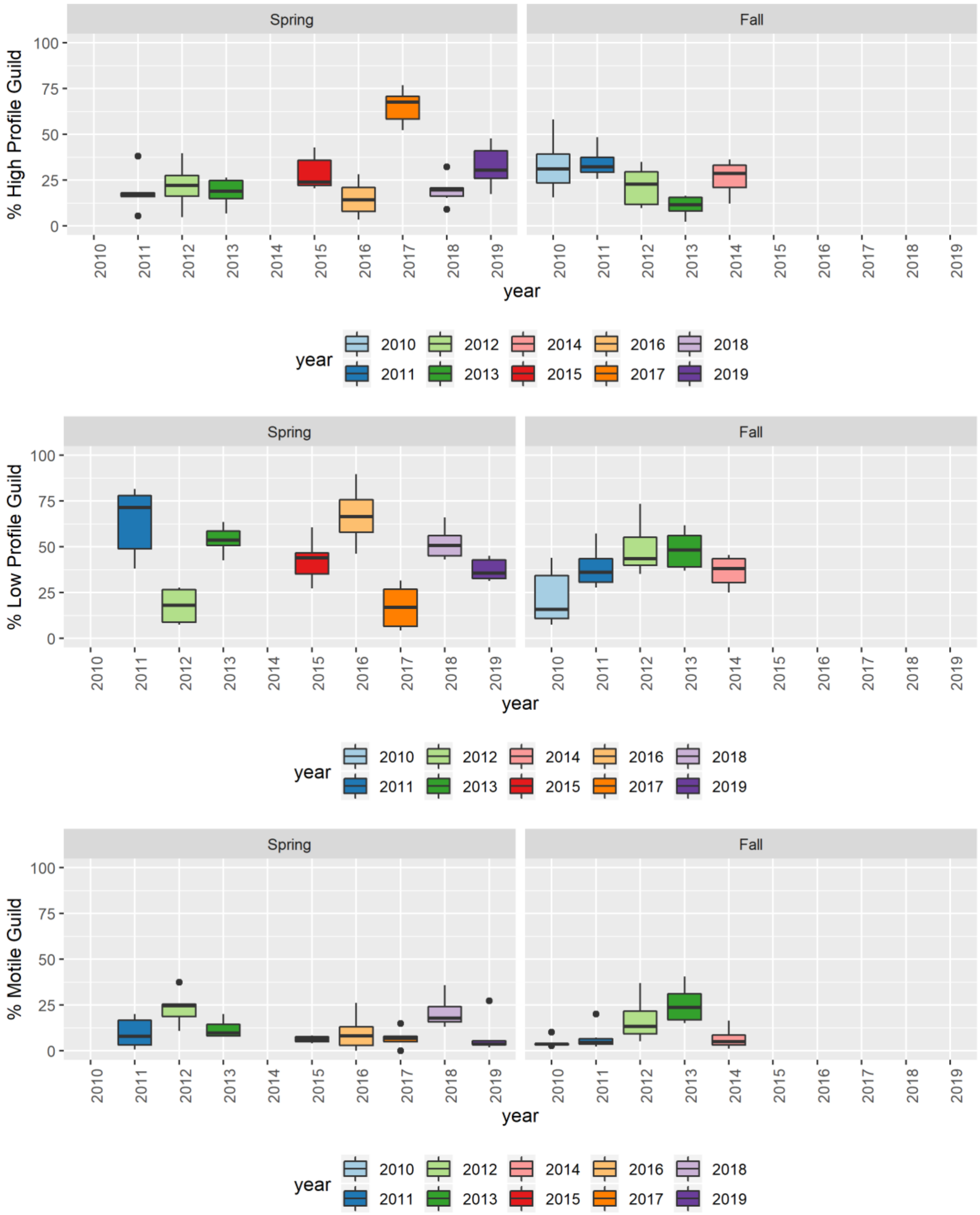

Figure A13 Upper varial zone (T5,T6) periphyton taxa composition as percent abundance in R3, 2010 – 2019 by year and season. All sampling periods were affected by some backwatering except Spring and Fall 2013

In most years, either fall or spring were sampled but in 2011 through 2013, both seasons were sampled. The pairwise t-test between sample pairs from fall and spring 2011-2013 sample sessions confirmed that fall had significantly greater periphyton abundance, biovolume, and chl-a compared to spring (p<0.001) (Figure A14). Fall productivity metrics were almost double the spring metrics. Statistical modelling indicated that the important drivers behind the greater fall periphyton productivity and diversity were flows (lower water velocities, greater backwatering) and warmer water temperatures. Greater fall productivity occurred despite receiving fewer hours (600-1000) over the 10 photons/m^2/sec photosynthetic minimum threshold compared to spring (500-1450) (Plewes et al. 2019).

The three true periphyton guilds (motile, high profile, low profile) were not significantly different for the spring and fall 2011-2013 sample pairs (Figure A15). For periphyton, community composition was more stable than productivity metrics. The low profile guild taxa were prevalent in both spring and fall with mean percentages of 44±20% and 39±19%, respectively. The mean percent high profile guild was 26±15% in spring and 30±18% in fall. The motile guild was the least common guild in MCR with mean percentages of 6.7±7.2% in Fall and 8.8±9.8% in Spring.

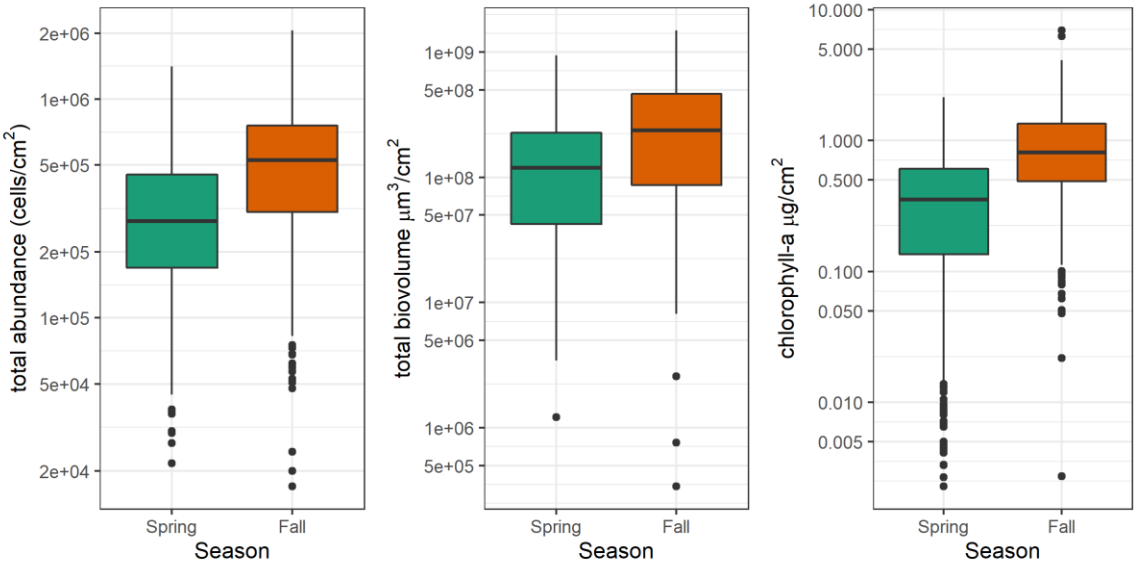

Figure A14 **Boxplots of periphyton production metrics for all MCR sites sampled from 2007-2019.**

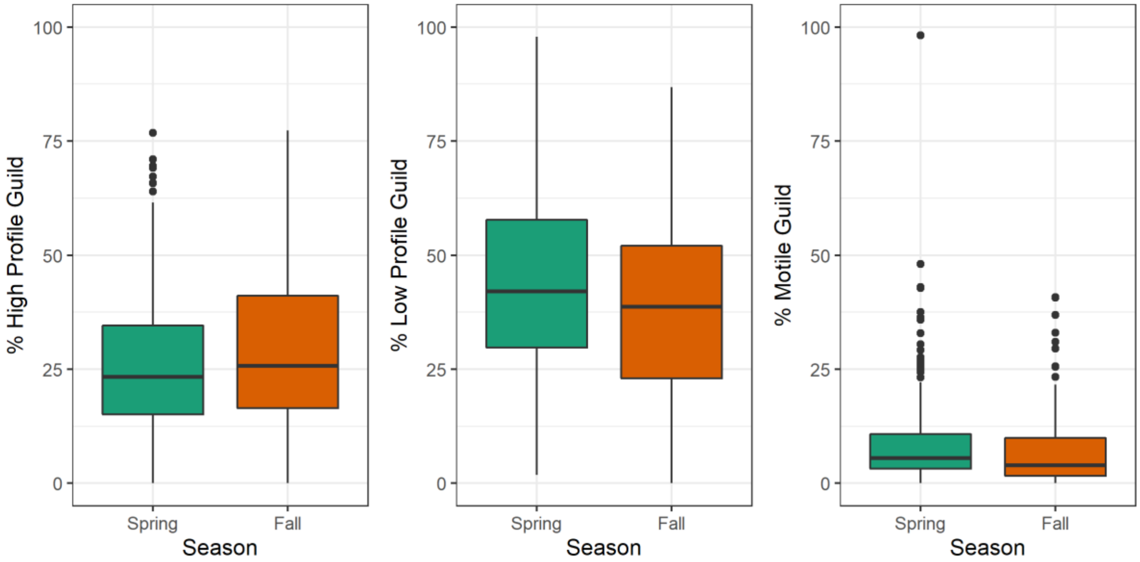

Figure A15 Boxplots of periphyton taxa composition as percent abundance for all MCR sites sampled from 2007-2019.

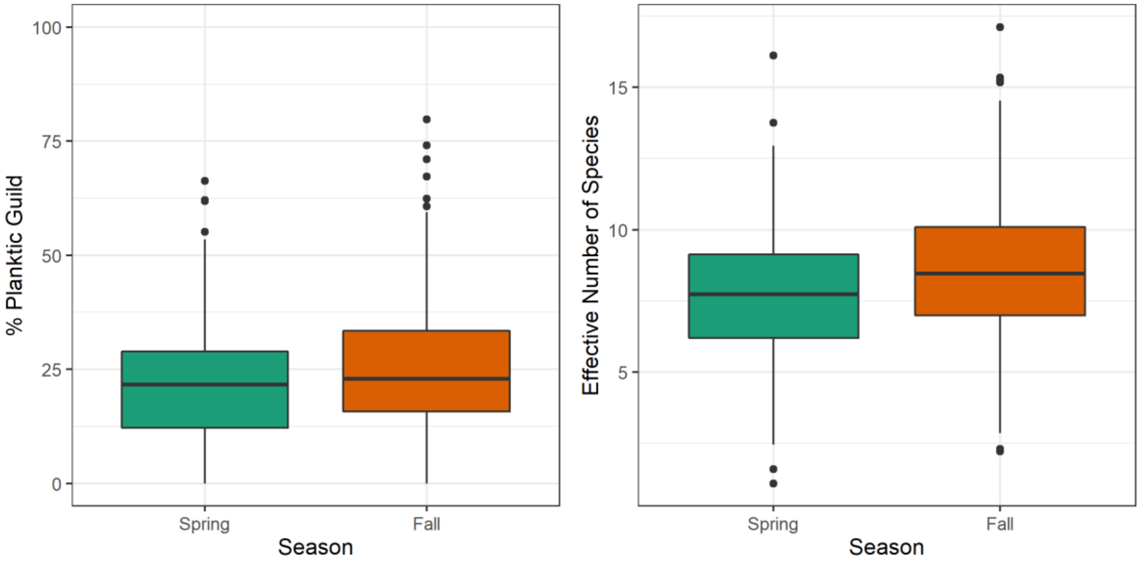

Figure A16 Boxplots of periphyton percent planktic guild by percent abundance and effective number of species for all MCR sites sampled from 2007-2019.

Didymo was minimal (<0.01% biovolume) in some spring sample sessions (e.g., 2017 and 2018), but other spring samples had significant Didymo growth (8% biovolume in 2016). In the final year of this study, spring 2019 had 2% biovolume of Didymo. Within a given year, the distribution of Didymo was patchy. For example, samples from spring 2015 transects and sites ranged from 0-82% by biovolume.

The Fall CART model showed that Didymo required submergence ratios greater than 0.95 (Figure A17). Node 5 had the highest mean percent Didymo and included sites from fall 2011 and 2013. Reach 3 upper varial zone sites in fall 2011 had high percent Didymo due to the extensive ALR backwatering. Didymo was prevalent in fall 2013 at R4 permanently submerged samplers. Fall

2013 had low peak hourly flows compared to other fall sampling sessions.

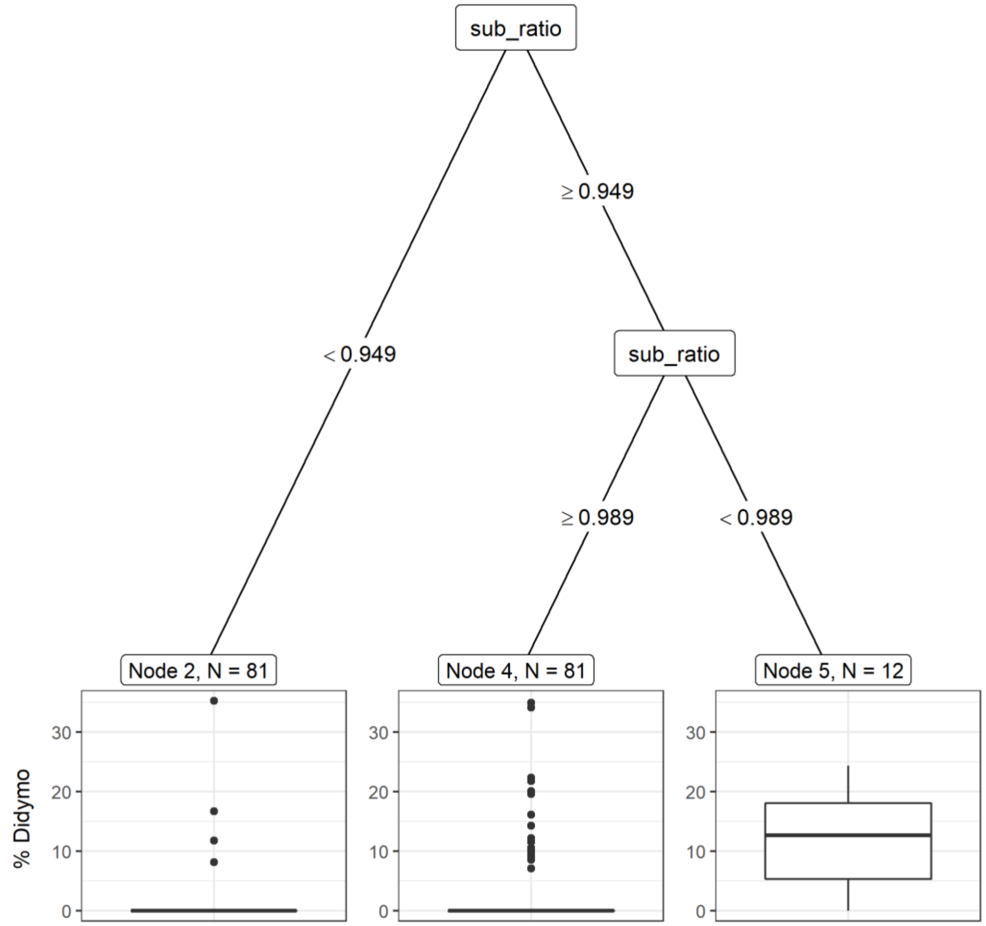

Figure A17 **Fall CART model for percent Didymo by biovolume for all mainstem T1-T6 sites.**

To assess the distribution of periphyton across different habitat types. The periphyton productivity and composition at Mainstem sites, Big Eddy (a large, deep eddy pool), bedrock units (immovable rock surface), backwater sites (altered flow pattern, low velocity), and white-water sites (high velocity) were compared (Figure A18). As with mainstem sites, productivity metrics for all substrate units were generally higher in the fall than in the spring (Figure A18). Of the three habitat types in R3, the mainstem sites had similar productivity to R4, but Big Eddy was more productive than the mainstem substrates, and the backwater substrates were less productive overall (Figure A18).

The mean percent of each ecological guild was similar among habitat substrate units. However, the low-profile guild at mainstem sites varied highly and ranged from 4-94% in spring and from 0-87% in fall (Figure A19). Small differences in the proportion of ecological guilds existed between some habitat substrate units. For example, mainstem substrates had more high profile taxa while bedrock had more low profile guild. These ecological preferences likely reflect water velocity differences in the water layer immediately adjacent to the substrates. Similarly, R3 substrate habitats were dominated by percent high profile guild with a greater proportion of the motile taxa in the sandy backwater areas. The low-profile guild is better suited to high water velocities, which may explain its prevalence in Spring high flows (Figure A19).

Many growth metrics were higher in Reach 3 than Reach 4 over the years of study, depending on factors including flows, backwatering, and weather. When all spring sample sessions were compared by reach, R3 had 21% higher cell abundance, 14% more biomass, and 55% higher chl-a than R4 averages. When all fall samples were compared, R3 had the same abundance and biovolume as R4, but had 41% higher chl-a than R4. Thus, spring was the season with the greatest difference between R3 and R4 periphyton productivity.

Substrate changes between R4 and R3 were reflected in shifts among periphyton dominants. For example, species that were planktonic or adherent (non-motile) were more common in R4 samples (e.g. *Synedra ulna, Achnanthidium minutissima*), while species that were stalked or motile increased in R3 samples (e.g. *Didymosphenia geminata, Navicula spp.*). These taxa changes were likely driven by substrate changes. R3 has greater sand concentrations, while R4 has more cobble and bedrock. Although species composition changed between reaches, overall species diversity was stable (Figure A20). The effective species number for all spring and fall sampling sessions was 8.02±2.44 in R3 and 8.04±2.46 in R4.

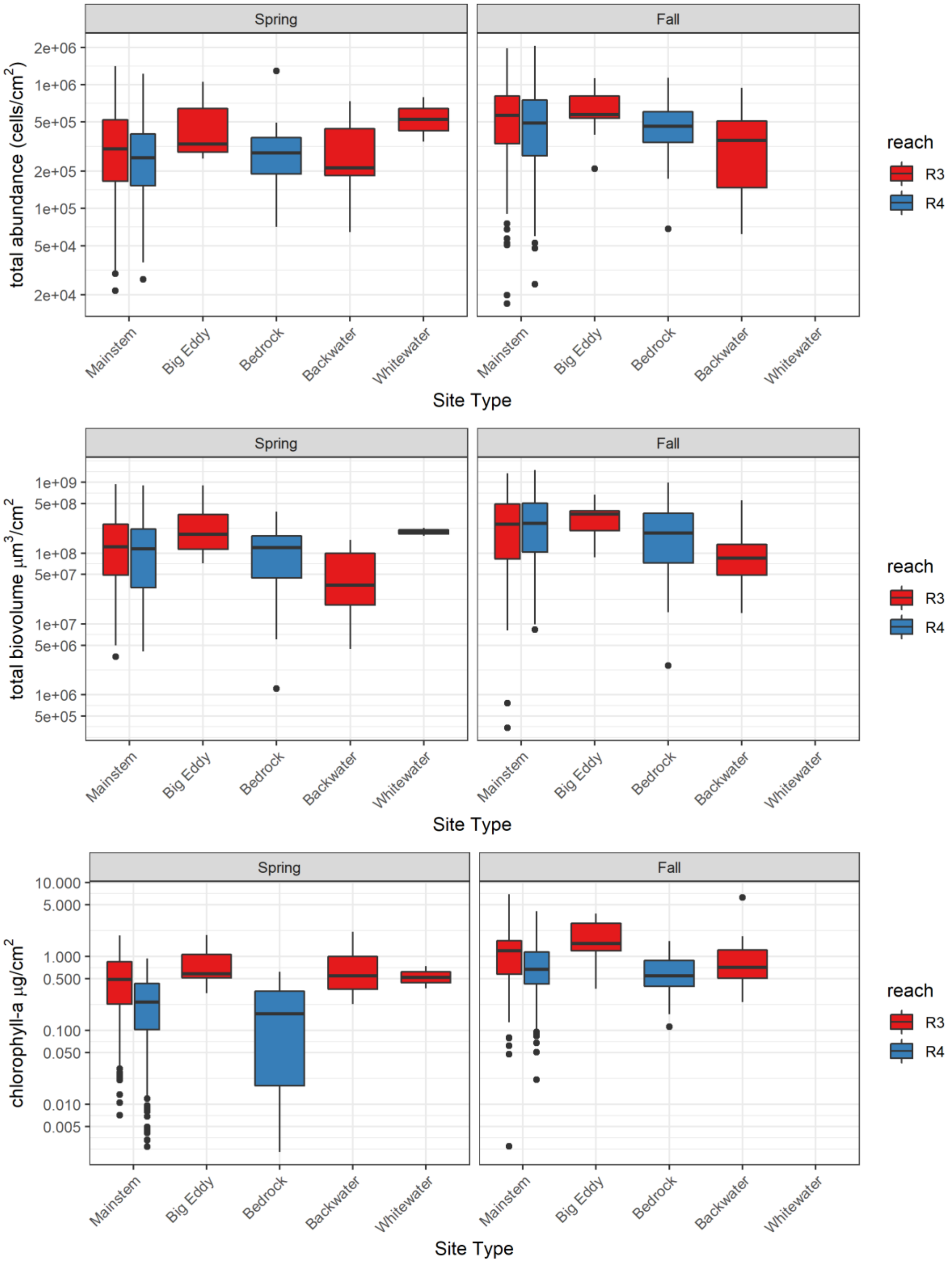

Figure A18 Boxplots of periphyton productivity metrics by habitat type for all MCR sites sampled from 2007-2019. Mainstem sites were sampled in all years and other site types were sampled less frequently. (Mainstem Fall n=276 Spring 284; Big Eddy Fall n=17 Spring=13; Bedrock Fall = 24 Spring = 24; Backwater Fall = 15 Spring = 9; Whitewater Fall = 0 Spring = 2)

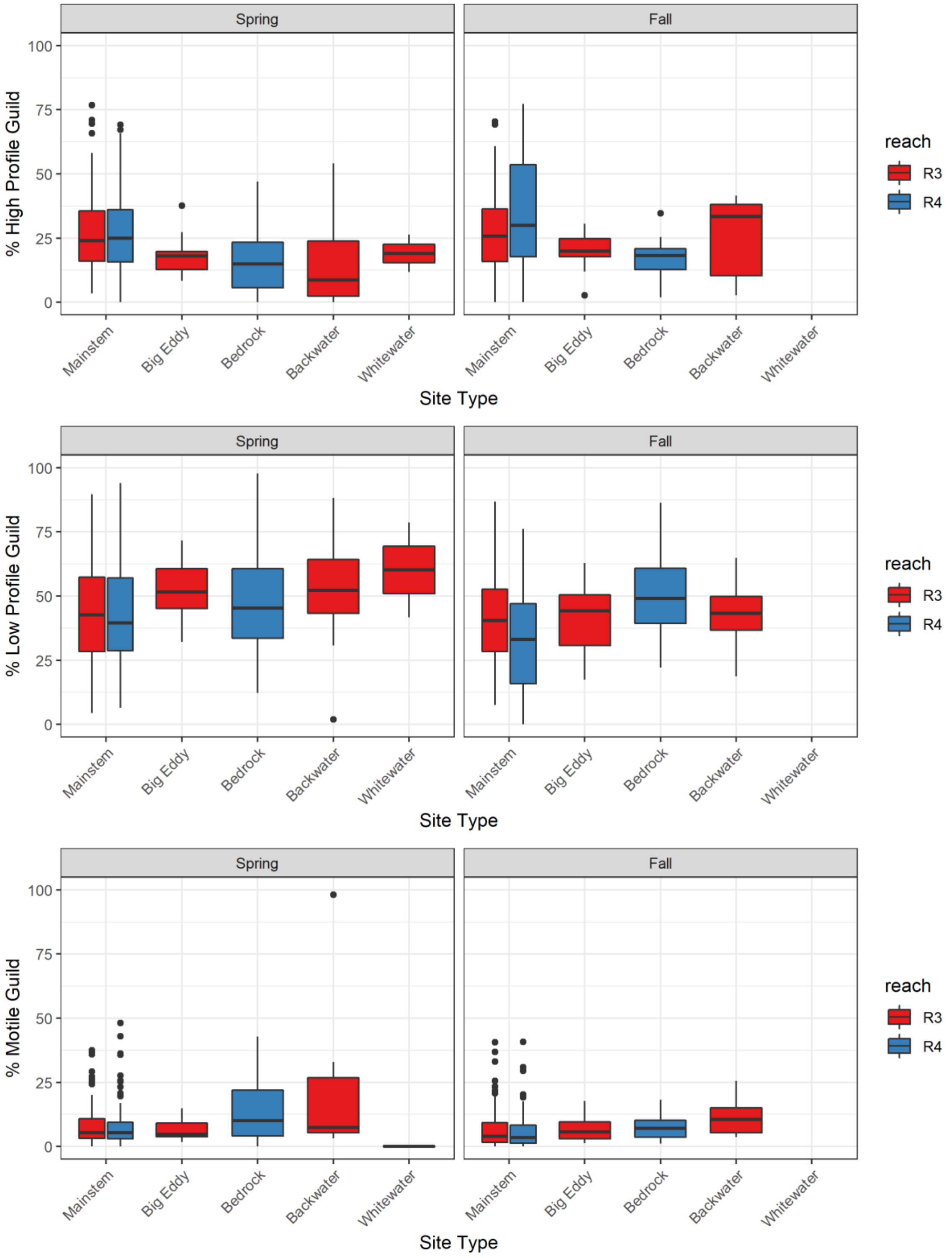

Figure A19 Boxplots of periphyton community composition as percent abundance grouped by habitat type for all MCR sites sampled from 2007-2019. Main sites were sampled for all years and all other site types were sampled less frequently. (Mainstem Fall n=276 Spring 284; Big Eddy Fall n=17 Spring=13; Bedrock Fall = 24 Spring = 24; Backwater Fall = 15 Spring = 9; Whitewater Fall = 0 Spring = 2)

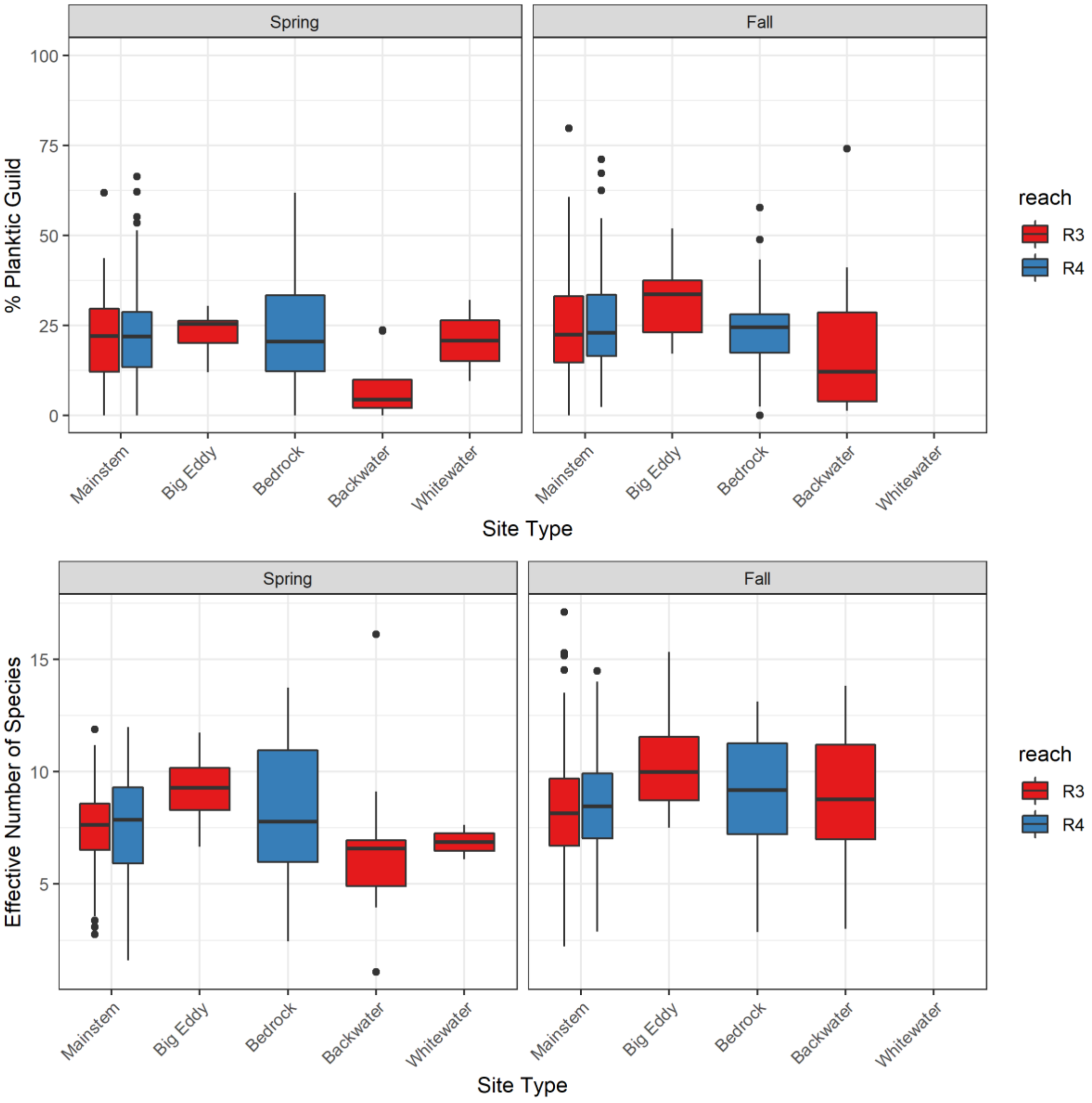

Figure A20 **Boxplots of periphyton percent planktic guild by percent abundance and effective number of species grouped by habitat type for all MCR sites sampled from 2007-2019. Main sites were sampled for all years and all other site types were sampled less frequently. (Mainstem Fall n=276 Spring 284; Big Eddy Fall n=17 Spring=13; Bedrock Fall = 24 Spring = 24; Backwater Fall = 15 Spring = 9; Whitewater Fall = 0 Spring = 2)**

Changes in periphyton productivity between transect positions correspond to substrate submergence time and secondarily to irradiance. All periphyton production metrics were significantly different in spring and fall across the river channel (T1-T6) (Table A9). Spring chl-a and biovolume showed a similar pattern across the river channel, while abundance had a slightly different pattern. Deeper T1-T3 samplers had significantly higher chl-a and biovolume than the shallow varial zone T4-T6 samplers in Spring (Table A10). Chl-a and biovolume were similar from T1 through T3, then decreased from the lower to upper varial zone (T3-T6) and these differences were statistically significant (Table A10). Periphyton abundance in the spring was significantly higher at T2 compared to all other transects. T1 and T3 had comparable periphyton abundances

(T=0.01. p=0.92), whereas abundances were significantly different for T4-T6. Like biovolume and chl-a, abundances decreased from T4-T6.

Table A9 Friedman test results comparing periphyton productivity metrics see Figure A21 between transects using site, season and year as blocking variable.

Metric	Season	Statistic	P value
Chlorophyll-a	Fall	57.200	**<0.001**
Chlorophyll-a	Spring	106.000	**<0.001**
Total Abundance	Fall	39.100	**<0.001**
Total Abundance	Spring	92.200	**<0.001**
Total Biovolume	Fall	40.200	**<0.001**
Total Biovolume	Spring	92.300	**<0.001**

Table A10 Post-hoc Conover-Test for Spring periphyton productivity metrics that had significant differences.

Metric	Transect1	Transect	T_stat	P value
Chlorophyll-a	T1	T2	1.804	0.078
Chlorophyll-a	T1	T3	2.105	**0.042**
Chlorophyll-a	T1	T4	7.417	**<0.001**
Chlorophyll-a	T1	T5	20.649	**<0.001**
Chlorophyll-a	T1	T6	26.963	**<0.001**
Chlorophyll-a	T2	T3	0.301	0.764
Chlorophyll-a	T2	T4	5.613	**<0.001**
Chlorophyll-a	T2	T5	18.844	**<0.001**
Chlorophyll-a	T2	T6	25.159	**<0.001**
Chlorophyll-a	T3	T4	5.312	**<0.001**
Chlorophyll-a	T3	T5	18.544	**<0.001**
Chlorophyll-a	T3	T6	24.858	**<0.001**
Chlorophyll-a	T4	T5	13.231	**<0.001**
Chlorophyll-a	T4	T6	19.546	**<0.001**
Chlorophyll-a	T5	T6	6.315	**<0.001**
Total Abundance	T1	T2	3.141	**0.002**
Total Abundance	T1	T3	0.095	0.924

Metric	**Transect1**	**Transect**	**T_stat**	**P value**
Total Abundance	T1	T4	5.901	**<0.001**
Total Abundance	T1	T5	15.324	**<0.001**
Total Abundance	T1	T6	22.558	**<0.001**
Total Abundance	T2	T3	3.046	**0.003**
Total Abundance	T2	T4	9.042	**<0.001**
Total Abundance	T2	T5	18.465	**<0.001**
Total Abundance	T2	T6	25.699	**<0.001**
Total Abundance	T3	T4	5.996	**<0.001**
Total Abundance	T3	T5	15.419	**<0.001**
Total Abundance	T3	T6	22.653	**<0.001**
Total Abundance	T4	T5	9.423	**<0.001**
Total Abundance	T4	T6	16.657	**<0.001**
Total Abundance	T5	T6	7.234	**<0.001**
Total Biovolume	T1	T2	1.713	0.102
Total Biovolume	T1	T3	0.952	0.367
Total Biovolume	T1	T4	5.520	**<0.001**
Total Biovolume	T1	T5	15.227	**<0.001**
Total Biovolume	T1	T6	23.030	**<0.001**
Total Biovolume	T2	T3	0.761	0.447
Total Biovolume	T2	T4	7.233	**<0.001**
Total Biovolume	T2	T5	16.940	**<0.001**
Total Biovolume	T2	T6	24.743	**<0.001**
Total Biovolume	T3	T4	6.471	**<0.001**
Total Biovolume	T3	T5	16.178	**<0.001**
Total Biovolume	T3	T6	23.982	**<0.001**
Total Biovolume	T4	T5	9.707	**<0.001**
Total Biovolume	T4	T6	17.511	**<0.001**
Total Biovolume	T5	T6	7.804	**<0.001**

Abundance and biovolume showed a similar pattern across the river channel in fall compared to chl-a. Overall, fall periphyton abundance and biovolume were similar throughout the permanently submerged (T1, T2) and the lower varial zone (T3, T4). The significant differences for abundance between site pairs of samplers in these two zones were likely a result of a few outliers

(Figure A21). The upper varial zone (T5, T6) had significantly lower periphyton abundance and biovolume than permanently submerged and the lower varial zone (Table A11). The most frequently dewatered varial zone sampler (T6) had a significantly lower periphyton abundance and biovolume compared to T5. The edge of the permanently wetted zone (T2) had significantly higher chl-a compared to all other transects in fall. Chl-a was similar at the T1 and T3 samplers in the fall. Chl-a decreased from the lower to upper varial zone (T3-T6) and these differences were statistically significant.

Table A11 Post-hoc Conover-Test for Fall periphyton productivity metrics that had significant differences.

Metric	Transect1	Transect	T_stat	P value
Chlorophyll-a	T1	T2	3.021	**0.004**
Chlorophyll-a	T1	T3	0.585	0.56
Chlorophyll-a	T1	T4	3.606	**0.001**
Chlorophyll-a	T1	T5	7.407	**<0.001**
Chlorophyll-a	T1	T6	13.645	**<0.001**
Chlorophyll-a	T2	T3	2.437	**0.017**
Chlorophyll-a	T2	T4	6.627	**<0.001**
Chlorophyll-a	T2	T5	10.429	**<0.001**
Chlorophyll-a	T2	T6	16.666	**<0.001**
Chlorophyll-a	T3	T4	4.191	**<0.001**
Chlorophyll-a	T3	T5	7.992	**<0.001**
Chlorophyll-a	T3	T6	14.230	**<0.001**
Chlorophyll-a	T4	T5	3.801	**<0.001**
Chlorophyll-a	T4	T6	10.039	**<0.001**
Chlorophyll-a	T5	T6	6.238	**<0.001**
Total Abundance	T1	T2	0.709	0.48
Total Abundance	T1	T3	2.126	**0.048**
Total Abundance	T1	T4	0.709	0.48
Total Abundance	T1	T5	3.720	**0.001**
Total Abundance	T1	T6	10.629	**<0.001**
Total Abundance	T2	T3	2.835	**0.008**
Total Abundance	T2	T4	1.417	0.183
Total Abundance	T2	T5	3.012	**0.005**

Metric	**Transect1**	**Transect**	**T_stat**	**P value**
Total Abundance	T2	T6	9.921	**<0.001**
Total Abundance	T3	T4	1.417	0.183
Total Abundance	T3	T5	5.846	**<0.001**
Total Abundance	T3	T6	12.755	**<0.001**
Total Abundance	T4	T5	4.429	**<0.001**
Total Abundance	T4	T6	11.338	**<0.001**
Total Abundance	T5	T6	6.909	**<0.001**
Total Biovolume	T1	T2	1.603	0.14
Total Biovolume	T1	T3	1.069	0.308
Total Biovolume	T1	T4	1.069	0.308
Total Biovolume	T1	T5	4.987	**<0.001**
Total Biovolume	T1	T6	11.042	**<0.001**
Total Biovolume	T2	T3	2.671	**0.012**
Total Biovolume	T2	T4	2.671	**0.012**
Total Biovolume	T2	T5	3.384	**0.002**
Total Biovolume	T2	T6	9.439	**<0.001**
Total Biovolume	T3	T4	0.000	1
Total Biovolume	T3	T5	6.055	**<0.001**
Total Biovolume	T3	T6	12.110	**<0.001**
Total Biovolume	T4	T5	6.055	**<0.001**
Total Biovolume	T4	T6	12.110	**<0.001**
Total Biovolume	T5	T6	6.055	**<0.001**

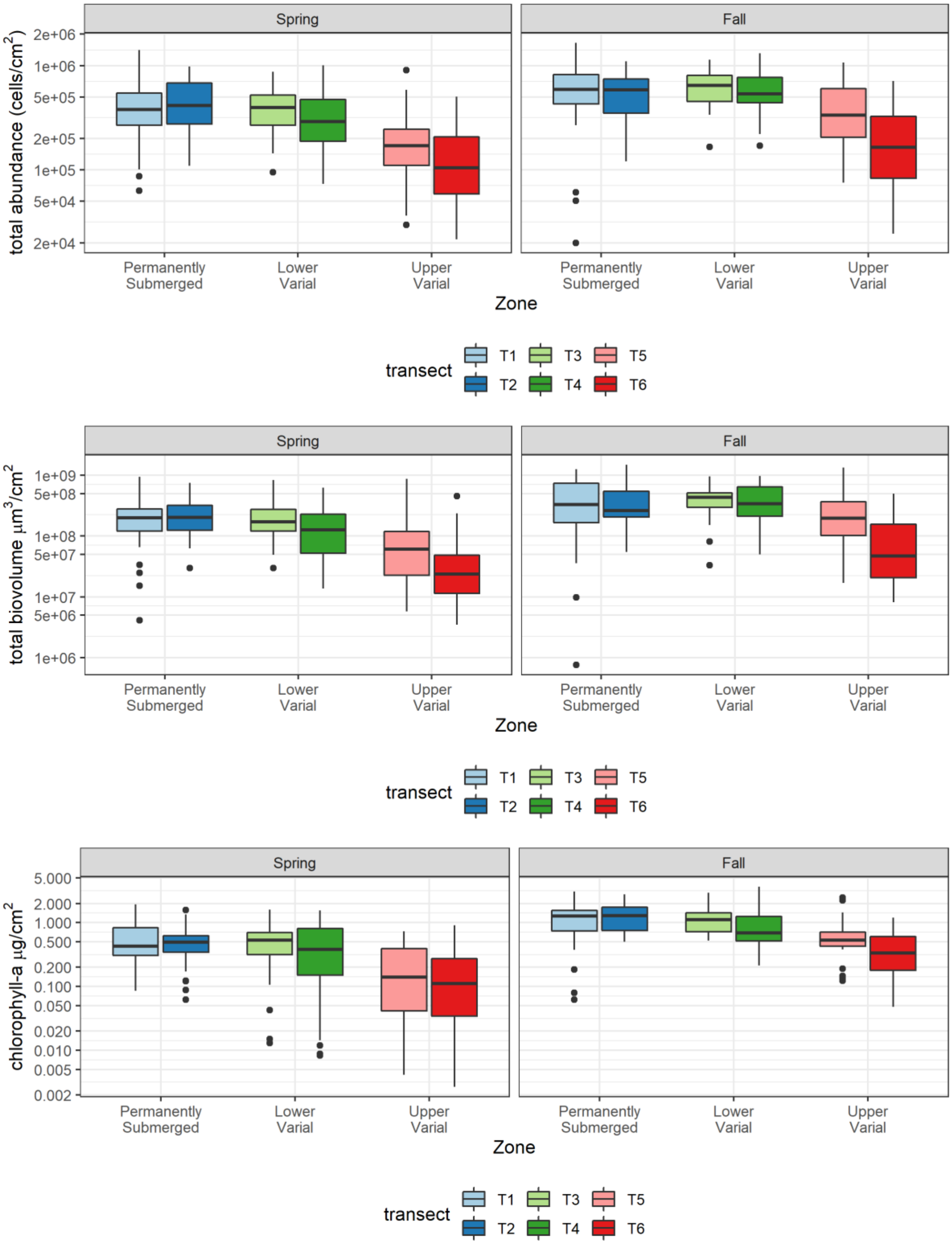

Figure A21 Boxplots of periphyton production metrics grouped by zone and transect for main sites sampled from 2010-2019. data for sites with all samplers retrieved (complete transects)

The rate of substrate de-watering (ramping) events influenced the mode of periphyton recovery The importance of phytoplankton originating from the Revelstoke Reservoir to MCR periphyton recovery was demonstrated by the proportions of the %planktic guild metrics. One of the largest ecological guilds is composed of the taxa donated by the Revelstoke Reservoir, accounting for an overall 23-24% of the periphyton in both reaches. Both spring and fall showed a similar pattern where deposition of these taxa on the substrates was proportional to the submergence time. With the exception of spring 2018, all spring samplers with submergence ratios greater than 0.58 had percent planktic near 30% (Figure A22). Interestingly, Spring 2012 samplers with submergence ratios less than 0.58 had mean percent planktic of ~30%. Samplers that were frequently dewatered (submergence ratio <0.58) in spring 2011, 2013, 2016-2018 had lower percentage of planktic guild compared to samplers that were wetted for more than 58% of the time.

The only two habitat types that had a significantly larger proportion of planktonic guild in Fall were backwater and Big Eddy, and chl-a and % high profile guild metrics also reflected this trend. The final and smallest ecological guild in MCR were the motile taxa that can evade burial. Interestingly, backwater habitats had the least % planktic guild of the habitat units, particularly in Spring (Figure A20).

The percent of low-profile guild taxa in spring was affected by water temperatures and annual variability (Figure A23). Spring 2013 and 2016 samples with mean water temperatures that exceeded 6°C had a mean % low profile guild of 59±14%.The lower and upper varial zone samplers from spring 2011 were dominated by the low profile guild (Figure A11 Nodes 8 and 14). The permanently submerged samplers from spring 2011 were not dominated by the low profile taxa with percentages ~30% (Node 7). All Spring 2012 samplers and spring 2017 samples with mean water temperatures less than 4.22°C had the lowest percentage of low profile guild compared to all other spring samples (Nodes 4 and 12). The lower percentage of low profile guild taxa was a result of a higher proportion of high profile guild taxa in spring 2017 and higher proportions of motile and planktic guild taxa in spring 2012.

The maximum flow during the spring 2017 deployment period was only 1,529.4 m^3/s. These low maximum flows in combination with cold water temperatures may have favoured the high profile guild and resulted in their prevalence. Conversely, periphyton recovery in cold water periods may be slower and biased against the low profile guild taxa resulting in lower overall Spring abundance than in Fall when all studied years are considered (Spring $3.45x10^5$ cells/cm^2; Fall $5.69x10^5$ cells/cm^2).

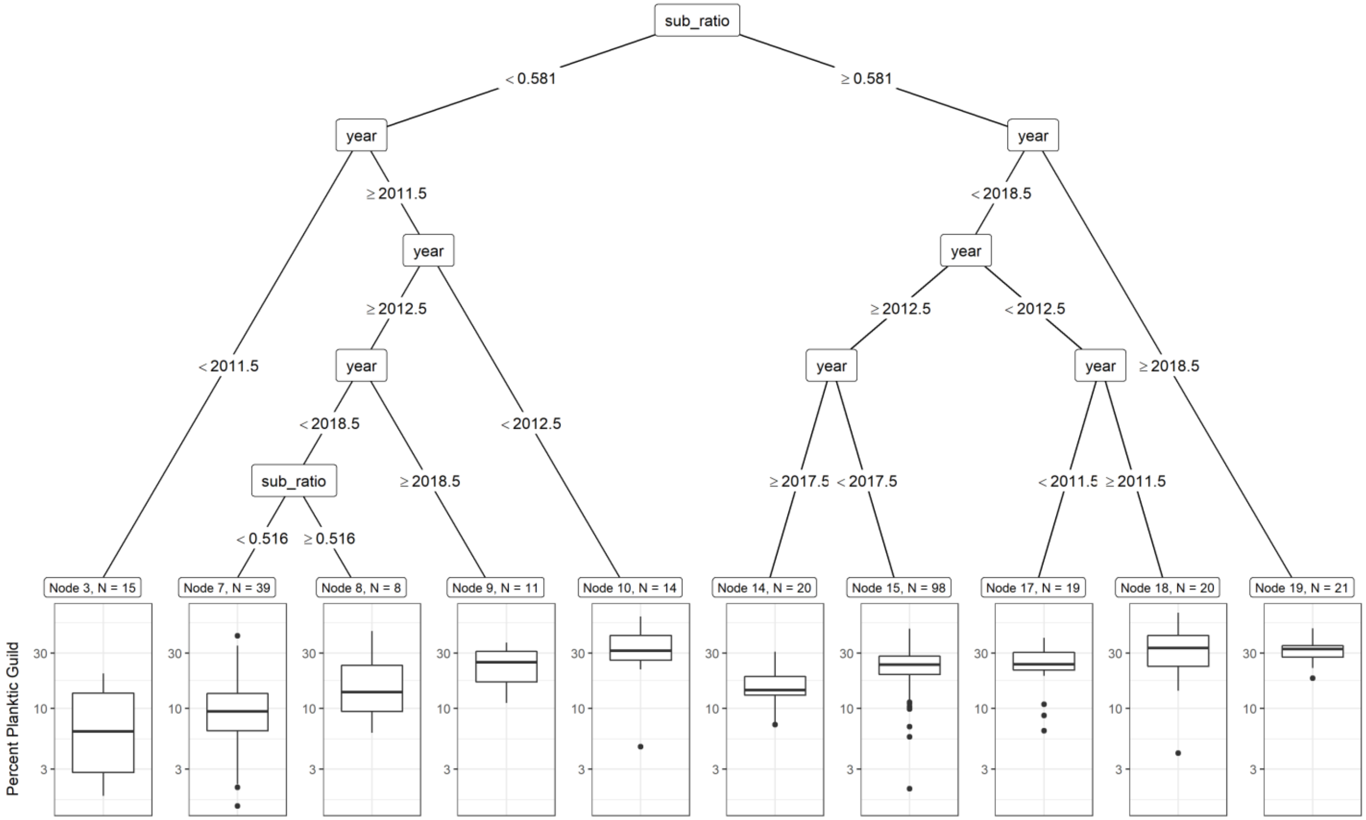

Figure A22 Spring CART model for percent planktic guild with splitting variables of substrate submergence ratio (sub_ratio), mean temperature while submerged (avg_temp_sub) and year.

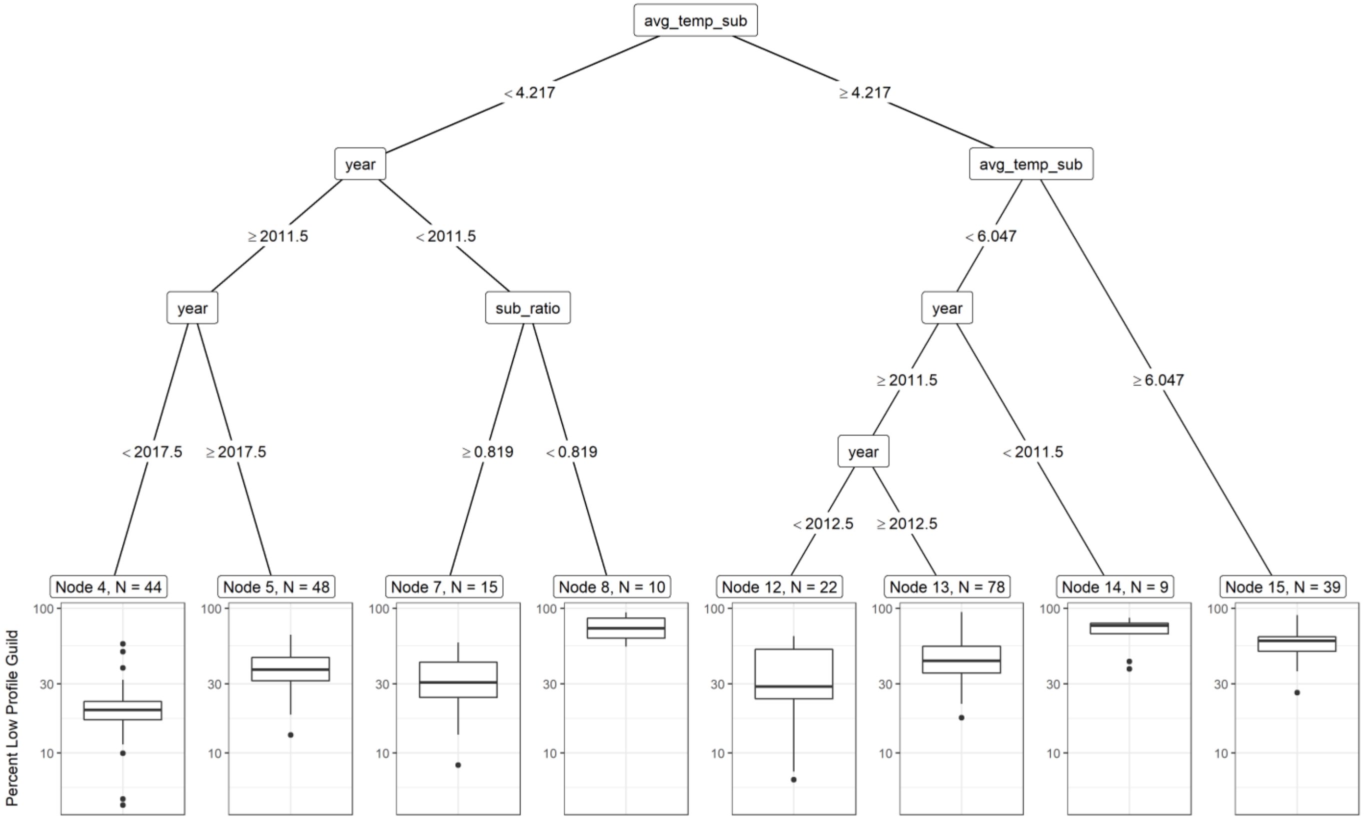

Figure A23 **Spring CART model for percent low profile guild with splitting variables of substrate submergence ratio (sub_ratio), mean temperature while submerged (avg_temp_sub) and year.**

The percent high profile, low profile, planktic and motile guilds were significantly different in spring across the river channel (T1-T6), while the fall guild metrics were not (Table A12). During spring sampling sessions, high profile taxa preferred the consistent conditions of the thalweg despite velocity peak around 2 m/sec in thalweg. These slow-growing, large taxa required near 100% submergence. The T1 samplers (close to the thalweg) had a significantly higher percent high profile compared to T2-T6, while T2 and T3 samplers had similar percentages of high profile guild (Table A13). The percent high profile guild at T4 and T5 were comparable and were lower than the samples closer to the thalweg, but T6 had a much lower percent high profile guild compared to T1-T5. The rate of substrate exposure at T6 locations appears to exceed the tolerances of the high-profile taxa.

Table A12 Friedman test results comparing MCR periphyton community composition metrics see Figure A24 between transects using site, season and year as blocking variable.

Metric	Season	Statistic	P value
% High Profile Guild	Fall	10.200	0.0689
% High Profile Guild	Spring	19.700	**0.00143**
% Low Profile Guild	Fall	5.960	0.31
% Low Profile Guild	Spring	20.700	**<0.001**
% Motile Guild	Fall	8.570	0.128
% Motile Guild	Spring	26.300	**<0.001**

Table A13 Post-hoc Conover-Test for Spring periphyton community composition metrics that had significant differences.

Metric	Transect1	Transect	T_stat	P value
% High Profile Guild	T1	T2	2.063	**0.046**
% High Profile Guild	T1	T3	2.381	**0.023**
% High Profile Guild	T1	T4	6.507	**<0.001**
% High Profile Guild	T1	T5	4.761	**<0.001**
% High Profile Guild	T1	T6	10.951	**<0.001**
% High Profile Guild	T2	T3	0.317	0.751
% High Profile Guild	T2	T4	4.444	**<0.001**
% High Profile Guild	T2	T5	2.698	**0.011**
% High Profile Guild	T2	T6	8.888	**<0.001**
% High Profile Guild	T3	T4	4.127	**<0.001**

Metric	**Transect1**	**Transect**	**T_stat**	**P value**
% High Profile Guild	T3	T5	2.381	**0.023**
% High Profile Guild	T3	T6	8.571	**<0.001**
% High Profile Guild	T4	T5	1.746	0.088
% High Profile Guild	T4	T6	4.444	**<0.001**
% High Profile Guild	T5	T6	6.190	**<0.001**
% Low Profile Guild	T1	T2	1.909	0.066
% Low Profile Guild	T1	T3	3.499	**0.001**
% Low Profile Guild	T1	T4	7.794	**<0.001**
% Low Profile Guild	T1	T5	6.521	**<0.001**
% Low Profile Guild	T1	T6	10.816	**<0.001**
% Low Profile Guild	T2	T3	1.591	0.121
% Low Profile Guild	T2	T4	5.885	**<0.001**
% Low Profile Guild	T2	T5	4.613	**<0.001**
% Low Profile Guild	T2	T6	8.907	**<0.001**
% Low Profile Guild	T3	T4	4.295	**<0.001**
% Low Profile Guild	T3	T5	3.022	**0.004**
% Low Profile Guild	T3	T6	7.317	**<0.001**
% Low Profile Guild	T4	T5	1.272	0.205
% Low Profile Guild	T4	T6	3.022	**0.004**
% Low Profile Guild	T5	T6	4.295	**<0.001**
% Motile Guild	T1	T2	1.530	0.147
% Motile Guild	T1	T3	2.737	**0.008**
% Motile Guild	T1	T4	7.326	**<0.001**
% Motile Guild	T1	T5	10.707	**<0.001**
% Motile Guild	T1	T6	10.063	**<0.001**
% Motile Guild	T2	T3	1.208	0.245
% Motile Guild	T2	T4	5.796	**<0.001**
% Motile Guild	T2	T5	9.178	**<0.001**
% Motile Guild	T2	T6	8.534	**<0.001**
% Motile Guild	T3	T4	4.589	**<0.001**
% Motile Guild	T3	T5	7.970	**<0.001**

Metric	Transect1	Transect	T_stat	P value
% Motile Guild	T3	T6	7.326	**<0.001**
% Motile Guild	T4	T5	3.381	**0.001**
% Motile Guild	T4	T6	2.737	**0.008**
% Motile Guild	T5	T6	0.644	0.52

Low profile taxa were more abundant in the upper than the lower varial zone during the spring sampling sessions (Figure A24). The T4-T6 spring samplers had significantly higher percent low profile guild compared to T1-T3 samplers (Table A13). The percent low profile guild at the edge of the permanently wetted zone (T2) was not significantly different than T1 or T3 in Spring (Table A13). However, T1 and T3 had significantly different percent low profile guild (T=3.5, p= 0.001). The T3 spring samplers had higher percent low profile compared to the T1 samplers (Figure A24).

Motile taxa increased during Spring sample sessions in the upper varial zones where sandy substrates occur (Figure A24). The percent motile guild was significantly higher in the upper varial zone (T5, T6) compared to T1-T4 (Table A13). The percent motile guild was significantly higher at T4 compared to T1-T3. The edge of the permanently wetted zone (T2) had similar percent motile guild to T1 and T3. However, T1 and T3 had significantly different percent motile guild (T=2.7, p= 0.001).

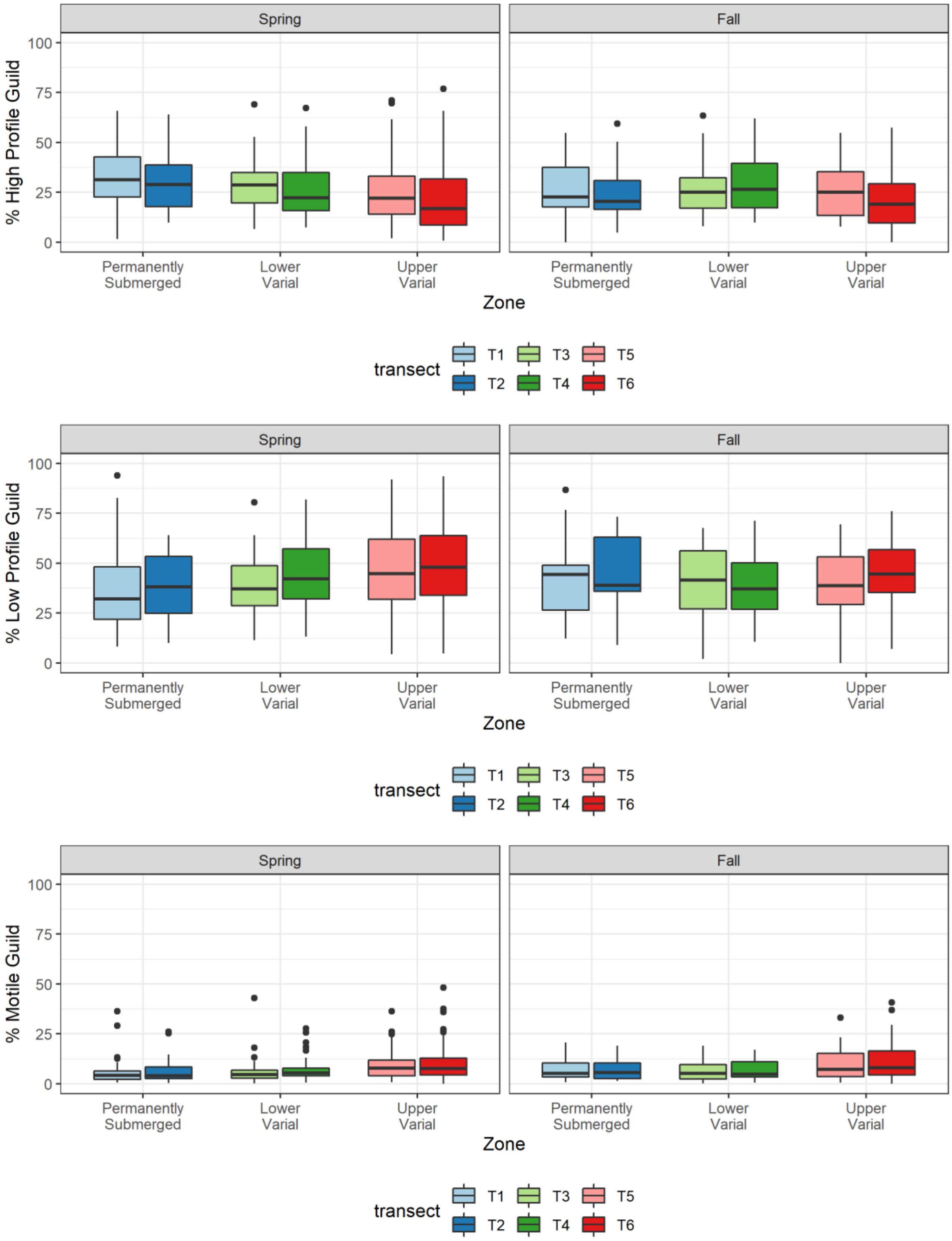

Figure A24 Boxplots of periphyton community composition as percent abundance grouped by zone and transect for main sites sampled from 2010-2019.

9.5.2 Benthic Invertebrates

The composition of benthic invertebrates in the MCR was predominately comprised of a few broad taxa groups. MCR invertebrate samples collected from 2007-2019 had taxa richness that ranged from 1-35 with a mean richness of 9±6. Chironomids were the most abundant taxa in both fall and spring, followed by Hydrozoans in the fall and Oligochaetes in the spring. Chironomid richness ranged from 0-17 species in all MCR samples. Most of the chironomid taxa in MCR were from the subfamilies of Orthocladiinae, Diamesinae, and Tanypodinae. Orthoclads were the most dominant subfamily; taxa included *Orthocladius complex*, *Eukiefferiella sp.*, *Heterotrissocladius sp.*, *Psectrocladius sp.*, *Brillia sp.* and *Cardiocladius sp*. Taxa in Diamesinae included *Diamesa sp.* and *Pagastia sp., Thienemannimyia group* was the dominant genus of Tanypodinae

The richness of Oligochaeta and Hydrozoan taxa were much lower in MCR compared to chironomid richness. Oligochaeta richness ranged from 0-5 in all MCR samples, whereas most hydrozoans found in MCR were *Hydra sp.* Most of the five Oligochaeta taxa were from the families of Naididae, Tubificidae, and Enchytraeidae. The most dominant family of Oligochaetes in the MCR was Naididae which included *Nais sp*.

EPT taxa made up a small portion of the MCR invertebrate community, the mean percent abundance of EPT in MCR was 2.63±6.40%. The EPT richness of MCR was limited, it ranged from 0-14 and had a mean EPT richness of 1±2. Ephemeroptera were the most abundant EPT in MCR. The most abundant families of Ephemeroptera included Ephemerellidae, Ameletidae, Baetidae, and Heptageniidae.

Invertebrate biomass and abundance exhibited a wide range of variability in the spring and fall sampling sessions (Figure A25). Fall had a higher mean invertebrate abundance of 379±715 compared to 182±254 in spring. The pairwise t-test between sample pairs from fall and spring 2011-2013, confirmed that fall had significantly higher biomass compared to spring ($p<0.001$). Spring and fall had comparable mean invertebrate biomasses when all sampling session were compared. However, when only spring and fall 2011-2013 were compared, fall had significantly higher invertebrate biomass than spring.

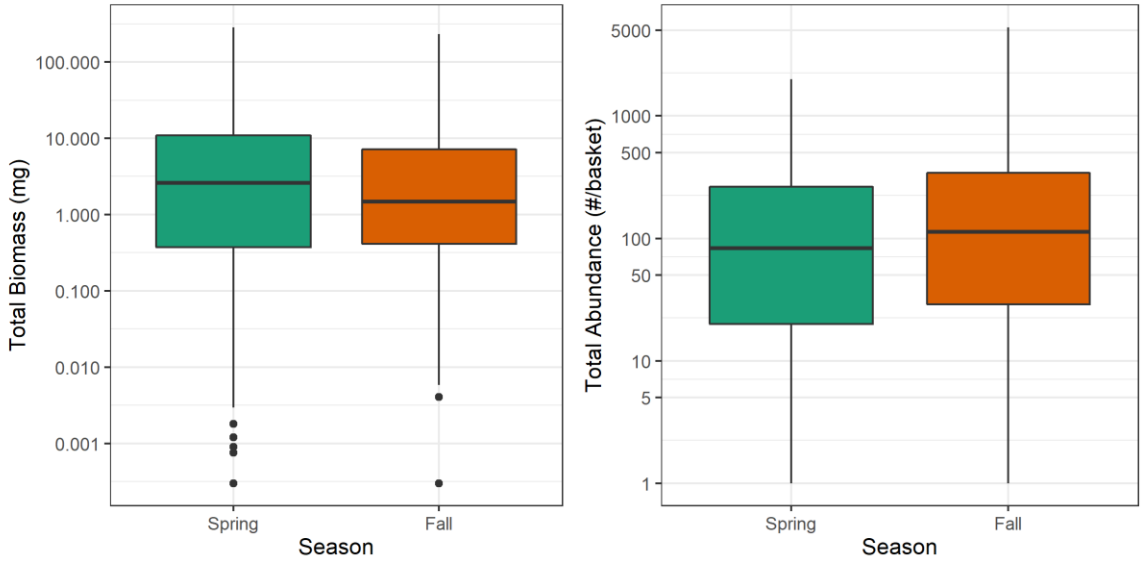

Figure A25 **Boxplots of invertebrate production metrics for all MCR sites sampled from 2007-2019.**

As previously stated, the MCR invertebrate community was primarily composed of chironomids, hydrozoans and oligochaetes in spring and fall (Figure A26). During spring sampling sessions, chironomids were consistently the dominant invertebrate with a mean percent abundance of 72±25%. Chironomids were the dominant invertebrate in some of the fall samples. However, the percentage of chironomids in fall in 2011-2013 were not significantly different from the percentage of chironomids in spring 2011-2013 (p=0.26). In some of the fall samples hydrozoans were the dominant invertebrate. Hydrozoans had a higher mean percent abundance of 33.2±31.5% in fall compared to 8.2±15% in spring. The percent hydrozoans were significantly higher in fall compared to spring (p<0.001). Oligochaetes has also had as significantly higher percent abundance in fall of 2011-2013 compared to spring 2011-2013. The mean percent Oligochaetes in fall was 10.9±16.2% and 6.92±10.1% in spring.

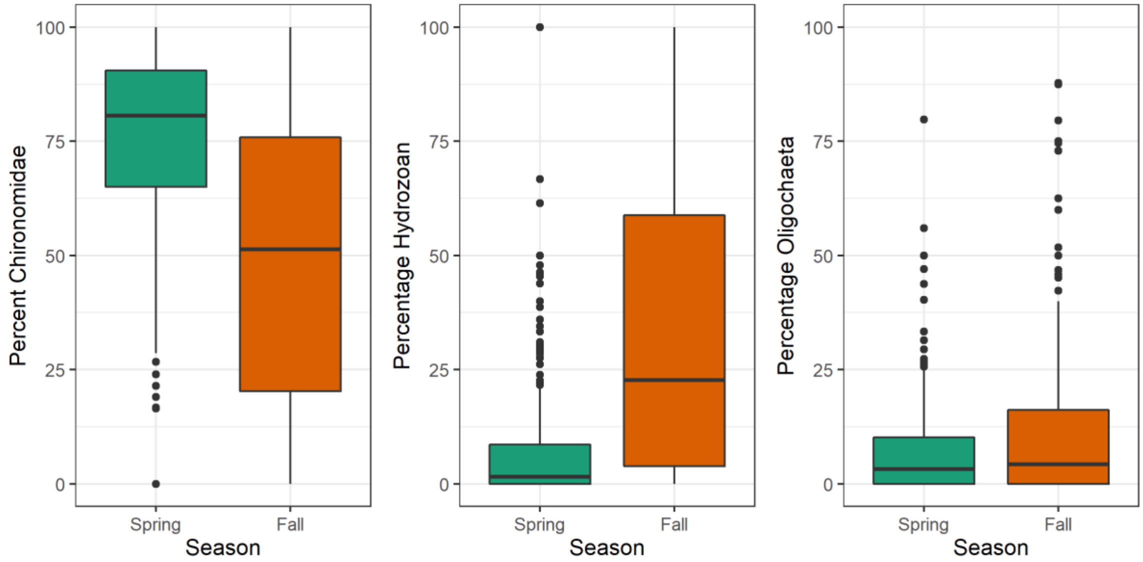

Figure A26 **Boxplots of invertebrate taxa composition as percent abundance for all MCR sites sampled from 2007-2019.**

The distribution of invertebrate taxa was documented across different habitat types and at various depths within the river channel. Invertebrate biomass from the spring and fall sampling sessions was highly variable within each habitat type (Figure A27). However, the whitewater sites did not have high variation in invertebrate biomass because it was only sampled once in spring. Backwater sites had the highest mean invertebrate biomass in both spring and fall compared to other sites. The mean invertebrate biomass for backwater sites was 35±29.3 mg in spring and 30.7±51.0 mg in fall.

Invertebrate abundance from the spring and fall sampling sessions was highly variable within each habitat type (Figure A27). In fall, the Big Eddy sites had the highest mean invertebrate abundance of 1270±1210 compared to all other sites. The three main sites in Reach 3 had higher mean invertebrate abundances of 425±662 in spring compared to 298±742 at the three main Reach 4 sites.

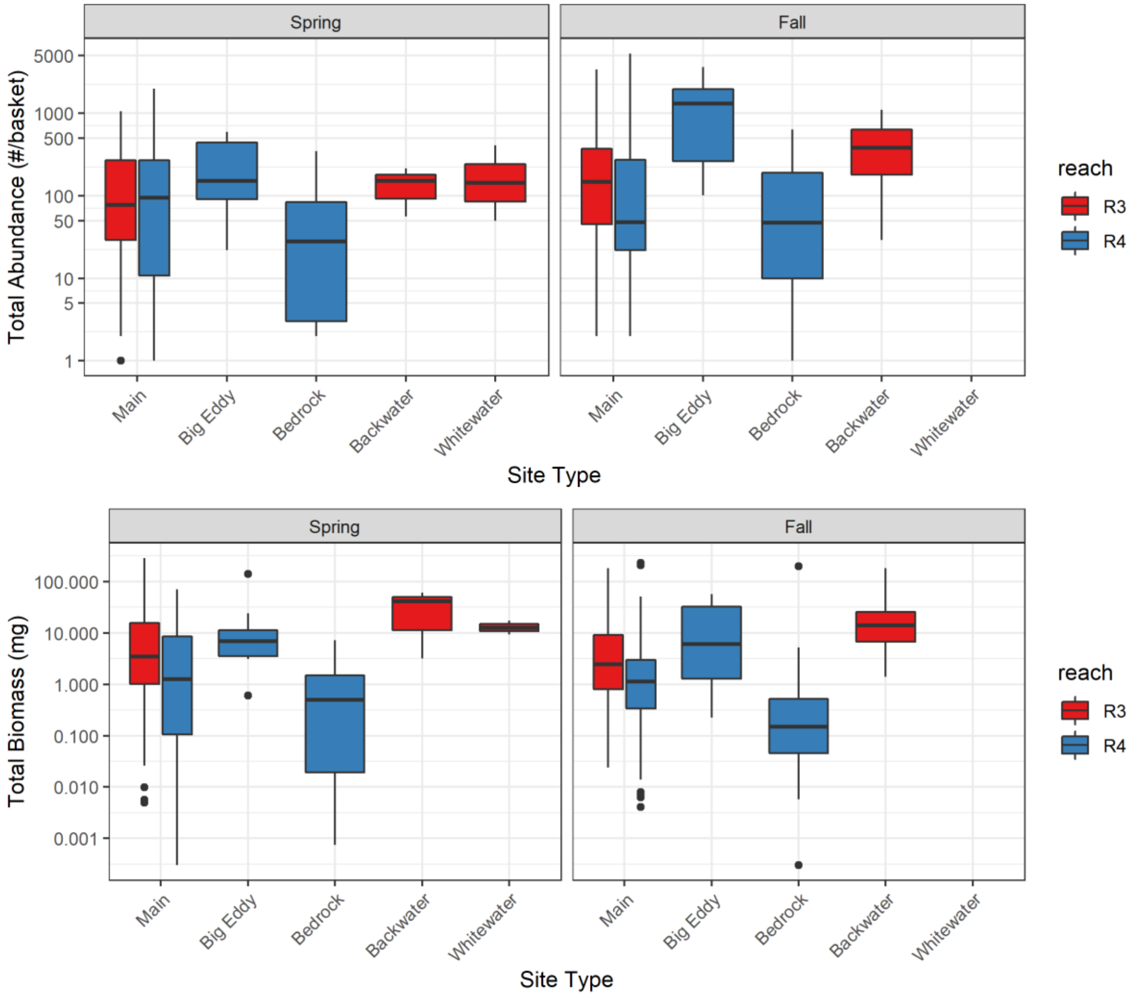

Figure A27 Boxplots of invertebrate productivity metrics by habitat type for all MCR sites sampled from 2007-2019. Main sites were sampled for all years and other site types were sampled less frequently.

The bedrock and backwater sites had a lower percentage of chironomids compared to other site types in spring and fall (Figure A28). The mean percent chironomids at the backwater and bedrock sites in spring were 53±16% and 50±35%, respectively. At the main, Big Eddy and whitewater sites the mean percent chironomids were ~75% during spring. The lower percent chironomids at bedrock sites was due to a higher percentage of hydrozoans. In fall, the mean percent of hydrozoans at the bedrock sites was 50±32% compared to a mean percent of hydrozoans ~30% at the main and Big Eddy sites. At backwater sites the lower percent of chironomids was because of a higher percentage of oligochaetes.

In both seasons, oligochaetes contributed more to the invertebrate community at Reach 3 compared to Reach 4 (Figure A28). Reach 3 sites had a mean percent abundance of 10.7±12.3% and Reach 4 had mean percent abundance of 7.42±14.3%. The backwater sites in Reach 3 had the highest percent oligochaetes compared to the other sites. The mean percent oligochaetes at the backwater sites were 21.7±5.17% in spring and 29.8±26.5% in fall.

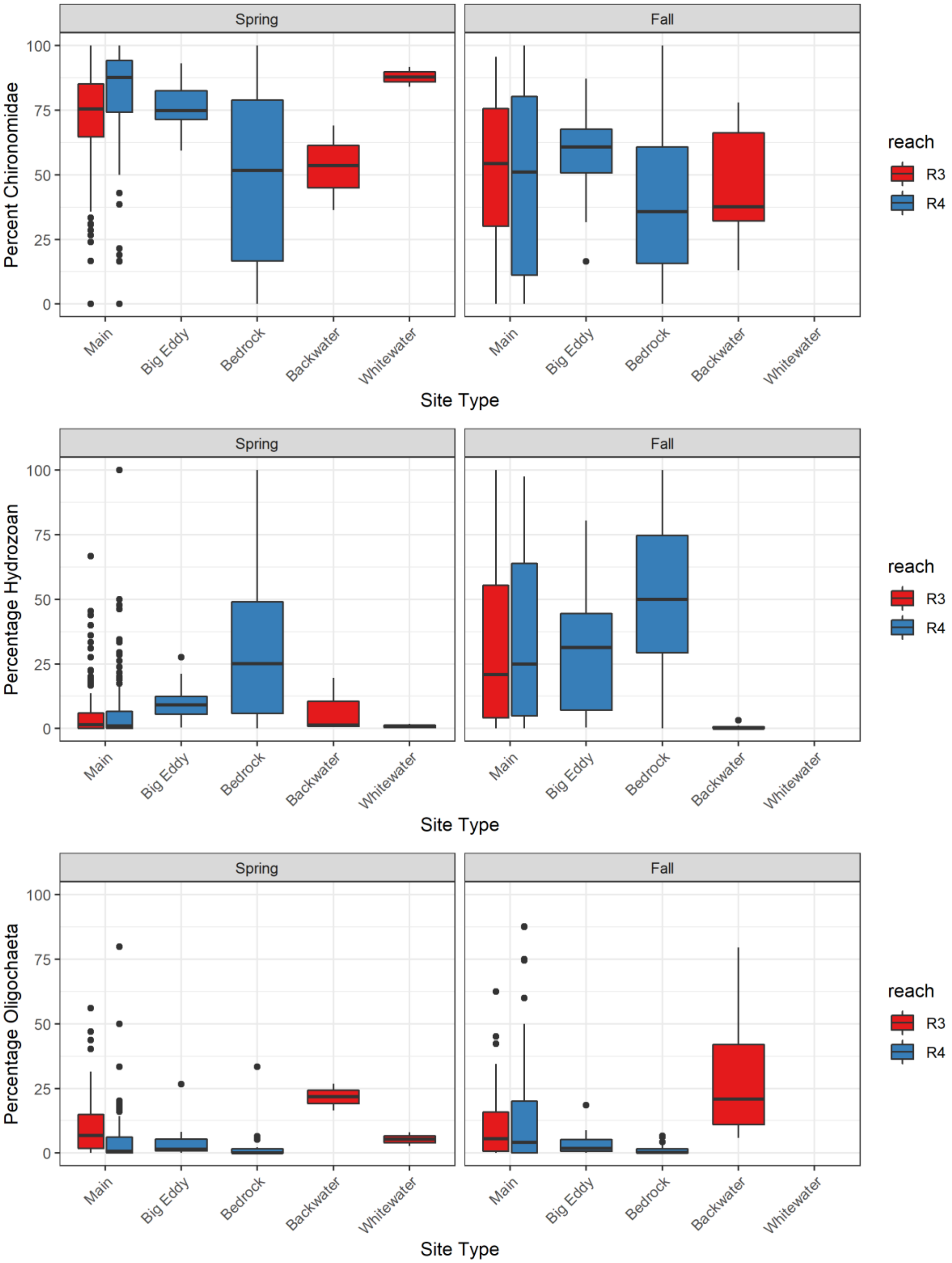

Figure A28 **Boxplots of invertebrate community composition as percent abundance grouped by habitat type for all MCR sites sampled from 2007-2019. Main sites were sampled for all years and all other site types were sampled less frequently.**

To simplify the interpretation, the distribution of invertebrate samplers across the various depths of the river channel are also described as either permanently submerged, located in the varial zone or located in the upper varial zone. Spring invertebrate abundance at the main sites was significantly different between the six transects (F=48.5, p<0.001). T2-T4 had a similar range of invertebrate abundances and were the most productive transects in spring (Figure A29). The deepest (T1) and the shallowest (T6) transects had the most significant pairwise differences for invertebrate abundance (Table A15). The deepest transect, T1, had a lower mean invertebrate abundance than T2-T4 and a higher mean invertebrate abundance than T6. The shallowest transect, T6, had the lowest invertebrate abundance and was significantly different than transects T1-T5.

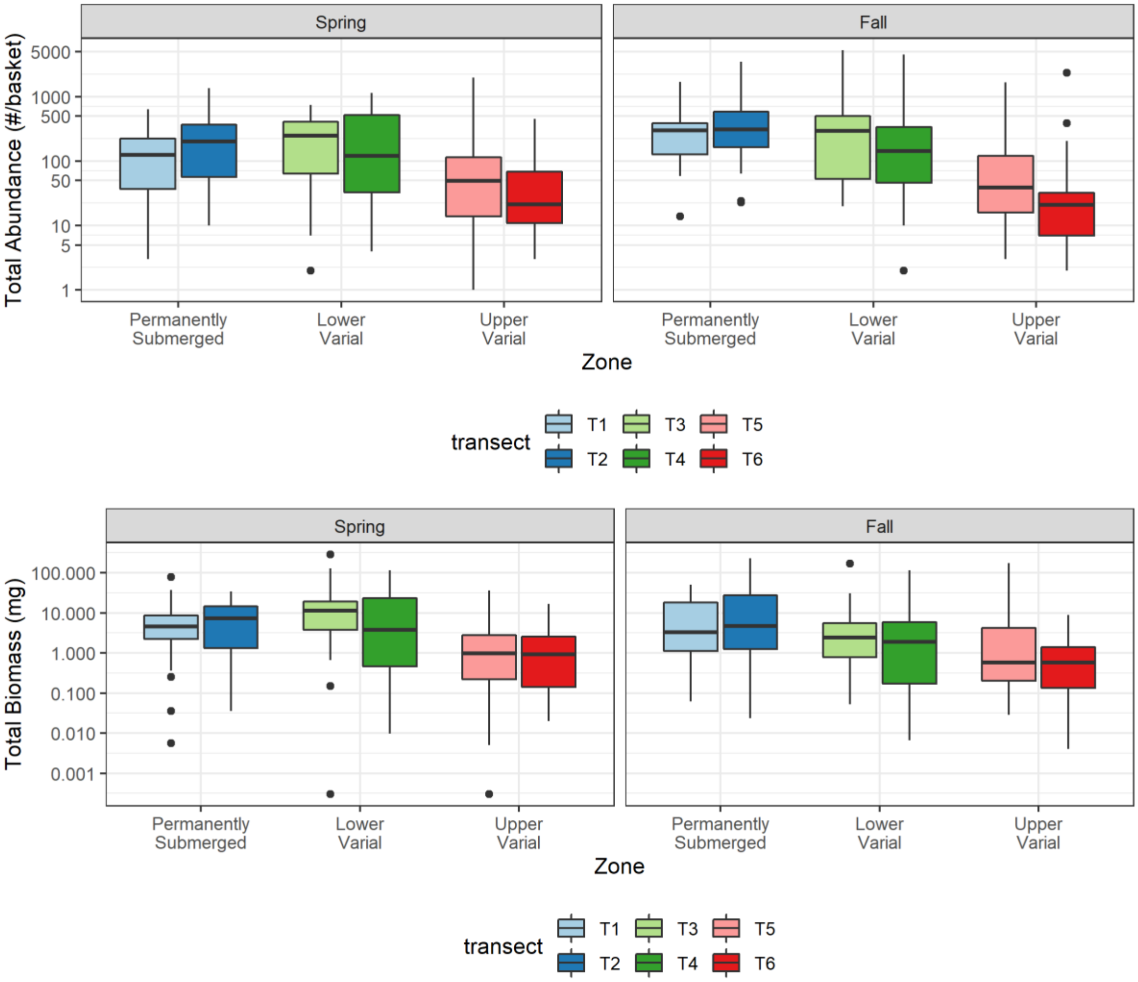

Figure A29 **Boxplots of invertebrate production metrics grouped by zone and transect for main sites sampled from 2010-2019.**

Table A14 **Friedman test results comparing invertebrate productivity and community composition see Figure A29 and Figure A30 metrics between transects using site, season and year as blocking variable.**

Metric	Season	Statistic	P-value
% Chironomidae	Fall	19.900	**0.00132**
% Chironomidae	Spring	6.140	0.293
% Hydrozoan	Fall	5.060	0.409
% Hydrozoan	Spring	13.300	**0.0206**
% Oligochaeta	Fall	8.370	0.137
% Oligochaeta	Spring	7.960	0.158
Total Abundance	Fall	48.500	**<0.001**
Total Abundance	Spring	33.800	**<0.001**
Total Biomass (mg)	Fall	17.300	**0.00405**
Total Biomass (mg)	Spring	30.300	**<0.001**

Table A15 **Post-hoc Conover-Test for spring invertebrate productivity and community composition metrics that had significant differences.**

Metric	Transect1	Transect	T-stat	P-value
% Hydrozoan	T1	T2	2.636	**0.014**
% Hydrozoan	T1	T3	1.531	0.16
% Hydrozoan	T1	T4	1.361	0.203
% Hydrozoan	T1	T5	4.932	**<0.001**
% Hydrozoan	T1	T6	5.357	**<0.001**
% Hydrozoan	T2	T3	4.167	**<0.001**
% Hydrozoan	T2	T4	1.276	0.219
% Hydrozoan	T2	T5	2.296	**0.031**
% Hydrozoan	T2	T6	2.721	**0.012**
% Hydrozoan	T3	T4	2.891	**0.008**
% Hydrozoan	T3	T5	6.463	**<0.001**
% Hydrozoan	T3	T6	6.888	**<0.001**
% Hydrozoan	T4	T5	3.572	**0.001**
% Hydrozoan	T4	T6	3.997	**<0.001**

Metric	**Transect1**	**Transect**	**T-stat**	**P-value**
% Hydrozoan	T5	T6	0.425	0.671
Total Abundance	T1	T2	3.367	**0.001**
Total Abundance	T1	T3	4.040	**<0.001**
Total Abundance	T1	T4	3.619	**0.001**
Total Abundance	T1	T5	2.188	**0.038**
Total Abundance	T1	T6	7.828	**<0.001**
Total Abundance	T2	T3	0.673	0.579
Total Abundance	T2	T4	0.253	0.801
Total Abundance	T2	T5	5.555	**<0.001**
Total Abundance	T2	T6	11.194	**<0.001**
Total Abundance	T3	T4	0.421	0.723
Total Abundance	T3	T5	6.228	**<0.001**
Total Abundance	T3	T6	11.868	**<0.001**
Total Abundance	T4	T5	5.808	**<0.001**
Total Abundance	T4	T6	11.447	**<0.001**
Total Abundance	T5	T6	5.639	**<0.001**
Total Biomass (mg)	T1	T2	0.996	0.344
Total Biomass (mg)	T1	T3	6.141	**<0.001**
Total Biomass (mg)	T1	T4	0.996	0.344
Total Biomass (mg)	T1	T5	3.817	**<0.001**
Total Biomass (mg)	T1	T6	6.307	**<0.001**
Total Biomass (mg)	T2	T3	5.145	**<0.001**
Total Biomass (mg)	T2	T4	0.000	1
Total Biomass (mg)	T2	T5	4.813	**<0.001**
Total Biomass (mg)	T2	T6	7.303	**<0.001**
Total Biomass (mg)	T3	T4	5.145	**<0.001**
Total Biomass (mg)	T3	T5	9.959	**<0.001**
Total Biomass (mg)	T3	T6	12.448	**<0.001**
Total Biomass (mg)	T4	T5	4.813	**<0.001**
Total Biomass (mg)	T4	T6	7.303	**<0.001**
Total Biomass (mg)	T5	T6	2.490	**0.017**

Spring invertebrate biomass was significantly different between the six transects (F=30.3, p<0.001). The upper varial zone transects had the lowest invertebrate biomass (Figure A29). Invertebrate biomass in the upper varial transects was significantly different than T1-T4 (Table A15). In the lower varial zone, invertebrate biomass was higher in T3 compared to T4 and this difference was significant. T3 had the highest mean invertebrate biomass of all transects and was significantly different than all other transects. Invertebrate biomass was similar in the permanently wetted zone transects and the T4.

Invertebrate community composition metrics varied among transects (Figure A30). However, percent chironomids and oligochaetes were not significantly different between transects (Table A14). Percent Hydrozoan was significantly different between the six transects (F=13.3, p=0.02). The upper varial zone transects had significantly different percent hydrozoan from all other transects (Table A15). T2 had a low percent hydrozoan that was significantly different from T1, T3, T5, and T6. In the lower varial zone, T3 had a significantly different and higher mean percent hydrozoan compared to T4.

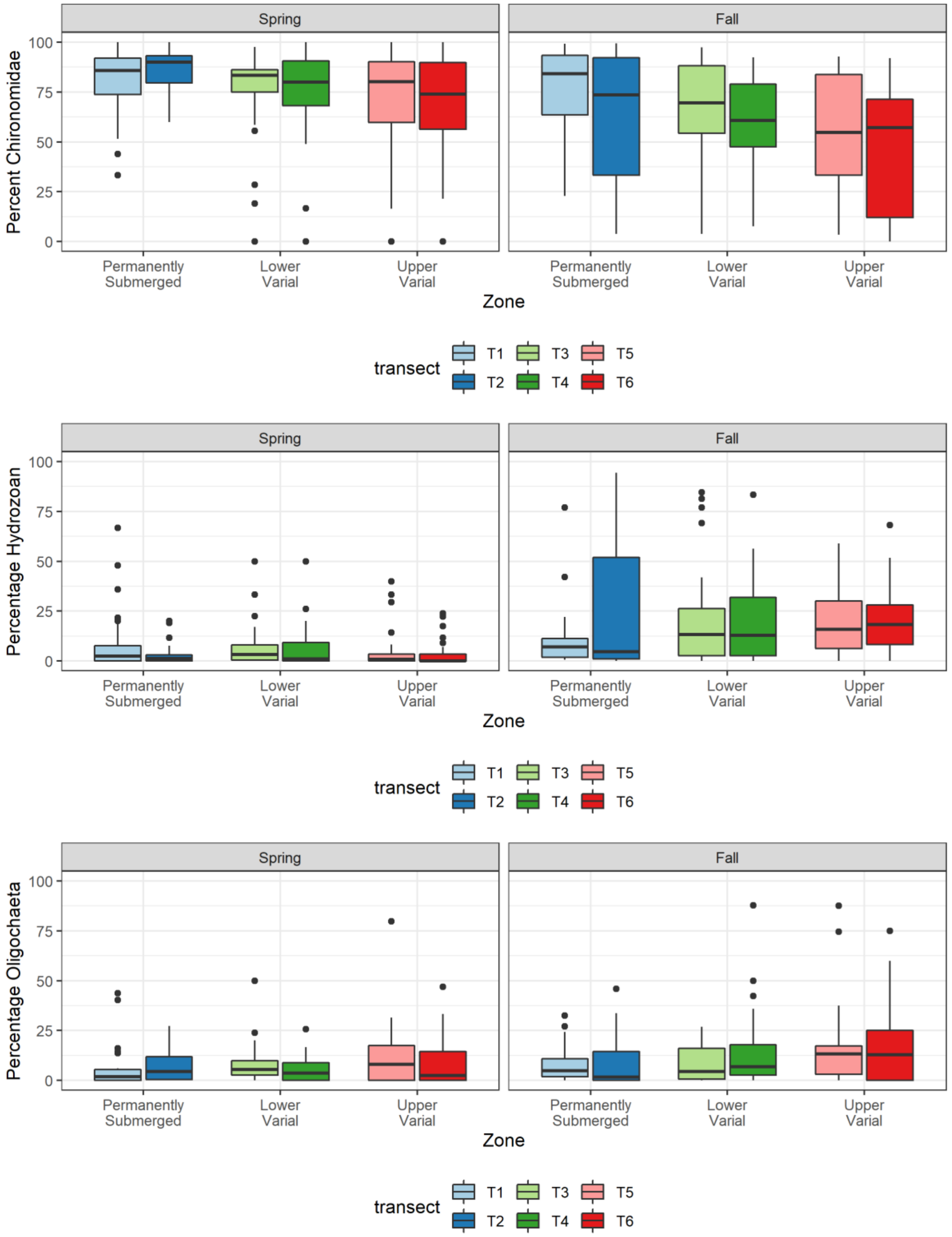

Figure A30 **Boxplots of invertebrate taxa percent abundance grouped by zone and transect for main sites sampled from 2010-2019.**

Invertebrate abundance and biomass were significantly different between the six transects during the fall sampling sessions (Table A14). The T1-T3 transects had similar invertebrate abundances that were higher and significantly different abundances from T4-T6 (Figure A29). In the varial zone, invertebrate abundances decrease from T4-T6 and these differences are significant. For invertebrate biomass, the upper varial zone transects had the lowest invertebrate biomass of all transects and had significant differences between T1-T4. The lower varial zone transects had similar invertebrate biomass and significantly different biomass than T1. The permanently submerged zone had the highest mean invertebrate biomass of all transects.

Table A16 Post-hoc Conover-Test for Fall invertebrate productivity and community composition metrics that had significant differences.

Metric	Transect1	Transect	T_stat	P value
% Chironomidae	T1	T2	3.745	**0.001**
% Chironomidae	T1	T3	5.048	**<0.001**
% Chironomidae	T1	T4	6.025	**<0.001**
% Chironomidae	T1	T5	7.328	**<0.001**
% Chironomidae	T1	T6	8.631	**<0.001**
% Chironomidae	T2	T3	1.303	0.209
% Chironomidae	T2	T4	2.280	**0.033**
% Chironomidae	T2	T5	3.583	**0.001**
% Chironomidae	T2	T6	4.885	**<0.001**
% Chironomidae	T3	T4	0.977	0.331
% Chironomidae	T3	T5	2.280	**0.033**
% Chironomidae	T3	T6	3.583	**0.001**
% Chironomidae	T4	T5	1.303	0.209
% Chironomidae	T4	T6	2.606	**0.017**
% Chironomidae	T5	T6	1.303	0.209
Total Abundance	T1	T2	0.558	0.667
Total Abundance	T1	T3	0.186	0.853
Total Abundance	T1	T4	3.904	**<0.001**
Total Abundance	T1	T5	8.180	**<0.001**
Total Abundance	T1	T6	12.641	**<0.001**
Total Abundance	T2	T3	0.372	0.761
Total Abundance	T2	T4	4.462	**<0.001**
Total Abundance	T2	T5	8.737	**<0.001**
Total Abundance	T2	T6	13.199	**<0.001**

Metric	Transect1	Transect	T_stat	P value
Total Abundance	T3	T4	4.090	**<0.001**
Total Abundance	T3	T5	8.365	**<0.001**
Total Abundance	T3	T6	12.827	**<0.001**
Total Abundance	T4	T5	4.276	**<0.001**
Total Abundance	T4	T6	8.737	**<0.001**
Total Abundance	T5	T6	4.462	**<0.001**
Total Biomass (mg)	T1	T2	1.773	0.099
Total Biomass (mg)	T1	T3	2.256	**0.035**
Total Biomass (mg)	T1	T4	2.739	**0.012**
Total Biomass (mg)	T1	T5	5.157	**<0.001**
Total Biomass (mg)	T1	T6	7.896	**<0.001**
Total Biomass (mg)	T2	T3	0.483	0.63
Total Biomass (mg)	T2	T4	0.967	0.387
Total Biomass (mg)	T2	T5	3.384	**0.002**
Total Biomass (mg)	T2	T6	6.124	**<0.001**
Total Biomass (mg)	T3	T4	0.483	0.63
Total Biomass (mg)	T3	T5	2.901	**0.009**
Total Biomass (mg)	T3	T6	5.640	**<0.001**
Total Biomass (mg)	T4	T5	2.417	**0.026**
Total Biomass (mg)	T4	T6	5.157	**<0.001**
Total Biomass (mg)	T5	T6	2.739	**0.012**

During the fall sampling sessions, percent hydrozoans and oligochaetes were not significantly different between transects (Table A14). However, percent chironomids was significantly different between the six transects (F=19.9, p=0.001). In the permanently submerged zone, T1 had the highest mean percent chironomids (Figure A30). T1 had significantly different percent chironomids from all other transects, whereas the percent chironomids at T2 was significantly different from T1 and T4-T6. The lower varial zone transects had similar percent chironomids. However, the percent chironomids at T3 were significantly different from the upper varial zone transects. The percent chironomids at T4 were significantly different from T6 but not T5

Dam operations exhibited annual variability and as a result the limits of three zones of submergence can shift. Based on analysis conducted in Section 12.5.3, a submergence ratio of -

0.64 provides a suitable threshold for identification of the upper varial zone. The upper varial zone had invertebrate abundances that ranged from 1-461 individuals/basket. The mean invertebrate abundance in the upper varial zone was 45±72 individuals/basket which was lower than 361±594 individuals/basket in the zone below the upper varial zone.

9.6 Discussion

9.6.1 Periphyton

9.6.1.1 Drivers of Periphyton Composition and Productivity

This study segment was designed to assess periphyton community composition and standing crop over the range of flow and habitat conditions in the MCR. The inherent variability of the MCR system was overcome in part by this study's 13-year duration that helped limit the impact of unusual years on summary statistics and modelling. Variability in substrate was controlled by using an artificial substrate although it is acknowledged that the rough open-celled Styrofoam employed in this project tended to exaggerate accrual rates and final biomass estimates by 20 - 25% or more compared to adjacent natural substrates.

The following section discusses the study results where the strength of evidence was strong and offers literature context for conclusions, as well as best estimates where the strength of evidence was weak. The level of uncertainty in the topics discussed herein is moderate, and could be lowered by extending the study from fall and spring into the summer and winter seasons.

Periphyton Composition Compared to Other Rivers

Like most large rivers, MCR periphyton was dominated by diatoms that accounted for over 90% of the biovolume in Spring and Fall and in both reaches. The dominant MCR diatom species were either the low-profile guild - rapid colonizing diatoms with firm attachment strategies, or large planktonic guild taxa imported from Revelstoke Reservoir that adhered to the periphyton biofilm. Selection pressure favouring low-profile guilds has also been found in other hydropeaking facilities (Passy and Larson 2011). Reservoir plankton are more important to MCR periphyton recovery than would be the case in an unregulated river. Although periphyton taxa are less sensitive than invertebrates to the rate of substrate de-watering as opposed to its duration, ramping down can be too rapid for spore/cyst formation and rapid ramping up can dislodge or abrade stressed taxa (Bondar-Kunze 2016; Biggs and Thomsen 1995). These flow-related stressors act to limit periphyton community diversity. With a mean taxa richness of ~20 ± 6 taxa, species richness in the MCR was lower than is typical for unregulated large rivers of similar latitude (Table A17).

Table A17 Summary of typical MCR periphyton metrics from spring and fall 2010 - 2012, with comparison to oligotrophic, typical, and productive large rivers

Metric	Oligotrophic or stressed	Typical large rivers	Eutrophic or productive	MCR (values bolded in bracket = 6 month samples)
Number of taxa (live & dead)	<20 – 40	25 - 60	variable	5 - 52 **(39-50)**
Chlorophyll-a ug/cm^2	<2	2 - 5	>5 – 10 (30+)	0.04 – 4.1 **(0.59-2.0)**
Algae density cells/cm^2	<0.2 x10^6	1 - 4 x10^6	>1 x10^7	<0.02 – 1.5 x10^6 **(0.9 – 13.1x10^6)**
Algae biovolume cm^3/m^2	<0.5	0.5 – 5	20 - 80	0.03 - 10 **(0.6 - 5.9)**
Diatom density frustules/cm^2	<0.15 x10^6	1 - 2 x10^6	>20 x10^6	<0.01 – 0.6 x10^6 **(0.2-1.0 x10^6)**
Biomass –AFDW mg/cm^2	<0.5	0.5 - 2	>3	0.12 – 4.8 **(0.35-3.5)**
Biomass –dry wt mg/cm^2	<1	1 – 5	>10	0.7 – 80 **(6-99)**
Organic matter (% of dry wt)		4 - 7		1 – 10 **(2-7)**
Bacteria count sediment. HTPC CFU/cm^2	<4 -10 x10^6	0.4 – 50 ×10^6	>50×10^6 – >10^{10}	0.2 – 5 x10^6
Bacteria count water CFU/mL	0.1 – 10 x10^4	0.1 – 100 x10^5	2.4 x10^7	Not sampled
Fungal count CFU/cm^2	<50	50 – 200	>200	<250 – 6000
Accrual chl-a ug/cm^2/d	<0.1	0.1 – 0.6	>0.6	0.0003 - 0.034 shallow; 0.001 - 0.038 deep

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

The rate of substrate de-watering (ramping) events restricted the mode of recovery to recolonization (Biggs 1996; Ahn et al. 2012). Periphyton originating from the Revelstoke Reservoir were important to regularly repeated periphyton recovery and this impacted periphyton community structure.

Large filamentous algae can act as ecosystem engineers, increasing substrate surface area for other organisms by orders of magnitude (Sigee 2005). In MCR these include Didymosphenia geminata (Didymo) and filamentous green algae. There was minimal nuisance algae Didymo in most spring sample sessions, while other spring samples that had significant Didymo growth. However, large nuisance mats that could impact MCR food chains were not observed in this 13-year study of MCR, likely due to regular substrate drying in the varial zones and velocities exceeding Didymo tolerance in the thalweg (Clancy et al. 2020; James et al. 2012; Cullis et al. 2013; Spaulding et al. 2015). Increased fall filamentous green algae growth was observed in R4 and R3 after 2010 under the new flow regime. These slow-growing algae can form visible mats in the summer under ideal conditions where shear is low under stable, lower flows. Less favourable conditions include high flows when their mats can be dislodged and desiccation when their filaments are destroyed. The area remaining wetted by minimum flows should retain short growths that could re-populate dewatered substrates. Thus, filamentous growth in the Reach 4 T2-T4 zone may continue to gradually increase over the years since minimum flows were implemented. This review of filamentous green algae distributions supports the assumption that flow management exerts a powerful influence on the MCR periphyton community.

Critical Flows

Abrupt changes in near-bed water velocity can arise naturally from storm flows or from operations ramping up. Periphyton mat shear/abrasion can be expected at velocities exceeding 0.30 m/s (Ahn et al. 2012) and mat removal is complete within 30 minutes of the velocity increase (Cullis, et al. 2013).

Backwatering

A key aspect of MCR flow regime affected by both BC Hydro releases and by watershed hydrology is back-watering of Arrow Lakes Reservoir (ALR). This seasonal water cover reduces desiccation on riverine substrates that would otherwise be exposed by low flow releases, particularly in Fall and with R3 receiving the greatest effect. Back watering also affects water velocity by causing a more variable relationship between discharge and velocity, particularly in R3, while in the absence of back watering, maximum velocities correspond to the highest discharge flows (Telemac 2-D model). As a result of this flow complexity, the Reach 3 upper varial zone was the most variable region for periphyton productivity in the MCR. With continuous backwatering, it can exceed the productivity of deeper areas but in seasons without backwatering, it can have minimal productivity.

Seasonal Variability in Periphyton Productivity

All statistical tests confirmed that Fall had significantly greater periphyton abundance, biovolume and chl-a compared to spring, where Fall productivity metrics were almost double the spring metrics. Statistical modelling indicated that the important drivers behind the greater fall periphyton productivity and diversity were flows (lower water velocities, greater backwatering), and warmer water temperatures. The greater Fall productivity occurred despite fewer hours over the photosynthetic minimum threshold compared to Spring (Plewes et al. 2019).

Habitat Differences impact Periphyton Productivity

As with mainstem sites, productivity metrics for all substrate units was generally higher in the fall than in the spring. Bedrock habitats and backwater habitats were less productive than the predominant mainstem units, while Big Eddy was the most productive. Periphyton community structure shifted reflecting velocity conditions in these habitats where mainstem substrates were dominated by high profile taxa while bedrock was dominated by the low profile guild and sandy R3 substrates showed a higher proportion of motile taxa. These ecological preferences are confirmed by other researchers (Passy 2006; Rimet and Bouchez 2012).

Reach and Transect Influences on Periphyton Productivity

The variable donations of Revelstoke planktonic diatoms were very important to mainstem MCR periphyton production and to recovery rates following desiccation, particularly in R4 (Plewes et al. 2019). Year by year, productivity in R3 and R4 showed the same patterns in all growth metrics, however in both the spring and fall samples, R4 periphyton community structure and productivity generally showed greater reactions to flows and growing conditions, while R3 reactions indicated greater periphyton stability despite variable flows and growing conditions. Average periphyton productivity decreased with increasing exposure from the permanently wetted T1 through the upper varial zone T6. In general, MCR substrates that were wetted for periods greater than nine hours per day experienced rapid periphyton growth (Schleppe et al. 2012).

There are numerous mechanisms that account for similarities in species distribution in large rivers like the MCR. These include flow events that can either shield (backwatering) or move (high flow events) benthic species to new substrate locations. Additionally, the T1/T2 area that remained wetted by minimum flows together with continuously received drifting algae from Revelstoke Reservoir, can function as a source of organisms to re-colonize exposed habitat areas with the same suite of taxa after catastrophic flow events.

MCR periphyton productivity changes with transect position corresponded to substrate submergence time and secondarily to irradiance. Overall, upper varial zone periphyton productivity was significantly lower than the productivity of the lower varial zone or the permanently submerged zone. The T1-T3 samplers were the most productive in spring, whereas the T1-T4 samplers were most productive in fall. ALR backwatering in fall results in more substrate submergence in the lower varial zone, resulting in higher production at T4 samplers.

The percent high profile, low profile, and motile guilds were significantly different in spring across the river channel (T1-T6), while the fall guild metrics were not. The high profile taxa were not able to withstand the cooler air temperatures of spring in the upper varial zone. The fast growing low-profile taxa replace the high profile taxa in the upper varial zone, as is indicated in the literature (Rimet and Bouchez 2012).

One of the largest ecological guilds is composed of the taxa donated by the Revelstoke Reservoir, accounting for an overall 23-24% of the periphyton in both reaches. Thus Revelstoke Reservoir in supports MCR productivity and recovery, and suggests that flows control the deposition of phytoplankton on the river substrates. For example, spring 2018 had high peak flows that prevented settling of planktic guild taxa in permanently submerged and lower varial zone areas. To have higher percentages of planktic guild submergence ratios had to exceed 0.58 in spring.

9.6.2 Benthic Invertebrates

This study segment was designed to assess benthic invertebrate community composition and productivity over the range of flow and habitat conditions in the MCR. The inherent variability of the MCR system was overcome in part by this study's 13-year duration that helped limit the impact of unusual years on summary statistics and modelling. This was particularly important for benthic invertebrate research because variable MCR flows intersect invertebrate life histories creating more variability and uncertainty than was evident for periphyton with their simple life history. The following section discusses the study results where the strength of evidence was strong and offers literature context for conclusions, as well as best estimates where the strength of evidence was weaker. The level of uncertainty in the topics discussed herein is moderate, and could be lowered by extending the study from fall and spring into the summer and winter seasons.

Invertebrate Composition and Productivity Compared to Other Rivers
The MCR invertebrate community composition was similar to other flow regulated rivers. The dominance of tolerant invertebrate taxa such as chironomids and oligochaetes are common downstream of dams (Phillips et al. 2016; Kjærstad et al. 2018). High abundances of Hydrozoans have been reported upstream and downstream of reservoirs (Hindle 2018; Schleppe et al. 2019). Chironomids are rapid recolonizers and many species of chironomids such as *Orthocladius sp.* are adaptive to a wide range of flow conditions (Kjærstad et al. 2018; Schmedtje and Colling, 1996). The subfamily of Orthocladiinae was the dominant chironomid taxa group in MCR. Orthocladiinae were also the dominant invertebrate in other large rivers in British Columbia (Reece and Richardson, 2000). The chironomid subfamilies of Diamesinae and Tanypodinae were also present in MCR and have been observed downstream of other dams (Arnwine et al. 2006; Szczerkowska-Majchrzak et al. 2010).

The invertebrate taxa richness of MCR was lower than other flow regulated rivers. All other flow regulated rivers presented in Table A18 had Ephemeroptera or Trichoptera as abundant taxa. MCR had a lower EPT richness compared to Peace River, Lower Columbia River (LCR), and Saskatchewan River (Schleppe et al. 2019, Olson-Russello et al. 2019, Mihalicz et al. 2019). Similar to MCR, the portion of the Colorado River downstream of the hydropeaking Glen Canyon Dam also had low EPT richness (Stevens et al. 1997). The low EPT richness in the Colorado River was largely due to low river water temperatures resulting from large hypolimnetic dam releases. The MCR also experiences large hypolimnetic dam releases and has cool water temperatures which rarely exceed 12°C in the summer (Golder 2014). The dominant invertebrate subfamilies Orthocladiinae and Diamesinae in the MCR are tolerant of cold water temperatures (Szczerkowska-Majchrzak et al. 2010). The water temperatures in LCR, Peace River and Saskatchewan River were higher and are more suitable for EPT taxa (Olson-Russello et al. 2019; Schleppe et al. 2019; Mihalicz et al. 2019).

The invertebrate densities in MCR were also lower than other flow regulated rivers in BC (Table A18). Lower invertebrate densities in MCR compared to the LCR and Peace River may have been a result of more extensive sampling of the varial and upper varial zones in MCR. The upper varial zones of rivers have lower invertebrate densities than the permanently submerged zone. Invertebrate densities in the upper varial zone (defined as less than 64% submerged) of MCR ranged from 11-5122 individuals/m^2 and were comparable to other hydropeaking rivers. The

Saskatchewan River and Baevera River in Norway had invertebrate densities that range from 39-2477 individuals/m^2 and 235.56-1835.56 individuals/m^2, respectively (Mihalicz et al. 2019; Herland 2012).

The low invertebrate biomass of the MCR was expected because the dominant benthic invertebrate organisms are small. There was limited biomass data available for rivers that had similar community compositions to the MCR. Oksrukuyik Creek in Alaska had the lowest invertebrate biomass compared to other studies. However, MCR had a lower biomass with a mean 0.13±0.33 g/m^2 whereas in Oksrukuyik Creek of Alaska biomass ranged from 0.8-2.0 mg/m^2. (Harvey et al. 1998). MCR had lower invertebrate biomass than Oksrukuyik Creek because of a different benthic invertebrate community composition. Oksrukuyik Creek had higher relative abundances of black files and the tolerant mayfly *Baetis sp.* compared to the MCR (Harvey et al. 1998). Black files and *Baetis sp.* have much larger individual biomass compared to orthoclads. The dominant chironomid subfamily Orthocladiinae of the MCR has very small biomasses that typically ranged from 0.015-0.032 mg/indiv (Niedrist et al. 2018). Orthocladiinae have small biomasses compared to other cold stenothermic chironomids such as Chironominae and Diamesinae (Anderson et al. 2012; Niedrist et al. 2018).

Table A18 Comparison of benthic invertebrate communities in different river systems.

River	Regulation Class	# of Invertebrates/m^2 Range (Median)	Taxa Richness Range (Median)	EPT Richness Mean±SD	Most Abundant Taxa
MCR (Revelstoke)	Hydropeaking	11-58,800 (1020)	1-35 (7)	1±2	Chironomids Hydra
Saskatchewan River (below E.B. Campbell Dam)	Hydropeaking	39-2477	13-37		Ephemeroptera Chironomids
Peace River (Downstream of Peace Canyon Dam)	Hydropeaking	44-583,000 (17,200)	4-41 (24)	7±4	Chironomids Oligochaetes Hydra Trichoptera
LCR (downstream of Hugh Keenleyside Dam)	Regulated River	344-349,000 (38,500)	7-51 (21)	6±2	Chironomids Trichoptera

Data sources include: Mihalicz et al. 2019, Schleppe et al. 2019, Olson-Russello et al. 2019

Seasonal Variability in Invertebrate Productivity

Benthic invertebrate production metrics were higher in fall compared to spring. The higher invertebrate production in fall could be a result of natural seasonal variation in invertebrate productivity or differences in wetted habitat area. In natural river systems, invertebrate production peaks in early fall (Giller and Twomey 1993), and similar trends have been reported in the regulated LCR Plewes et al. 2017). Arrow Lakes Reservoir (ALR) backwatering was more extensive in fall and as a result substrate remained wetted for longer periods of time. The reduced drying of substrates in fall may also contribute to an increased invertebrate production.

Hydrozoans and oligochaetes contribute more to the MCR invertebrate community in fall compared to spring. Downstream of the Cow Green dam in the River Tees, the abundance of hydrozoans was highest in September (Armitage 2006). More extensive ALR backwatering in the fall provides favourable habitat for hydrozoans and oligochaetes because the backwatering reduces velocity. Hydrozoans prefer slower current velocities (Schmedtje and Colling, 1996). Most species of the oligochaete including *Nais sp.* also have a preference for slower velocities (Schmedtje and Colling 1996). The ALR backwatering may also enhance the invertebrate community by providing transport of hydrozoans from ALR to upstream riverine reaches.

Habitat Differences impact Invertebrate Productivity

Backwater and Big Eddy sites had the largest differences in productivity and/or community composition. As expected, Backwater sites had a different invertebrate community composition than other sites which included a higher abundance of oligochaetes and a lower abundance of chironomids. Backwater sites have slower velocities and finer substrates. Oligochaetes, such as *Nais sp.,* prefer habitats that have finer substrates including sand, silt mud and/or detritus (Tachet et al. 2010). Backwater and Big Eddy sites had higher invertebrate production compared to the other site types. Two of the four Big Eddy sites exhibit backwater characteristics. Backwater sites in other rivers have been shown to have higher invertebrate production than main channel sites (Wolz and Shiozawa, 1995).

Invertebrate Productivity Across the River Channel

Productivity across the river channel is variable by metric and influenced by season. The shallowest permanently submerged sample (T2) and both lower varial zone samplers had the highest invertebrate production in spring. In the fall, the permanently submerged zone and the lower varial zone sample with the least exposure (T3) had the highest invertebrate production. The reduced invertebrate production at the deepest permanently submerged zone sample were a result of higher spring velocities near the thalweg. Higher velocities near the thalweg result in the loss of invertebrates through drift and the velocities that are too fast for some invertebrates to colonize the area (Plewes et al. 2019). At the least exposed varial zone site (T3), the substrate dewatering did not decrease the invertebrate production, likely because the dewatering was infrequent and occurred mostly at night. Chironomids in MCR appeared to tolerate and effectively withstand short periods of nighttime dewatering and exposure. These taxa are documented as tolerant to a wide range of environmental conditions including velocity and temperature (Mihalicz et al. 2019).

The upper varial zone (T5 and T6) consistently had the lowest invertebrate productivity. The reduced invertebrate production has been reported in varial zones of other regulated rivers (Jones et al. 2013; Kjærstad et al. 2018). The frequent daytime and nighttime dewatering in the upper varial zone caused loss of invertebrates through death from harsh environmental conditions (i.e. high ambient temperatures that result in substrate drying and thermal increases) and predation from terrestrial biota (Jones et al. 2013). Substrates also do not remain wetted long enough to allow for complete invertebrate recovery of rapid recolonizers such as chironomids (Kjærstad et al. 2018).

Differences in community composition across the river channel was inconsistent in spring and fall. The percent of chironomids was significantly different between transects in fall but not in spring, whereas the percent hydrozoans was significantly different in spring but not fall. In fall, chironomids were most abundant in the permanently submerged zone of MCR and chironomid abundances were lower in the shallower zones. Chironomids have been found to increase with depth in regulated river systems and have the lowest abundances in the varial zone that frequently experiences dewatering (Kjærstad et al. 2018; Jones et al. 2013). In spring, percent hydrozoans were variable across transects. The distribution of hydrozoans across the river channel was sporadic and did not show patterns within the three zones. Hindle (2018) observed that the abundance of hydrozoans was highest in the thalweg section of the river.

The invertebrate community composition in MCR did not experience large shifts across the river channel. In other studies, there was a big difference in invertebrate community composition when the permanently submerged zone was compared to the frequently dewatered varial zone. In the permanently submerged zone of the Magpie River there was a higher proportion of Ephemeroptera, Trichoptera and Dipterans compared to the varial zone (Jones et al. 2013). The permanently submerged zone of River Bævra had higher proportions of Ephemeroptera, Plecoptera, and Chironomidae compared to the varial zone (Kjærstad et al. 2018). There was a large difference in the relative abundance of Hydra between the permanently submerged zone and varial zone of the Upper Columbia River upstream of Lake Roosevelt (Hindle 2018). In the MCR, the diversity of the invertebrate community was restricted by cold water temperatures and high variability in flow and velocity. As a result, invertebrate community compositions was similar across transects because they include invertebrates that can withstand high variability in velocity, cold water temperatures and substrate dewatering.

Flow ramping

The rate of MCR substrate de-watering (down-ramping) events influenced the mode of invertebrate recovery by interactions with their life histories. In large rivers, rapid water loss through ramping down of hydro releases restricted in-situ benthic recovery and caused recovery to be driven by recolonization through drift (Stanley et al. 2004; Kennedy et al. 2016; Griemel et al. 2018). However, since the full suite of environmental data including detailed submergence predictor variables was not studied before REV5 flows, a statistical model to test the importance of ramping was not possible.

Composition Summary

The invertebrate community composition of MCR was consistently dominated by chironomids, hydrozoans and oligochaetes. Variations in the relative abundances of these invertebrate groups were caused by differences in habitat (i.e. substrates), velocity and duration of substrate exposure and dewatering. The higher percent hydrozoans and oligochaetes in ~~the~~ MCR was primarily caused by lower velocities from the creation of backwater habitat through extensive ALR backwatering. The finer substrates found at backwater sites also provide favourable habitat for oligochaetes.

Distribution

The distribution of invertebrate taxa across the river channel was influenced by high velocities and frequent substrate dewatering. The high velocities at the sample closest to the thalweg (T1) reduced spring invertebrate production. However, in the fall invertebrate productivity close to the thalweg was comparable to the shallowest permanently submerged sample (T2) because fall velocities are usually reduced due to ALR backwatering and lower average flows. Invertebrate production was not significantly reduced by nighttime dewatering in the lower varial zone. However, the combination of frequent daytime and nighttime dewatering in the upper varial zone limited invertebrate production. The frequent dewatering in the upper varial zone reduced the percent of chironomids; the reduction of chironomids in the upper varial zone was more noticeable in fall.

Abundance and Biomass Metrics Summary

The invertebrate abundance of MCR was similar to other rivers downstream of hydropeaking dams. Invertebrate abundance and biomass had high variation between season, habitat type and location across the river channel. Invertebrate biomass in the MCR was low because of the dominance of the chironomid subfamily Orthocladiinae. Similar to both natural and regulated river systems, invertebrate production of MCR was higher in fall compared to spring.

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10.0 APPENDIX 5. MQ #2

10.1 Introduction

MQ#2: *What is the effect of implementing minimum flows on the area of productive benthic habitat?*

10.2 Methods

Productive habitat area was determined separately for periphyton and invertebrates using reach-wide productivity models. The Reach-wide productivity (RWP) model determined benthic productivity based on the hourly wetted history of each polygon. If a polygon was wetted it was assumed the polygon was in a state of growth, whereas if the polygon was dry in a state of death. Periphyton chl-a and invertebrate biomass were selected as the benthic productivity metrics. The submergence and exposure were determined using a hydrological model. Productive areas for invertebrate and periphyton were compared pre and post minimum flows for Reach 3 and 4.

The RWP model provides a simplified approach to modelling periphyton and invertebrate production while accounting for hourly flow fluctuations. The simplified approach assumed that periphyton and invertebrate productivity were a function of the wetted history only. This is justified because substrate submergence has been consistently identified as the most important parameter controlling invertebrate and periphyton productivity in the MCR (Schleppe and Larratt, 2016). While the simplicity of the RWP model results in inaccuracies when determining the absolute reach-wide productivity for a given season or year, it can address relative differences within a given season to answer management questions regarding minimum flow. For the final year of this study, the number of years included in the RWP was expanded to capture a broader range of operations pre-minimum flow. The RWP model was run for 2000-2019 but only 2001-2019 were included in the model to account for the lag in productivity at the start of the model. Outputs of the RWP were compared for 2001-2010 (pre) and 2010-2019 (post).

10.3 Dataset

Table A19 **Predominant ecological productivity datasets.**

Name/Description	Source	Years Obtained
Productivity Datasets		
Hourly Discharge at Revelstoke Dam and Hourly ALR Elevations	Data obtained from BC Hydro	2000 - 2019
Benthic Invertebrates	Data collected at each productivity sampler during each deployment session. Biomass data was used in this modelling exercise.	2007 – 2010 (fall only); 2011 – 2013 (spring and fall); 2014 (fall only); 2015 – 2019 (spring only)
Chlorophyll-a Time Series	Chl-a data collected at time series sites throughout the deployment periods on a weekly basis. Used T1 samplers to adjust periphyton growth curves.	Fall 2010-2014, Spring 2011-2013, 2015-2019
Periphyton	Data collected at each productivity sampler during each deployment session. Chlorophyll-a was used in this modelling exercise.	2007 – 2010 (fall only); 2011 – 2013 (spring and fall); 2014 (fall only); 2015 – 2019 (spring only)

10.4 Analysis

10.5 *Reach-wide Productivity Model*

The Reach-wide productivity model was implemented to calculate daily productivity for chl-a and invertebrate dry biomass from 2001 to 2019. These model results were used to test the effect of minimum flows on the area of productive benthic habitat. The first component of the model was a hydrologic river elevation model that determined water depth on an hourly basis and defined the wetted perimeter of the river. The second component of the model used wetted history to determine riverine production using growth/ death curves for chl-a and colonization/death curves for invertebrate dry biomass.

10.5.1 River Model

Ecoscape completed the hydrologic modelling using a calibrated Telemac-2D model developed by Northwest Hydraulic Consultants (NHC 2016). Initially Northwest Hydraulic Consultants completed two models referred to as the Full MCR Model and the Upper MCR Model. As indicated in the NHC report the model coverages are as follows:

1. “The Full MCR Model extends from the Revelstoke Dam to Shelter Bay. The model has in the order of 320,000 nodes and 631,500 elements. The mean mesh element length is 15 metres.
2. The Upper MCR Model extends from the Revelstoke Dam to Greenslide Creek (from the Revelstoke Dam to 25km downstream). The model has in the order of 533,000 nodes and 1, 051,000 elements. The mesh element length ranges from

> 5 metres in the regions where wetting and drying processes are expected to occur to 15 metres in the main channel." (NHC 2016)

Ecoscape compared the Full MCR Model and the Upper MCR Model for use in the study area. The study area covers Reaches 3 and 4 that cover approximately 10 kilometers below the Revelstoke Dam. After running simulations of the two models, Ecoscape determined that the Upper MCR Model best represented the physical and hydraulic characteristic of the study area compared to the Full MCR Model. Increased complexity and magnitude of the Upper MCR Model caused much longer runtimes, but these were needed to achieve maximum resolution.

The Upper MCR Model was run for Reaches 3 and 4 using hourly discharge data from BC Hydro covering January 1, 2007 to December 31, 2018. The 12 years of data were divided up into monthly runs and programmed into the Telemac-2D simulations. The last simulated data from a given month was extracted and used as a seed file for the next monthly computation to ensure seamless transitions and accurate flow results between time blocks. This was done to manage both database size and runtime.

The Telemac-2D simulations output selafin files (.slf) containing all the programmed attributes for any given hour within the programmed date-time range. Each monthly selafin output was read into the program Blue Kenue. Blue Kenue was developed by the National Research Council Canada and is used as an analysis, data preparation, and visualization tool for hydraulic models. Blue Kenue was used to extract the hourly water depths for each point in the study area. The resulting data from the intersection was exported to a CSV file for use in the productivity analysis within R.

A full resolution intersection is currently not feasible within R due to the large sizes of the databases. To accommodate this limitation, Ecoscape created a polygon mesh covering the maximum potential water level within reaches 3 and 4. This was done by drawing a polyline from the thalweg of the river and offsetting it to both sides by 1 meter. This process was repeated until the full breadth of the maximum inundation potential of the river was covered. The linear polygons were then cut in 20 meter lengths perpendicular to the thalweg polyline essentially dividing the river into 1 meter by 20 meter polygons oriented with the flow of the river. A point file was generated from the centroids of each polygon and the area of each polygon was added as an attribute to the database.

All hourly depth data was imported into a PostgreSQL database using RPostgreSQL package version 0.6-2 (Conway et al. 2017). Each point had a polygon associated with it. The areal productivity of each polygon was calculated hourly using growth or death curves that were developed based upon the time spent either exposed or submerged. The growth and death functions were derived as part of the BRX productivity work (Schleppe et al. 2015), then coded in C++ by Sean Anderson and subsequently modified slightly by Ecoscape to address transitions between different seasons and the specific growth or death function that was used for each metric.

10.5.2 Productivity Model Notation

The following reach-wide productivity model notation was employed:

- $C(t)$ – total overall response as a function of time

- $c_i(t)$ – response for an individual river polygon of area s_i
- $\mu_i(t)$ – response per unit area for an individual river polygon of area s_i

Since the output of all functions are density- dependent responses (units/m^2), the derivation of formulae is identical between responses with only the coefficient values differing among them. For periphyton, we considered chl-a and for benthic invertebrates we considered benthic biomass, each with their respective units.

The total response at any time is given by the sum of the responses of each individual polygon:

$$C(t) = \sum_i c_i(t) = \sum_i \mu_i(t) \cdot s_i \quad (1)$$

10.5.2.1 Model for Individual Polygon

In a regulated flow regime, growth and death processes determine river production in the varial zone. In a given river polygon, a particular site can either be in a state of growth (submerged) or a state of death (exposed), and these processes cannot occur simultaneously; rather there are consecutive periods of growth and death that vary with submergence in the river. Upon switching from either a state of growth or death, the final value of a response at the end of one period is the initial value for the next. A given river polygon can move between growth (submergence) or death (exposure) independently of all other river polygons at any time and the state of a river polygon submergence is entirely dependent upon the regulated flow. The Telemac model was used to determine the state of submergence on an hourly basis.

10.5.2.1.1 Growth Phase

Growth at a given time will occur between time $t = t_a \dots t_b$, where time t_a and t_b represent the start of submergence and the time period where a polygon transitions from submergence to exposure, respectively. At the beginning of this time period, the initial response in a river polygon is $c_i(t_a)$, that may be zero or a positive number for any river polygon occurring within the maximum extents of the varial zone. This value will be peak production of the response in permanently submerged polygons.

At any point during this period we denote additional response growth by $c_i^g(t)$, that must equal zero at time $t = t_a$, the beginning of the period of growth. Thus:

$$c_i(t) = c_i(t_a) + c_i^g(t - t_a) \quad (2)$$

At the end of this phase, the total amount of the response of this polygon is

$$c_i(t_b) = c_i(t_a) + c_i^g(t_b - t_a) \quad (3)$$

10.5.2.1.2 Logistic Growth

At submergence, t_a, growth is initiated using a logistic growth function. The productivity response (e.g., abundance or biomass), $\mu_i(t_{a-1})$, is used to find the time on the growth curve, h_{a-1}

$$h_{a-1} = xmid - ln\left(\frac{asym}{\mu_i(t_{a-1})} - 1\right) \cdot scal \quad (4)$$

Where $asym$, $xmid$ and $scal$ are the parameters of the logistics growth function: $asym$ is the asymptotic height or peak biomass, $xmid$ is the inflection point, or the time to achieve 50% peak biomass ($0.5 \cdot asym$) and $scal$ is the time to grow from 50% or $xmid$ to 75% peak biomass ($0.75 \cdot asym$).

Furthermore, $h_a = h_{a-1} + 1$, where h_a is the predictor time for the growth curve when the polygon is initially submerged. The relationship between h and t can be written as a function of t, $h(t) = (t - t_a) + h_a$. Thus, the total response in a river polygon i during the growth phase is

$$(5) \qquad c_i(t) = \frac{asym}{1+exp^{(xmid-h(t))/scal}} \cdot s_i \qquad \text{if } t_a \le t < t_b$$

The parameters $asym$, $xmid$ and $scal$ for the same river polygon vary with season for periphyton, and not for invertebrates. If a time period $t = t_a \ldots t_b$ spans a change in season, growth will occur until the season peak biomass (asymptotic height) is reached. If the season peak biomass is greater than the following season, the biomass is reduced to the peak biomass for that season using the death curves.

10.5.2.1.3 Death Phase for an Individual Polygon

Death or loss within any given time period will occur between time $t = t_a \ldots t_b$, where time t_a represents the start of exposure and the time period t_b, where a polygon transitions from exposure to submergence. At the beginning of this time period, the initial response in this river polygon is $c_i(t_a)$, that may be zero or a positive number up to peak biomass.

At any point during this period we denote how much of the response was lost by $c_i^d(t)$, which must equal zero at time $t = t_a$, the beginning of the period of death. Thus:

$$(6) \qquad c_i(t) = c_i(t_a) - c_i^d(t - t_a)$$

At the end of the death or loss phase, the total amount of the response in this polygon is

$$(7) \qquad c_i(t_b) = c_i(t_a) - c_i^d(t_b - t_a)$$

We may rewrite this in terms of a percentage loss $\theta_i(t)$ for convenience:

$$(8) \qquad \theta_i(t) = \frac{c_i(t_a) - c_i(t)}{c_i(t_a)}$$

in which case

$$(9) \qquad c_i(t) = c_i(t_a) \cdot [1 - \theta_i(t)]$$

For periphyton, the start of the death or loss phase is offset by a fixed amount of time (starting values discussed above) that is dependent upon season, and this is easily incorporated by modifying the start time t_a used in these equations.

10.5.2.1.4 Exponential Decay

During the death phase, a response decays exponentially in time to an asymptotic value of $[c_i(t) \cdot A]$ such that the *total* amount of the response for a river polygon i during this period is:

$$(10) \qquad c_i(t) = c_i(t_a) \cdot \left\{A + [1 - A] \cdot e^{-\gamma \cdot (t - t_a)}\right\}$$

Where the decay constant γ and asymptote *A* are the same for every river polygon, such that the percentage loss is a river polygon-independent function of time only:

$$(11) \qquad \theta(t) = (1 - A) \cdot \left[1 - e^{-\gamma \cdot (t - t_a)}\right]$$

10.5.2.2 Full Production Model for All Polygons

At any given time there are river polygons which are both growing denoted with i, polygons which are saturated at peak biomass denoted with j, and polygons which are dying denoted with k. To find out the total overall response at any given time, we sum all the responses of all the individual river polygons since the beginning of the last time period at $t = t_a$:

$$(12) \qquad C(t) = \sum_i \left(\frac{asym}{1+exp^{(xmid-h(t))/scal}} \cdot s_i \right) + \sum_j \left(\mu_p \cdot s_j \right)$$

$$+\sum_k (c_k(t_a) \cdot [1-\theta(t)])$$

10.5.2.3 Model Assumptions and Limitations

The following are a list of assumptions used to develop the derived functions for growth, death, and peak biomass:

1. Several assumptions are required for starting response values $c_i(t_a)$. For permanently submerged polygons within the river, we assume that peak production for that metric was achieved, whereas in varial zones where polygons are alternately submerged and exposed, the starting value is assumed to be zero until submergence occurs. The minimum time that can be considered in any given operational scenario must span the period necessary for peak production for that response.
2. All river cells are considered independent of all other river cells, meaning that growth, death or peak biomass in any cell have no direct effect on any other given river cell. Factors including invertebrate drift from natural migration or effects associated with flow regulation (via changes in velocity) are not accounted for.
3. As mentioned above, hourly is the most appropriate time period, and all associated functions have been derived assuming that production will be calculated on an hourly basis. We have assumed that for a given hour, a river polygon cannot change from a state of submergence to exposure and that starting conditions within that period will be maintained for the entire hour in question. Although this considers flow in a stepwise approach, this unit of time is sufficiently small to reduce substantial error in our determination of river productivity.
4. This model assumes that when a given river cell transitions from a state of submergence to a state of exposure, emigration to adjacent submerged cells does not occur and vice versa. It is acknowledged that emigration of invertebrates likely occurs and presumably emigration rates are species-dependent. Further, the ramping rates may affect emigration rates, where high ramping results in more rapid elevation changes within the river, reducing the ability of invertebrates to move, whereas lower ramping would increase movement potential. Despite this consideration, the clear relationship between submergence and production shown in the MCR (with its high associated ramping rates) suggests that emigration rates do not adversely influence predicted estimates of production responses within the proposed reach-wide models.
5. This model assumes that growth and death curves do not differ with weather or between years. High annual variation in growth was observed, but the specific reasons for the variability are not yet well understood. Other specific parameters that might be important include velocity, substrate, weather, and substrate stability. Both the peak biomass and the rate of growth to peak biomass have been observed to vary between years on the MCR.
6. Production is greater than zero upon the first hour of growth and is equal to the minimum predicted growth at hour 1 in logistic regressions for each season. This is necessary for logistic growth curves to be predicted as values cannot start outside of the range of production predicted by the model.

7. In cases where the previous production value is higher than the maximum predicted growth for a given season, production will exponentially decrease until it reaches the maximum predicted growth for that season. Currently, the same exponential decay death function for exposure is used to transition between seasons, and is likely more abrupt than what would occur naturally. Realistically, this process is governed by processes of natural slough, and we do not currently have any data to this transition. This process could be easily added to the reach-wide model to further develop seasonal transitions. Since seasonal transitions occurred on the first of the month, data was not analyzed spanning any month.
8. Data that was collected since 2007 for a variety of different projects on the Columbia River for both BC Hydro and Columbia Power Corporation (CPC) was used to develop the reach-wide productivity model. The data collected in these assessments was integrated into one data set and relies upon the full suite of work completed by CPC and BC Hydro. This dataset is primarily based on data from the LCR. The LCR has higher periphyton and benthic productivity than the MCR and also different periphyton and benthic community compositions. From this data set, predictive growth and death functions have been developed that are directly linked to submergence times. The predictive growth curves have been adjusted to better represent the productivity in MCR. However, no data was collected in the summer and winter in the MCR. Professional judgement was used to adjust the summer and winter curves. It is acknowledged that productivity estimates in these seasons have large uncertainties. High annual variation was observed on these systems, and the data was condensed to consider only one growth or death curve for each season. A full investigation of the potential consequences of dataset reduction like this was not considered, but is likely an important factor.

10.5.3 Growth and Death Curves

The following provides a summary of the periphyton and benthic invertebrate growth and death curves used in the reach-wide model of productivity. Periphyton chl-a and invertebrate dry biomass (measured as AFDW) growth curves were generated and applied to the reach-wide productivity model using the same rationale as Schleppe et al. 2015. During the growth phase, production starts almost immediately upon submergence and continues until peak biomass is achieved. At peak biomass, growth still occurs, but is offset by rates of natural death or loss from physical factors including periphyton slough or invertebrate drift (Schleppe et al. 2015). The formula used for growth is represented as follows:

$$y = \frac{asym}{1 + e^{\frac{xmid - x}{scal}}}$$

where *y* is the response (productivity), *x* is the predictor (hours in the water), *asym* is the asymptotic height (peak biomass), *xmid* is the value of *x* that gives half the height of *asym* or the inflection point (i.e., the time to 50%), *scal* is the time to get from 0.5*asym to 0.75*asym, and e (natural log constant) is ~2.71828.

Details how growth and death curves were modified for MCR from Schleppe et al. (2015) were provided in Plewes et al. 2019. For invertebrate dry biomass, the growth curve measures the increase in invertebrate numbers through colonization drift processes and it does not account for growth or size increases of individual invertebrates.

The invertebrate growth and death curves were based on the AFDW of invertebrates. AFDW is the weight of organic matter in a sample which is obtained by calculating the loss from ignition at 550°C. The AFDW of invertebrates was not measured in MCR. As a result, after the invertebrate productivity model was run the AFDW was converted into invertebrate biomass to determine the productive invertebrate area. The conversion factor used for AFDW to biomass was 15.24 and was derived from a regression of CPC invertebrate biomass and AFDW data (Schleppe et al. 2015).

10.5.4 Determination of Productive Area

The daily productivity of chl-a and invertebrate biomass for each polygon was estimated by taking the modelled productivity at 12 o'clock noon each day. The daily productive estimates for each polygon were used to determine the area of productive habitat pre and post minimum flows.

The area of productive benthic habitat in R3 and R4 was determined for one day in each season from 2001-2019. February 25th, May 25th, July 25th and October 25th were the dates selected to correspond with the end of spring and fall sampling sessions. The invertebrate biomass and chl-a for each of these days at noon was extracted from the productivity databases. The production values for each polygon were converted to production densities by dividing by the polygon area. Polygons were above the production threshold were extracted. The total area of productive polygons was calculated for each reach and date.

The threshold for productive invertebrate habitat was determined by using invertebrate biomass, whereas the threshold for periphyton productive habitat used chl-a. The first quartile (Q_1) for mainstem sites at T1-T6 locations from all sampling sessions was calculated for chl-a and invertebrate biomass. Any polygon that had production greater than Q_1 for chla- and invertebrate biomass was considered productive.

The productive habitat areas for invertebrate and periphyton for each reach were compared pre and post minimum flows using a one-tailed Wilcoxon rank test. The Wilcoxon rank test was used because the productive area for each month had outliers and could not be transformed to meet normality assumptions. There were eight Wilcoxon rank test performed for each production metric (biomass, chla) to compare the habitat area by season and reach. A one-tailed Wilcoxon rank test and a significant level of 0.10 was used to increase the power the test because of small sample sizes (n_{pre}= 10, n_{post}= 9). With a large effect size, the power of the Wilcoxon rank test was 0.65, meaning there was a 65% chance of a true effect being detected.

10.6 Results

The threshold for classifying a polygon as productive was determined by using the first quartile (Q_1) of chl-a and invertebrate biomass based on all T1-T6 samplers from the mainstem. The invertebrate biomass productive threshold was 4.48 mg/m^2 (Figure A31). For periphyton, the productive chl-a threshold was 0.21 µg/cm^2 (Figure A32).

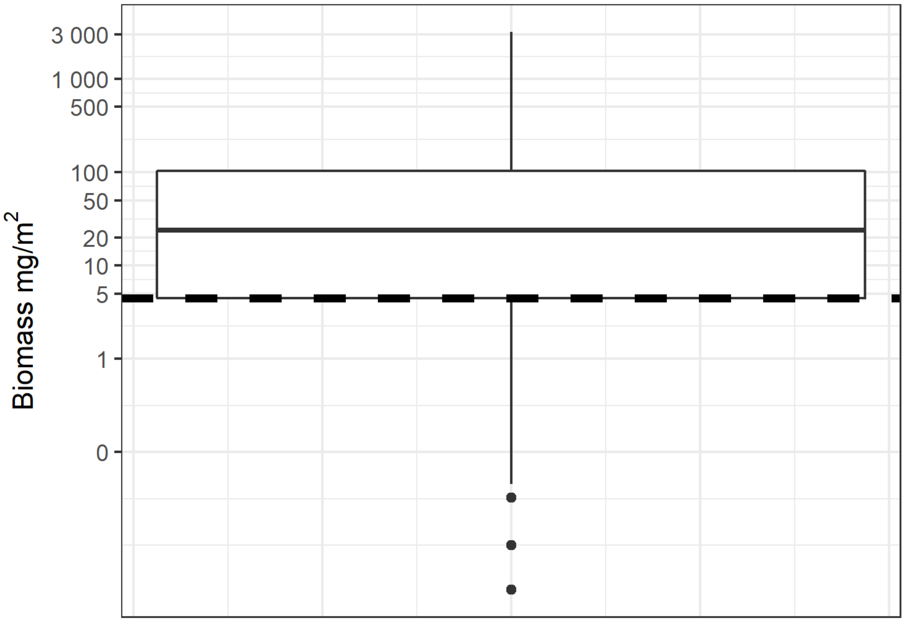

Figure A31 Boxplot of invertebrate biomass for mainstem sites from fall and spring sampling sessions 2010-2019. The dash line represents the first quartile of 4.48 mg/m².

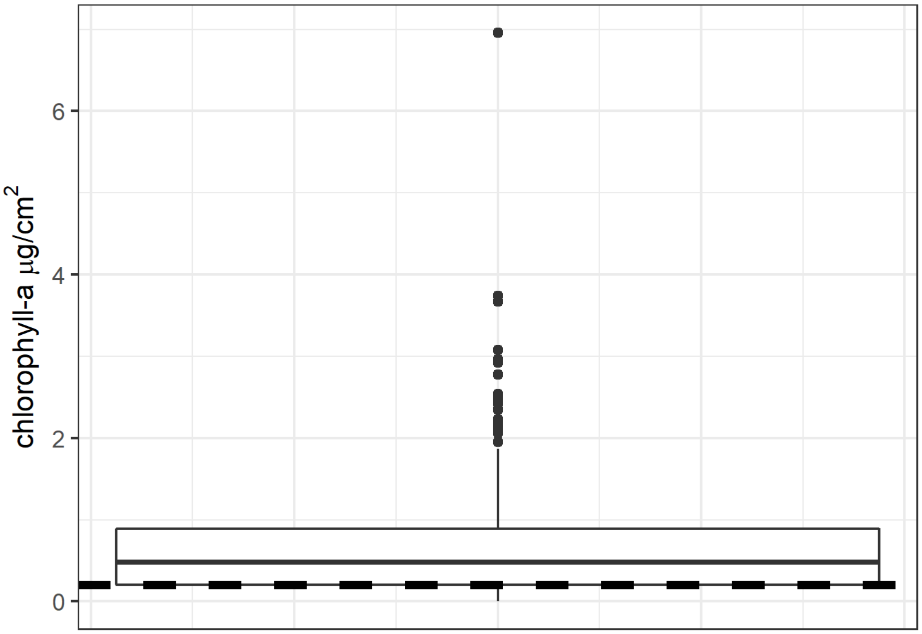

Figure A32 Boxplot of chl-a for mainstem sites from fall and spring sampling sessions 2010-2019. The dash line represents the first quartile of 0.21 µg/cm².

10.6.1 Periphyton Productive Area

The mean productive periphyton area in February was significantly larger post minimum flow in both reaches (Table A20). In R3, the mean productive area was 1.21±0.05 km² pre and 1.30±0.13 km² post minimum flows (Figure A33). The R4 mean productive area was 1.04±0.03 km² pre minimum flow and 1.09±0.05 km² post minimum flows. February 2019 had the highest mean productive area compared to February during 2001-2018 in both reaches. The periphyton productive area in February 2019 was 1.62 km^2 in R3 and 1.20 km^2 in R4.

Table A20 **Results for one-sided Wilcoxon rank for pre-post periphyton productive area.**

Reach	Month	Statistic	P.value
R3	Feb	18.000	**0.014**
R4	Feb	17.000	**0.011**
R3	May	18.000	**0.014**
R4	May	18.000	**0.014**
R3	Jul	35.000	0.223
R4	Jul	32.000	0.158
R3	Oct	25.000	**0.056**
R4	Oct	22.000	**0.033**

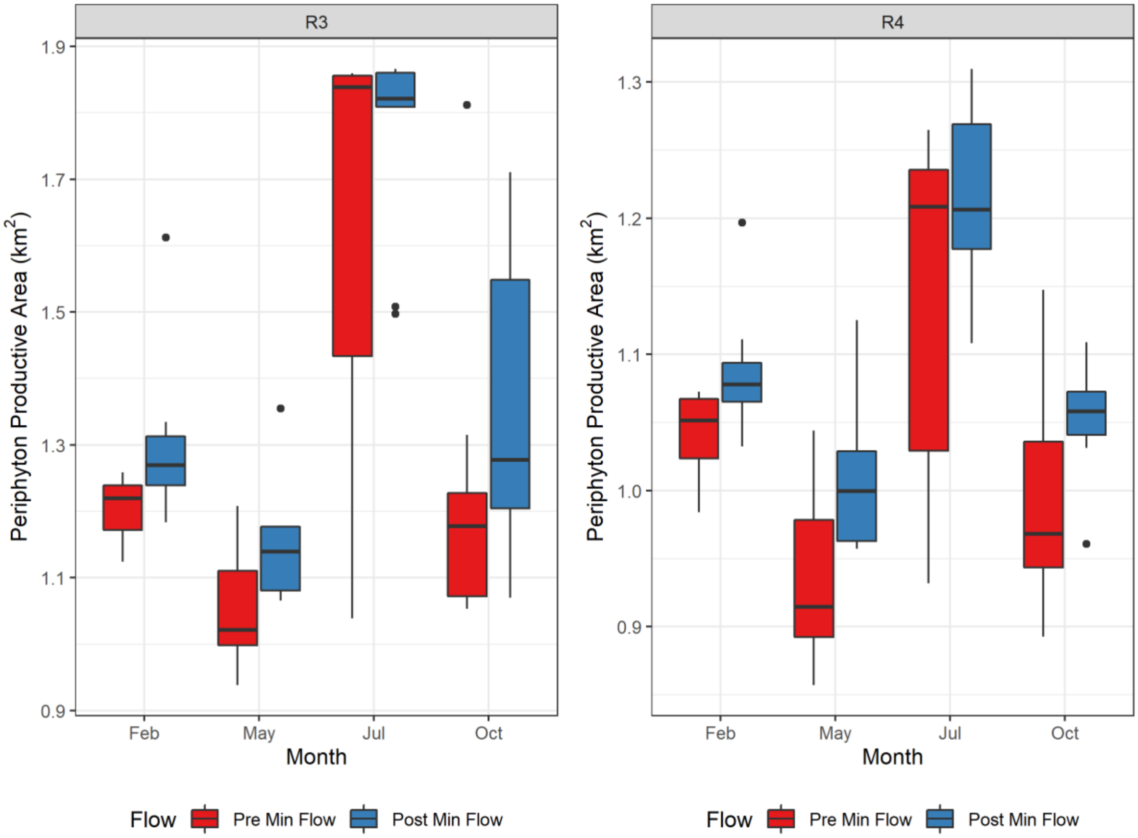

Figure A33 **Boxplots of productive habitat area for periphyton pre (2001-2010) and post (2010-2019) minimum flows.**

Similar to February, the mean productive periphyton area in May was significantly larger with the implementation of minimum flows in both reaches (Table A20). In R3, the mean productive area was 1.05±0.09 km^2 pre and 1.15±0.09 km^2 post minimum flows for a ~9% increase (Figure A33). The R4 mean productive area was 0.93±0.06 km^2 pre minimum flow and 1.01±0.05 km^2 post minimum flows for a ~8% increase. The R3 May 2015 productive area of 1.35 km^2 was much larger than other years.

Although the mean productive periphyton area was similar pre and post minimum flows in July (Table A20), the July productive periphyton habitat was highly variable pre minimum flows in both reaches (Figure A33). The productive habitat area in July pre minimum flows ranged from 1.04-1.86 km^2 in R3 and 0.93-1.27 km^2 in R4. The high variability in the pre minimum flow years was a result of July 2001, 2004 and 2005 that had smaller productive areas relative to other pre years. The productive habitat area was less variable post minimum flows in R3 and R4 with productive areas that ranged from 1.57-1.87 km^2 and 1.11-1.31 km^2. July 2015 and 2016 in R3 had productive habitat areas of 1.51 km^2 and 1.50 km^2 that were much lower than other post minimum flow years.

The post minimum flow mean productive area in October was significantly higher that the pre minimum flow area in both reaches (Table A20). The R3 mean productive periphyton area was 1.22±0.23 km^2 pre and 1.35±0.22 km^2 post minimum flows. The R4 post mean productive area was 1.05±0.04 km^2 which was higher than the mean pre productive area of 0.99±0.08 km^2 (Figure A33). October 2013 had the smallest R4 productive area of all post minimum flows years (0.96 km^2).

10.6.2 Invertebrate Productive Area

The mean productive invertebrate area of both reaches in February was significantly larger post minimum flow in February (Table A21). The R4 mean productive habitat area of 1.06±0.02 km^2 was higher post minimum flows compared to of 1.01±0.04 km^2 pre minimum flows (Figure A34). The R3 mean productive habitat area of 1.25±0.04 km^2 was higher post minimum flows compared to 1.17±0.07 km^2 pre minimum flows. February 2006 had the smallest R3 productive habitat area of 1.03 km^2 compared to all other years.

Table A21 **Results for one-sided Wilcoxon rank for pre-post invertebrate productive area.**

Reach	Month	Statistic	P.value
R3	Feb	15.000	**0.007**
R4	Feb	12.000	**0.003**
R3	May	26.000	**0.067**
R4	May	22.000	**0.033**
R3	Jul	21.000	**0.027**
R4	Jul	23.000	**0.039**
R3	Oct	26.000	**0.067**
R4	Oct	25.000	**0.056**

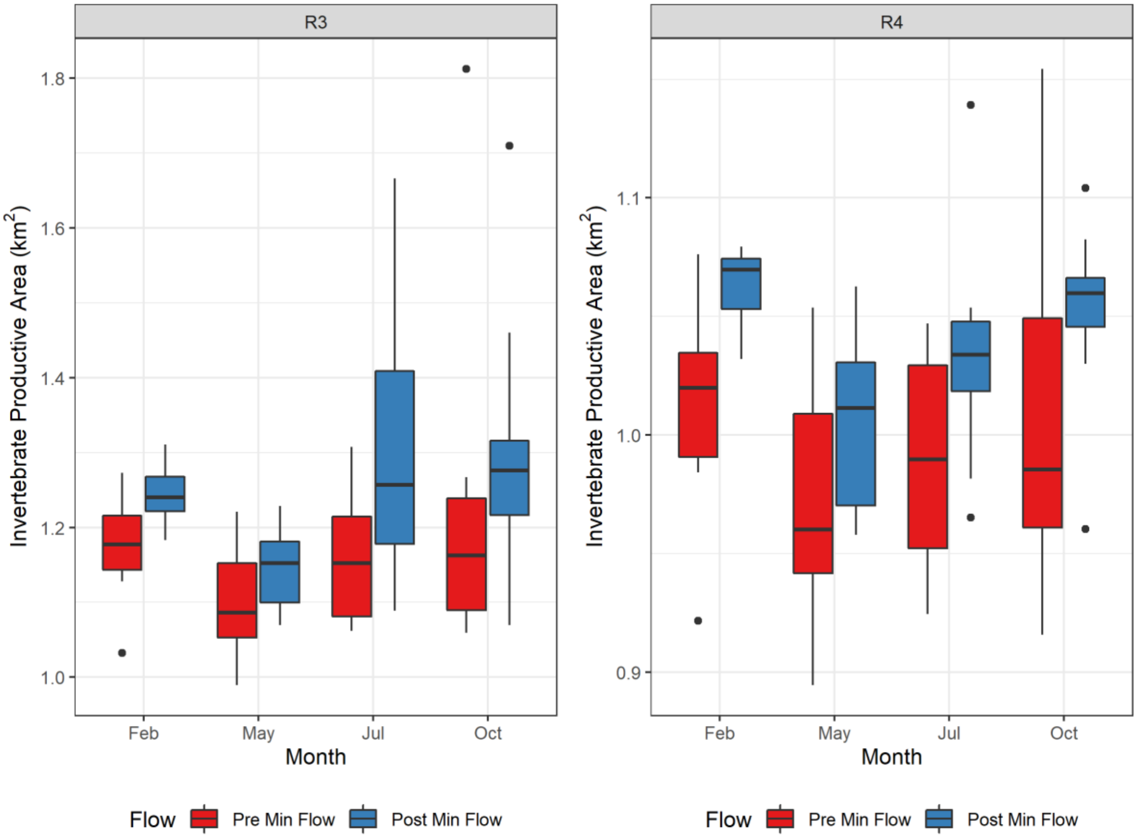

Figure A34 **Boxplots of productive habitat area for invertebrate pre (2001-2010) and post (2010-2019) minimum flows.**

The mean productive invertebrate area in May was significantly larger after minimum flows than before them in both reaches (Table A21). In R3, the mean productive area was 1.10±0.07 km^2 pre minimum flows and 1.15±0.05 km^2 post minimum flows (Figure A34). The mean productive area in R4 was 0.97±0.05 km^2 pre minimum flows and 1.00±0.04 km^2 post minimum flows. May 2015 had a substantially higher productive habitat area in R3 (1.23 km^2) and R4 (1.06 km^2) compared to other years.

The mean productive invertebrate area in October was significantly larger after minimum flows than before them in both reaches (Table A21). The productive habitat area in July pre minimum flows ranged from 1.06-1.31 km^2 in R3 and was less variable than the productive habitat area post minimum flows that ranged from 1.09-1.63 km^2 (Figure A34). The mean productive area in R4 was 0.99±0.05 km^2 pre and 1.03±0.05 km^2 post minimum flows. The R4 productive area in July 2015 was 1.14 km^2 which was larger than other years, whereas the productive area was lower in July 2011 (0.97 km^2).

Reach 3 and Reach 4 had significantly larger mean productive invertebrate areas post minimum flows compared to pre minimum flows in October (Table A21). During post minimum flows, the R3 productive invertebrate area ranged from 1.07 km^2 in 2013 to 1.71 km^2 in 2011, whereas pre minimum flows it ranged from 1.06 km^2 in 2003 to 1.81 km^2 in 2008. Overall, the R3 mean productive area was 1.22±0.22km^2 pre and 1.31±0.19 km^2 post minimum flows. The mean productive area pre minimum flows in R4 was 1.01±0.07 km^2, whereas the mean productive area post minimum flows was 1.05±0.07 km^2.

10.7 Discussion

Minimum flows increased the area of productive invertebrate and periphyton habitat in February, May, and October. R3 and R4 had significantly higher invertebrate and periphyton mean productive areas post minimum flows compared to pre minimum flows. The effect of minimum flows on the productive area in July was complicated by annual variability in ALR backwatering in all years of study. The invertebrate productive area benefitted from the effect of minimum flows in July, whereas the periphyton productive area did not benefit from minimum flows.

The mean periphyton productive area in July was similar before and after implementation of minimum flows. Annual variations in ALR elevations were more important determinants of periphyton productive area in July than minimum flows. July had the highest mean periphyton productive habitat area pre and post minimum flows compared to February, May, and October. High ALR elevations in the summer months increased the wetted habitat area because backwatering extended through R3 and R4 in most years. Years with lower July ALR elevations such as 2015 and 2016 had smaller productive habitat areas because of low ALR elevations in those summers (Figure A8). Likewise, July 2001, 2004 and 2005 had smaller productive areas because of low ALR elevations (Figure A35).

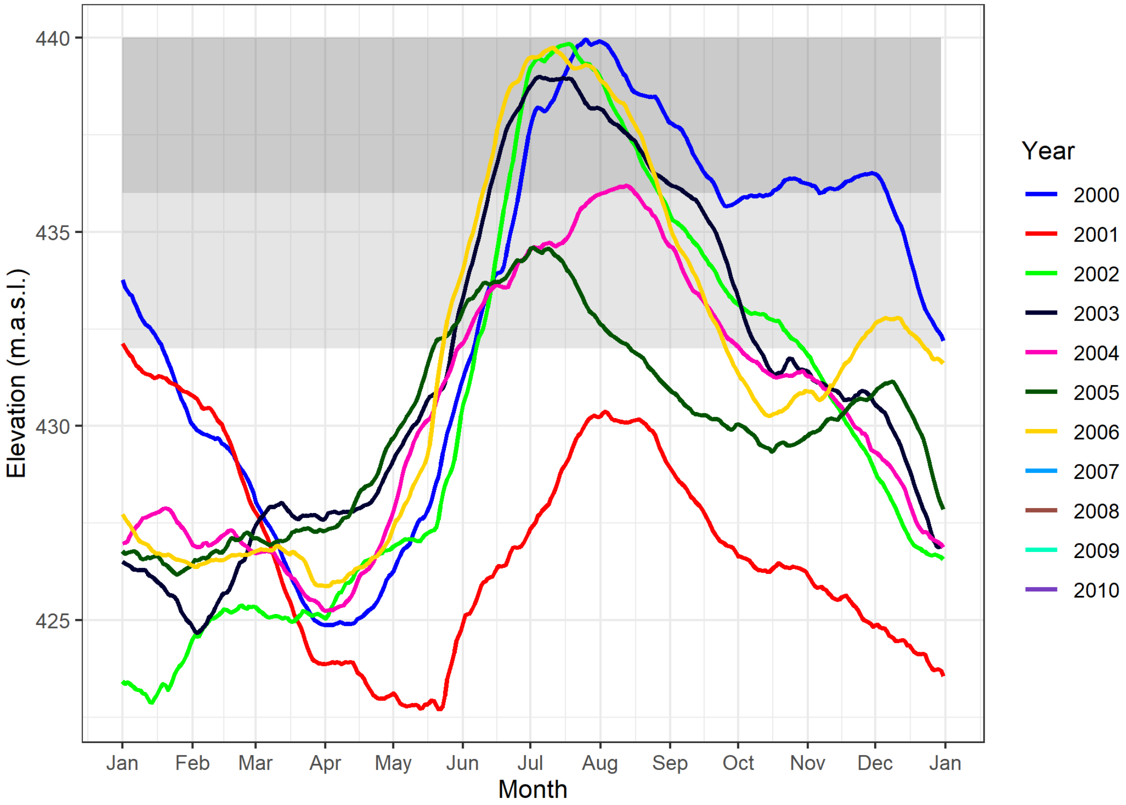

Figure A35 Backwatering of Arrow Lakes Reservoir (ALR) into the MCR Reach 3 (R3) and Reach 4 (R4) pre minimum flows. The vertical axis shows elevations in the normal operating range of ALR. Light grey shading denotes when R3 was backwatered; dark grey shading denotes when R3 and R4 were backwatered.

In July, the invertebrate productive area was significantly greater after the implementation of minimum flows than it was before them. The reach-wide productivity models had faster invertebrate death rates compared to periphyton death rates. The faster invertebrate death rates resulted in a larger difference of productive habitat area post minimum flows because periods of dewatering have a larger effect of invertebrate productive than periphyton productivity.

Based on reach-wide productivity models and the understanding of periphyton and invertebrate recovery gained from this study, minimum flows benefitted R4 more than R3 because of more extensive ALR backwatering in R3 and the resultant faster periphyton and invertebrate recovery rates. Reach 3 has more backwater habitat and tributaries that act as sources of periphyton and invertebrates to aid in recovery. Tributaries provide invertebrates by drift which resulted in increased colonization rates in R3 pre minimum flows. Shallows including backwaters and back-eddies are a source of recruitment and maintenance of some planktonic and periphytic species (Reynolds and Descy 1996; Butcher 1992). When ALR backwatering was limited in R4, minimum flows provided a permanently wetted area that protected invertebrates from harsh environmental conditions and acted a source of invertebrate organisms that could recolonize adjacent areas and aid in recovery (Plewes et al. 2019).

We expect that minimum flows had a greater benefit on the productive invertebrate area in the winter than our reach-wide productivity has indicated because the winter colonization rates of invertebrates in the MCR are slower than what was used in the model (Doeg et al. 1989). The reach-wide productivity model for invertebrates used the same colonization curve for all seasons because there was a lack of seasonal data. The colonization curve likely overpredicts the biomass of invertebrates in winter because chironomids and other invertebrates have slower colonization rates in winter. For example, after a disturbance in Acheron River, it took chironomids 71 days in winter and 8 days in summer to recover to the pre-disturbance density (Doeg et al. 1989).

Years that did not have typical operations had invertebrate and periphyton productive areas that were substantially larger or smaller relative to other years. For example, May and July 2015 had large productive areas because of high average flows for the spring and summer months. October 2013 had a small productive area compared to other Octobers because of lower ALR elevations in fall 2013. Fall 2008 and 2011 had larger productive areas because of high ALR elevations that resulted in extensive backwatering throughout R3 and R4.

In summary, with typical operating conditions and ALR elevations during Winter, Spring and Fall, minimum flows resulted in a larger spatial area of productive benthic habitat for both invertebrates and periphyton. In summer, minimum flows increased the area of invertebrate habitat but there no statistical difference in periphyton habitat area. The faster death rates of invertebrates in summer compared to periphyton, resulted in only the invertebrate habitat area benefiting from minimum flows. ***Therefore, we reject the hypothesis that minimum flows does not change the spatial area of productive benthic habitat for periphyton or benthic invertebrates in MCR.***

10.8 References

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11.0 APPENDIX 6. MQ # 3

11.1 Introduction

MQ#3: *What is the effect of implementing minimum flows on the accrual rate of periphyton biomass in the MCR? Is there a long-term trend in accrual?*

Ho_3: *The implementation of the 142 m^3/s minimum flow release does not change the total biomass accrual rate of periphyton in the MCR.*

Ho_{3A}: *There are no changes in accrual rates of periphyton at channel elevations that remain permanently wetted by minimum flow releases.*

Ho_{3B}: *There are no changes in accrual rates of periphyton at channel elevations that are periodically dewatered during minimum flow releases.*

11.2 Methods

Time Series artificial substrate samplers were similar to those described in *Appendix 2* but were used to assess periphyton accrual rates. Unlike the typical substrate samplers used for other sampling, the time series samplers had the float line directly attached to the rear of the periphyton sample plate rather than the anchor as on typical artificial substrate samplers. In addition, a 10 lb weight was attached to the float line approximately 10 m from the periphyton plate to assist with multiple retrieval and deployments over the sampling period. Time series sampling for benthic invertebrates was explored during the program, but the data was deemed insufficient for analysis, given its inconsistencies and low numbers (Table A22).

The purpose of time series collections was to understand the rates of periphyton accrual and to detect differences that may exist between permanently submerged areas and periodically dewatered areas within the varial zone. Time series samplers were retrieved once per week for 6 weeks following deployment, as opposed to sampling once at retrieval. Artificial substrate time series samplers were deployed across the river at transect positions from T1 through T7 in 2010. In these positions, observed accrual rates were very complex in response to rapid flow changes, weather during dewatered periods, and varying degrees of exposure. Subsequent effort was focussed in two key areas to develop better statistical models: the deep area permanently wetted by minimum flows (T1) and the lower varial zone (T3/T4), located above the permanently wetted edge. T3 and T4 time series samplers represent the conditions of the varial zone because samplers cannot be accurately placed, retrieved and re-deployed at the same location/depth during sample collection in MCR's swift water (Table A22). These time series samples are therefore considered representative of accrual in the varial zone rather than accrual at a discrete sampling location.

The success of weekly retrieval of time series samplers was dependent on flow conditions. Some weekly Styrofoam punches were not taken due to high flows, or the inability to retrieve samplers. In Table A22, the number retrieved reflects the samplers pulled on the final time series trip.

Table A22 **Summary of time series artificial substrate sampler deployment and retrievals between 2010 – 2019.**

Season	Reach	Site	Periphyton Samplers		Invertebrate Basket Samplers	
			# Deployed	# Retrieved (% Recovery)	# Deployed	# Retrieved (% Recovery)
Fall (September 10 - October 29 2010)	Reach 4 (R4)	Time Series (TS)	5	5 (100)	20	20 (100)
	Reach 3 (R3)	Time Series (TS)	5	5 (100)	3	3 (100)
2010 Totals			**10**	**10 (100)**	**23**	**23 (100)**
Spring (April 9 - May 27 2011)	Reach 4 (R4)	Time Series (TS)	5	5 (100)	10	7 (70)
	Reach 3 (R4)	Time Series (TS)	5	5 (100)	10	5 (50)
Spring Totals			**10**	**10 (100)**	**20**	**12 (60)**
Fall (September 10 - October 28 2011)	Reach 4 (R4)	Time Series (TS)	10	10 (100)	10	10 (100)
	Reach 3 (R4)	Time Series (TS)	0	-	10	8 (80)
Fall Totals			**10**	**10 (100)**	**20**	**18 (90)**
2011 Totals			**20**	**20 (100)**	**40**	**30 (75)**
Spring (April 10 - May 25 2012)	Reach 4 (R4)	Time Series (TS)	10	8 (80)	0	-
Fall (September 6 - October 19 2012)	Reach 4 (R4)	Time Series (TS)	10	6 (60)	0	-
2012 Totals			**20**	**14 (70)**	**0**	**-**
Spring (April 10 - May 29 2013)	Reach 4 (R4)	Time Series (TS)	10	10 (100)	10	10 (100)
Fall (September 9 - October 30 2013)	Reach 4 (R4)	Time Series (TS)	10	10 (100)	10	10 (100)

2013 Totals			**20**	**20 (100)**	**20**	**20 (100)**

Season	Reach	Site	Periphyton Samplers		Invertebrate Basket Samplers	
			# Deployed	# Retrieved (% Recovery)	# Deployed	# Retrieved (% Recovery)
Fall (September 9 - October 30 2014)	Reach 4 (R4)	Time Series (TS)	10	10 (100)	10	10 (100)
2014 Totals			**10**	**10 (100)**	**10**	**10 (100)**
Spring (April 12 - May 27 2015)	Reach 4 (R4)	Time Series (TS)	10	10 (100)	10	10 (100)
2015 Totals			**10**	**10 (100)**	**10**	**10 (100)**
Spring (April 11 - May 25 2016)	Reach 4 (R4)	Time Series (TS)	10	9 (90)	0	-
2016 Totals			**10**	**10 (100)**	**0**	**-**
Spring (April 10 - May 24 2017)	Reach 4 (R4)	Time Series (TS)	10	10 (100)	0	-
2017 Totals			**10**	**10 (100)**	**0**	**-**
Spring (April 10 - May 25 2018)	Reach 4 (R4)	Time Series (TS)	10	9 (90)	0	-
2018 Totals			**10**	**10 (100)**	**0**	**-**
Spring (April 8 - May 23 2019)	Reach 4 (R4)	Time Series (TS)	10	10 (100)	0	-
2019 Totals			**10**	**10 (100)**	**0**	**-**
2010 – 2019 Totals			**130**	**124 (95)**	**103**	**93 (90)**

Each week, periphyton punches were collected randomly from the Styrofoam artificial substrate and were immediately placed in the dark, on ice. The single punch for chl-a analysis was shipped overnight to the Cultus Lake DFO laboratory (2007 – 2012) or the Caro Analytical Lab (2013 – 2019), and the other punch was transported to H. Larratt for taxa identification/enumeration (Fall 2010 – 2013; Spring 2011). NOTE: The rough open-celled Styrofoam employed in this project since 2007 tends to exaggerate accrual rates and final biomass estimates by 20 - 25% or more compared to adjacent natural substrates.

Time series rock baskets were field processed in the same manner as regular samplers. During each weekly sample, the light/temp loggers were wiped clean with a paper towel so light measurements were accurate during time series sampling. The assumptions described in *Appendix 2* can also be attributed to the time series artificial substrate samplers.

11.3 Dataset

All benthic artificial substrate samplers collected after 2009 had HOBO light/temperature loggers that recorded data every 30 minutes. For most years time series samplers had two artificial samplers deployed at each site for five sites in R4. All T1 samples at R4 sites within a given deployment session may be pseudo-replicates because of the proximity of these sites (Figure A36). For periphyton samplers, the sites were widely spaced, thus pseudo-replication may occur at the site level for periphyton production within a given sampling session. Data from light/temperature loggers, hourly discharge and air temperature data were used to derive submergence ratio and mean temperature of water while submerged.

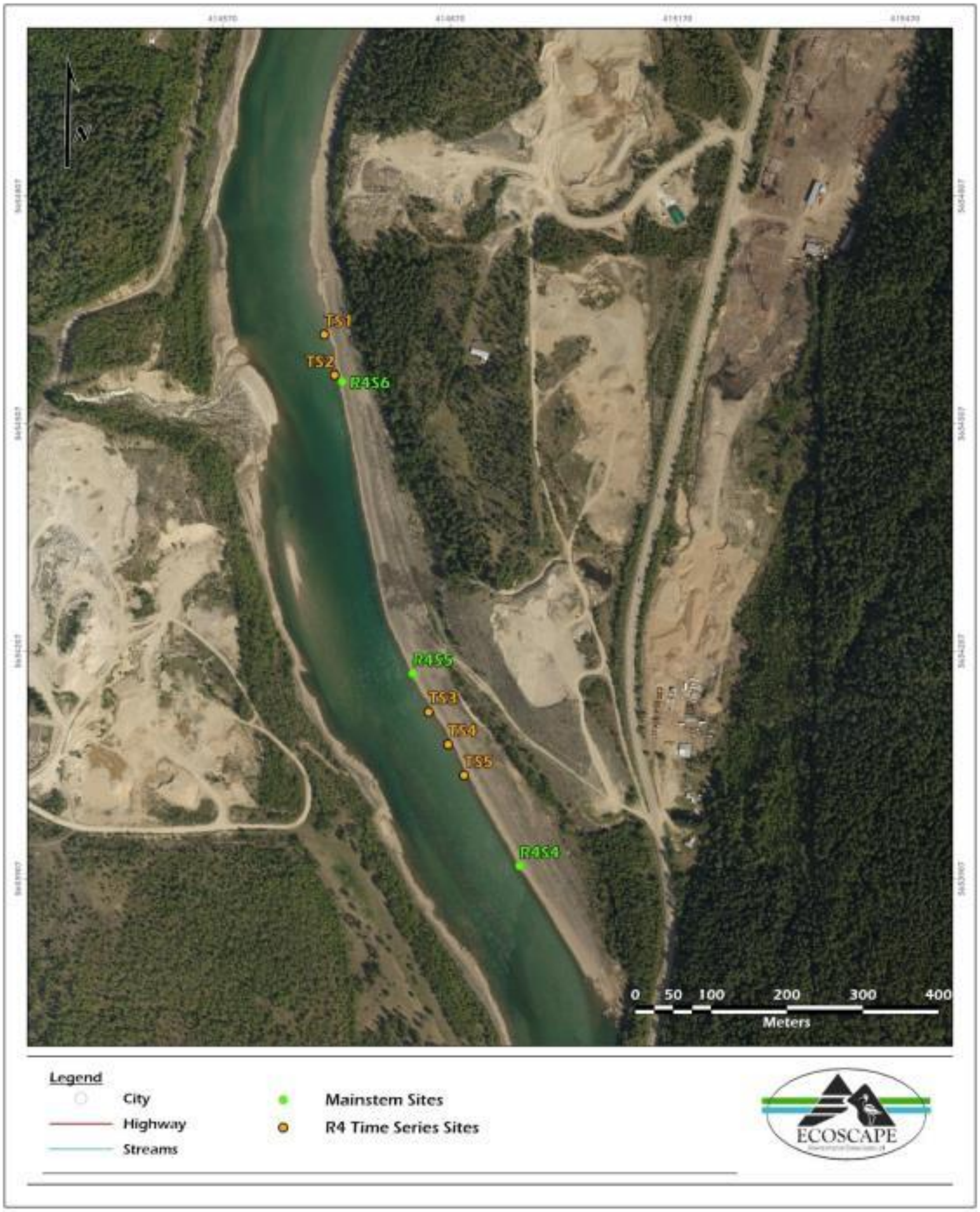

Figure A36 **Map of R4 time series sites.**

Table A23 **Datasets used in the analysis of management question #3.**

Name	Data Source/Description	Years Obtained
Light / Water Temp	Data collected at each productivity sampler during each deployment session	Fall 2007-2014, Spring 2011-2013, 2015-2019 (Temp) Fall 2010-2014, Spring 2011-2013, 2015-2019 (Light)
Chlorophyll-a Time Series	Chl-a data collected at time series sites throughout the deployment periods on a weekly basis	Fall 2010-2014, Spring 2011-2013, 2015-2019
Periphyton	Data collected at each productivity sampler during each deployment session. Data produced in the laboratory included abundance, chlorophyll-a, and associated metrics.	Fall 2007-2014, Spring 2011-2013, 2015-2019
Hourly Discharge at Revelstoke Dam (REV)	Data obtained from Poisson Consulting	2000-2019
Hourly Air Temperatures from Revelstoke Airport	Data obtained from Environment Canada	Fall 2010-2014, Spring 2011-2013, 2015-2019

Table A24 **Metrics derived from datasets.**

Variable	Definition
Submergence Ratio	Total time submerged divided by duration of deployment
Mean Water Temperature While Submerged	Average temperature of the water for the duration of deployment

11.4 Analysis

Determination of Submergence

To determine the effect of minimum flows on benthic invertebrate productivity and diversity the submergence ratio was calculated for all samplers from 2010 onwards. Submergence ratio was calculated by determining the hourly wetted history for each sampler. Water and air temperature data obtained from the HOBO light/temperature loggers was the primary dataset used to determine how long an artificial sampler was submerged. Four HOBO light/temperature loggers were placed in the upland areas above the maximum 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°C was used to compare samplers from permanently submerged locations with samplers across a transect. A sampler was considered exposed to air when the logger temperature differed from the permanently submerged logger by more than ±0.5°C. This analysis of submergence was only partially reliable as there were times during the deployment when the air and water temperatures were within 1.5°C of each other (Schleppe *et al.* 2011).

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

Descriptive Statistics

Descriptive statistics and boxplots were used to compare periphyton productivity metrics pre and post minimum flows. The T1 samples represented the area that remained permanently wetted at minimum flow, whereas the T3 samples represented areas periodically dewatered by minimum flow releases. The periphyton metrics of abundance and chl-a at T1 and T3 during fall sampling sessions were compared pre (2007-2010) and post (2011-2014), minimum flows.

Modelling

Random Forest (RF) models were used to better understand the effects of submergence on periphyton productivity. In addition, these models were used to assist in evaluating long-term trends in invertebrate productivity while accounting for differences in submergence and other factors. Separate RF models were run for spring and fall for chl-a. Random Forest is a non-parametric machine learning technique which does not require random distribution of residuals and can accommodate categorical predictor variables (Read *et al.* 2015). The explanatory variables used for RF models included site, reach, mean water temperature, submergence ratio, and year.

Random Forest determines the importance of each predictor variable and the relationships between each predictor variable and response variable. The variable importance measure for each predictor is determined by calculating the mean decrease in prediction error (Mean Squared Error), if the predictor is dropped from the model (Liaw and Wiener 2002). Predictor variables that have a strong relationship have large variable importance. Dropping these predictors from the model causes a large increase in prediction error. Variable importance plots for all predictors included in each model were generated to help identify predictors associated with the invertebrate production and diversity metrics. Partial dependence plots were generated to better understand the relationship between the selected top predictor and the response variable while considering the effects of the other variables in the RF model (Liaw and Wiener 2002).

Random Forest uses Classification and Regression Tree (CART) models as the base model. CART is a non-parametric tree-based method that splits data into separate groups based on the response variable (De'ath and Fabricius 2000; Jun 2013). CART initially partitions the data into two groups based on a split point and splitting variable that minimizes the sum of squares of the response variable of each group (De'ath and Fabricius 2000; Hastie et al. 2001). A recursive algorithm is used to search through every possible combination of explanatory variables and values to determine the best splitting variable and split point (Hastie et al. 2001). The CART algorithm continues to make binary splits at each tree node until a stopping criterion is reached (Jun 2013).

Random Forest builds different CART models by bagging, using a subset, the data and the explanatory variables tried - at each split. Each CART model uses a random subset of the dataset and at each split in the tree a random subset of predictor variables is tried as a potential splitting variable (Jones and Linder 2015). The default setting used in the R package Random Forest were used for the LCR water temperature models. The Random Forest models contain 500 trees (CART models) and in our case, one of the predictor variables out of the five predictors was randomly chosen as the splitting variable at each node (Liaw and Wiener 2002).

To better visualize the effects of annual variability, submergence and water temperature on chl-a CART models were run for spring and fall chl-a using the same explanatory variable as the RF. The CART models used R package rpart version 4.1-15 (Therneau and Atkinson 2019). The R package ggparty version 1.0.0 was used to visualize the CART models (Borkovec and Madin 2019).

Accrual Rates

Accrual rates were calculated for all R4 T1 and T3 time series samplers by using linear regression in R Statistical Software (R Core Team 2019). A linear regression was fit for each individual sample within a given deployment session. For each regression, the y-intercept was set to 0 because we assumed chl-a concentrations should be negligible before deployment. The accrual rates of each sampler were compared visually by boxplots group by sampling session and transect. Descriptive statistics were also calculated for accrual rates.

The Regional Kendall test was used to determine if long-term trends occurred in spring accrual rates. For Spring R4 time series accrual rates the Regional Kendall test was run separately for T1 and T3 samplers. The Regional Kendall test is a non-parametric test that accommodates for pseudo-replication because it accounts for correlation between samples (Helsel and Frans 2006). The R package rkt version 1.5 was used for the Regional Kendall test (Marchetto 2017).

11.5 *Results*

11.5.1 Overview of MCR Periphyton Accrual

MCR periphyton accrual depends on the sum of gains and losses over the time series sampler deployment periods. Chlorophyll-a was selected as the measure of periphyton productivity to assess accrual because it is a standard measure of production, it is available for the longest period in MCR, and it is highly correlated with abundance and biovolume in MCR data (e.g. Spring 2019 abundance R^2 = 0.85; biovolume R^2 = 0.78). Accrual samplers were deployed at two key depths to develop better statistical models: the deep area permanently wetted by minimum flows (T1) and the lower varial zone (T3), located above the permanently wetted edge, but with frequent wetting. Over this 13-year study period, MCR periphyton accrual demonstrated non-linear gains over the deployment period, gradual accrual over long periods exceeding six months and different accrual rates with depth and season in MCR. These results are explained in this appendix.

Due to costs, taxonomy on the time series accrual samplers was only collected in Fall 2010 through 2013 and in Spring 2011. In those years, the early colonizers in R4 included five common diatom genera (*Achnanthidium, Diatoma, Tabellaria, Synedra, Cymbella*), along with very small flagellates and cyanobacteria. T1 samplers developed a more diverse periphyton mat faster than shallower T3 sites did. For example, Spring species richness accrual was initially slow and was ultimately less diverse (26-31 species) than the fall samplers (37-38 species) (Please refer to Schleppe et al. 2015 for more taxonomic information).

11.5.2 Peak Biomass

Spring and fall chl-a accrual at T1 locations did not show a plateau typical of peak biomass after the 42 to 51 day deployment period (Figure A37). Rather, chl-a can continue to climb with incubation times exceeding 50 days. This was supported by very high chl-a and biovolume found on samplers that were incubated in MCR for 6 months (Schleppe et al. 2014). Chlorophyll-a showed a complex accrual curve that was still increasing after 1200 hours in the water. The periphyton accrual did not approach an asymptote within the 6 week or the 6-month accrual periods, but instead showed a continuing linear increase. Growth rates during the first few weeks were similar between permanently submerged and varial zone areas, but by the end of deployment, permanently submerged locations had achieved a greater quantity of chl-a (Figure A37).

MCR Periphyton accrual rates were calculated by linear regression for the 2010 to 2019 study years from chlorophyll-a data (chl-a) collected from T1 (permanently wetted) and T3 (frequently wetted) accrual transects deployed at five R4 sites. T1 and T3 time series accrual samplers were statistically distinct ($p<0.001$) for both the spring and fall deployment periods.

Time series samplers showed overall linear trends in growth over most deployment periods despite responses to flow events within those deployments. The linear slope of the accrual rates were significant for 86% of the time series samplers, and for these, the days of incubation explained 58-99% of the variation in chl-a. Figure A37 shows an example of accrual rates for Fall 2014 and Spring 2019 deployment periods.

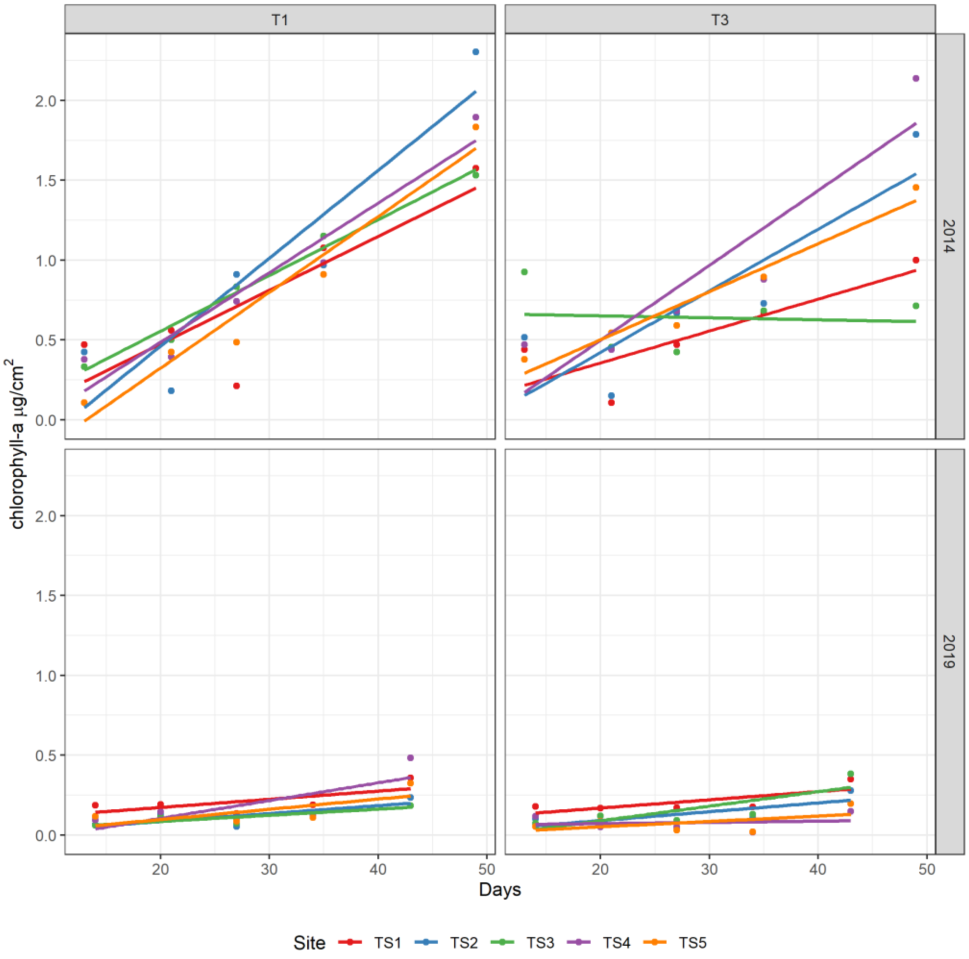

Figure A37 **Representative years Fall 2014 and Spring 2019 time series samplers with accrual rates plotted by site and transect.**

Spring 2018 had the most time series samplers that did not have significant linear accrual rates because accrual was variable over the deployment period. Chl-a increased from day 0-27 on the spring 2018 time series samplers and then decreased from day 27 to 35, likely in response to 8 high flow events that totalled 40 hours with flows exceeding 1800 m^3/s (Figure A38; Table A25). All other Spring sample sessions did not have flows >1800 m^3/s (corresponds to ~2m/s) beyond one hour. Figure A38 highlights the response of periphyton accrual rates to flows.

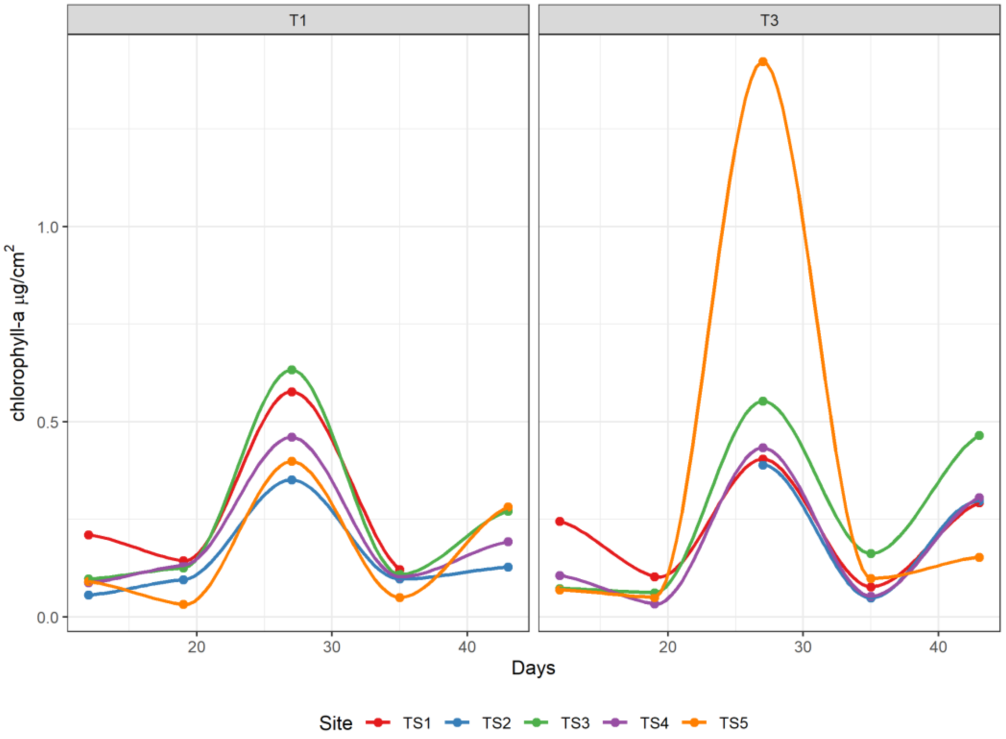

Figure A38 Spring 2018 T1 and T3 time series samplers grouped by site and transect.

Table A25 Duration and frequency of maximum and minimum flows in MCR 2011 – 2019.

Year	Season	Minimum	Maximum	Hours under 143 m³/s	Hours over 1800 m³/s	# of events over 1800 m³/s
2011	Fall	150.56	1,948.57	0	2	1
2012	Fall	154.46	2,160.58	0	27	9
2013	Fall	153.68	1,677.80	0	0	0
2014	Fall	152.38	1,866.69	0	4	4
2011	Spring	145.38	1,677.77	0	0	0
2012	Spring	127.72	1,725.88	1	0	0
2013	Spring	150.07	1,810.06	0	1	1
2015	Spring	156.91	1,705.20	0	0	0
2016	Spring	159.84	1,680.20	0	0	0
2017	Spring	141.64	1,529.40	2	0	0
2018	Spring	1.79	2,187.97	3	40	8
2019	Spring	163.95	1,673.39	0	0	0

11.5.3 Permanently Wetted at Minimum Flow: Productivity T1

Due to constrains in the data collected prior to implementation of minimum flows, the full T1 data set was used to address the effects of minimum flows on the thalweg area. When all sampled Fall T1 thalweg samplers were considered before and after implementation of minimum flows, comparable periphyton chl-a and abundance detected between these two periods (Figure A39;Table A26). Fall 2012 had the lowest mean abundance and chl-a of all fall sampling sessions (mean 0.61±0.65 ug/cm^2) and it had the highest peak flows with 27 hours exceeding 1800 m^3/s.

After velocity exceeds the shear threshold for a periphyton mat, reduced productivity metrics are expected. Both R3 and R4 had lower productivity metrics across the river transects with flows exceeding 1800 m^3/s. For example, chl-a was low at the T1 thalweg samplers in Fall 2012 (0.61±0.65 µg/cm^2) (Figure A39). With flows exceeding 1800 m^3/s for 40 hours in 8 events during Spring 2018 and 27 hours in 9 events during Fall 2012, the chl-a and biovolume at T1 samplers were 37-56% lower compared to previous spring and fall sampling sessions, likely due to velocity-driven shear stress. Although ALR backwatering frequently increased periphyton growth metrics in the varial zones, T1 thalweg samplers in Fall 2008 showed very low growth (0.59±0.38 µg/cm^2) perhaps due to the unusually high and prolonged backwatering that year.

Table A26 **Periphyton productivity metrics pre-and post-minimum flows.**

Flow	Name	Transect	Min	Max	Mean	Stdev	N
Pre	chlorophyll-a	T1	0.0217	2.56	1.17	0.694	23
Post	chlorophyll-a	T1	0.0619	3.08	1.24	0.708	21
Pre	Total Abundance	T1	50600	1.19e+06	663000	312000	23
Post	Total Abundance	T1	19900	1.66e+06	673000	414000	21

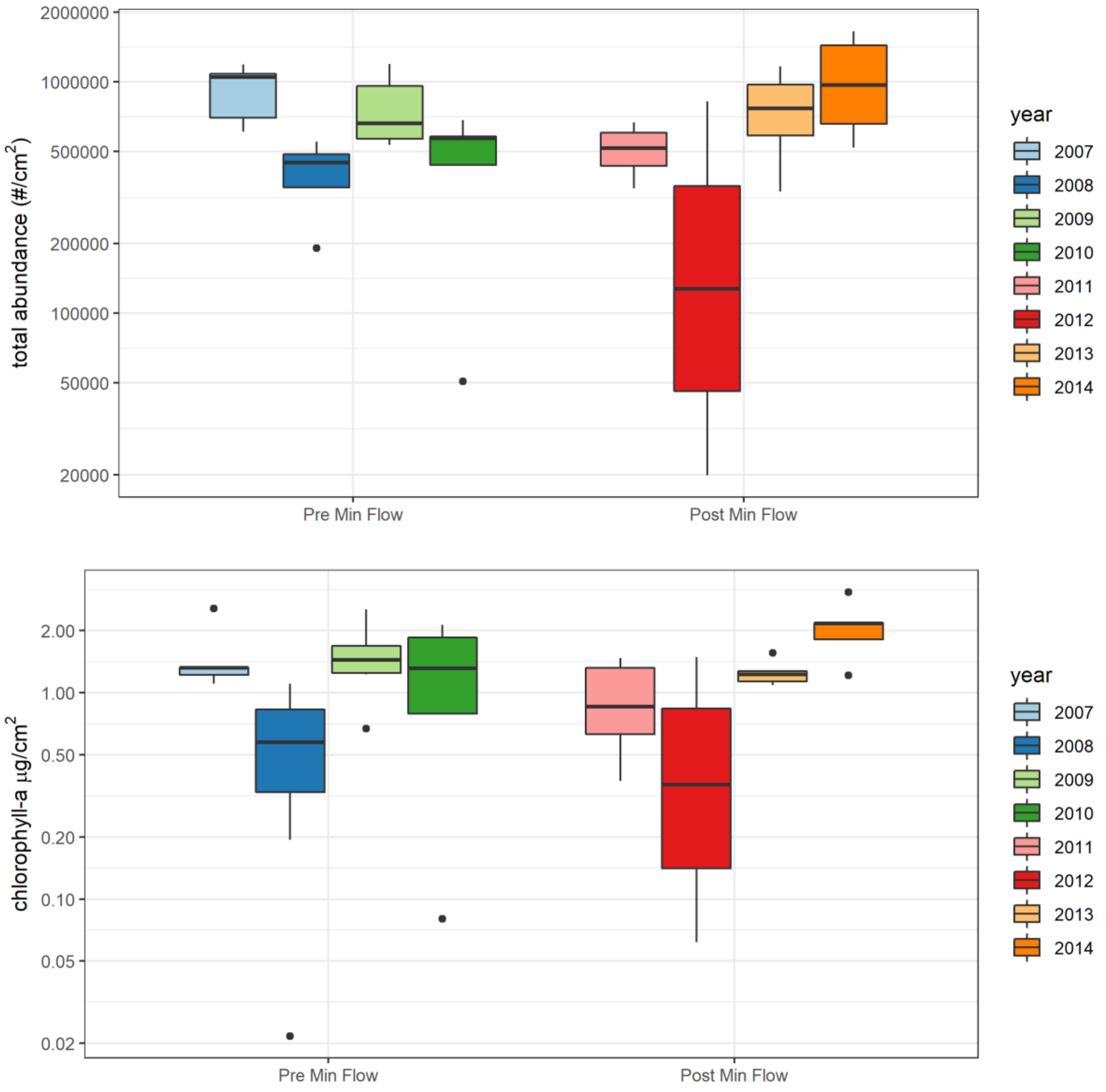

Figure A39 **Boxplots of periphyton productivity metrics for Fall T1 samplers at main sites for pre-implementation of minimum flows (Pre Min Flow) and post-implementation of minimum flows (Post Min Flow).**

11.5.4 Periodically Dewatered: Productivity

Due to low data volumes collected prior to implementation of minimum flows, the full T3 data set from 2007 to 2014 was used to address the effects of minimum flows on the frequently wetted lower varial zone. Figure A40 demonstrates the lack of clear benefit to periphyton growth post-minimum flows. Mean periphyton abundance was 8.31 $\times10^6$ ± 4.58$\times10^6$ cells/cm^2 pre minimum flows compared to 5.99 $\times10^6$ ± 2.88$\times10^6$ cells/cm^2. Fall 2012 had a low periphyton abundance which contributed to a lower post minimum flows mean abundance. Chlorophyll-a was comparable pre minimum flows with a mean of 1.23±0.81 µg/cm^2 and post minimum flows that had a mean of 1.09±0.55 µg/cm^2.

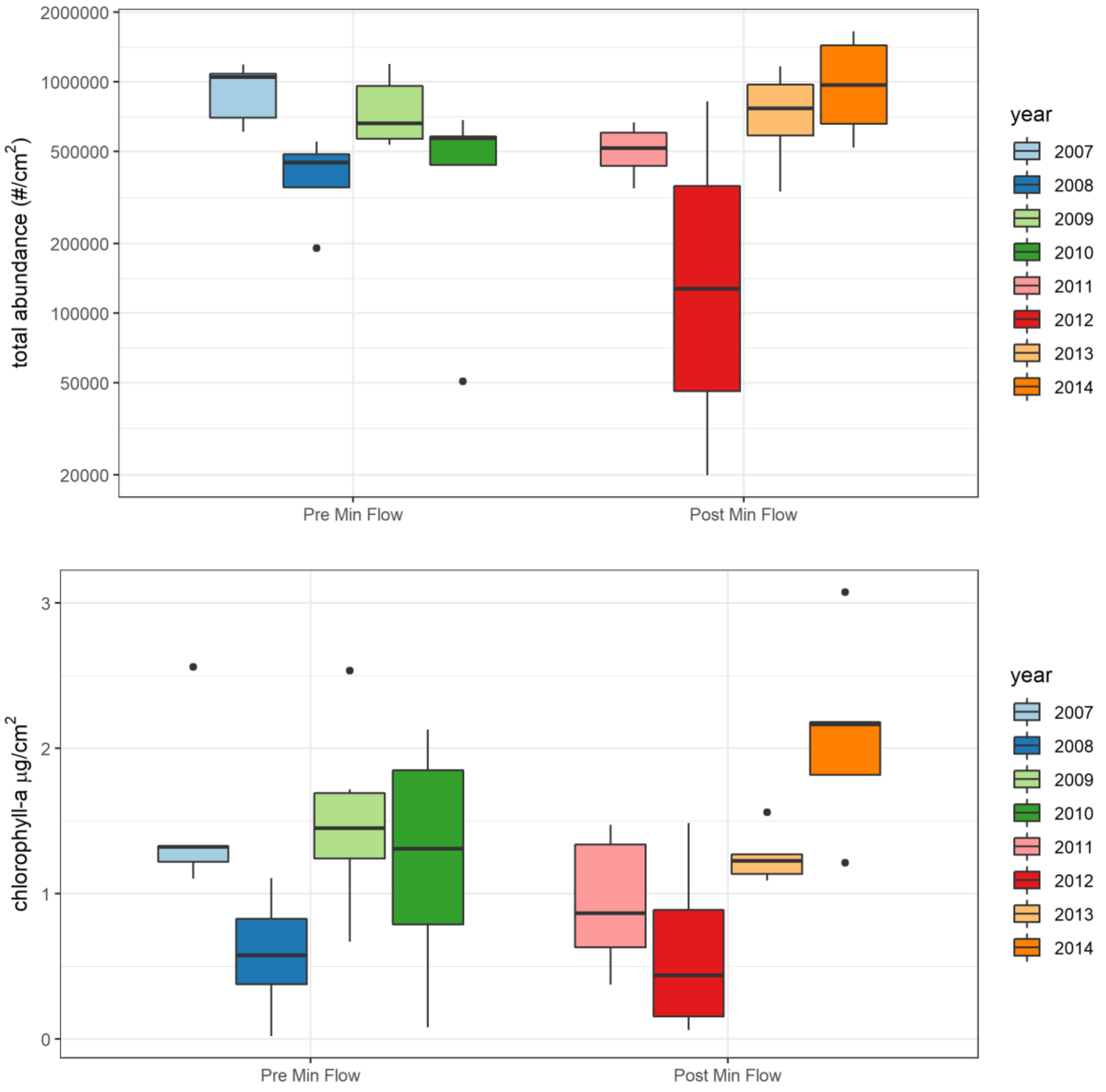

Figure A40 Boxplots of periphyton productivity metrics for Fall T3 samplers at main sites for pre-implementation of minimum flows (Pre Min Flow) and post-implementation of minimum flows (Post Min Flow).

11.5.5 Trends in Periphyton Accrual Rate

As shown in Figure A41 and Figure A42, accrual rates were highly variable from year to year, particularly in the fall. For example, accrual rates were highest in Fall 2013-2014 in the areas that remained permanently wetted by minimum flow releases (T1 avg 0.031± 0.003 ug/cm^2/day) and in the areas periodically dewatered during minimum flow releases (T3 avg 0.022± 0.0007 ug/cm^2/day). Accrual rates were lowest in Spring 2011 (T1 avg 0.0009 ug/cm^2/day) and (T3 avg 0.0003 ug/cm^2/day). The difference between highest and lowest accrual rates over the years of study spans an order of magnitude. In every year and season, T1 samplers had faster periphyton accrual than T3 samplers.

With the conclusion of this study, long-term annual trends were sought. A possible decline in productivity occurred in the Spring 2011 - 2018 accrual rates, but it was not significant at T1 samplers (τ=-0.071, p=0.65), or at T3 samplers (τ=-0.00, p=1.0). However, short-term trends were detected in adjacent years in which 2011-2012 had low productivity while 2013-2015 had high productivity and these trends were linked to years that did not have typical operating conditions (Figure A41 and Figure A42).

Spring accrual trends were similar to the fall and indicated that there were differences between T1 and T3/T4, although the differences were not as apparent in the fall. Additionally, spring chl-a accrual was slower than the fall chl-a accrual rate (Figure A41 and Figure A42).

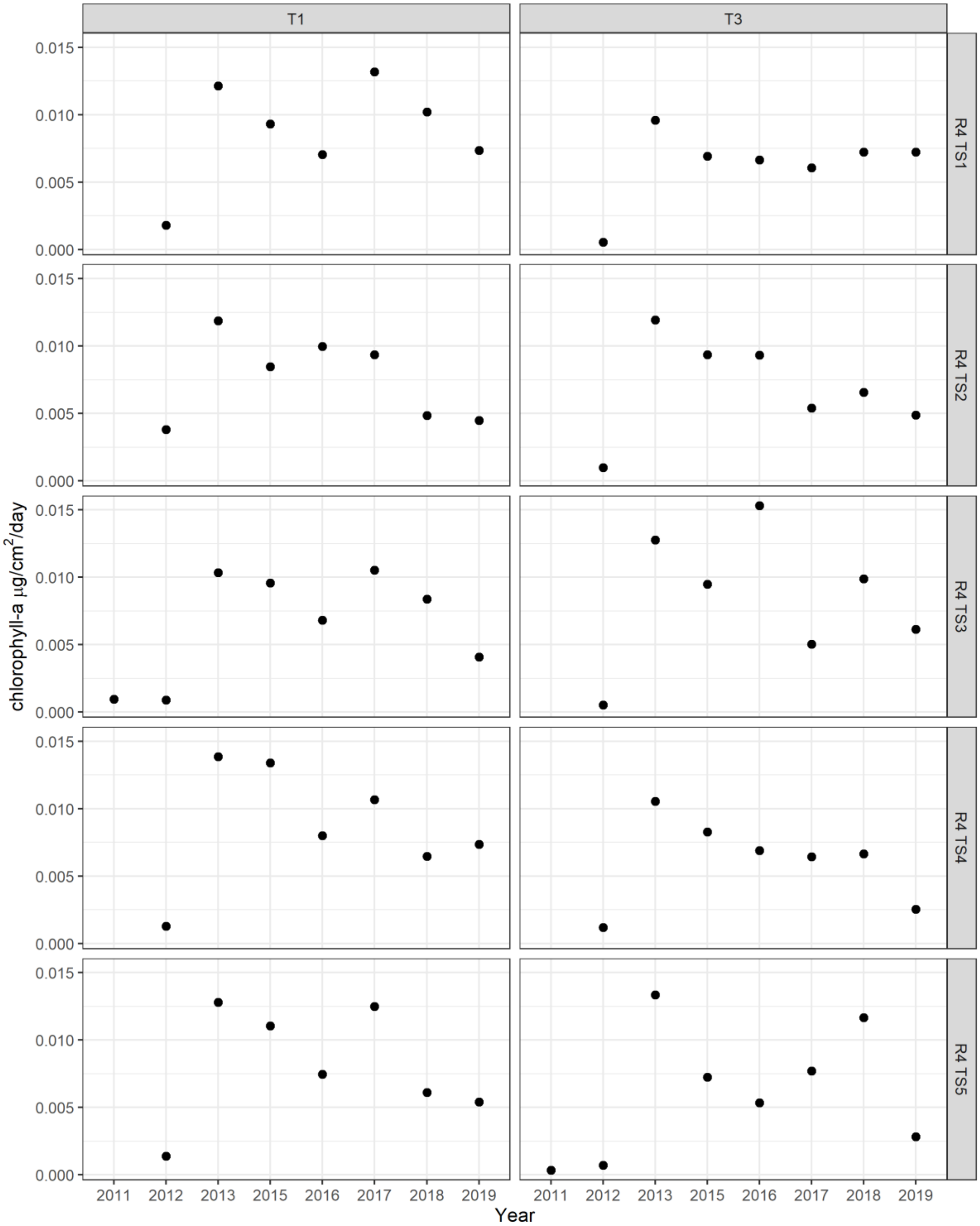

Figure A41 **Spring accrual rates for R4 time series sample by year.**

Fall trends could not be tested statistically because there were five years of data (six years is the minimum requirement for these trend tests).

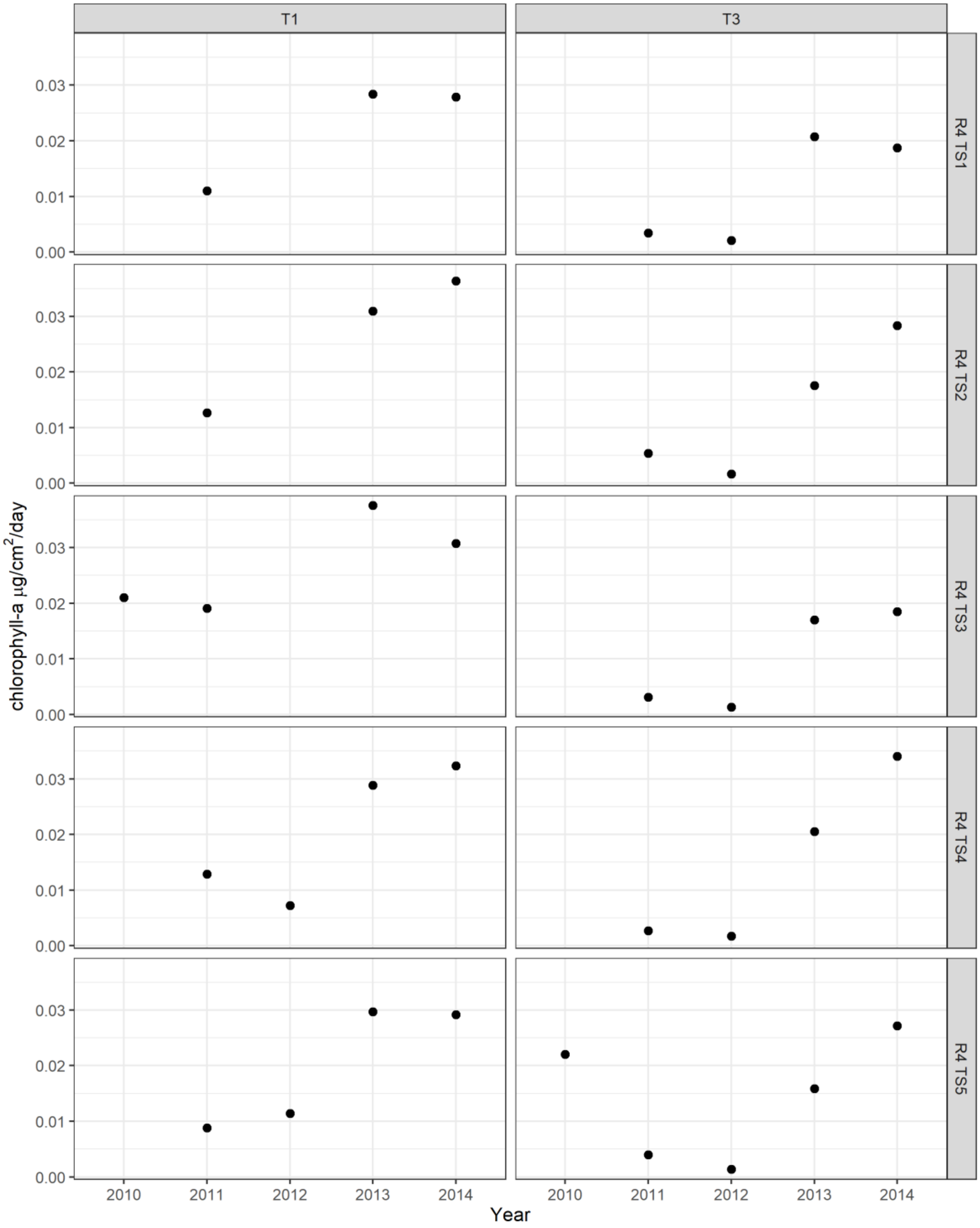

Figure A42 **Fall accrual rates for reach R4 time series sample by year.**

Accrual sampler arrays at adjacent R4 sites tended to behave similarly among the periodically dewatered T3 samplers, particularly from the fall sample sessions (Figure A41 and Figure A42).

11.5.6 Drivers of Periphyton Chlorophyll-a

Due to cost constraints, physical data were not collected for the accrual (time series) sampler arrays. In lieu of that data, the mainstem sites sampled from Spring 2011-2013; 2015-2019 and Fall 2010-2014 were investigated for key periphyton drivers including submergence ratio, maximum water velocity, water temperature and year/reach/site. In addition, water velocity and light effects were also considered. Although the importance of water velocity is well established in MCR, maximum water velocity was considered and rejected in this analysis due to the rare occurrence of velocities exceeding the 2 m/s threshold where extensive periphyton thinning is expected.

The Random Forest (RF) model for Spring data identified substrate submergence (total time in water) as the most important predictor of chl-a, based on eight years of spring data (Figure A43). Chl-a increased linearly from submergence ratios of 0 to 0.6 (Figure A44). Mean water temperature >5°C and year were the second and third most important predictors of Spring chl-a, where water temperatures above 5°C increased periphyton production (Figure A44). The RF model showed that Spring 2011 and 2012 had lower chl-a compared to the other spring sampling sessions. Reach was the fourth most important predictor, with R3 demonstrating more spring productivity than R4.

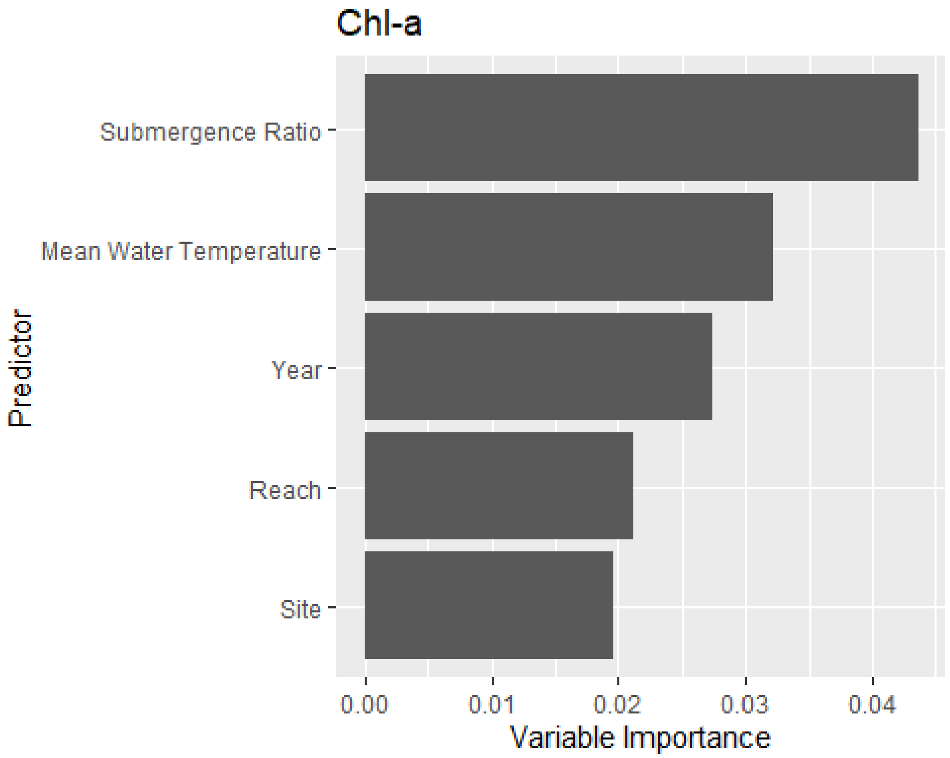

Figure A43 Variable importance plots for spring RF model.

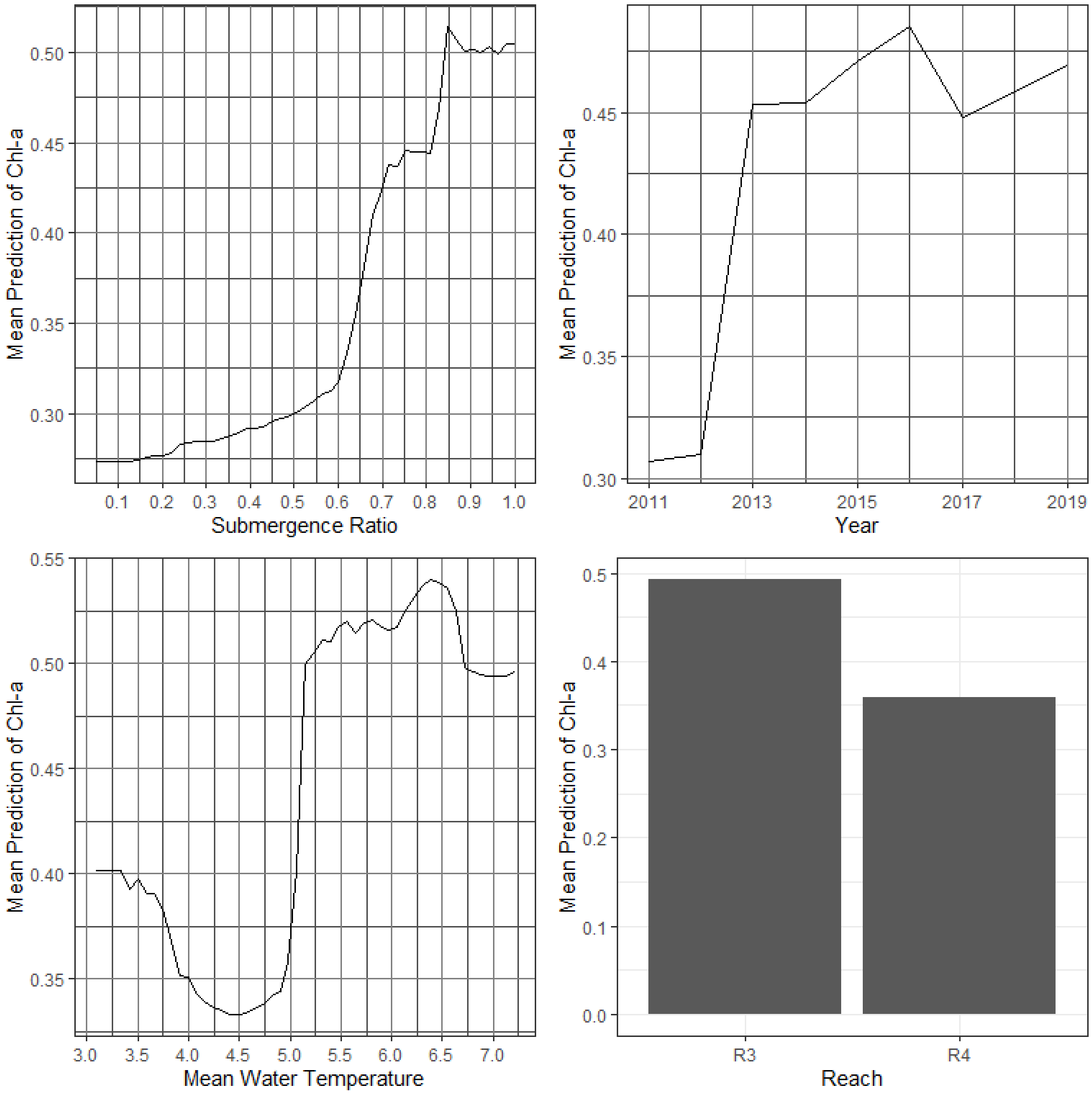

Figure A44 Random forest model partial dependence plots for the top four explanatory variables for chl-a in spring.

Figure A45 illustrates the complexity of factors driving the range of chl-a productivity measured during the eight spring sample sessions in MCR. The CART model showed that mean water temperatures and annual variability (a composite interacting weather and ecological conditions) became important drivers of chl-a for samples with submergence ratios greater than 0.83 (Figure A45), with year/submergence ratio important in the low production years and reach/water temperature important in high periphyton productivity years.

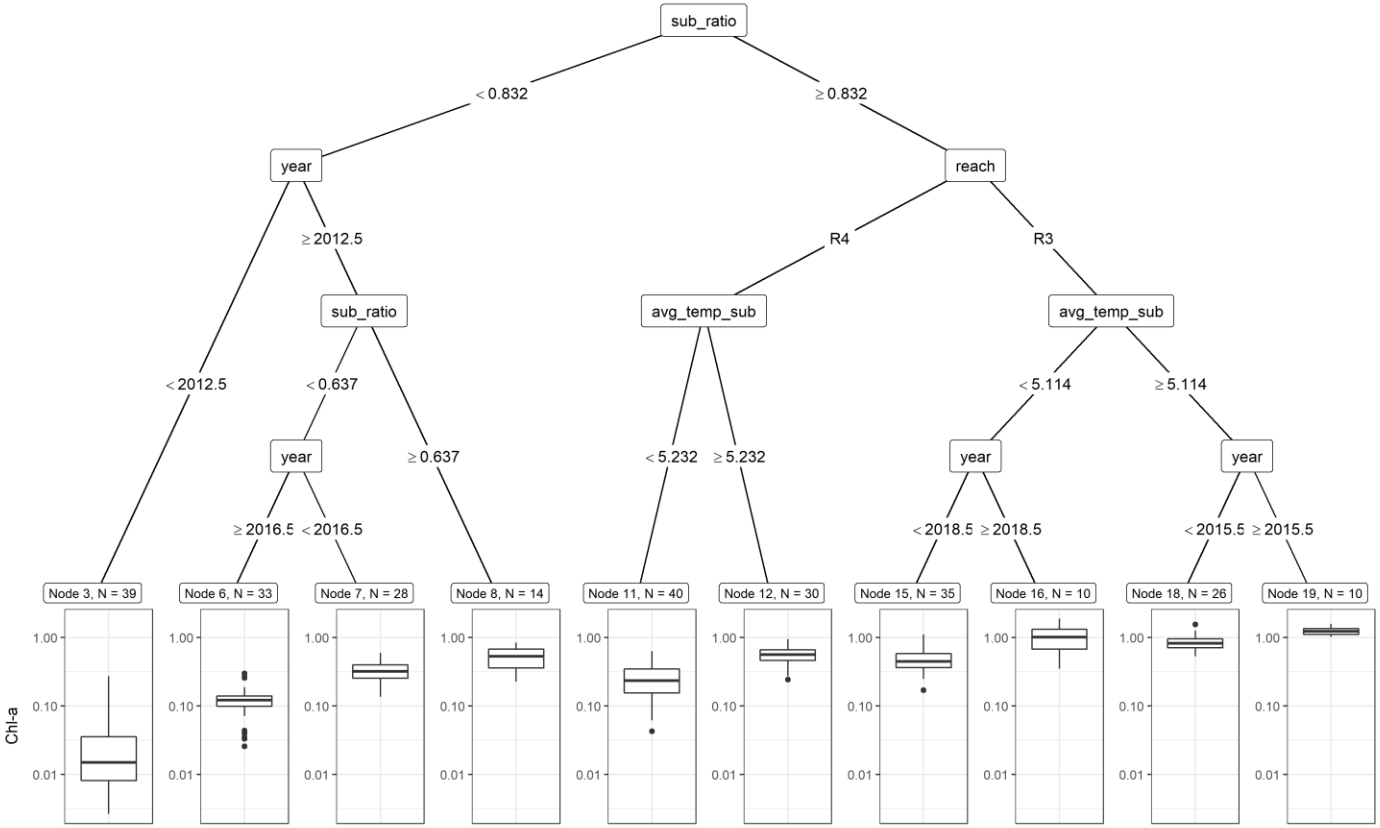

Figure A45 CART model for Spring chl-a with splitting variables of substrate submergence ratio (sub_ratio), mean temperature while submerged (avg_temp_sub), reach and year.

Spring RF models explained 64% of the variation in chl-a, whereas the fall model explained 45% of the variation of chl-a. The fall RF model had a smaller number of sampling sessions (n=5) compared to the spring model.

Year was the most important predictor of Fall chl-a, and Fall 2014 had the highest chl-a (Figure A46). Year gained importance from unusually high productivity in 2014 - a year when samplers were positioned so they got more submergence time with only 13 – 14 hours of exposure over the entire Fall 2014 deployment period. Substrate submergence and mean water temperature were the 2nd, and 3rd important drivers of Fall chl-a production, similar to Spring results. Reach and site were less important to Fall periphyton production than the top three drivers.

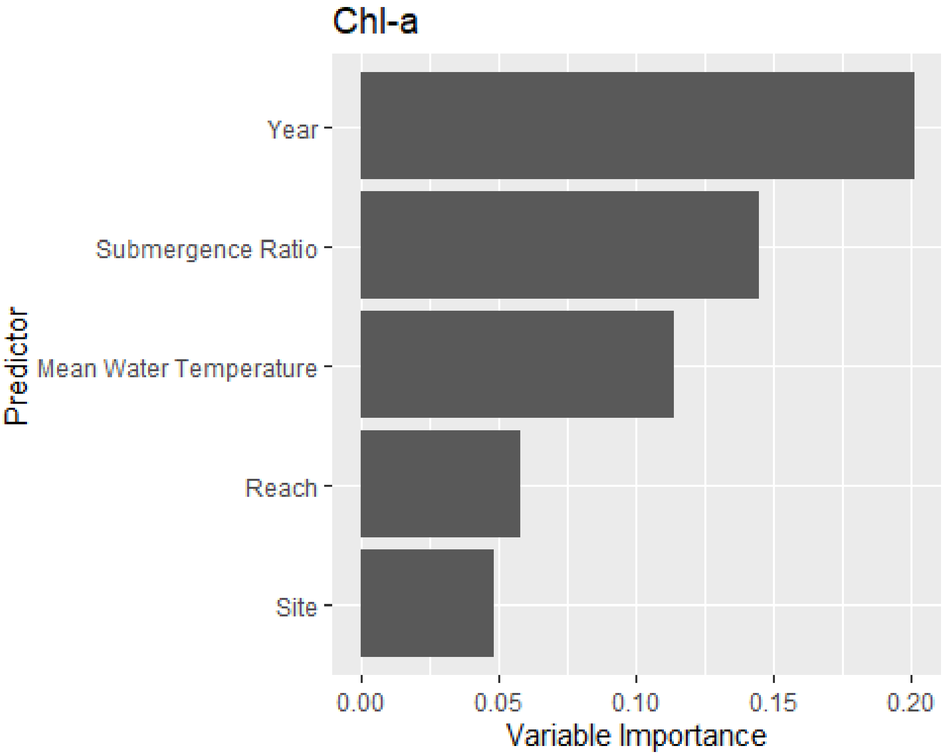

Figure A46 **Variable importance plots for fall RF model.**

In the Fall sample sessions, substrate submergence ratios showed a gradual linear increase in chl-a to 0.77, before increasing dramatically (Figure A47). The effect of water temperature may be an artefact of annual variability because the CART model found that all samples with submergence ratios greater than 0.77 and water temperatures over 11°C were from fall 2012 (Figure A48). The fall 2012 samples had low chl-a values compared to other fall deployment sessions with similar submergence ratios. As in the spring sample sessions, the fall chl-a productivity was greater in mainstem R3 than in mainstem R4.

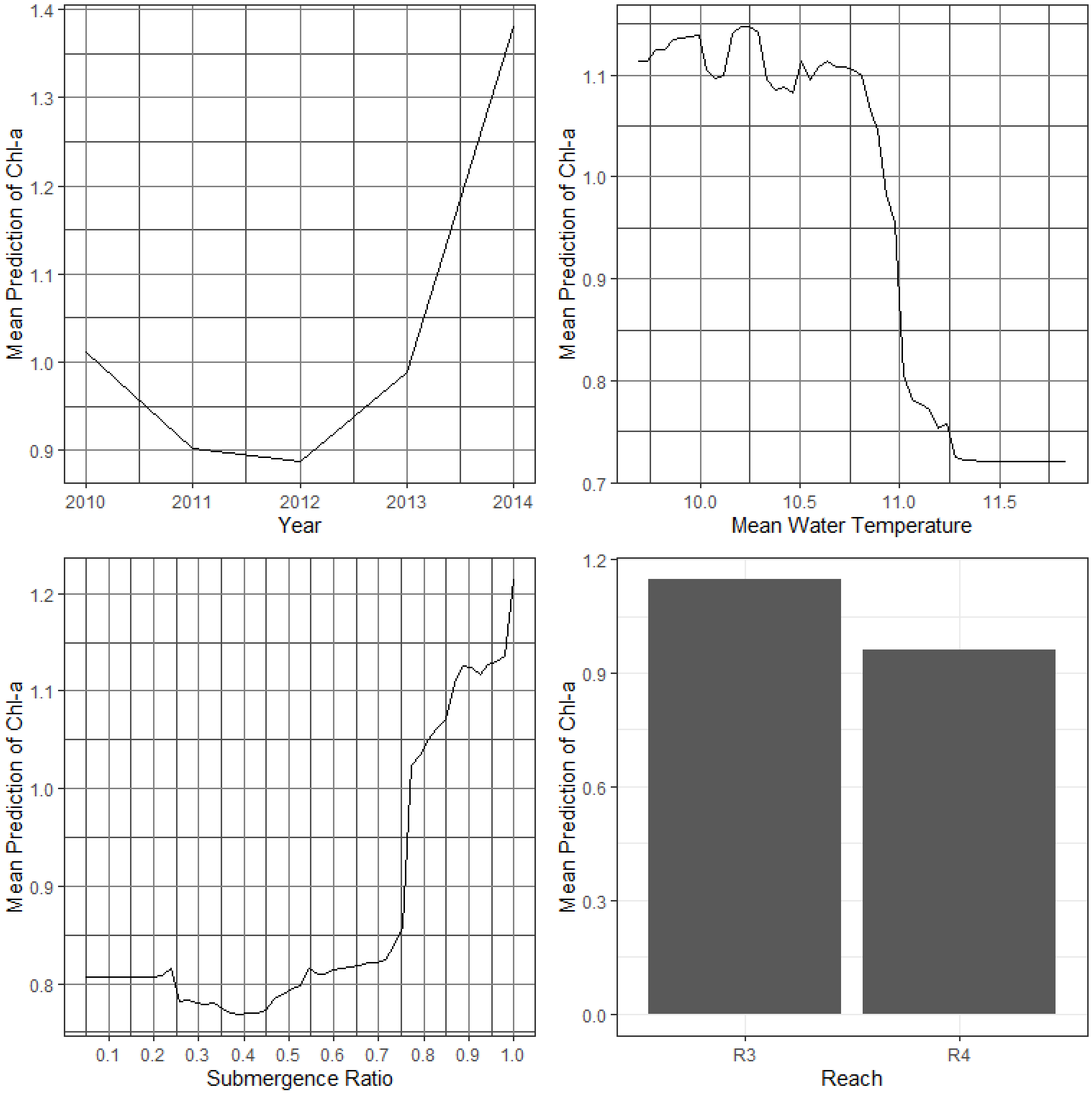

Figure A47 **Random forest model partial dependence plots for the top four explanatory variables for chl-a in fall.**

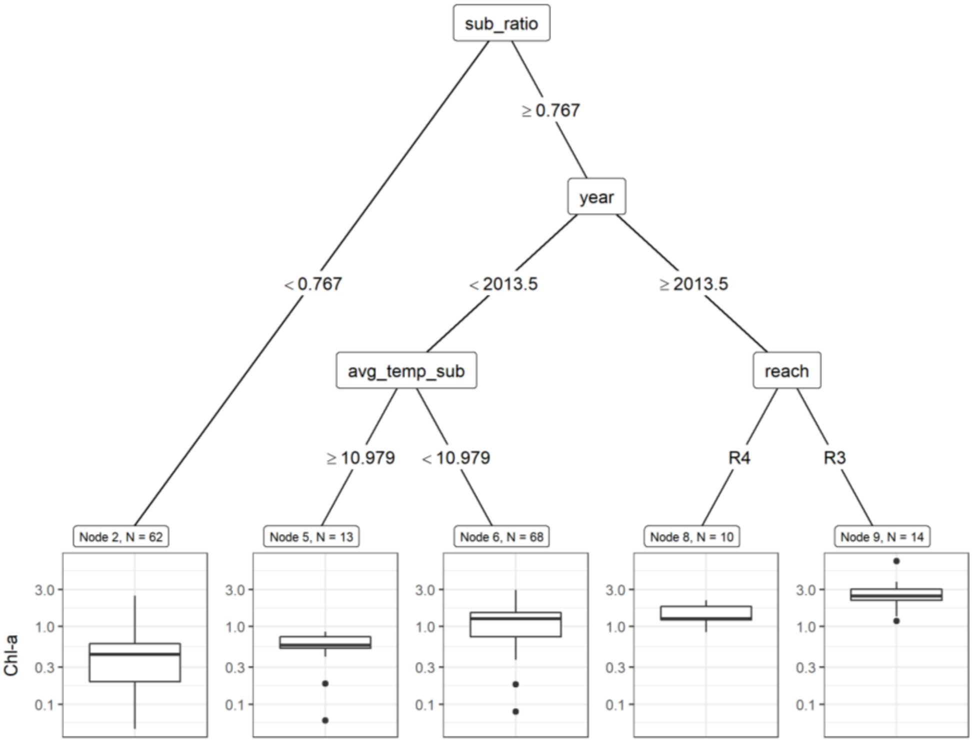

Figure A48 **CART model for Fall chl-a with splitting variables of submergence ratio (sub_ratio), mean temperature while submerged (avg_temp_sub), reach and year.**

11.6 *Discussion*

Historically, BC Hydro avoided daytime dewatering and this operating regime was implemented prior to the establishment of 142 m^3/s minimum flows. After the initiation of this study, the REV5 turbine also came online. This means that no clear before/after periods where the benefits of minimum flows can be studied in isolation from other flow changes on the MCR exist over the 13-year study period. We therefore contrasted production in the regularly dewatered varial zones with production in the permanently wetted zones to address MQ3.

MQ#3 questions the effect of implementing minimum flows on the periphyton accrual rate and if a long-term trend in accrual developed in the MCR, using one hypothesis and two sub-hypotheses that are discussed individually in this section.

As in economics, the MCR periphyton accrual rate is the net sum of gains and losses over time. Periphyton standing crop was a product of in-situ growth rates and of periphyton immigration from upstream areas. Periphyton losses resulted from flow-related scour, sloughing driven by the periphyton death rate, and invertebrate grazing. The introduction of minimum flows had a minimal effect on the periphyton growth rate because it is sensitive to seasonal and annual variations in water temperature and light in addition to flow-related variables.

This study segment was designed to assess periphyton community composition and standing crop over the range of flow and habitat conditions in the MCR. The inherent variability of the MCR system was overcome in part by this study's 13-year duration that helped limit the impact of unusual years on summary statistics and modelling. The following section discusses the study results where the strength of evidence was strong and offers literature context for conclusions, as well as best estimates where the strength of evidence was weak. The level of uncertainty in the topics discussed herein is moderate, and could be lowered by extending the study from fall and spring into the summer and winter seasons.

11.6.1 Overall Rates, Trends and Drivers of Periphyton Accrual

Ho_3: *The implementation of the 142 m^3/s minimum flow release does not change the total biomass accrual rate of periphyton in the MCR.*

Establishment and accrual of periphyton communities in MCR occurred at slow rates similar to other large oligotrophic rivers (Table 4-3). The combined time series data collected across year, season and river depth indicate that accrual on MCR continued linearly to the end of the 46-51-day deployment period. Therefore, incubation periods of greater than 46 days are required to achieve peak periphyton biomass in MCR. Limited six-month MCR deployments indicated that peak biomass in the varial zone required many months to accrue. Since periphyton communities can take from weeks in mesotrophic and eutrophic habitats to as many as three years in oligotrophic habitats to stabilize following a change in flow regime (Wu et al. 2009; Biggs 1996), it is reasonable to expect a slow stabilization of MCR periphyton. Given its variable operating regime, it is reasonable to expect the MCR periphyton communities to be in a perpetual state of recovery.

The effect of minimum flows on the accrual rate of periphyton biomass in MCR was dependent on the spatial area under consideration, the environmental conditions, annual patterns of operations and natural inflows, and ALR backwatering. After minimum flows were implemented, the permanently submerged thalweg substrates benefitted from increased submergence, while the varial zones experienced greater substrate exposure and increased rates of mortality that slowed periphyton accrual in proportion to substrate exposure.

Maximum water velocity is universally important to lotic periphyton accrual, particularly velocities exceeding 2 m/sec that instigate mat shearing (Ahn et al. 2012; Biggs and Thomsen 1995; Biggs et al. 1998; Ghosh and Gaur 1998). The occurrence of water velocities exceeding 2 m/s in MCR were rare because of complex dynamics between operational flows instigated velocities and ALR backwatering that reduced velocity despite operational flows. This led to complex patterns of velocity across the river transects, and obscured its importance in statistical modelling.

When all MCR periphyton accrual data are considered together, periphyton accrual was affected by the flow regime during sampler deployment, where the most recent event exerted the greatest influence on measured productivity. Both R3 and R4 had lower productivity metrics across the river transects with flows exceeding 1800 m^3/s for 40 hours in 8 incidents during spring 2018 and 27 hours in 9 incidents during fall 2012, likely due to high shear stress that resulted in a loss of periphyton. The literature indicates that where velocities exceed the shear strength of a periphyton mat, losses occur within a few hours of the onset of increased flows (Battin et al. 2003; Ahn et al. 2012). We expect that the frequency of high flow incidents, regardless of their duration, will reduce the periphyton standing crop. Beyond the thalweg, the effect of water velocity declined and the effect of substrate exposure increased in importance.

Catastrophic events where periphyton mortalities exceeded 50% have been detected on several occasions over the time series deployments throughout the 13-year study period. These events reset MCR periphyton community structure and productivity. Catastrophic losses occurred most often during long periods of exposure that exceeded 72 hours or lasted until channel substrate and interstitial spaces between the substrate was completely dry, when temperatures were either above 20 ˚C or below -5 ˚C.

Like other researchers, we found that irreversible periphyton damage certainly occurred in days and often within hours of substrate exposure (Biggs and Thomsen 1995). The thickest periphyton mats survived desiccation the longest, likely by maintaining moist conditions at the base of the periphyton mat (Schleppe et al. 2014; Blinn et al., 1995). Catastrophic events had a far greater effect on productivity than physical processes such as water velocity or light intensity (Schleppe and Larratt 2014; Schleppe et al. 2015). Taxonomic analysis of the fall 2010 through 2013 time series accrual samplers also demonstrated that catastrophic losses of periphyton occurred occasionally in response to high flow events, and that the small fast-growing diatoms were among the first to resume growth following a spate.

Light is a critical driver of periphyton production. Although light intensity on submerged samplers increased from deep T1 locations to shallow T6 locations in the spring and the fall as expected, the total hours over 10 photons/m^2/sec confirmed that all MCR samplers were within the MCR photic zone (Plewes et al. 2019). Since the entirety of MCR was within the photic zone where periphyton growth can be supported, available light did not emerge as an important driver of periphyton productivity in mathematical models.

The total time periphyton incubated in the light and water was positively correlated with abundance. Generally, samplers that were submerged for at least 650 (Spring) to 860 (Fall) hours in the light and water over the deployment time were the most productive (~9 hours per day in the light and water) (Figure A45 and Figure A48). Beyond 400 hours, periphyton growth continued through 6 months and likely longer, thus the 46 – 52 day deployments periods designed for this study did not capture peak biomass. Periphyton communities can take from weeks in mesotrophic and eutrophic habitats to as many as three years in oligotrophic habitats to stabilize following a change in flow regime (Wu et al. 2009; Biggs, 1996).

When the seasons (Fall 2010-2014 and spring 2011-2013, 2015-2019) sampling sessions were investigated for key periphyton production drivers, substrate submergence time, water temperature and year (flows, water velocity, weather) were important in both Spring and Fall sample sessions. In both seasons, R3 was consistently more productive than R4 as a function of flow-related drivers.

Throughout this study and in both reaches, Spring river conditions such as higher peak flows, low water temperature and short day length resulted in lower biomass and accruals than were observed in the fall. The most important predictor of chl-a in spring was substrate submergence, where chl-a increased linearly from submergence ratios of 0 to 0.6. Mean water temperatures and annual variability (a composite of all habitat conditions) became important drivers of chl-a accrual only after submergence ratios exceeded 0.83 and the periphyton growth requirement for submergence was met, typically 1 to 5 days for small and large diatoms, respectively (Azim et al. 2005; Biggs 1990; Chorus and Bartram 1999; Luring et al. 2013).

In the fall sample sessions, substrate submergence ratios showed a gradual linear increase in chl-a to 0.7 before increasing dramatically. The RF hierarchy of factors driving Fall chl-a production showed that substrate submergence was the most important periphyton driver throughout, with year/water temperature important in the low production years and year/reach important in high periphyton productivity years.

The rate of periphyton recovery and accrual rates were influenced by seasonal differences in growth and by peak flows. Minimum flows were particularly advantageous during the fall sessions when periphyton recovery were highest, while the benefits were less evident in the spring with slow periphyton recovery rates and high peak flows. However, the benefits of minimum flows were obscured in Falls with ALR backwatering. Further, peak flows associated with REV5 may reduce the benefits of minimum flows if they result in sheer stresses sufficient to thin established periphyton communities in the lower varial zone and thalweg. Although improved periphyton production stemming from the implementation of minimum flows has occurred periodically, it was not possible to separate benefits attributable to minimum flows from the effects of flows resulting from recent operating regimes.

Channel areas covered by minimum flows are not the only areas of MCR that can maintain and act as sources of species to aid recovery. Drifting limnoplankton contributed by Revelstoke Reservoir important to MCR periphyton standing crop and accrual rates, particularly in late growing season at Reach 4. Limnoplankton that becomes trapped in the periphyton matrix (Middleton 2010) can subsidize periphyton for many kilometers below a dam (Doi et al. 2008; Larratt et al. 2013). This means phytoplankton events occurring in Revelstoke Reservoir and the timing and depth of reservoir releases exerted an influence on MCR periphyton accrual and recovery rates, as well as its community structure.

Shallows including backwaters and back-eddies are another source of recruitment and maintenance of some planktonic and periphytic species (Reynolds and Descy 1996; Butcher 1992, Costello et al. 2018). These areas are more abundant in Reach 3 than in Reach 4, and may enable Reach 3 periphyton to recover faster after catastrophic flow events. Many of these areas may also act as impoundments to fish resulting in mortalities, thus, trade-offs are probable and should be considered in any flow management decisions.

With the conclusion of this study, long-term trends were sought. The detected declining trend was not significant for spring 2011-2019 accrual rates at T1 or at T3, indicating that the sum of operational releases ALR elevations and natural runoff were sufficiently variable to prevent a declining trend post-REV5. Similar behaviour among T3 accrual sampler arrays at adjacent R4 in Fall did not indicate a trend over years pre-and post minimum flows, but instead they showed variable productivity because of the sum effect of ecological drivers. Short-term trends were detected in adjacent years in which 2011-2012 had low productivity while 2013-2015 had high productivity and these trends were linked to years that did not have typical operating conditions. High productivity was linked to years with high average hourly flows with moderate peak flows that increased upper varial zone submergence, effectively increasing the area of productive MCR habitat.

Like other systems, MCR periphyton production was reduced immediately after the high flows of summer and fall 2012 (Biggs 1996; Ahn et al. 2012). Periphyton productivity recovered quickly so that productivity in the subsequent sampling season was high. However repeated flow-related pruning of the periphyton mats from high water velocities and from desiccation have contributed to a community structure indicative of a stressed river system (Table 4-3)

11.6.2 Accrual Rates in the MCR Thalweg

Ho$_{3A}$: *There are no changes in accrual rates of periphyton at channel elevations that remain permanently wetted by minimum flow releases.*

Spring thalweg samples were not collected prior to the implementation of minimum flows, but Fall samples were. When all Fall T1 sampler data before and after implementation of minimum flows were compared, only minimal differences were detected. Prior to implementation, the periods in which the area covered by minimum flows commenced drying were often brief and occurred most often at night. CART modelling of submergence ratios for all T1 to T6 samplers indicate that after 83% submergence in Spring and 77% in Fall, other drivers are responsible for the observed periphyton productivity. The estimated submergence ratios before the implementation of minimum flows had medians of 0.88 in Spring and 0.82 in Fall; these numbers exceed the CART thresholds, thus a loss of periphyton productivity is not expected. In conclusion, differences in peak flows and water temperature were more important than minimum flows to periphyton productivity in the thalweg. For example, Fall 2012 had the lowest T1 productivity in response to the highest peak flows of the study period. Unusual years such as 2012 contributed to periphyton metric variability.

The theoretical benefit from minimum flows may have been offset by concurrent increased REV5 maximum velocities during very high flow years. These potentially conflicting flow-related benefits and constraints may have obscured the benefit of minimum flows. Further, T1 thalweg productivity had high submergence with high periphyton productivity prior to the implementation of minimum flows under average operations. For this reason, minimum flows did not induce a significant improvement in MCR thalweg productivity.

11.6.3 Accrual Rates in the MCR Varial Zones

Ho$_{3B}$: *There are no changes in accrual rates of periphyton at channel elevations that are periodically dewatered during minimum flow releases.*

Periphyton accrual rates varied significantly from year to year, particularly in the fall within the lower varial zone (T3). As expected, T3 locations had slower accrual rates than T1 as a function of substrate submergence.

Over the years of study, T3 accrual rates were lowest in the 2011/2012 seasons which were followed by very high productivity in the following years, suggesting that flood years impact productivity beyond the year in which they occurred. This apparent systemic increased productivity may have been the result of altered hydrologic (e.g., tributary inputs, hyporheic exchange) or altered flows and flow-related variables (e.g., water temperature, irradiance, nutrients). The difference between highest and lowest accrual rates over the years of study spanned an order of magnitude.

Varial zone accrual sampler arrays at adjacent R4 sites tended to behave similarly due to similarities in growing conditions led by flow-induced factors including submergence time, velocity and light, and by flow-independent water temperature which is a composite of weather and Revelstoke Reservoir discharge depth. Like other researchers, we concluded that periphyton accrual depends on river flow variability and flow magnitudes (Kilroy et al. 2020).

Estimated submergence ratios over Fall and Spring 2000-2019 period in the periodically dewatered lower varial zone, were similar before and after minimum flows because operations simultaneously decreased the frequency of low 200 – 400 m^3/s flows when the minimum flow regime commenced. With similar submergence ratios under typical operations, we would not expect differences in periphyton accrual rates in the periodically dewatered lower varial zone following the commencement of the minimum flow regime.

11.6.4 Summation

MCR periphyton communities were more dependent upon the overall operating regime (daily, monthly, and annual patterns of flow release, ALR backwatering) than the specific effects of minimum flow because the entire flow regime determines the wetted edge of the channel during daytime periods. Using field data gained in this study and other research we conclude that minimum flows could be most beneficial to periphyton accrual by preventing catastrophic desiccation losses:

> 1) in the lower varial area above or adjacent to the edge wetted by minimum flows that would otherwise be exposed to rapid desiccation in the absence of ALR backwatering; and
> 2) in the thalweg substrate area below the edge wetted by minimum flows that would otherwise be exposed to desiccation during dry weather in summer or winter.

This 13-year study did not detect a significant benefit of minimum flows to periphyton productivity in the spring and fall sample sessions, however, benefits may have occurred in the winter and summer as a response to unique flow-driven stressors in those seasons.

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12.0 Appendix 7. MQ #4

12.1 Introduction

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

Ho$_{4A}$*:* *The implementation of the 142 m*^{3}*/s minimum flow release does not change the total abundance / biomass / diversity of benthic invertebrates in the MCR.*

Ho$_{4B}$*:* *There are no changes in abundance/biomass/diversity of benthic invertebrates at channel elevations that remain permanently wetted by minimum flow releases.*

Ho$_{4C}$*:* *There are no changes in abundance/biomass/diversity of benthic invertebrates at channel elevations that are periodically dewatered by minimum flow releases.*

12.2 Methods

Benthic invertebrate samples were collected and analyzed following the methods described in *Appendix 2*.

12.3 Dataset

All benthic artificial substrate samplers collected after 2009 had HOBO light/temperature loggers that recorded data every 30 minutes. For most sampling sessions, there were six artificial samplers deployed at each site. Pseudo-replication may occur at the site level for benthic invertebrate production and diversity metrics within a given sampling session. Data from light/temperature loggers, hourly discharge and air temperature data were used to derive submergence ratio and mean temperature of water while submerged (Table A27 and Table A28).

Table A27 **Datasets used in the analysis of management question #4.**

Name	Data Source/Description	Years Obtained
Light / Water Temp	Data collected at each productivity sampler during each deployment session	Fall 2007-2014, Spring 2011-2013, 2015-2019 (Temp) Fall 2010-2014, Spring 2011-2013, 2015-2019 (Light)
Benthic Invertebrates	Data collected at each productivity sampler during each deployment session. Data produced in the laboratory included abundance, biomass, and associated metrics. Additional metrics described in Table A29were calculated.	Fall 2007-2014, Spring 2011-2013, 2015-2019
Hourly Discharge at Revelstoke Dam (REV)	Data obtained from Poisson Consulting	2000-2019
Hourly Air Temperatures from Revelstoke Airport	Data obtained from Environment Canada	Fall 2010-2014, Spring 2011-2013, 2015-2019

Table A28 **Metrics derived from datasets.**

Variable	Definition
Submergence Ratio	Total time submerged divided by duration of deployment
Mean Water Temperature While Submerged	Average temperature of the water for the duration of deployment

12.4 Analysis

Determination of Submergence

To determine the effect of minimum flows on benthic invertebrate productivity and diversity the submergence ratio was calculated for all samplers from 2010 onwards. Submergence ratio was calculated by determining the hourly wetted history for each sampler. Water and air temperature data obtained from the HOBO light/temperature loggers was the primary dataset used to determine how long an artificial sampler was submerged. Four HOBO light/temperature loggers were placed in the upland areas above the high water level within Reaches 4 and 3 to measure air temperature. Similar to Schleppe *et al.* (2011), a script that considered a temperature difference of ± 0.5°C was used to compare samplers from permanently submerged locations with samplers across a transect. A sampler was considered exposed to air when the logger temperature differed from the permanently submerged logger by more than ±0.5°C. This analysis of submergence was only partially reliable as there were times during the deployment when the air and water temperatures were within 1.5°C of each other (Schleppe *et al.* 2011).

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

Descriptive Statistics

Descriptive statistics and boxplots were used to compare invertebrate diversity and productivity metrics before and after the implementation of minimum flows. The T1 samples represented the area that remained permanently wetted at minimum flow, whereas the T3 samples represented areas periodically dewatered by minimum flow releases. The invertebrate metrics of effective number of species, abundance and biomass at T1 and T3 during fall sampling sessions were compared before (2007-2010) and after (2011-2014), the implementation of minimum flows. EPT Richness and Percent Chironomidae were also calculated to better understand what was driving changes in invertebrate diversity (Table A29).

Table A29 Benthic invertebrate productivity metrics used to address management question 4.

Variable	Description
Total Abundance	Total Abundance across all species
Total Biomass	Total Biomass across all species
Effective Number of Species	A measure of community diversity that is the e^s. S= Shannon-Wiener index.
EPT Richness	Number of unique Ephemeroptera, Plecoptera, and Trichoptera taxa
Percent Chironomidae	The percentage of Chironomids based on abundance

Modelling

Random Forest (RF) models were used to better understand the effects of submergence on invertebrate productivity and diversity. In addition, these models were used to assist in evaluating long-term trends in invertebrate productivity while accounting for differences in submergence and other factors. Separate RF models were run for spring and fall for the following invertebrate metrics: abundance, biomass and effective number of species. Random Forest is a non-parametric machine learning technique which does not require random distribution of residuals and can accommodate categorical predictor variables (Read *et al.* 2015). The explanatory variables used for RF models included site, reach, mean water temperature, submergence ratio, and year.

Random Forest determines the importance of each predictor variable and the relationships between each predictor variable and response variable. The variable importance measure for each predictor is determined by calculating the mean decrease in prediction error (Mean Squared Error), if the predictor is dropped from the model (Liaw and Wiener 2002). Predictor variables that have a strong relationship have large variable importance. Dropping these predictors from the model causes a large increase in prediction error. Variable importance plots for all predictors included in each model were generated to help identify predictors associated with the invertebrate production and diversity metrics. Partial dependence plots were generated to better understand the relationship between the selected top predictor and the response variable while considering the effects of the other variables in the RF model (Liaw and Wiener 2002).

Random Forest uses Classification and Regression Tree (CART) models as the base model. CART is a non-parametric tree-based method that splits data into separate groups based on the response variable (De'ath and Fabricius 2000; Jun 2013). CART initially partitions the data into two groups based on a split point and splitting variable that minimizes the sum of squares of the response variable of each group (De'ath and Fabricius 2000; Hastie et al. 2001). A recursive algorithm is used to search through every possible combination of explanatory variables and values to determine the best splitting variable and split point (Hastie et al. 2001). The CART algorithm continues to make binary splits at each tree node until a stopping criterion is reached (Jun 2013).

Random Forest builds different CART models by bagging, using a subset, the data and the explanatory variables tried - at each split. Each CART model uses a random subset of the dataset and at each split in the tree a random subset of predictor variables is tried as a potential splitting variable (Jones and Linder 2015). The default setting used in the R package Random Forest were used for the LCR water temperature models. The Random Forest models contain 500 trees (CART models) and in our case, one of the predictor variables out of the five predictors was randomly chosen as the splitting variable at each node (Liaw and Wiener 2002).

The exact split point for submergence ratio was determined for spring invertebrate biomass and abundance and fall invertebrate abundance using CART. The CART models only predictor variable was submergence ratio and used R package rpart version 4.1-15 (Therneau and Atkinson 2019). The R package ggparty version 1.0.0 was used to visualize the CART models (Borkovec and Madin 2019).

12.5 Results

12.5.1 Periodically Dewatered: Productivity and Diversity

To examine the effects of minimum flow on areas that were periodically dewatered by minimum flow releases, invertebrate production and diversity metrics were compared at T3 samplers for fall 2007-2010 and fall 2011-2014. T3 samplers were placed in the lower varial zone above the edge of minimum flow. During the fall in Reach 3, T3 samplers experienced minimal dewatering and had submergence ratios close to 100%, as a result of high ALR elevations and backwatering (Figure A49). Backwatering also extended through most of Reach 4 in the fall of 2011 due to high ALR elevations. Submergence ratios could not be calculated for the T3 samplers in fall 2007-2009 because hourly temperature data was not available. However, T3 samplers in Reach 4 experienced very little dewatering in fall 2008 also because of very high ALR elevations.

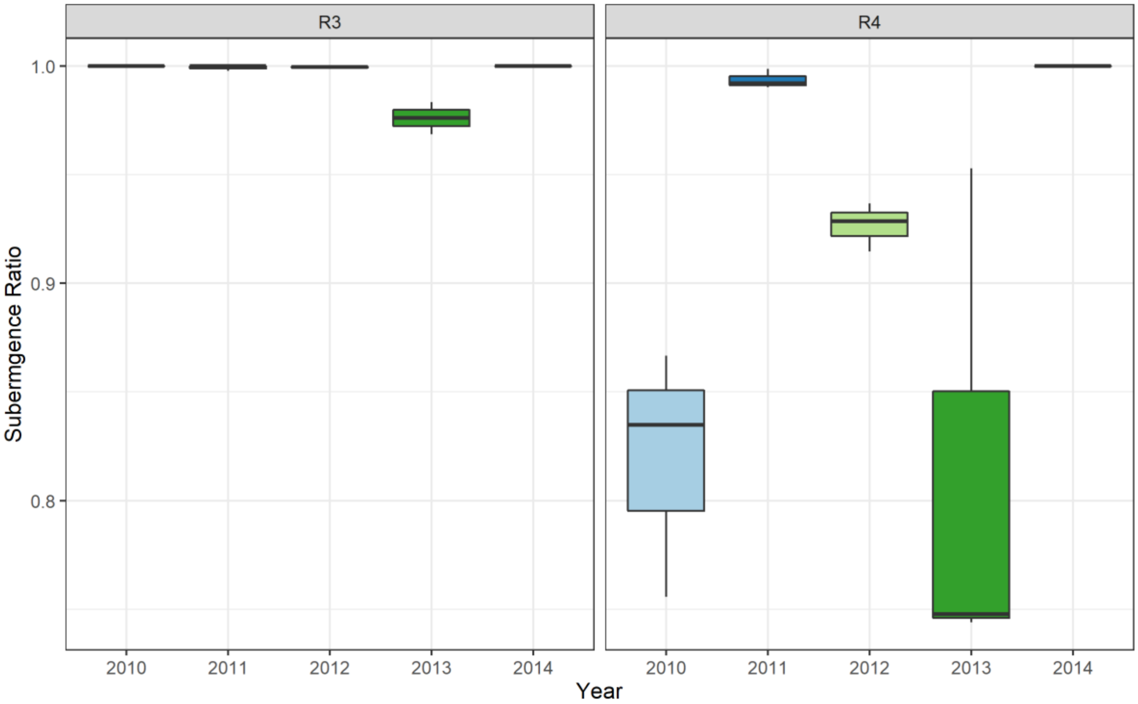

Figure A49 **Boxplots of submergence ratios for T3 samplers at mainstem sites split by reach.**

Invertebrate abundance at T3 samplers was more variable and on average higher after the implementation of minimum flows, where it ranged from 20-5,300, whereas before the implementation of minimum flows invertebrate abundance ranged from 10-836 (Figure A50). The high variability in invertebrate abundance after the implementation was partially a result of high annual variability in flow. For example, fall 2011 and 2014 had mean invertebrate abundances of 733±298 and 1,310±2,050, whereas fall 2012 had a mean invertebrate abundance of 152±187. Fall 2011 and 2014 samplers experienced minimal exposure ranging from 0-11 hours. After the implementation of minimum flows the mean invertebrate abundance was 602±1,090, which was higher than the mean invertebrate abundance before the implementation of minimum flows (159±215).

Invertebrate biomass was also highly variable after the implementation of minimum flows at T3 samplers (Figure A50). However, the mean invertebrate biomass after implementation (11.8±34.3 mg) was higher compared to the mean invertebrate biomass before implementation of minimum flows (3.95±5.44 mg). Fall 2012 had the widest range of invertebrate biomass from 0.05-169 mg. The highest mean invertebrate biomass was 10.3±11.2 mg in fall 2014. The T3 samplers in fall 2014 did not experience any hours of substrate dewatering (Figure A49).

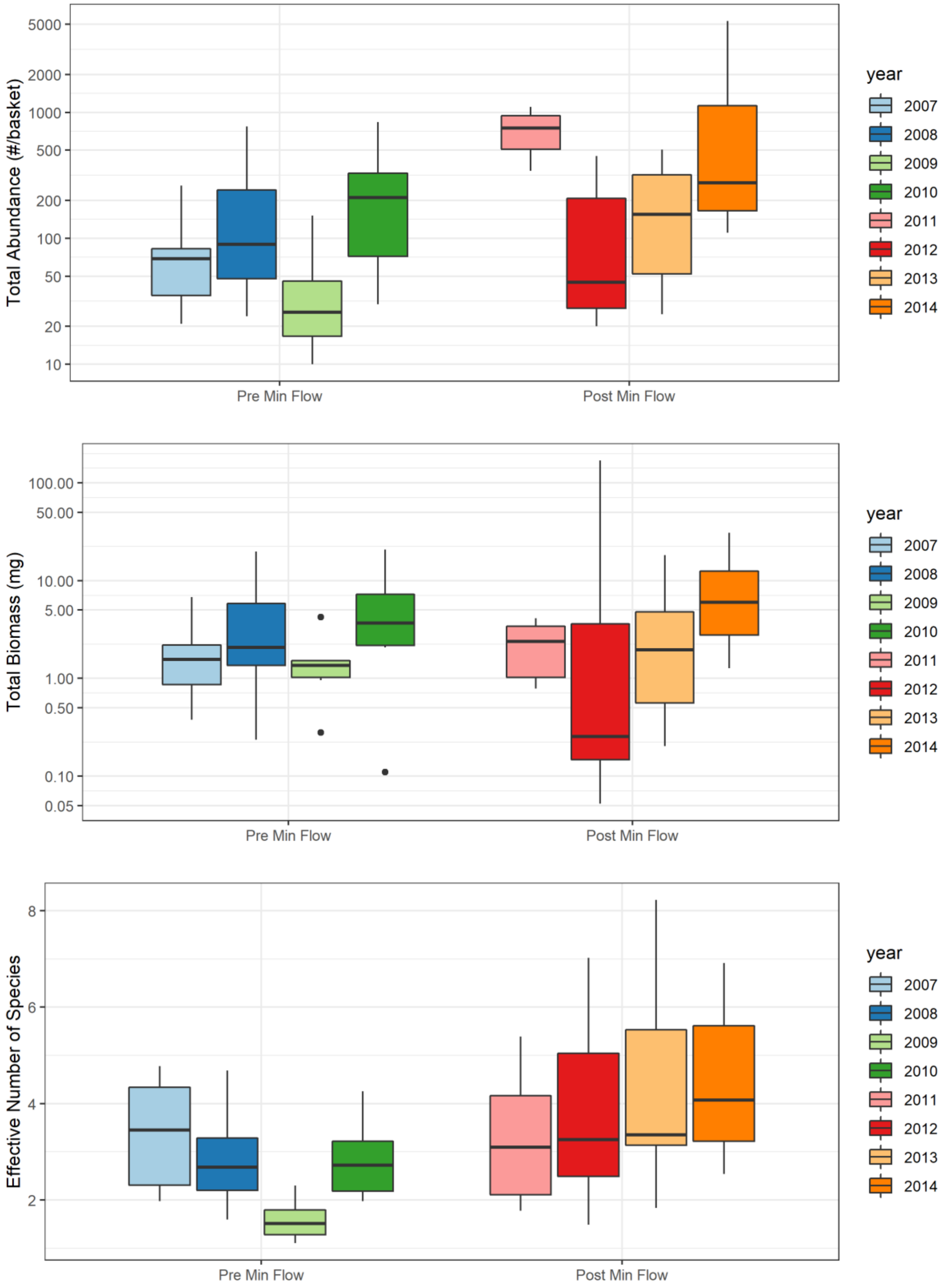

Figure A50 **Boxplots of benthic invertebrate diversity and productivity metrics for fall T3 samplers at main sites for pre-implementation of minimum flows (Pre Min Flow) and post-implementation of minimum flows (Post Min Flow).**

The diversity at T3 samplers was lower before the implementation of minimum flows (Figure A50). The mean effective number of species was 2.7±1.7 before the implementation of minimum flows and 4.0±1.9 after. In the fall sampling sessions before the implementation of minimum flow, fall 2007 had the highest mean effective number of species and fall 2009 had the lowest. Fall 2007 had higher mean hourly flows than fall 2008-2010 (Table A3). These higher flows would cause less hours of substrate dewatering at the T3 samplers.

The more diverse community after the implementation of minimum flows was partially attributed to higher EPT diversity. EPT richness was higher after the implementation of minimum flows for T3 fall samplers (Figure A51). Most Reach 4 sites had EPT Richness of 0 before the implementation of minimum flows, whereas after the implementation of minimum flows EPT Richness ranged from 0-2. Reach 3 T3 samplers had higher EPT Richness in fall 2012 compared to other fall sampling sessions. EPT Richness was highly variable at Reach 3 sites in fall 2013 ranging from 0-14 (Figure A51).

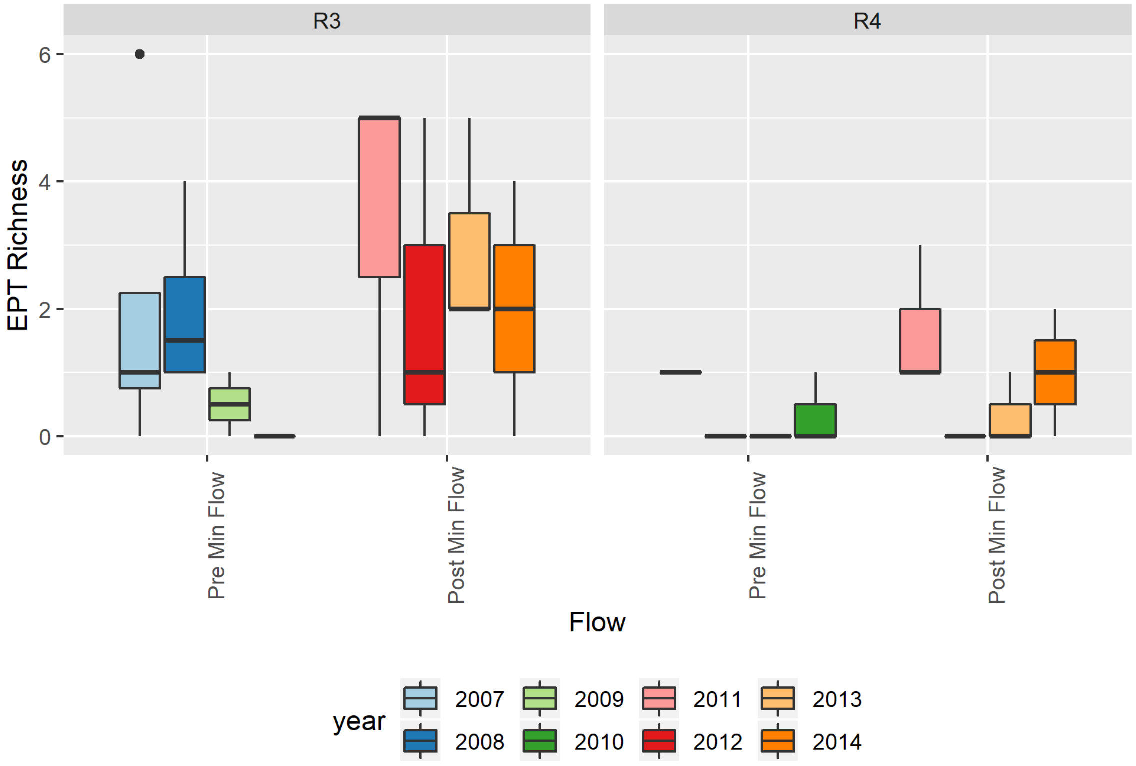

Figure A51 Boxplots of EPT Richness at Fall T3 samplers grouped by year and reach pre-implementation of minimum flows (Pre Min Flow) and post-implementation of minimum flows (Post Min Flow).

12.5.2 Submergence Ratios

Annual variation in operations and seasonal variations in ALR elevations caused differences in submergence ratios for all MCR samplers. The median of fall submergence ratios ranged from 0.83-1.0 (Figure A52). Fall 2011 and 2014 had the highest median submergence ratios of 1.0. Most of the median spring submergence ratios were lower than fall because ALR backwatering was more extensive in fall resulting in less exposure of samplers. In spring, the median submergence ratios ranged from 0.72-1.0. Spring 2015 samplers had higher submergence ratios compared to other spring sampling sessions because of high mean hourly flows (Figure A52). The submergence ratios ranged from 0.8-1.0 in spring 2015.

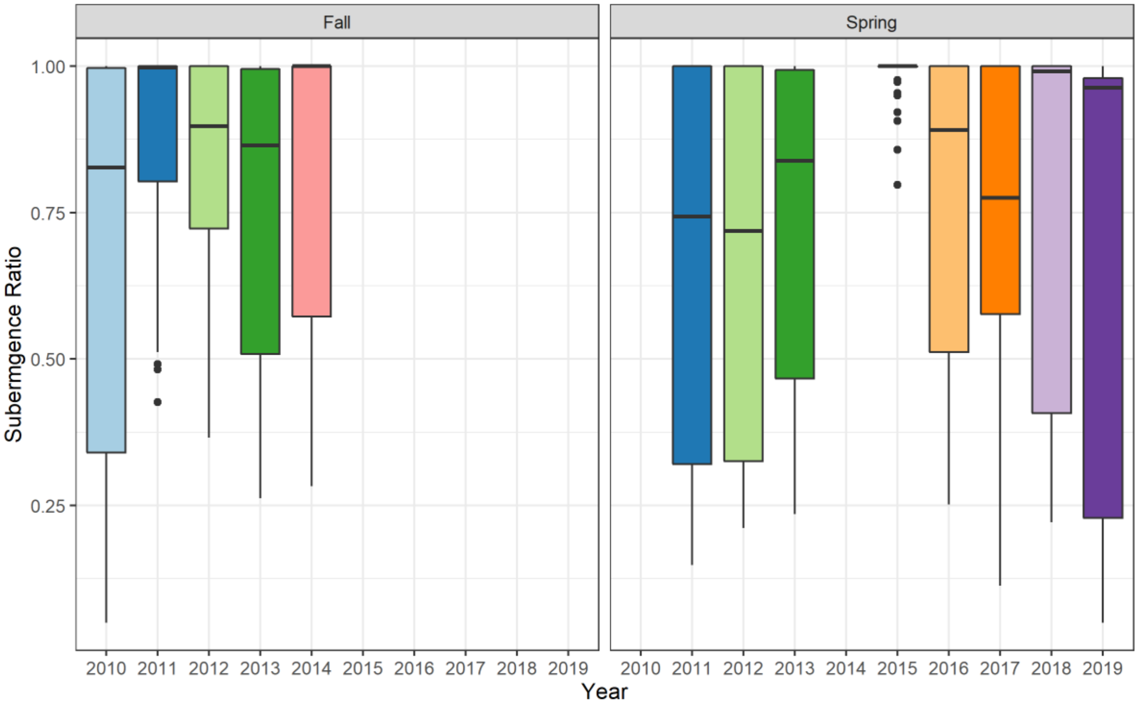

Figure A52 Submergence ratios for mainstem sites by year and season.

12.5.3 Random Forest and CART Models

Annual variations in operations caused a shift in the section of river that is periodically dewatered. The submergence ratios can be used to identify what samplers were in the periodically dewatered zone. Testing the effect of varying submergence ratios on invertebrate abundance, biomass and diversity metrics can assist in the extrapolation of the effects of minimum flows on the periodically dewatered zone. RF and CART models were used to understand the effects of submergence ratio on invertebrate abundance, biomass and diversity metrics.

Submergence ratio was the top predictor of abundance for both fall and spring RF models (Figure A53 and Figure A54). In spring, invertebrate abundances were lower for submergence ratios less than 0.6, whereas invertebrate abundance increased from submergence ratios of 0.6-1.0 (Figure A55). The Spring CART model identified that submergence ratios greater than 0.64 had higher invertebrate abundance (Figure A56). In fall, the invertebrate abundance was low for submergence ratios less than 0.9 (Figure A57). There was a sharp increase in invertebrate abundance from submergence ratios of 0.9-1.0. The fall CART model identified submergence ratios greater than 0.94, as having an increased invertebrate abundance (Figure A58). The variation in spring invertebrate abundance was better explained by the RF model than fall invertebrate abundance. The spring and fall RF models explained 30% and 17% of the variation in invertebrate abundance, respectively.

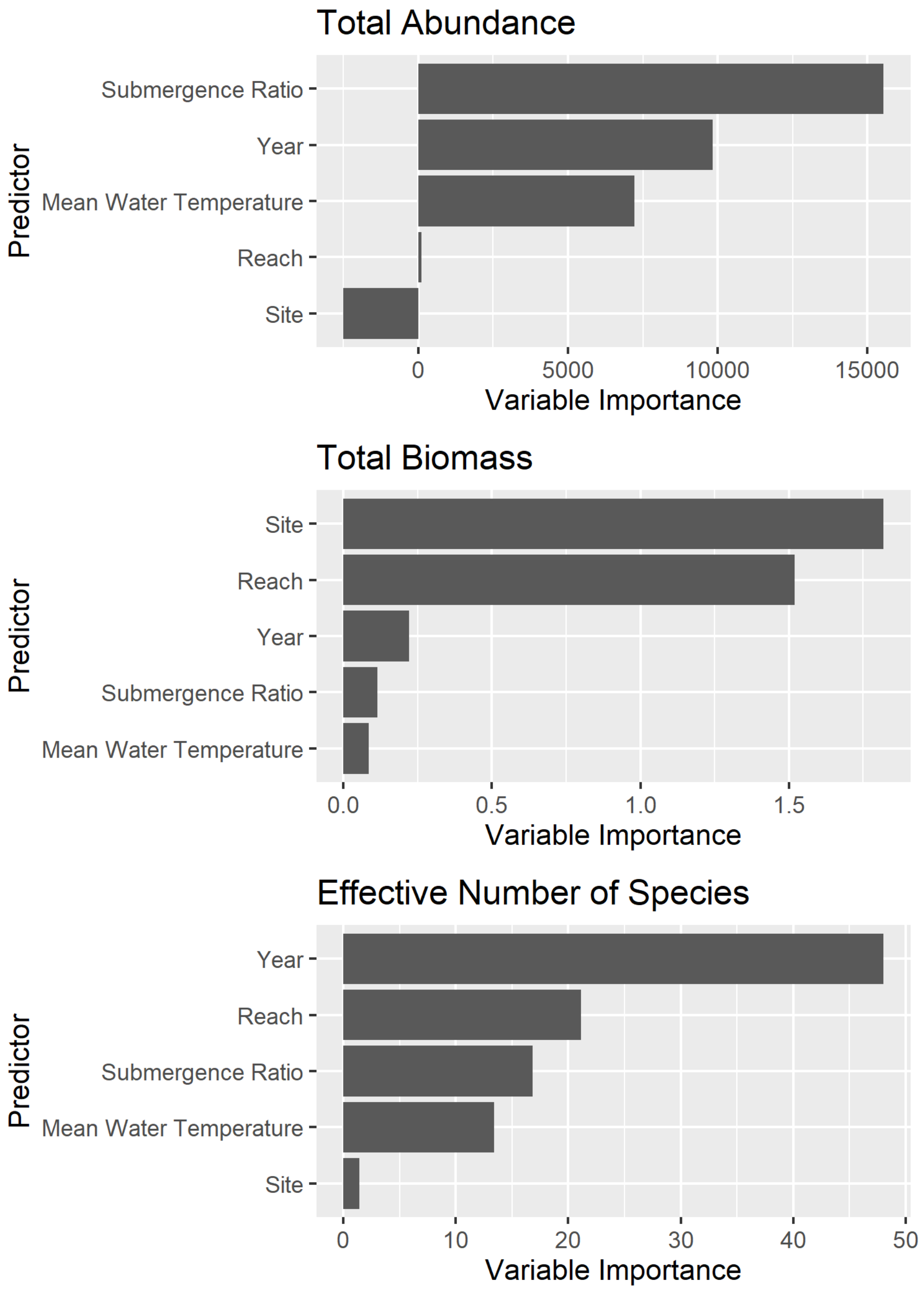

Figure A53 Variable importance plots for spring RF models.

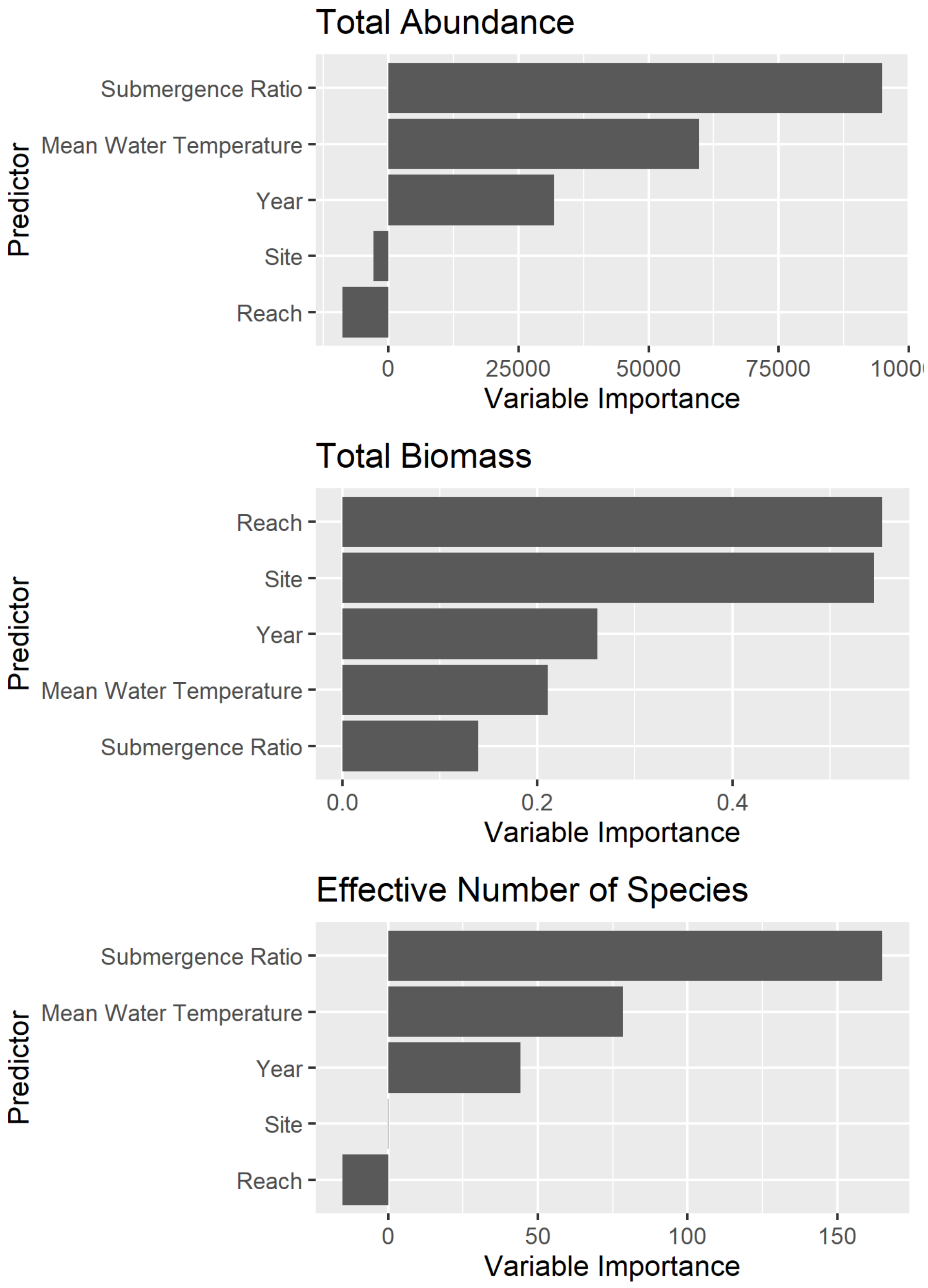

Figure A54 **Variable importance plots for fall RF models.**

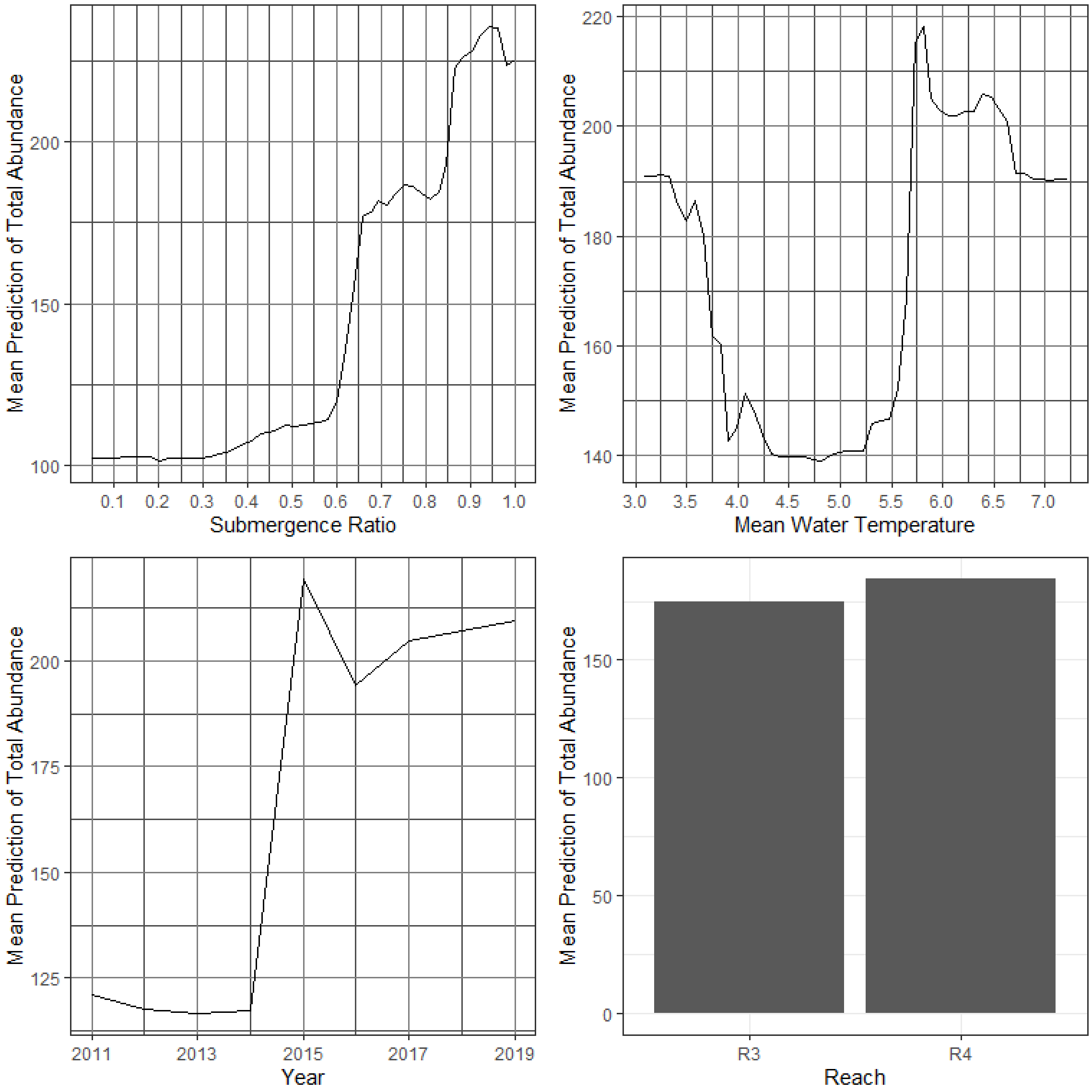

Figure A55 Random forest model partial dependence plots for the top four explanatory variables for total abundance in spring.

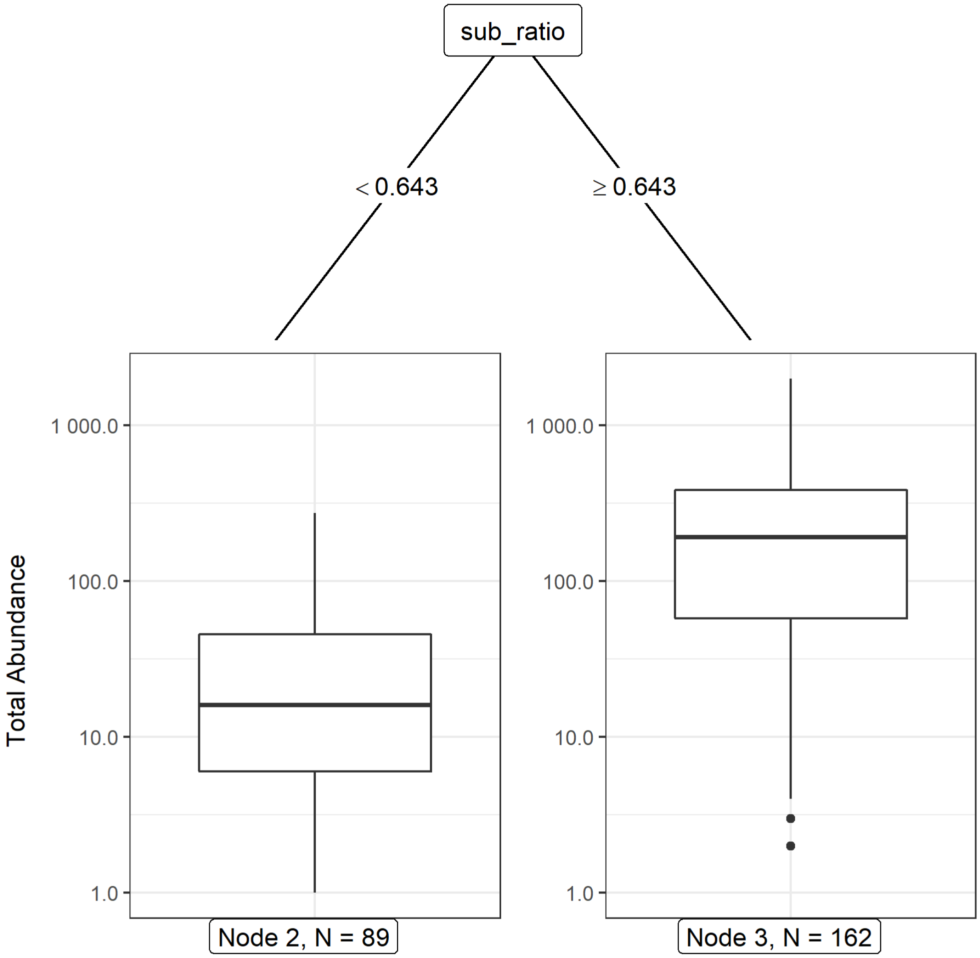

Figure A56 CART model for spring invertebrate abundance with submergence ratio as the only spitting variable.

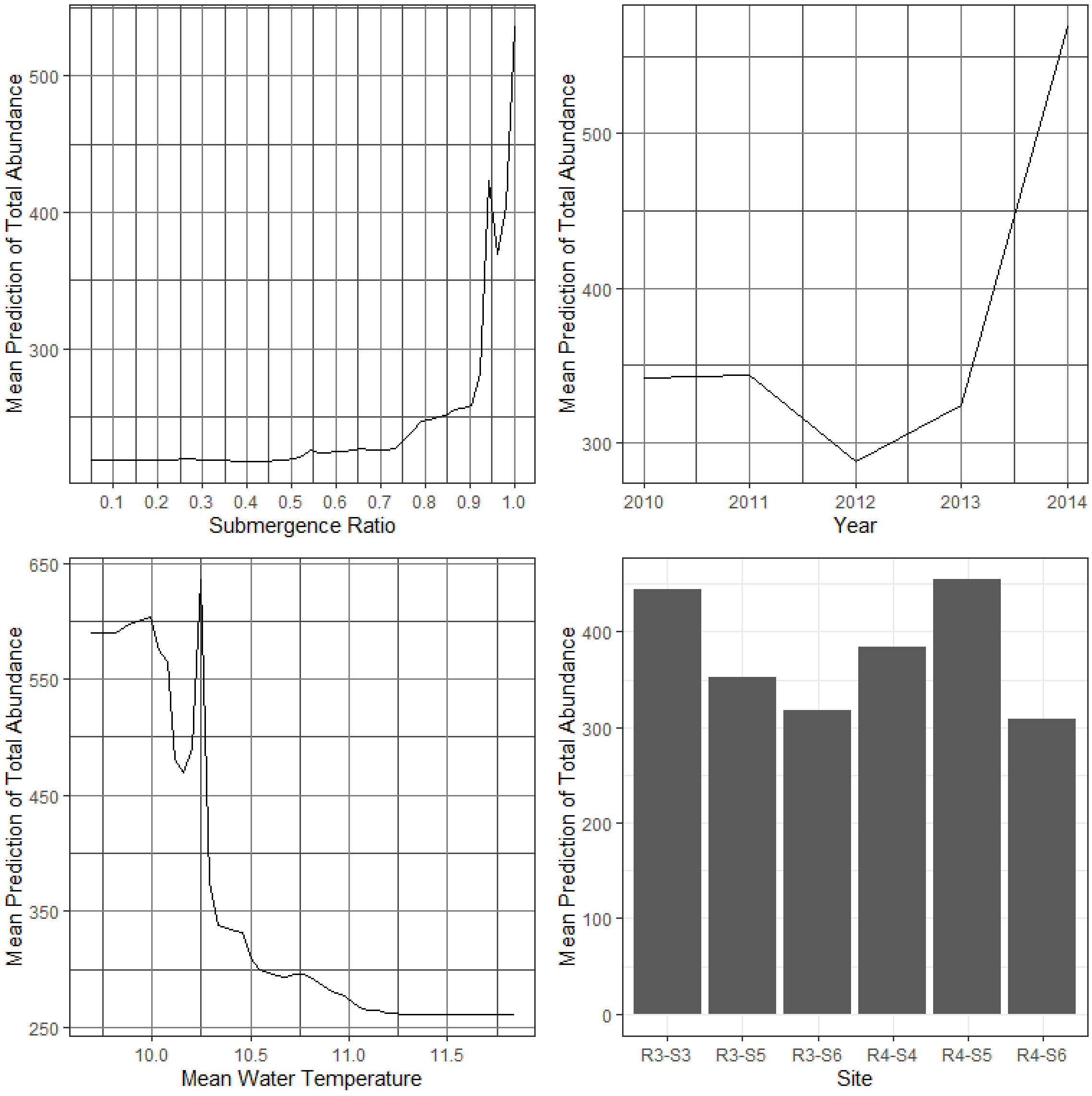

Figure A57 Random forest model partial dependence plots for the top four explanatory variables for total abundance in fall.

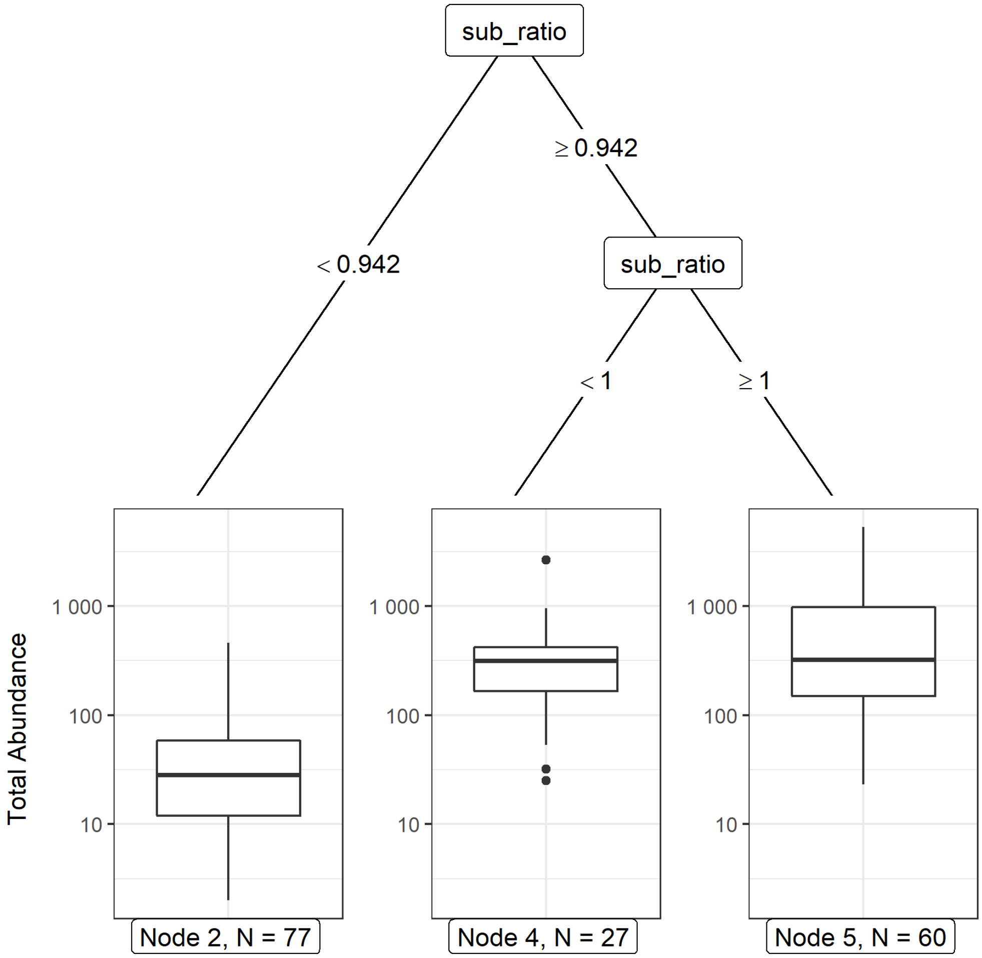

Figure A58 **CART model for fall invertebrate abundance (2010-2014) with submergence ratio as the only spitting variable.**

Submergence ratio had low variable importance for both the fall and spring invertebrate biomass RF models (Figure A53 and Figure A54).). However, the spring CART model identified submergence ratios greater than 0.64 had higher invertebrate biomass than samplers that had submergence ratios less than 0.64 (Figure A61). Reach and site were the two most important predictors of fall and spring invertebrate biomass. Reach 3 sites had higher invertebrate biomass than Reach 4 sites in spring and fall (Figure A59 and Figure A60). The invertebrate biomass models explained 51% of the variation of biomass in spring and 32% of the variation of biomass in fall.

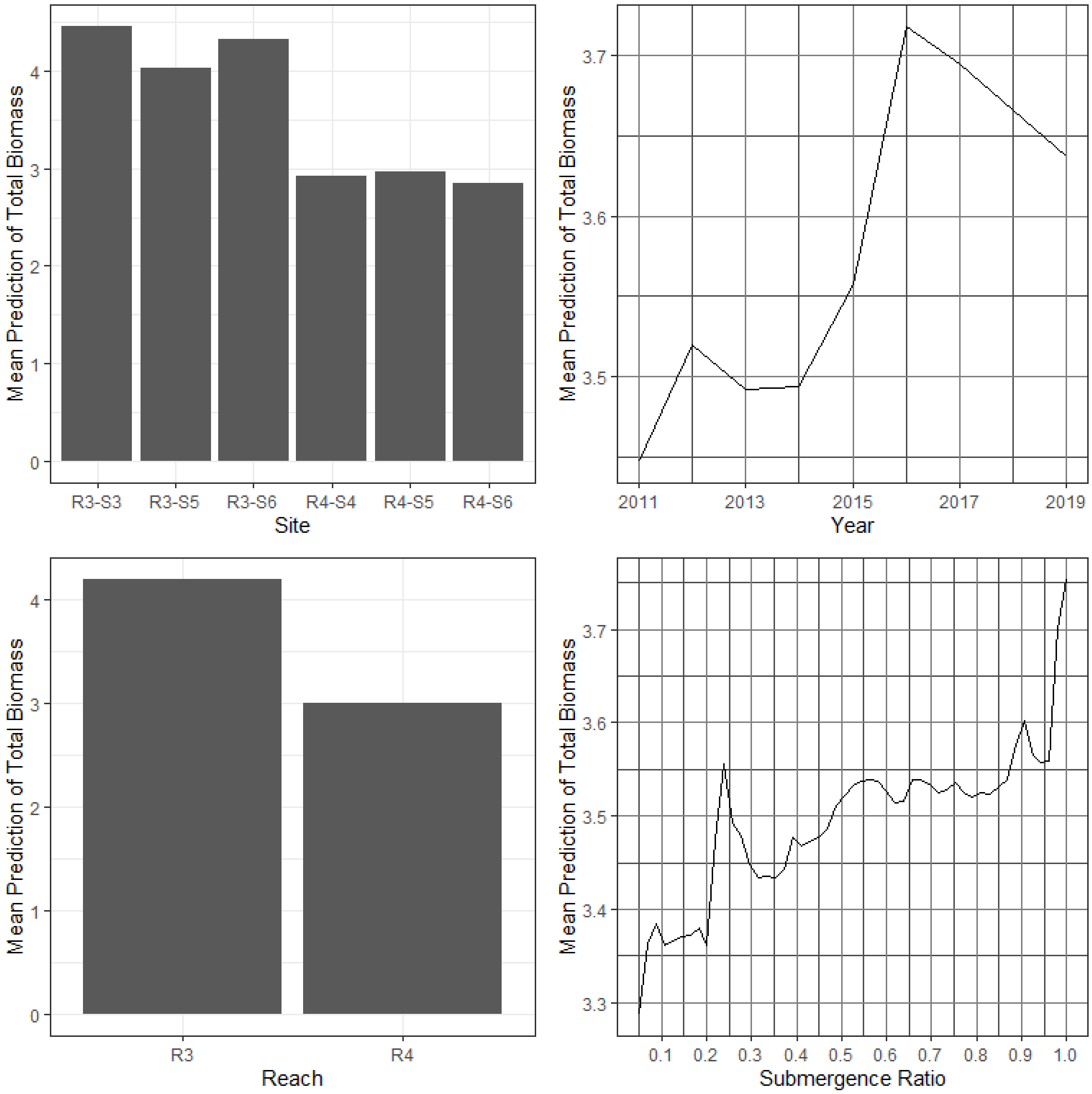

Figure A59 Random forest model partial dependence plots for the top four explanatory variables for total biomass in spring.

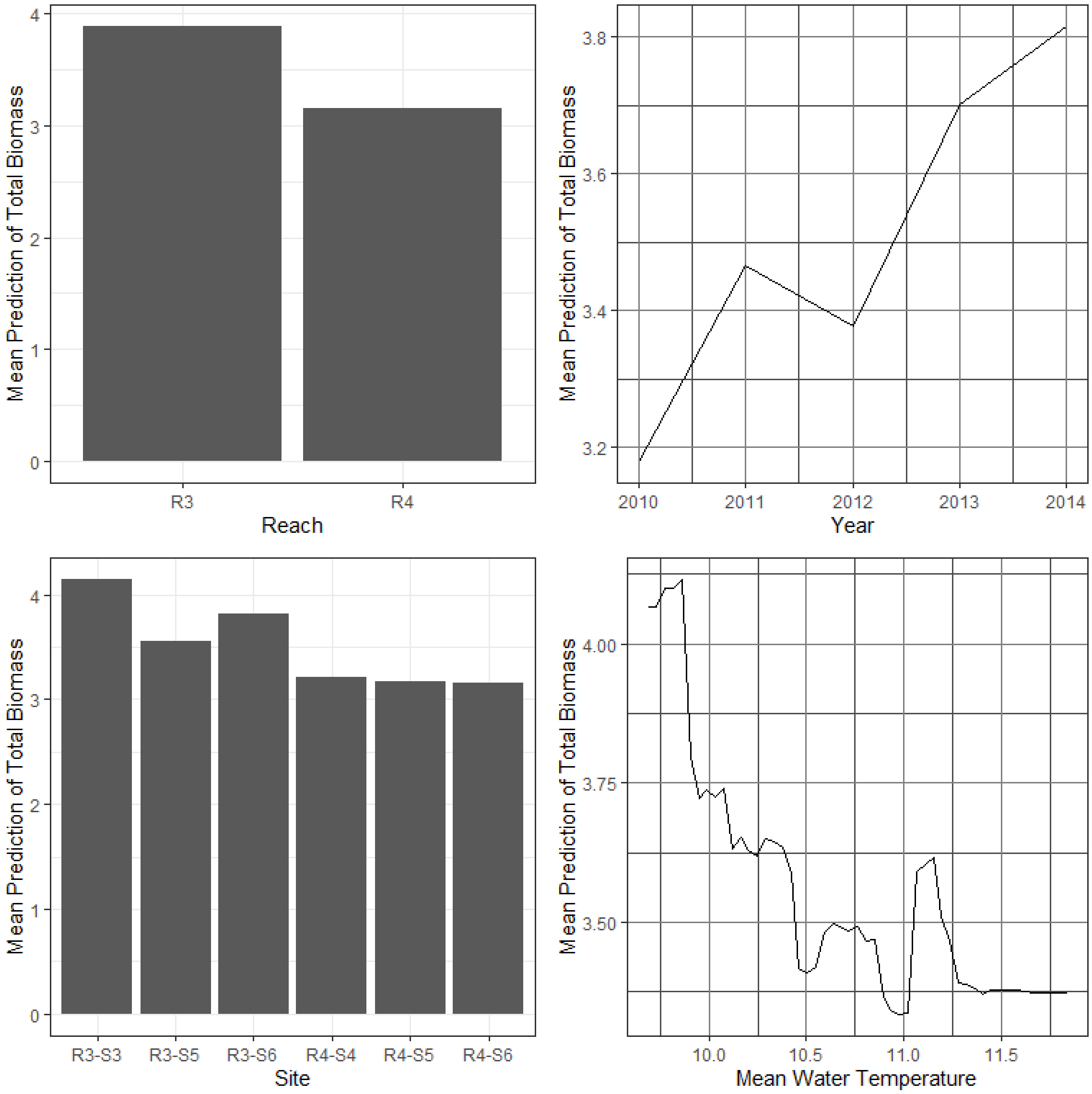

Figure A60 Random forest model partial dependence plots for the top four explanatory variables for total biomass in fall.

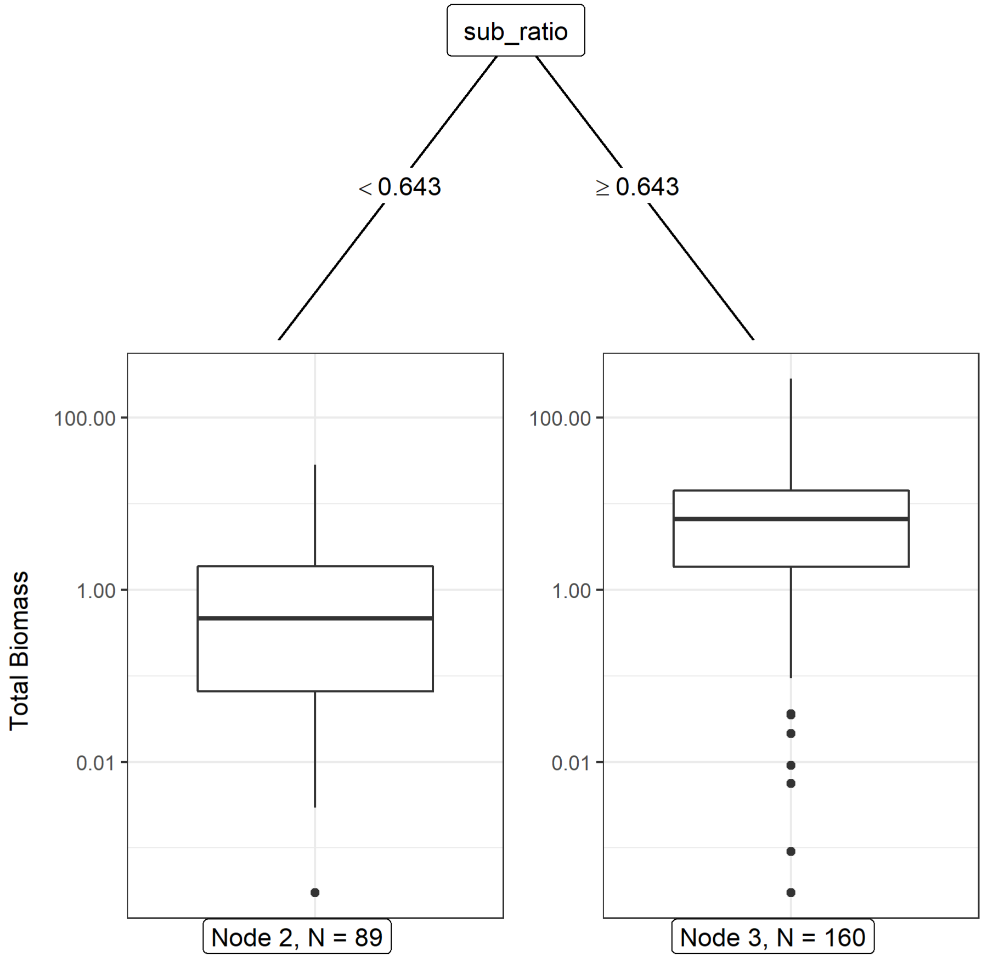

Figure A61 **CART model for spring invertebrate biomass with submergence ratio as the only spitting variable.**

The effective number of species models are only discussed for spring because the fall RF model only explained 3% of the variation for effective number of species. The spring RF model explained 16% of the variation of effective number of species and the top predictor was year (Figure A53). Spring 2011-2013 had lower effective number of species compared to spring 2015-2019 (Figure A62). Reach was the second most important predictor of effective number of species in spring. Reach 3 sites had higher effective number of species compared to Reach 4 sites.

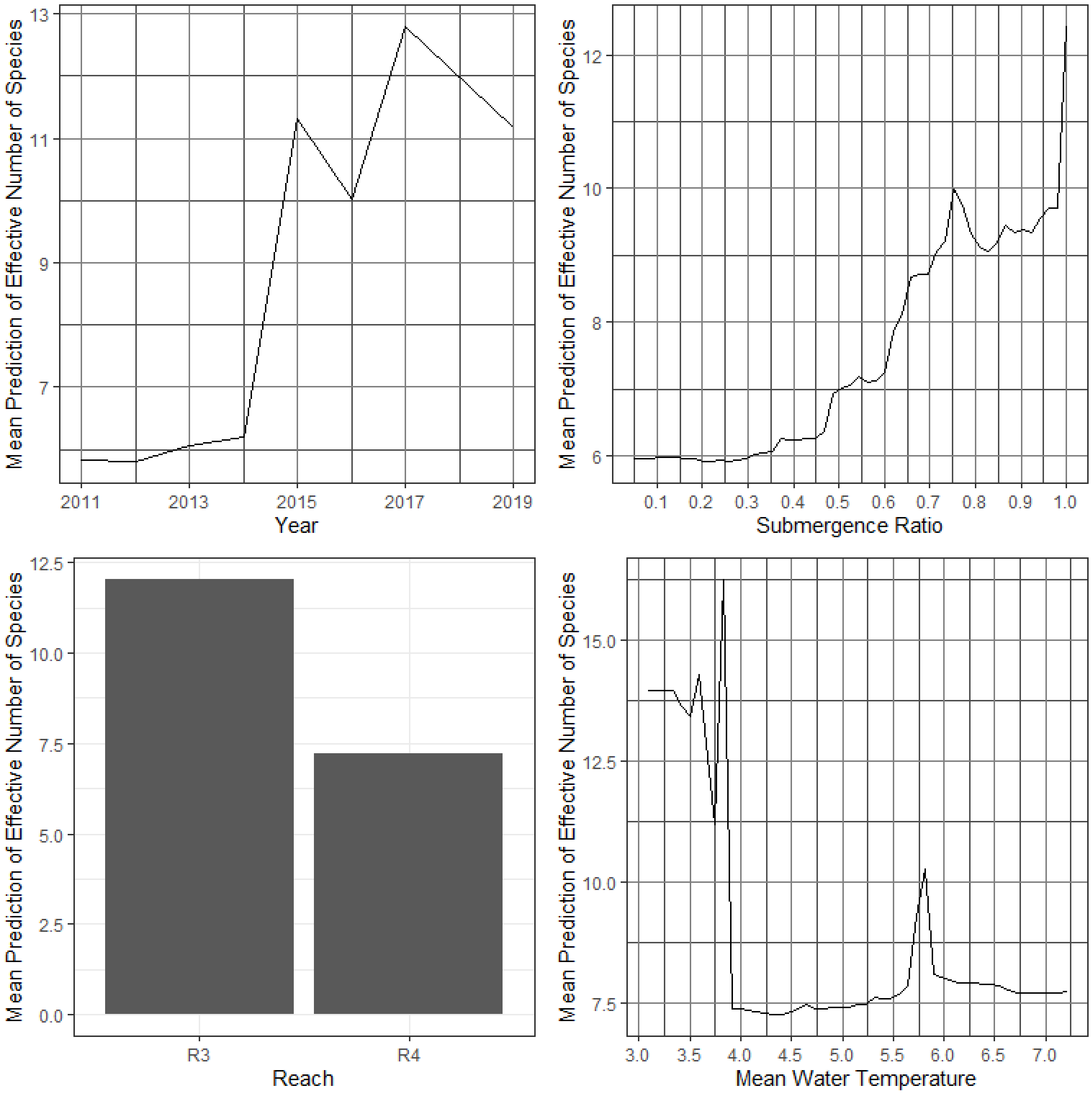

Figure A62 **Random forest model partial dependence plots for the top four explanatory variables effective number of species in spring.**

The variation in effective number of species at the spring T1 sampler locations was examined by year and reach because of the RF results. Reach 4 sites had consistent effective number of species across years, effective number of species ranged from 1.41-3.76 in spring 2011-2019. The effective number of species at Reach 3 T1 samplers had high annual variability. The annual mean effective species number for spring Reach 3 T1 samplers ranged from 2.56 in 2013 to 8.40 in 2018. Spring 2016-2018 had higher mean effective number of species compared to other spring sampling sessions (Figure A63).

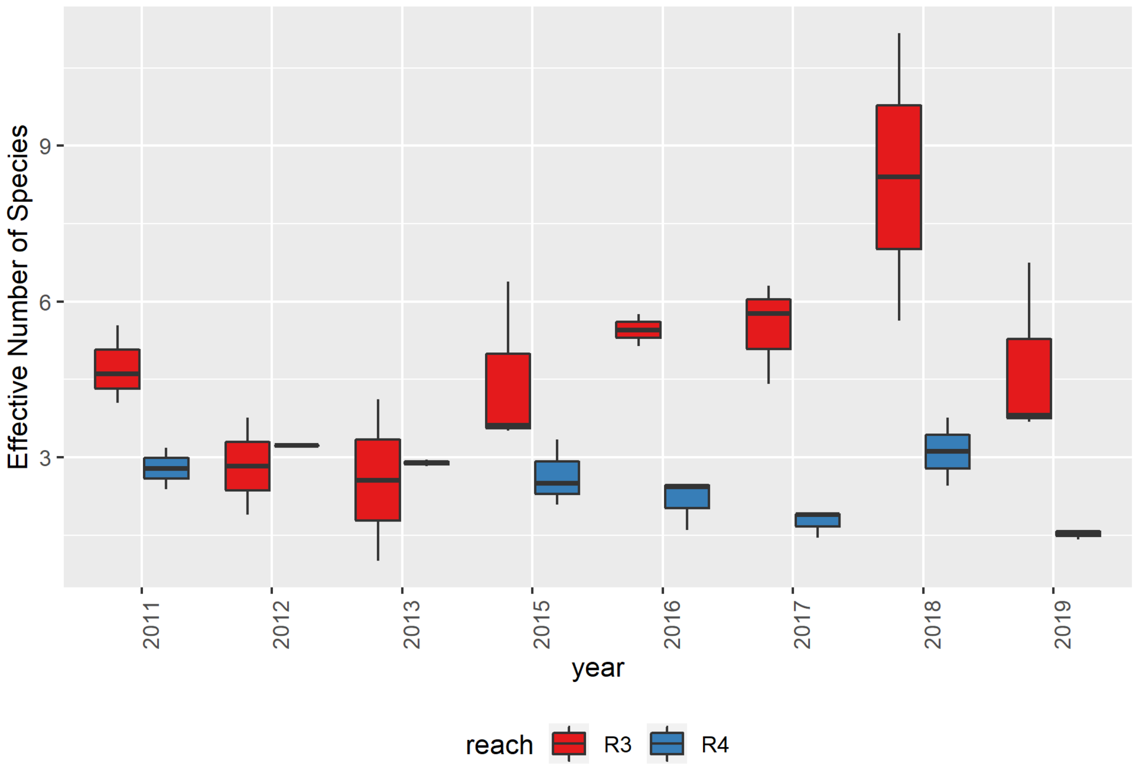

Figure A63 Boxplots of effective number of species at T1 samplers in spring grouped by year and reach.

12.6 Discussion

12.6.1 Annual Differences

In the area below the elevation wetted by minimum flows, annual differences in fall invertebrate production were influenced by extreme flows and high ALR elevations. The low invertebrate abundance and biomass at some sites in fall 2008 was a result of extensive ALR backwatering. ALR backwatering caused a reduction in current velocities and less optimal riverine habitat for invertebrates. In Fall 2012, the low invertebrate abundance and biomass were a result of high flows that likely caused chironomids to be lost through drift. Fall 2013 had the highest invertebrate biomass of all fall sampling sessions because high 2012 flows likely increased instar survival throughout MCR, resulting in a higher colonization rate of permanently submerged habitat in 2013 (Plewes et al. 2019).

12.6.2 Minimum Flows and Permanently Wetted Areas

MCR fall invertebrate abundance data collected to date was similar before and after the implementation of minimum flows, indicating that minimum flows did not affect the invertebrate abundance and biomass in the area below the elevation wetted by minimum flows. Before the implementation of minimum flows, substrate dewatering only occurred for 4-7 hours at night (Plewes et al. 2019). The most abundant invertebrates, chironomids and oligochaetes, appear to be able to withstand this nighttime dewatering. Spring RF and CART models support that short periods of dewatering do not cause large decreases in invertebrate abundance.

RF spring models and estimated submergence ratios were used to estimate the effects of the implementation of minimum flows on spring invertebrate production because no spring benthic invertebrate data was collected before the implementation of minimum flows. The duration of substrate submergence was the most important factor that determined invertebrate abundance and the fourth most important factor of invertebrate biomass in the spring RF models. The spring invertebrate abundance RF model suggested that invertebrate productivity benefits from submergence ratios greater than 0.64. Submergence ratio still explained some variation in biomass as demonstrated by invertebrate biomass benefitting from submergence ratios of greater than 0.64 in the CART biomass model.

The spring RF invertebrate models suggested that reach differences were more important than the duration of substrate submergence in determining invertebrate biomass. The spring RF model demonstrated that Reach 3 sites had more invertebrate biomass than Reach 4 sites. The Jordan River was an important source of invertebrates for the Reach 3 sites. Ephemeroptera families are commonly found in drift and are much larger than chironomids (Anderson and Lehmkul 1968; Plewes et al. 2019). The increased abundances of Ephemeroptera taxa, likely originating from the Jordan River, caused increased invertebrate biomass at Reach 3 sites.

The CART models for invertebrate biomass and abundance had the same split point for submergence ratio of 0.64. For the average spring deployment period, a submergence ratio of 0.64 was equal to 700 hours or 29 days of submergence. Other studies support a threshold response in invertebrate production. Schleppe et al. (2013a), found the density of chironomids increased after 24 days of incubation. The abundance of chironomids have also increased after a duration of artificial sampler incubation. *Orthocladius sp.* exhibited a large increase in abundance after 12 days of incubation, whereas *Eukiefferiella sp.* had a large increase in abundance after 26 days of incubation (Meier et al. 1979).

The estimated submergence ratios in the area below the elevation wetted by minimum flows were greater than 0.64 before the implementation of minimum flows in spring. The invertebrate abundance and biomass CART model suggested that invertebrate abundance experiences a sharp decrease around a submergence ratio of 0.64. Before the implementation of minimum flows, the area below the elevation wetted by minimum flows experienced mostly nighttime dewatering. We suspect that the combination of nighttime dewatering and sufficient submergence times before the implementation of minimum flows, did not cause a decrease in invertebrate abundance and biomass. Therefore, we accept the hypothesis that the implementation of minimum flow release does not change the total abundance / biomass of benthic invertebrates in the area below the elevation wetted by minimum flows.

However, the implementation of minimum flows appeared to benefit the diversity of the invertebrate community (measured as effective number of species), in the area below the elevation wetted by minimum flows under typical fall operating conditions. Minimum flows provided a smaller range of environmental conditions, including temperature and velocity, which appeared to facilitate better colonization for a wider range of invertebrate taxa. Fall 2011 and 2013-2014 exhibited a typical operating regime, where peak hourly flows rarely exceeded 1,800 m^3/s. Invertebrate data from fall 2012 suggested that the benefit of minimum flow on R4 diversity was minimal in years with hourly flows that exceed typical operations. Only some invertebrate taxa could withstand the high flows of fall 2012 and as a result invertebrate diversity was reduced.

The spring RF effective number of species model identified annual and reach differences in invertebrate diversity. The higher invertebrate diversity at Reach 3 was a result of the Jordan River which is an important source of EPT taxa. Reach 3 also had higher annual variability in invertebrate diversity compared to Reach 4. The higher invertebrate diversities in spring 2016-2018 were likely a result of more invertebrate drift from the Jordan River. During spring 2016-2018, the Jordan River likely had higher flows because the Columbia basin experienced an earlier freshet in 2016 and higher snowpack levels in 2017-2018. Higher flows in the Jordan River likely resulted in an increased number of invertebrate taxa that were mobilized in drift (Irvine and Henriques 1984).

Based on the fall invertebrate data and the spring RF models, it appears that minimum flows benefit the spring invertebrate diversity of Reach 3 in the areas below the elevation wetted by minimum flows. Minimum flows likely have a minimal effect on invertebrate diversity in Reach 4 because of the high velocities near the thalweg and a limited source of invertebrates from upstream areas. Velocity modelling conducted in Plewes et al. (2019) suggested that higher Reach 4 velocities caused losses of invertebrate taxa through drift. However, in Reach 3 velocities were not high enough to cause reduction in invertebrate taxa. The cold water temperatures and no major tributaries upstream of Reach 4 sites limit the diversity of the spring invertebrate community in in the areas below the elevation wetted by minimum flows.

We therefore reject the hypothesis that the implementation of minimum flow release does not change the diversity of benthic invertebrates in the area below the elevation wetted by minimum flows. However, it is acknowledged that the effect is greater in Reach 3 than Reach 4. It is also acknowledged that Dam operations also play a role in benthic invertebrate diversity, and they may be more important than maintaining a minimum flow release.

12.6.3 Minimum Flows and Periodically Dewatered Areas

Determining the effect of minimum flows on areas periodically dewatered was difficult in fall because of annual variation in ALR elevations and operations. In most fall sampling sessions, after the implementation of minimum flows, T3 samplers rarely experienced substrate dewatering. Fall 2011 and 2014 had the highest invertebrate abundance of the fall sampling sessions because T3 samplers in 2011 and 2014 had less than 12 hours of exposure during these fall deployment periods. The lack of exposure in fall 2011 T3 samplers was because of high ALR elevations that resulted in backwatering of Reach 3 and Reach 4. The high invertebrate production at the fall 2014 T3 samples was likely a result of sampler placement. Based on the calculated submergence ratios, hourly flows and ALR elevations it was inferred that the fall 2014 T3 were placed at a lower elevation in the river.

Based on estimated submergence ratios and RF models, we estimate under typical operating conditions in spring and fall there was minimal differences of invertebrate abundance and biomass before and after the implementation of minimum flows in areas periodically dewatered by minimum flow. In fall, the estimated submergence ratio for areas periodically dewatered by minimum flow were similar before and after the implementation of minimum flows. Most estimated submergence ratios for spring in the areas periodically dewatered by minimum flow ranged from 0.4-0.6 before and after the implementation of minimum flows. The Spring RF model suggested that invertebrate abundances were similar from submergence ratios of 0.4-0.6. Spring periods with atypical operating conditions that had submergence ratios greater than 0.64 were expected to have greater invertebrate abundance.

The higher submergence ratios of spring 2007, 2009, 2015 and 2017 were related to different operating conditions and independent of minimum flows. Submergence ratios greater than 0.64 benefit invertebrate production and the RF model supports this result with higher invertebrate production in spring 2015. Spring 2015 had very high mean hourly flows compared to all other spring sampling sessions and as a result the lower varial zone rarely was dewatered. Therefore, based on estimated submergence ratios and RF models we accept the hypothesis that the implementation of minimum flow release does not change the total abundance / biomass of benthic invertebrates in the periodically dewatered areas.

The diversity for areas periodically dewatered by minimum flow was lower in fall sampling sessions before the implementation of minimum flows compared to after. The higher diversities after the implementation of minimum flow were caused by atypical operations in fall 2012. REV-5 caused higher average velocities in areas periodically dewatered by minimum flow. These higher average velocities provide suitable habitat for a wider range of EPT taxa. The higher flows in summer and fall 2012 caused more drift from the Jordan River which resulted in an increase of EPT taxa in Reach 3 (Schleppe et al. 2013b).The high flows of fall 2012 provided the opportunity for EPT taxa to colonize Reach 3 and as a result subsequent fall sampling sessions had higher EPT richness in Reach 3.

We estimate, invertebrate diversity of areas periodically dewatered by minimum flow were similar before and after the implementation of minimum flows in spring, under typical operating conditions. In typical spring sampling sessions, the estimated submergence ratios for areas periodically dewatered by minimum flow suggested that minimum flows did not increase the duration of submergence in the lower varial zone. Comparable durations of submergence would support a similar invertebrate community before and after the implementation of minimum flows. Our spring RF models and fall 2007-2014 fall invertebrate data suggest annual differences in Jordan River flows and dam operations were more important factors determining invertebrate diversity in areas periodically dewatered by minimum flow. We therefore accept the hypothesis that the implementation of minimum flow release does not change the diversity of benthic invertebrates in the periodically dewatered areas.

12.6.4 Long-term Trends in Production

The ability to detect long-term trends in the MCR invertebrate productivity data was complicated by annual variation in dam operations, ALR elevations, and tributary flows. Short-term trends were detected and were linked to years that did not have typical operating conditions. The above average hourly flows in spring 2015 increased the area of productive invertebrate habitat. Additionally, peaks flows in spring 2015 were less 1800 m^3/s which minimized the invertebrates lost through drift. The above-average flows caused an increase in invertebrate colonization in the lower and upper varial zones which benefitted invertebrate production in subsequent years.

The higher flows in summer and fall 2012 caused an increase of production in subsequent fall sampling sessions because it caused increased drift and more wetted habitat area that provided higher colonization rates. Similar to other systems, the MCR invertebrate production was reduced immediately after the high flows of summer and fall 2012 in the MCR (Hajdukiewicz et al. 2018; Robinson et al. 2003). The invertebrate community recovered within a year from the fall 2012 flood. However, there was a shift in the invertebrate community composition. In other studies, invertebrate community composition changes after floods have also been reported (Robinson 2012). In the MCR, there was a higher percent of chironomids after the flood of 2012. Chironomids recover quickly after disturbances such as floods (Robinson et al. 2003). The shift in invertebrate community composition towards chironomids may be related to an increase of biomass and abundance observed in fall 2013-2014.

The invertebrate productivity of the MCR does not exhibit a long-term trend in the fall or spring sampling sessions. Rather, spring and fall invertebrate data suggest that atypical operations can cause short term trends in invertebrate production.

12.7 References

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13.0 APPENDIX 8. MQ #5

13.1 Introduction

MQ#5: *If changes in the benthic community associated with minimum flow releases are detected, what effect can be inferred on juvenile or adult life stages of fishes?*

Ho_5: *The implementation of the 142 m^3/s minimum flow release does not change the availability of fish food organisms in the Middle Columbia.*

13.2 Methods

Stomach contents from Bull Trout (BT) (*Salvelinus confluentus*), Mountain Whitefish (MW) (*Prosopium williamsoni*), and Rainbow Trout (RB) (*Oncorhynchus mykiss*) in the MCR were collected between 2007 – 2010 using gastric lavage (Bowen 1989, Brosse *et al.* 2002, Baldwin *et al.* 2003, Budy *et al.* 2007) with an apparatus modified from that described by Light *et al.* (1983). The collection of fish stomach contents by gastric lavage was detailed in Perrin and Chapman 2009. The collected samples were washed from the sieve into a collection jar and preserved in 10% formalin for later identification and enumeration of contents. Stomachs were removed from ingested fishes and preserved in 10% formalin for identification of stomach contents. All stomach contents were identified to the lowest reliable taxon (same level as macroinvertebrate samples where possible) and counted. Head counts were used for the enumeration of partly digested animals.

13.3 Dataset

Stomach contents from 65 BT, 66 MW and 61 RB were collected from 2007-2010 (Table A30). Most of the fish collected were adults with the exception of 4 RB, 4BT and 1 MW. Fish were collected as part of the MCR fish indexing program in the fall and corresponded with the fall invertebrate sampling session (Perrin and Chapman 2009).

Table A30 **Summary of fish stomachs collected by year and species in the MCR.**

Year	Bull Trout	Mountain Whitefish	Rainbow Trout
2007	14	17	15
2008	16	15	16
2009	15	14	7
2010	20	20	23
Total	65	66	61

13.4 Analysis

The stomach contents of BT were not included in statistical analyses because 44 out of the 65 samples only included other fish or fish eggs. Bull trout are piscivores that primarily feed on kokanee in the Columbia basin (Arndt 2004). The analysis focused on the forage preferences of MW and RB that are known to forage on invertebrates. The benthic invertebrate community composition of RB and MW stomach contents were analyzed at the family level. For Non-metric multidimensional scaling (NMDS), the stomach contents of RB and MW that were terrestrial or fish were excluded from this analysis because the abundance of these organisms are not within the scope of this study. An NMDS using the Bray-Curtis dissimilarity index was conducted on the fish stomach community data. A PERMANOVA was used to determine if there were significant differences in community compositions according to species.

To identify unique taxa in fish stomachs, taxa were related to the community differences by fitting them to the ordination plot as factors using Envfit (Oksanen et al. 2016). Only the taxa that were significant ($p<0.05$) and had r^2 greater than 0.1 were considered. These taxa described the most observed variation between fish stomachs. Counts per stomach for each fish species were grouped into six categories of prey: chironomids, larvae of the EPT (Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies)), zooplankton, other aquatic taxa, terrestrial invertebrates, and fish. The percent composition of the ingested groups was qualitatively compared among RB and MW.

The community composition and fish food availability in fall 2007-2010 from invertebrate samplers, T1 and T3, were examined to better understand how the availability of fish food impacts what invertebrate taxa are consumed by RB and MW. Relative biomass was calculated based on nine general benthic invertebrate groups for all T1 and T3 samples from main sites during fall 2007-2010.

To test how the availability of fish food was influenced by minimum flows, the total biomass of EPT+D was calculated for benthic invertebrate samples before and after the implementation of minimum flows. The percent EPT and chironomids by biomass were also calculated to better understand community compositions of fish food items. The three fish food metrics were compared for benthic invertebrate samples from T1 and T3 locations from fall 2007-2014.

13.5 Results

The community composition of aquatic organisms in the fish stomachs of RB and MW were compared by NMDS (Figure A64). There were significant differences between the stomach contents of RB and MW ($R=0.09$, $F=9.90$, $p<0.001$). The positive correlation of the first MDS axis with Trichoptera and Limnephilidae was caused by a few RB and MW stomachs that had abundances of these invertebrates. The zooplankton family Daphniidae was negatively correlated with the first MDS axis. This negative correlation was associated with MW fish stomachs that had higher abundances of zooplankton than RB stomachs.

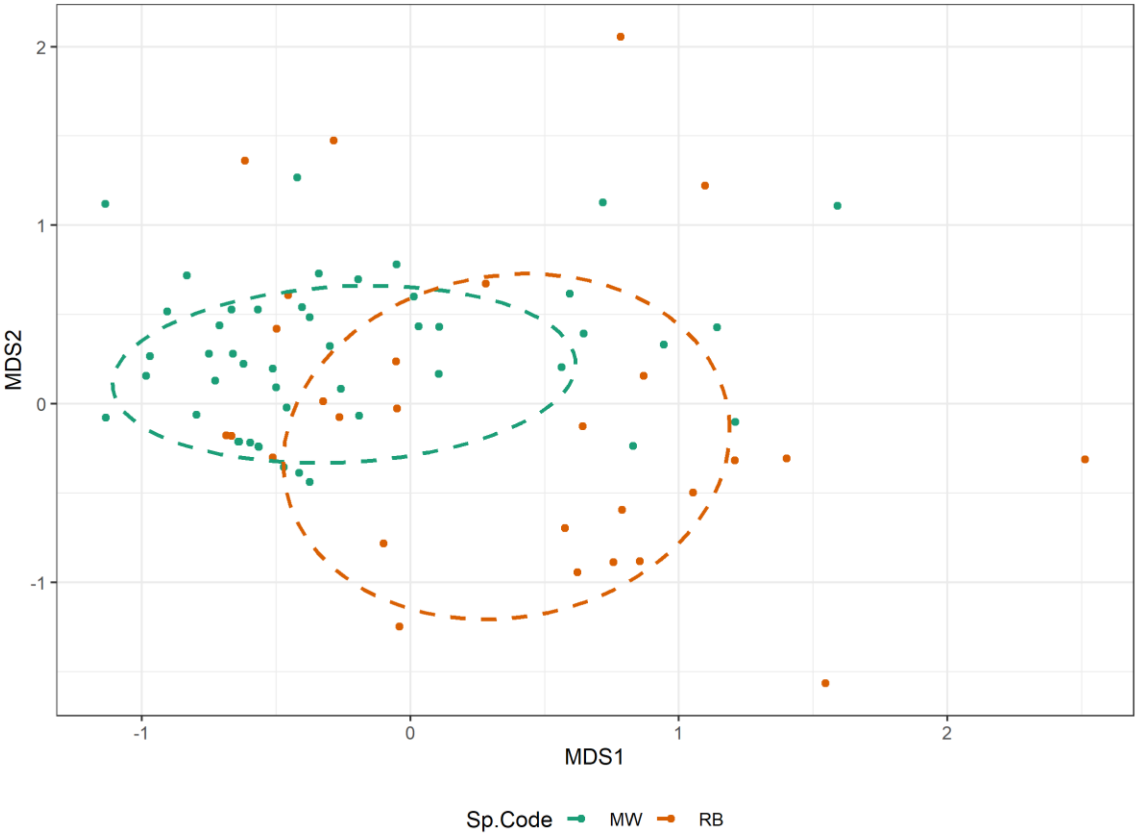

Figure A64 NMDS plot of fish stomach contents collected in 2007-2010 only including aquatic invertebrate and zooplankton taxa. Stress index was 0.15.

The six fish food groups of chironomids, fish, terrestrial invertebrates, EPT larvae, other aquatic and zooplankton were compared by fish species. The stomachs of RB had higher mean percent abundances of chironomids, and terrestrial invertebrates compared to the stomach contents of MW (Figure A65). The mean percent of chironomids was 23±31% in RB stomachs and 4.7±11% in MW stomachs. Mountain Whitefish had a mean percent abundance of terrestrial invertebrates of 1.1±6.4%, whereas RB had a mean percent abundance of 7.6±21.1%. The mean percent abundance of zooplankton was 70±38% in the stomachs of MW which was higher than the mean percent abundance of 24±40% in RB stomachs. The mean percent abundance of EPT in RB and MW were low, 2.4±10.7% and 2.5±12.0%, respectively. However, there were four MW and two RB that had percent abundances of EPT >55% (Figure A65).

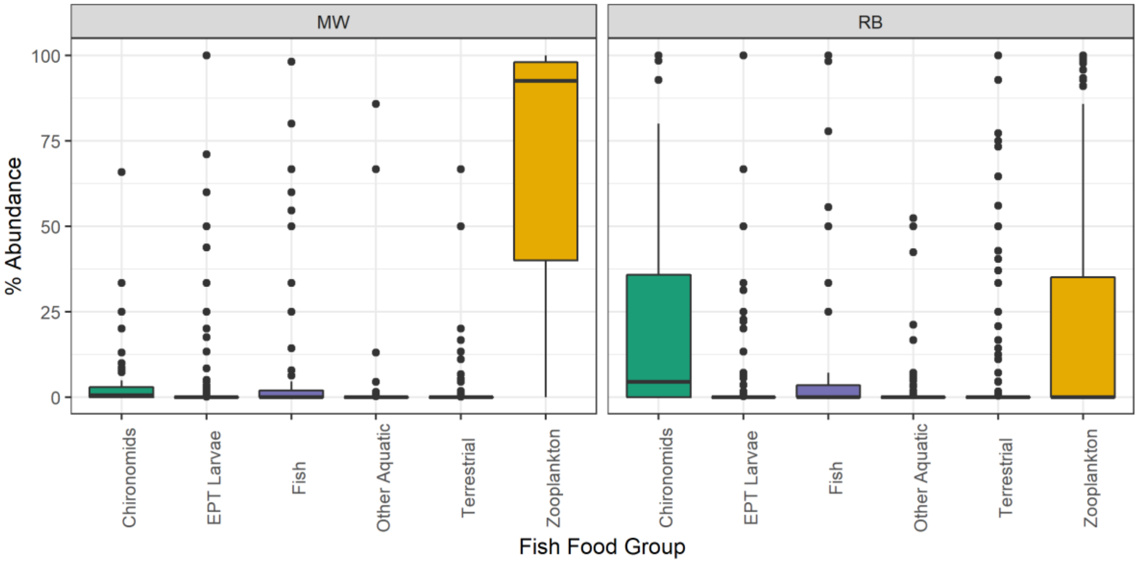

Figure A65 **Percent abundance of fish food groups in the stomachs of Rainbow Trout (RB) and Mountain Whitefish (MW).**

Hydrozoans were the dominant invertebrates in most fall 2007-2010 invertebrate samples based on percent biomass (Figure A66). However, there were some samples with higher percent biomasses of dipterans and oligochaetes. Reach 3 samples from fall 2007 had lower percent biomass of hydrozoans and higher percent biomass of dipterans and oligochaetes. In fall 2010, Reach 4 samples had small percent biomass of hydrozoans and were dominated by either dipterans or oligochaetes. EPT taxa were only present in 22% of the benthic invertebrate samples and most of these samples had percent biomass of EPT <7%.

Figure A66 Percent biomass of benthic invertebrate groups from T1 and T3 samples fall 2007-2010.

13.6 Discussion

The invertebrate samples and the stomach contents from fall 2007-2010 suggested that RB and MW were consuming chironomids but not consuming Hydrozoans or oligochaetes. Hydrozoans are likely not ingested by fish because of their small size and secure attachment to substrates that makes them unavailable. Oligochaetes were also not ingested by fish because they are also small and mostly buried in sediment or attached to periphyton. Although chironomids had small proportions in both the stomachs of RB and MW, the higher abundances of chironomids in RB stomachs suggested RB consume more chironomids than MW.

The stomach contents of MW and RB had small percent abundances of chironomids and EPT. However, the benthic invertebrate samples demonstrated that chironomids and EPT were not readily available in fall 2007-2010. Despite chironomids and EPT not being readily available, they were still found in the stomachs of RB and MW. Based on literature, we suggest that the biomass of EPT +D was suitable as a fish food index. In fall 2012-2014 the invertebrate community was primarily chironomids, in other rivers with invertebrate communities dominated by chironomids, MW and juvenile RB had a high percentage of chironomids in their stomachs (DosSantos et al. 1985). Adult RB consumed a large portion of Ephemeroptera (E) and Trichoptera (T) taxa when these ET taxa were available in the Kootenai River (DosSantos et al. 1985).

Mountain Whitefish have shown a feeding preference to aquatic insect larvae of Dipterans, Ephemeroptera and Plecoptera (Crossman and Scott 1973). However, in less productive invertebrate systems MW adapt and feed on other organisms such as zooplankton and fish eggs (Northcote 1957). The stomach contents of MW were collected in fall 2007-2010 when the availability of fish food (EPT+D taxa) was low because of a higher dominance of Hydrozoans. As a result, the MW in MCR fed primarily on zooplankton. In more productive systems, juvenile and adult MW have a dominance of chironomids in their fish stomachs (Brown 1972). However, adult MW have a higher content of EPT taxa in their stomachs compared to juvenile MW (Brown 1972; DosSantos et al. 1985).

Rainbow Trout have shown feeding preferences to terrestrial invertebrates, EPT available in drift, chironomids and other fish (Cada et al. 1987; Oscoz et al. 2005). The RB stomach contents collected from MCR support that RB feed on terrestrial invertebrates, chironomids, and other fish. RB can adapt their feeding habits based on what was available in the water column (Cada et al. 1987). However, older RB are better suited as opportunistic feeders because they are able to feed on drift without predation pressures (Oscoz et al. 2005). Adult RB had a higher diversity of fish food items in their stomachs including terrestrial invertebrates, fish and aquatic invertebrates (Oscoz et al. 2005). The stomach contents of juvenile RB were primarily composed of aquatic organisms including chironomids, EPT and zooplankton (Oscoz et al. 2005; Beauchamp 1990).

Small shifts in the benthic invertebrate community were detected after the implementation of minimum flows. These shifts in invertebrate composition resulted in a higher availability of fish food because of higher biomasses of chironomids and EPT. The implementation of minimum flows caused an increase in invertebrate diversity in the area below the elevation wetted by minimum flows. The increased invertebrate diversity was partially a result of a greater richness and abundance of EPT taxa in Reach 3. The implementation of minimum flows allowed more EPT to colonize Reach 3 because it provided permanently submerged habitat with a narrower range of velocities. EPT taxa are sensitive to desiccation and some EPT taxa have specific velocity preferences (Jones 2013; Schmedtje and Colling, 1996).

The results from CLBMON-16 and this study suggested that an increased availability of fish food organisms does not affect the growth rate or body condition of adult MW and RB. However, there may have been antagonistic effects. An increased availability of food may not have effected body condition because REV5 resulted in higher peak discharges which increases the energetic costs of MW and RB (Golder et al. 2018). Body condition and growth rates of adult RB and MW were similar before and after the implementation of minimum flows (Golder et al. 2018). Juveniles are expected to be more sensitive to changes in the availability of invertebrate fish food because they have more selective diets and primarily forage on zooplankton and chironomids; however, the effect of minimum flows on juvenile body condition and growth rates was not directly tested. Given the ultra-oligotrophic conditions of the MCR, we suspect that the increases in fish food associated with post minimum flows, are likely insufficient to alter body condition or increase growth rates in juveniles.

We reject the hypothesis that the implementation of the 142 m^3/s minimum flow release does not change the availability of fish food organisms in the Middle Columbia. The implementation of minimum flows caused an increased availability of fish food organisms including dipterans and EPT. However, the increased availability of fish food was not substantial enough to cause changes in fish condition of either juvenile or adult life stages.

13.7 References

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