Site C Clean Energy Project

Site C Reservoir Fish Food Organisms Monitoring Program (Mon-6)

Peace River Fish Food Organisms Monitoring Program (Mon-7)

Construction Year 3 (2017)

Ecoscape Environmental Consultants Ltd.

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Kelowna, BC V1V 2M2

March, 2018

Site C Clean Energy Project
Site C Reservoir and Peace River Fish Food Organisms Monitoring

Prepared For:

British Columbia Hydro and Power Authority

Prepared By:

Ecoscape Environmental Consultants Ltd.

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Reservoir Fish Food Organisms Monitoring

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ACRONYMS AND ABBREVIATIONS

AFDW	ash free dry weight
AICc	Akaike information criterion corrected for small sample sizes
ANCOVA	Analysis of covariance
BC Hydro	British Columbia Hydro and Power Authority
CFU	colony forming unit
chl-a	Chlorophyll-a
CLs	Confidence Limits
Didymo	*Didymosphenia geminate*
EAC	Environmental Assessment Certificate
EPT	Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies)
FAHMFP	Fisheries and Aquatic Habitat Monitoring and Follow-up Program
FNU	Formazin Nephelometric Unit
km	kilometer
L	litre
m	metre
masl	metres above sea level
max	maximum value
min	minimum value
n	sample size
NMDS	Non-metric multidimensional scaling
NTU	nephelometric turbidity units
PAR	Photosynthetically active radiation
PERMANOVA	permutational multivariate analysis of variance
RVI	relative variable importance
RTK	real-time kinematic
SD	standard deviation
TSS	total suspended solids

DEFINITIONS

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

Term	Definition
Accrual rate	A function of cell settlement, actual growth and losses (grazing, sloughing)
Algae bloom	A super-abundant growth of algae
Anaerobic/anoxic	Devoid of oxygen
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	The production within the benthos 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
Diel	Denoting or involving a period of 24 hours
Epilithic algae	Algae that grow on hard inert substrates, such as gravel, cobbles, boulders
Eutrophic	Nutrient-rich, biologically productive water body
Flow	The instantaneous volume of water flowing at any given time (e.g.1200 m^3/s)
Freshet	The flood of a river from melted snow in the spring
Functional Feeding group	(FFG) Benthic invertebrates can be classified by mechanism by which they forage, referred to as functional feeding or foraging groups
Heteroscedasticity	Literally “differing variance”, where variability is unequal across the range of a second variable that predicts it, from errors or sub-population differences.
Heterotrophic	An organism that cannot synthesize its food and is dependent on complex organic substances for nutrition.
Laminar	Non-turbulent flow of water in parallel layers near a boundary
Light attenuation	Reduction of sunlight strength during transmission through water
Limitation, nutrient	A nutrient can limit or control the growth of organisms e.g. P or N limitation
Linear Regression Model	Linear regression attempts to model the relationship between two variables by fitting a linear equation to observed data
Macroinvertebrate	An invertebrate that is large enough to be seen without a microscope
Mainstem	The primary downstream segment of a river, as contrasted to its tributaries
Mesotrophic	A body of water with moderate nutrient concentrations
Microflora	The sum of algae, bacteria, fungi, *Actinomycetes,* etc., in water or biofilms
Morphology, river	The study of channel pattern and geometry at several points along a river
Oligotrophic	A body of water with low nutrient concentrations
PAR	Photosynthetically Active Radiation -sunlight spectra used by plants
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
Redd	A spawning nest made by a fish, especially a salmon or trout
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
Salmonid	Pertaining to the family *Salmonidae*, including the salmons, trouts, chars, and whitefishes.
Substrates	Substrate (sediment) is the material (boulder cobble sand silt clay) on the bottom of a stream or lake.
Taxa Taxon	A taxonomic group(s) of any rank, such as a species, family, or class.
Thalweg	A line connecting the lowest points of a river, usually has the fastest flows
Zooplankton	Minute animals that graze algae, bacteria and detritus in water bodies

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Key Word Tags:

Mon-6: fish food organisms | periphyton production | Benthic invertebrates | Dinosaur Reservoir | Williston Reservoir | Peace River sites PR1 PR2 PR3 | Halfway River | Moberly River | areal biomass | photic zone | trophic condition |

Mon-7: Q1. areal biomass | fish food organisms | primary productivity | benthic invertebrates Peace River sites PD1 PD2 PD3 PD4 PD5 | reach-wide biomass |

Mon-17: hydrologic regime | catchability estimates | fish habitat | periphyton production | Benthic invertebrate | flow fluctuation effects |

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EXECUTIVE SUMMARY

This study is year 3 of the Fisheries and Aquatic Habitat Monitoring and Follow-up Program (FAHMFP) that began in 2015. It builds on the research completed since 2010 using compatible methods and sample sites. It covers 2017, the third year of construction on Site C. This study has been developed in accordance with Condition 7 of the Environmental Assessment Certificate (EAC). It is a principled and through approach, and it calls for regular monitoring through to 2023 and MON-6 Site C Reservoir Fish Food Organisms Monitoring Program; MON-7 Peace River Fish Food Organisms Monitoring Program, and MON-17 Peace River Water Level Fluctuation Monitoring Program are covered in this report.

The transformation of the Site C reach of the Peace River to an approximately 50 m deep reservoir will create a new aquatic environment that is expected to support a community of equal or greater productivity than the existing riverine ecosystem. The Site C Clean Energy Project (the Project) will result in a loss of 29.6 km^2 of lotic habitat in the mainstem and the lower reaches of tributaries, and a gain of 9.4 km^2 of littoral habitat and 83.6 km^2 of pelagic habitat, resulting in a net gain of 63.4 km^2 of aquatic habitat. These expected changes could alter fish food communities within and downstream of the future Site C reservoir. Key management questions about the effects of construction and operation of the Project on food for fish were identified during the project approval process. Management questions focused on two critical aspects of fish forage that may result from anticipated habitat changes. The first suite of questions in Mon-6 and Mon-7 consider the area, density, and biomass of important fish food items pre- and post-flood of the Site C reservoir. The second suite of management questions consider the influence of operations (changes in magnitude and timing of flow) on food for fish in the reservoir and in downstream areas (Mon-17). To address these key management questions, a conceptual model of productivity was developed and will be subsequently used to create a spatial model to estimate productivity at a reach scale. Sampling in 2017 was the fourth year of data collection in British Columbia, and included two new, additional sites in Alberta. The 2017 sampling session focused on identifying how physical processes in reservoirs (Williston and Dinosaur reservoirs) and the Peace River can affect benthic productivity and subsequent availability of fish forage items.

In 2017, samples were collected in upstream Dinosaur and Williston reservoirs (control), and at twelve other sites from within the future Site C reservoir (PR/MD/HD sites) and downstream of the future Site C reservoir (PD sites). Sampling included key locations above and below tributaries (Halfway and Moberly rivers) that are within the future Site C reservoir. Sampling was undertaken using methods that built on previous study methods for periphyton (artificial Styrofoam substrate), phytoplankton (net hauls), zooplankton (net hauls), and benthic invertebrates (natural substrate sampling and artificial rock baskets). Physical data collection included water velocity, light, water temperature, sediment accumulation, water depth and water quality parameters including turbidity and TSS.

Data collected to date indicates that many factors influence both the structure and productivity of reservoir and riverine areas. Both Williston and Dinosaur reservoir phytoplankton samples showed very low productivity that were numerically dominated by pico-cyanobacteria with brief pulses of diatoms, flagellates and green algae. The depths of the reservoir photic zones were turbidity-driven, dynamic, and varied seasonally from 4 to 8 m in Williston Reservoir and from 2 to 10 m in Dinosaur Reservoir. Both reservoir pelagic areas were classified as ultra-oligotrophic using standard nutrient and productivity metrics. All measurements to date in Williston and Dinosaur reservoirs confirmed the importance of their littoral productivity.

The Peace River downstream of the Project is a bar/pool system where turbidity typically exceeds 5 to 10 NTU. Light data was collected using a handheld PAR meter, Secchi depths and light loggers; all of which indicated a photic zone of only 0.8 to 2.2 m under typical conditions. Numerical modelling of light data indicated that turbidity strongly influenced light penetration to the riverbed. During clear low flow periods, light penetration ranged between 2.8 to 4.5 m depth, whereas models indicate that in periods of high turbidity (100 NTU), light penetration ranges from 0.2 to 0.5 m depth and is less than 10% of the light at the water surface.

In riverine areas, submergence and water velocity were identified by statistical modelling as the most important factors affecting both periphyton and benthic invertebrate measures of productivity. Submergence of riverbed substrate was the most important factor determining productivity in areas partially exposed over the deployment period. Interestingly, modelling did not identify light as an important determinant of periphyton productivity. We expect this occurred because light penetration to the riverbed was limited by turbidity of >5 to 10 NTU for large portions of the deployment period. In situ periphyton production in the Peace River was therefore limited to narrow bands that were restricted by submergence at the upper boundary and by light penetration on the deep boundary. Modelling of the light data confirmed that light extinction increases quickly with small increases in turbidity between 0 and 25 NTU. The artificial substrate sampling transects covered areas from those regularly exposed to over 2 m depth, but our spacing of 0.5 to 1 m depth between samples may not capture the most active band of production during turbid flows. Data from 2017 indicated that a reasonable portion of productivity in the Peace River originates from settlement of upstream production or from recruitment from upstream reservoirs, acting to inflate productivity metrics in light-limited areas.

Periphyton community structures were mostly influenced by annual and seasonal variability, as each series (year/season combined) was distinct. Upstream reservoir communities were different and less productive than those in riverine areas. The main producers of chlorophyll-a in the Peace River were algae, while the contributions made by photosynthetic bacteria were small in the Site C reach and more important at the downstream PD sites. PR1 and PR2 showed the highest periphyton production of all sites in part due to reservoir recruitment and Didymo proliferation. Halfway and Moberly rivers showed much lower periphyton productivity compared to Peace River mainstem sites. Chlorophyll-a, abundance and biovolume were used to estimate the algal productivity in the Peace River. For periphyton, these metrics were modelled in response to the physical environment parameters that are known to be most closely correlated with algal productivity.

Like periphyton, benthic invertebrate community structure was mostly influenced by annual and seasonal variability. Upstream reservoir communities were distinct from those in riverine areas. The site in Dinosaur Reservoir had a similar percentage of Chironomidae as riverine sites. However, the percentage of EPT taxa was considerably lower in the reservoir (<25%) compared to riverine sites that were typically greater than 25% EPT. The percent Chironomidae was generally less than 20% in both the reservoir and the river. Percent Chironomidae and percent EPT did not demonstrate any trends among sampling years. When considering all years of data, percent Chironomidae in reservoir areas was greatest at shallow sites, but in riverine areas, no specific trends with depth were observed. Percent EPT in 2010 to 2017 appeared to increase from PR1 to PR2, and subsequently, the densities stabilized at downstream sites. Abundance or biomass were used to determine the spatial production of invertebrates, and their models explained the highest variation compared to other invertebrate metrics Velocity was identified as a key physical factor that influences invertebrate productivity. Finally, similar to periphyton, submergence should be considered in the spatial model.

Ephemeroptera, Plecoptera, Trichoptera, and Dipterans were important forage for fish, consisting of at least 75% of the taxa sampled from stomach contents in Arctic Grayling, Mountain Whitefish, and Rainbow Trout. Fish forage preference is difficult to determine because fish diets can be variable due to food availability, fish species, and habitat preferences. However, since EPT and Dipteran taxa are the dominant taxa in all fish samples, these taxa provide a reasonable index for understanding fish forage.

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APPENDICES

1.0 INTRODUCTION

The transformation of the Site C reach of the Peace River into an approximately 50 m deep reservoir will create a new aquatic environment that is expected to support a community of equal or greater productivity than the existing riverine ecosystem (BC Hydro 2013). These expectations are based on prior research in the upstream Williston and Dinosaur reservoirs. The Site C Clean Energy Project (the Project) will result in a loss of 29.6 km^2 of lotic habitat in the mainstem and the lower reaches of tributaries, a gain of 9.4 km^2 of littoral habitat, and a gain of 83.6 km^2 of pelagic habitat, for a net gain of 63.4 km^2 of aquatic habitat.

This study is year 3 of the Fisheries and Aquatic Habitat Monitoring and Follow-up Program (FAHMFP) that began in 2015. It builds on the research completed since 2010 using compatible methods and sample sites. It covers 2017, the third year of construction on Site C. This study has been developed in accordance with Condition 7 of the Environmental Assessment Certificate (EAC). It is a principled and thorough approach, and it calls for regular monitoring through to 2023 (BC Hydro 2015) and MON-6 Site C Reservoir Fish Food Organisms Monitoring Program, MON-7 Peace River Fish Food Organisms Monitoring Program, and MON-17 Peace River Water Level Fluctuation Monitoring Program are covered in this report.

In addition to the obvious altered hydraulic conditions, the major physical changes to aquatic habitats include increased habitat volume, altered water chemistry, a reduction in diversity of the types of habitat available for fish and aquatic organisms and changes to thermal regimes. With moderate alkalinity, neutral to slightly basic pH, and moderate metal concentrations in the Peace River, the bio-available nutrients and available light will be important drivers of productivity. The newly flooded reservoir will likely experience trophic upsurge tapering off through an estimated 10 years, followed by trophic depression. The daily range in Site C reservoir levels is expected to be 0.6 m with occasional fluctuations of >1.2 m. Littoral drawdown and turbidity from shoreline erosion will limit periphyton, aquatic macrophyte and benthic invertebrate productivity in portions of the reservoir and result in pelagic-based phytoplankton and profundal food webs dominated by Chironomids Oligochaetes and zooplankton. The Halfway River flows into the Site C reservoir approximately 46 km downstream of Peace Canyon Dam, while the smaller Moberly River flows into the Peace River less than 1 km upstream of the Project. These inflows can contribute higher concentrations of total phosphorus to the Peace River in summer, while all tributaries contribute total phosphorus during freshet and stormflows. Except for the shallow 20 km downstream of Peace Canyon Dam, the Site C reservoir is expected to develop a dimictic thermal structure, with maximum summer water temperatures of 16-21°C at the surface, while the bottom water temperatures would reach only 9-11°C. The outlet of the Site C reservoir will span depths between ~3 m and 21 m, blending warm and cool water during summer stratified conditions (BC Hydro 2013).

Post flood, a smaller daily temperature range is also expected in the Peace River downstream of the Project, where outflows will be warmer than existing conditions from July to January and cooler from March to June. Additionally, hydrologic changes downstream of the Project are expected to include lower suspended sediment loads and turbidity, moderation of flows, reduced bed material mobility, and because of these processes, a reduction in the active channel width of the Peace River. The minimum outflow requirement of the Project is 390 m^3/s, with maximum discharges occurring during daylight hours. The range of operational releases will increase from 1,699 m^3/s to ~2,130 m^3/s with the Project. This translates into an expected daily range of water levels predicted to increase from 0.5

to 1.0 m in the dam tailrace, increase from 0.4 to 0.8 m near Taylor BC, and increase from 0.5 to 0.9 m near the Alces River confluence (BC Hydro 2013).

Baseline monitoring for Mon-6, Mon-7 and Mon-17 was conducted in 2010 through 2012. Datasets from these years were combined with the dataset generated from 2017 and analysed for this report.

This report is organized into reservoir sites and river sites, rather than organizing by Mon-6 and Mon-7. Splitting the report up by reservoir and river prevented repetition since there are river sites in Mon-6 and reservoir recruitment are relevant to Mon-7. The Mon-17 section follows the reservoir and river sections. Finally, the following conceptual model of the factors affecting fish food organisms in the Peace River based upon expected physical and wetted habitat conditions helps elaborate on the questions and approaches taken in this document (Figure 1-1).

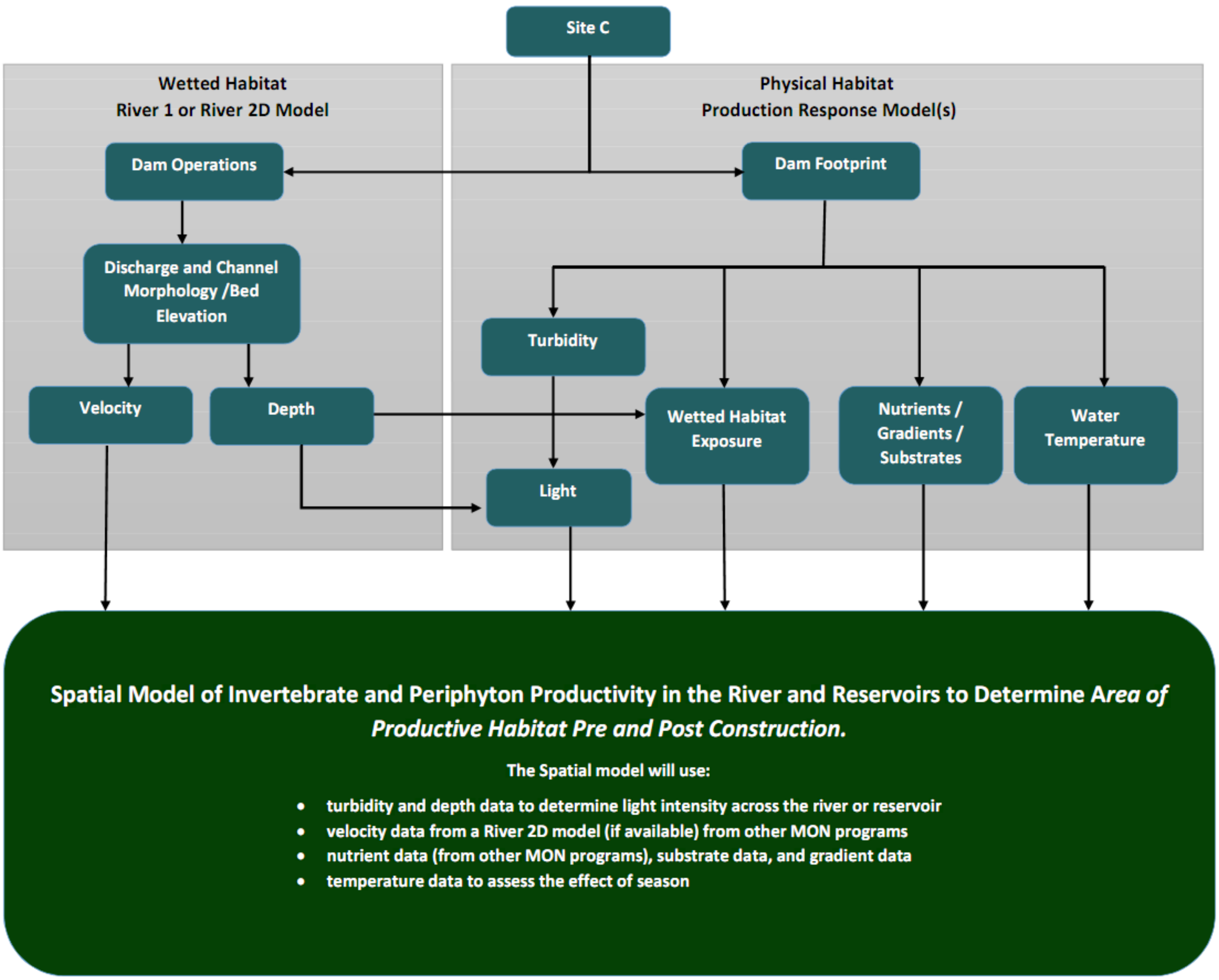

Figure 1-1: Conceptual model of fish food organism responses to habitat change associated with construction of Site C.

1.1 Mon-6 Management Questions

The purpose of the Mon-6 monitoring program is to understand and compare biomass and production of food for fish and the underlying processes that support benthos productivity in the Site C reach, pre- and post-flooding and to compare the Site C reach against reference sites in Williston and Dinosaur reservoirs in a BACI design. The Mon-6 management questions are as follows:

1) What is the change in areal biomass (mass/m^2) and reach-wide biomass (mass-km^2/yr) of fish food organisms in the Site C reach between years before and after construction of the Project?

2) What is the change in production of fish food organisms in the Site C reach between years before and after construction of the Project?

The following are the management hypotheses for Mon-6:

H_1: Reach-wide biomass of invertebrates in the Site C reach will be the same between years before and after reservoir formation.

H_2: The production of fish food organisms in the Site C reach will be the same between years before and after reservoir formation.

1.2 Mon-7 Management Questions

The purpose of the Mon-7 monitoring program is to investigate the effects of dam construction and operations on the biomass and production of invertebrates, including fish food organisms, downstream of the Project to Many Islands in Alberta where we have previously conducted a similar sampling program. The monitoring format for Mon-7 follows a reference design that was developed specifically for the Peace River during the regulatory process. The Mon-7 management questions are as follows:

1) What is the change in areal biomass of fish food organisms in the Peace River between years, before, during and after construction of the Project?

2) What is the change in production of fish food organisms in the Peace River between years before, during and after construction of the Project?

The following are the management hypotheses for Mon-7:

H_1: Reach-wide biomass of invertebrates in the Peace River between the Project and the Many Islands area in Alberta will remain the same over time before, during, and after the construction of the Project.

H_2: The production of fish food organisms in the Peace River between the Project and the Many Islands area in Alberta will remain the same over time before, during, and after the development of the Project.

1.3 Mon-17 Management Questions

This monitoring program investigates the effects of water level fluctuations on the catchability of Peace River fish and benthos biomass and production, from the Project to Many Islands in Alberta, by providing insights into the causal links between Project-related hydrological effects and the resultant changes in the trophic structure. Mon-7 will synthesize data from all relevant components of the Site C Fisheries and Aquatic Habitat Monitoring Follow-up Program (FAHMFP). This is made possible by consistent sample locations and methodologies. The Mon-17 management questions are as follows:

1) How do changes in the hydrologic regime affect estimates of catchability used in the Peace River Fish Community Monitoring Program (Mon-2)?

2) How do changes in the hydrological regime affect fish and fish habitat of the Peace River?

The following are the specific sub hypotheses to be addressed by this monitoring program:

H_2: Periphyton production among and within sites in the Peace River is independent of the magnitude and timing of flow fluctuations.

H_3: Biomass of invertebrates (benthos) among and within sites in the Peace River is independent of the magnitude and timing of flow fluctuations.

1.3.1 Conceptual Model

To address the hypotheses (Mon-17 H_2 and H_3), reach-scale estimates of periphyton and invertebrate production will be calculated from a hydrologic model and a spatial productivity model. Both models will be developed from field data collected as part of this program. This year has focused on understanding how growth occurs and what physical factors affect growth. Identifying relationships between the physical variables of water depth, light, turbidity, and water temperature with periphyton and invertebrate production is a focus of this report.

Once a calibrated hydrologic model is provided for the Site C and downstream reaches, a spatial model of productivity can be generated using this data. The hydrologic model will be a key component in addressing how timing and magnitude of flow peaking effect periphyton and benthic productivity. A key output of the hydrologic model is hourly water depths throughout areas of the river based on river bed morphometry and discharge. The hourly water depths of a location on the river can be used to determine the wetted history. Periphyton and invertebrate productivity are known to be strongly influenced by wetted history of flow-regulated systems (Schleppe et al. 2015).

The spatial productivity model will be developed once the hydrologic model is finalized and this model will build on spatial productivity models that have been previously developed for sections of the Lower and Middle Columbia River. The relationships between physical variables and productivity in the Site C and downstream reaches may be integrated into the spatial model, if feasible. Growth and death curves from the Lower Columbia will be adapted to better represent invertebrate and periphyton growth in the Peace River. Details about the proposed spatial model are presented in Appendix C.

2.0 METHODS

2.1 Study Area and Sampling Locations

The study area is in northeastern British Columbia on the Peace River, extending from the Williston Reservoir to immediately upstream of Many Islands, Alberta. There are several tributaries including the Moberly and Halfway rivers in the future reservoir footprint, and the Pine and Beatton rivers downstream of the future reservoir. The study area is divided into three general areas: 1) Upstream control reservoirs including Williston and Dinosaur reservoirs; 2) Site C reach from Peace Canyon Dam to the Project, and 3) Downstream of the Project to immediately upstream of Many Islands on the Peace River in Alberta. Table 2-1 and Table 2-2 provide the locations of the sites sampled in 2017 for Mon-6 and Mon-7 and Figure 2-1 provides a map of the general site locations. Detailed site maps are found in Appendix A.

Table 2-1: Mon-6 monitoring stations, sample types, UTM coordinates, and site description.

Site Name & Site Code	Pre Reservoir Sampling	Post Reservoir Sampling	UTM Coordinates (UTM 10)		Description
			Easting	Northing	
Williston (W1)	Pelagic	Pelagic	175783	6221552	Reference reservoir site
Dinosaur (D1)	Pelagic and Littoral	Pelagic and Littoral	187708	6214364	Reference reservoir site
Upper Site C Reservoir (PR1)	Lotic	Pelagic and Littoral	192170	6218363	Near the community of Hudson's Hope
Middle Site C Reservoir (PR2)	Lotic	Pelagic and Littoral	222732	6237370	Upstream of the Halfway River confluence
Lower Site C Reservoir (PR3)	Lotic	Pelagic and Littoral	255937	6236428	Upstream of the Moberly confluence
Halfway River Downstream (HD)	Lotic	Pelagic and Littoral	224666	6239272	After reservoir creation, this site will monitor water quality in the reservoir embayment created by the inundation of the Halfway River
Moberly River Downstream (MD)	Lotic	Pelagic and Littoral	256420	6235153	After reservoir creation, this site will monitor water quality in the reservoir embayment created by the inundation of the Moberly River

Table 2-2: Mon-7 Monitoring Stations, Sample Types, UTM Coordinates and Site Description.

Site Name & Site Code	Sampling Type	UTM Coordinates (UTM 10 and 11)		Description
		Easting	Northing	
Peace River Immediately Upstream of the Pine River (PD1)	Periphyton and Invertebrate Production	267672	6230284	Peace River upstream of the Pine River confluence
Peace River immediately upstream of the Beatton River (PD2)	Periphyton and Invertebrate Production	288776	6222437	Peace River upstream of Beatton River
Peace River immediately upstream of the Kiskatina River (PD3)	Benthic Drift	299341	6221976	Peace River upstream of the Kiskatina River
Peace River immediately upstream of the Pouce Coupe River (PD4)[1]	Benthic Drift	317989	6225175	Peace River upstream of the Pouce Coupe River[1].
Peace River at Many Islands (PD5)[1]	Benthic Drift	364653	6242006	Upstream of the Moberly confluence[1]

1. 2017 was the first year these sites were sampled; both sites are in UTM 11.

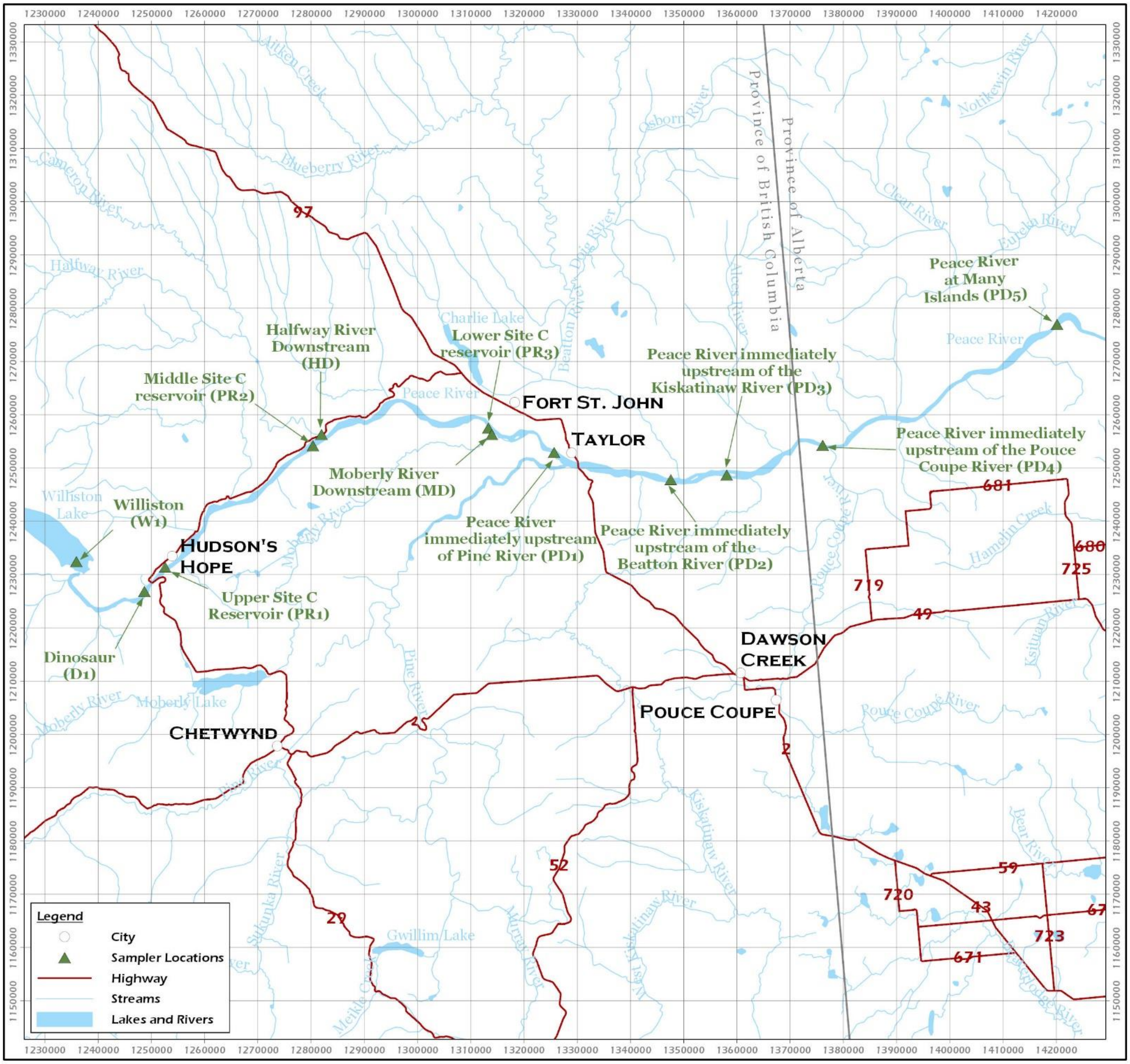

Figure 2-1: Map of the Peace River study area and sampling locations.

2.2 Site Level Water Elevation

River channel and bathymetric surveys were completed for each site. The upstream and downstream survey limits were set in the field to encompass the predetermined sampler placement and provide a detailed three-dimensional spatial understanding of the river channel.

The water surface profile, river banks, and bathymetric survey were completed using a real-time kinematic (RTK) survey instrument paired with a bathymetric sounder. Vertical and horizontal precisions were ± 0.02 m. This information was fundamental in understanding the relative position of each sampler in the river channel and their wetted depths over the deployment period (Appendix E).

With the primary setline anchored in place, the boat was positioned over the target sampler depth and the sampler was deployed. After deployment, the depth and location of each of the five samplers (along the setline) were surveyed using the RTK and sounder. A water level data logger (Onset® Hobo U20 (Bourne, MA, USA)) was securely fastened to the mid-depth sampler (permanently wetted - upper zone). The logger was configured to provide hourly water levels for the mid-depth sampler.

Hourly water depths were calculated from a combination of the bathymetric data, the hourly water levels at the mid-depth sampler, and the water depths recorded at deployment. Water levels at each site were plotted over the duration of the deployment period to understand how much water covered each sample over time. The average depth at each transect sample was also considered to understand the submergence pattern at each site.

2.3 Productivity Sampling Program Overview

Productivity sampling was carried out using a variety of different sampling methods for zooplankton, periphyton, and benthic invertebrates and detailed field methods for each of these techniques can be found in Appendix B. For zooplankton and phytoplankton, hauls were collected once each month from June through October in 2017 in the littoral and pelagic regions of Dinosaur Reservoir and the pelagic regions of Williston Reservoir.

Benthic invertebrate biomass was determined using artificial sampling substrates (rock baskets). Invertebrate samplers were placed at each of the sampling sites, with samplers in a transect that covered the different depths of the river (Table 2-3) or reservoir in the summer and fall field seasons (Figure 2-1, Table 2-1 and 2-2). Four samples from depositional areas in Dinosaur Reservoir (D1) and the Peace River Site C sites (PR1-PR3, HD, and MD) were collected using an Ekman dredge. Using both sampling techniques allowed comparison of the two predominant habitat types that will exist pre- and post-flooding of the reservoir.

Periphyton growth was measured using an artificial substrate (open-cell Styrofoam) deployed for 49 to 58 days in the Peace River and Dinosaur Reservoir in a transect with five samplers at different depths during two seasons (Figure 2-2, Table 2-1 and Table 2-2). Each periphyton artificial substrate was mounted with a HOBO Pendant temperature/light logger that continuously collected data every 30 min throughout each deployment session.

The periphyton and invertebrate artificial substrates were deployed across transects to sample different depths, from the upper varial zone to deeper river areas greater than 2 m (Table 2-3). At each site, the depth of the samplers was collected using a HOBO level logger placed on the middle sampler of the transect. The water depth at each artificial sampler in the transect was then determined using a bathymetric survey to estimate the depth of each sampler over the duration of deployment. A sediment trap was also deployed at each river site with a level logger sensor. Finally, continuous turbidity meters (YSI EXO5 w/ wiper (Yellowsprings, OH, USA)) were deployed at each downstream river site (PD1 through PD5). The continuous turbidity meter was set to record turbidity every hour.

Table 2-3: Naming Convention of Sampling Depths and Corresponding Depth Strata

Depth Label	Depth (alpha / numeric)	Depth Strata (m)	Periphyton (P) / Invertebrate Sample (B)
Upper Varial Zone	UV / (0)	0.3 - 0.8	P
Lower Varial Zone	LV / (1)	0.9 – 1.5	P / B
Permanent Wetted Upper Photic Zone	PW / (2)	1.3 – 1.8	P / B
Mid Photic Zone	PM / (3)	1.5 - 2.6	P / B
Deep Photic Zone	PD / (4)	2.0 – 4.8	P / B

The literature suggests that Ekman-grab samples (species-level taxonomy and 200 µm mesh sieves) sample different benthic invertebrate communities than rock baskets, likely due to large differences in substrate size between the baskets and surrounding natural substrates (Beak 1995). However, both types of samples were collected in parallel from selected sites to facilitate pre- and post flood comparison.

2.3.1 Artificial Sampling Design, Deployment, and Retrieval

In 2017, a single artificial sampler apparatus design was used for the summer and fall periods (Figure 2-2). The samplers were deployed from June 13 through August 9 during the summer and from August 9 to October 1 during the fall. Artificial substrates were placed at depths from 0 m (partially exposed at some flows; photo-inhibition can occur) to 2.8 – 4.8 m (beyond expected limit of the riverine photic zone).

After approximately seven to eight weeks of deployment, three periphyton Styrofoam punches were randomly collected from each sampler to assess the following metrics: 1) chlorophyll-a to give an estimate of only live autotrophic biomass; and 2) taxa and biovolume to give an accurate estimate of both live and dead cells. Styrofoam punches were placed in pre-labeled vials and stored on ice until further processing.

Benthic invertebrate baskets were retrieved following a similar protocol to the one described in Perrin and Chapman (2010). A 250 µm mesh net was placed beneath baskets while still in the water column to collect any invertebrates that could have been lost as baskets were lifted from the water. The net was inverted and any contents were rinsed into a labeled bucket with pre-filtered river water. The retrieved baskets were also placed in the labeled buckets until further field processing.

Upon completion of sampler retrievals from each site, individual rocks from each basket were scrubbed with a soft brush to release clinging invertebrates. Washed rocks were then rinsed in the sample water, prior to being placed back in the basket and stored for re-use. The contents from each bucket were then captured on a 250µm sieve, placed in pre-labeled containers and then fixed in an 80% ethanol solution. Detailed protocols on the retrieval and field processing of samples are available upon request.

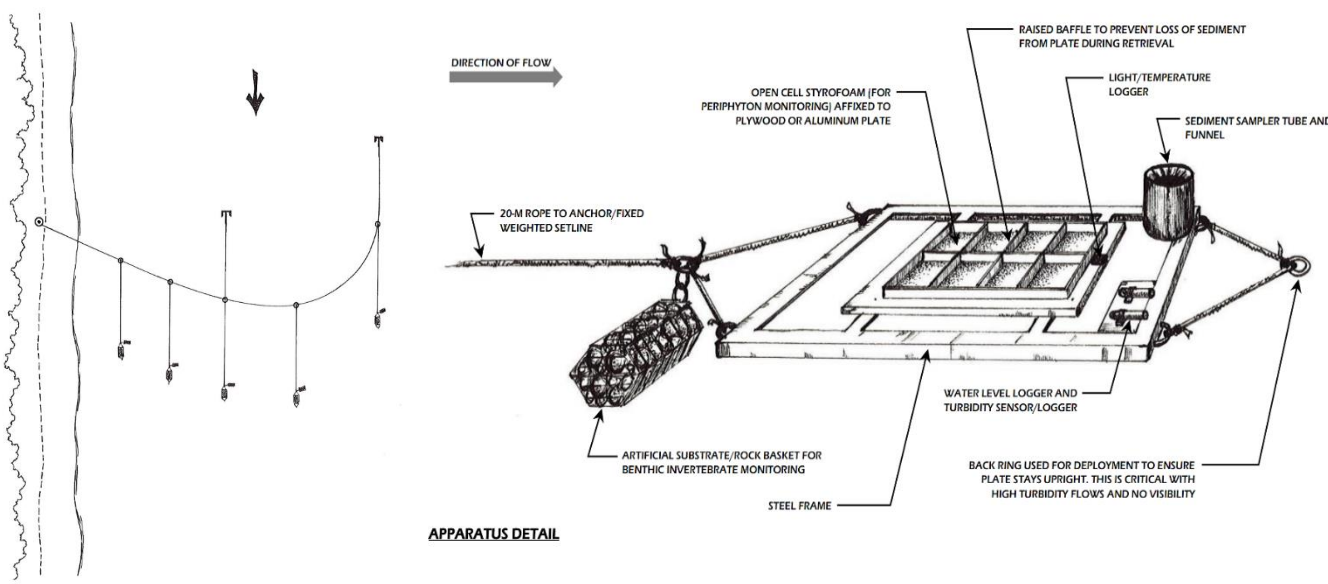

Figure 2-2: The typical deployment (left) of the sampling apparatus (right) used.

Sampler designed by Ecoscape and illustrated by K. Hawes of Ecoscape

2.3.2 Mon-6 and Mon-7 Sampling Program Summary

Table 2-4 summarizes the samplers deployed and retrieved for periphyton and benthic invertebrates to sample productivity in Mon-6 and Mon-7 study areas.

Table 2-4: Artificial Sampler Deployment and Recovery Rates in 2017.

Season	Program	Site	Periphyton Samplers	Invertebrate Basket Samplers	Invertebrate Ekman Samplers
			#Retrieved / #Deployed	#Retrieved / #Deployed	# Sampled
Summer (Jun. 13 - Aug. 08) 49-54 days	Mon-6	D1	5/5	5/5	5/5
		HD	2/4	5/5	4/4
		MD	2/4	5/5	4/4
		PR1	3/4	5/5	4/4
		PR2	4/4	5/5	4/4
		PR3	4/4	5/5	4/4
	Mon-7	PD1	4/4	5/5	0/0 (Not sampled)
		PD2	3/4	4/5	
		PD3	0/4	1/5	
		PD4	4/4	5/5	
		PD5	4/4	5/5	
Fall (Aug. 08 - Oct. 1) 52-58 days	Mon-6	D1	5/5	5/5	5/5
		HD	5/5	4/4	4/4
		MD	5/5	4/4	4/4
		PR1	4/5	4/4	4/4
		PR2	5/5	4/4	4/4
		PR3	5/5	4/4	4/4
	Mon-7	PD1	5/5	4/4	0/0 (Not sampled)
		PD2	4/5	3/4	
		PD3	5/5	4/4	
		PD4	5/5	4/4	
		PD5	5/5	4/4	

2.3.3 Periphyton and Invertebrate Post Processing

2.3.3.1 Periphyton Post Processing

Of the three Styrofoam punches obtained from each artificial substrate, one was frozen and transported to ALS Environmental in Fort St. John, BC for the processing of low-detection limit fluorometric chlorophyll-a (chl-a) analysis. The remaining two punches were used for taxonomic identification. Fresh, chilled punches were examined for protozoa and other microflora that cannot be reliably identified from preserved samples. Larratt Aquatic had previously tested Lugol's solution compared to freezing the Styrofoam and determined that freezing provided enhanced long-term viability. Therefore, one of the two punches was frozen and stored until taxonomic identification and biovolume measurements could be undertaken. Species cell density and total biovolume were recorded for each sample. A photographic archive was also compiled. Detailed protocols on periphyton laboratory processing are available from Larratt Aquatic.

2.3.3.2 Benthic Invertebrate Post Processing

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

2.3.3.3 Fish Stomach Contents Post Processing

Golder collected fish stomachs by gastric lavage from August 22, 2017-September 30, 2017. Fish stomach contents were collected from Arctic Grayling (*Thymallus arcticus*), Mountain Whitefish (*Prosopium williamsoni*), and Rainbow Trout (*Oncorhynchus mykiss*). Additional fish species were collected but were not included in subsequent analysis. Detailed methods are described in Golder (2009b). The samples were preserved in 10% formalin and transported to Cordillera Consulting in Summerland, BC. The methods described above were used for benthic invertebrate identification at the family level. However, only invertebrate abundance was calculated.

2.4 Statistical Procedures

All statistical analyses and the creation of most figures were conducted in R (Version 3.4.3, R Development Core Team 2017) or ArcGIS Desktop 10.4 (ESRI, 2016). Prior to carrying out statistical analyses, the data collected in 2017 were combined with datasets from previous years (2010-2012). Details related to specific data analysis tasks are provided below.

2.4.1 River and Reservoir Water Elevations

To understand the general hydraulic conditions at each site, plots of the water elevations, and the study period mean and standard deviation were created for May through October (Appendix C). The station (elevation) / site (our assessment) references are found in Table 2-5. Similarly, the elevation of both Williston and Dinosaur reservoirs were plotted with the 2017 data, and the study mean and standard deviation.

Table 2-5: River Elevation Stations Graphed on the Peace River

Gauge Identifier	River Station Name	Closest Reference Site
07FD010	Peace River above Alces River	PD3
07FD010	Peace River above Alces River	PD4
07FD010	Peace River above Alces River	PD5
07FA004	Peace River above Pine River	PD1
07FA006	Halfway River near Farrell Creek	HD
07FB008	Moberly River near Ft. St. John	MD
07FD002	Peace River near Taylor	PD2
07EF001	Peace River at Hudson Hope	PR1
07EF001	Peace River at Hudson Hope	PR2
07EF001	Peace River at Hudson Hope	PR3

2.4.2 River and Reservoir Water Levels

No specific statistics were performed on river and reservoir water levels. As mentioned above, the data from 2017 were visually compared to the mean and standard deviation of all study years to understand how flows may have affected productivity in the study area.

2.4.3 Physical Habitat Parameters

Exploratory analysis of production responses to predictors was completed for raw or log-transformed data using scatterplots for all response-predictor combinations. These plots were completed for summer and fall periods. The graphical representation of data was used as an initial assessment of the relationships between variables and gauge the applicability of potential explanatory variables prior to their inclusion in modelling of benthic invertebrate and periphyton community composition and productivity Table 2-6 provides a description of the explanatory variables that were considered for both periphyton and benthic invertebrate models.

Water and air temperature data obtained from the HOBO light/temperature loggers, and hourly water depths were used as the primary dataset to determine how long an artificial sampler was submerged. Submergence or exposure of a sample was determined by using a combination of hourly temperature differences greater than ± 0.75ºC, water depths of less than 0.1 m, and high light intensity.

The large suspended sediment load in the Peace River affects both water clarity and sedimentation rates. As sediment load in river water increases, the depth light penetrates decreases, with consequences for photosynthetic organisms. Light attenuates by a factor of four for every 5 m of depth in pure water. The depth of light penetration in the Peace River was considered using numerous metrics:

- 1% of incident light at water surface (standard limit for photosynthesis)
- PAR > 10 photons/m^2/sec
- Secchi depth x1.7
- Secchi depth $Z_{eu} \sim \sqrt{5\,Z_s}$ Where $\boldsymbol{Z_{eu}}$ = euphotic zone $\boldsymbol{Z_s}$ **=** Secchi depth in meters (Tilzer, 1988)

The Secchi depth is reached when the reflectance equals the intensity of light back-scattered from the water.

In contrast to Secchi depth, which is not sensitive to light wavelengths, the light loggers primarily measured the visible part of the light spectrum with wavelengths between 400 and 700 nm, which is also the photosynthetically available radiation (PAR) used by phytoplankton for photosynthesis. Metrics using these measurements were used to determine the photic zones.

Dynamics of the reservoir photic zone, water layers and light intensity were determined using logger lines, PAR meter (400-700 nm) and Tidbits (400-1000 nm). PAR helped define the depth of the photic zone and its lateral extent in the littoral zone, both of which are dynamic - expanding or contracting with changing turbidity and TSS. For example, light penetration of the Williston water column was very low in June during freshet, measuring only 122 photons/m^2/sec at 0.5m depth.

A broader sampling transect was employed in 2017 than in previous years to ensure that better sampling coverage of the photic zone occurred. Artificial substrates were placed at depths from 0 m (partially exposed at some flows; photo-inhibition can occur) to 2.8 – 4.8 m (beyond expected limit of the riverine photic zone).

Table 2-6: Explanatory Variables for both Periphyton and Benthic Invertebrates

Variable	Definition
Total Exposure Hours	Total time exposed (hrs) or time substrate is out of the water
Daily Average Exposure	The average number of hours spent out of the water each day
Maximum Cumulative Exposure Time	The longest period of continuous time the sampler was exposed.
Total Submergence Time	Total time spent submerged (hrs) in the water
Daily Average Submerged	The average number of hours spent submerged in water during each day
Average Light Intensity	The average daily light intensity over the duration of time deployed, regardless of submergence or exposure
Cumulative Light Intensity while submerged	Sum of the maximum observed light intensity each day over the duration of deployment while submerged
Average Daily Light Intensity while submerged	The average daily light intensity while submerged over the duration of deployment
Total Daytime Submergence	Total time (hrs) spent in the light and water
Total Submergence	Total time (hrs) spent in the water over the duration of deployment
Submergence Ratio	Total time submerged divided by duration of deployment
Mean Water Temperature While Submerged	Average temperature of the water the duration of deployment
Mean Water Temperature during exposure	Average temperature during periods when the sampler was exposed.
Water Velocity	The average velocity of two data points observed collected during either deployment, retrieval, or during sampler maintenance
Average turbidity over deployment	The average turbidity at submerged samplers over the duration of deployment.
Sediment Depositional Rate	The sediment depth measured in the sediment trap (cm/day)
Mean Depth over Deployment	The average depth (m) of the sampler over the duration of deployment

2.4.1 Light Availability

Light availability at the riverbed is expected to strongly influence periphyton productivity in the Peace River. To better understand the effect of light attenuation in the river, light intensity, turbidity and depth were all modelled using data from PD sites. Model parameters were estimated using Bayesian estimates that were produced using STAN (Carpenter et al. 2017). Refer to McElreath (2016) for additional information on Bayesian estimation.

Unless indicated otherwise, the Bayesian analyses used uninformative normal prior distributions (Kery and Schaub 2011, 36). The posterior distributions were estimated from 1500 Markov Chain Monte Carlo (MCMC) samples thinned from the second halves of three chains (Kery and Schaub 2011, 38–40). Model convergence was confirmed by ensuring that $\widehat{R} \leq 1.1$ (Kery and Schaub 2011, 40) and $\mathrm{ESS} \geq 150$ for each of the monitored parameters (Kery and Schaub 2011, 61). $\widehat{R}$ is the potential scale reduction factor and ESS is the effective sample size.

The parameters are summarized in terms of the point *estimate*, standard deviation (*sd*), the *z-score*, *lower* and *upper* 95% confidence limits (CLs) and the *p-value* (Kery and Schaub 2011, 37, 42). The estimate is the median (50th percentile) of the MCMC samples, the z-score is $\mathrm{sd/mean}$ and the 95% CLs are the 2.5th and 97.5th percentiles. A p-value of 0.05 indicates that the lower or upper 95% CL crossed zero.

Model adequacy was confirmed by examination of residual plots for the full model(s).

The results are displayed graphically by plotting the modeled relationships between variables and the response(s) with the remaining variables held constant. In general, continuous and discrete fixed variables were held constant at their mean and first level values, respectively, while random variables were held constant at their typical values (expected values of the underlying hyper distributions) (Kery and Schaub 2011, 77–82). When informative, the influence of variables is expressed in terms of the *effect size* (i.e., percent change in the response variable) with 95% confidence intervals (CLs, Bradford, Korman, and Higgins 2005).

Analyses were conducted using the custom code scripted in R (R Development Core Team 2017).

2.4.1.1 Light Attenuation Model

The attenuation of light with water depth has been well-studied (Julian, Doyle, and Stanley 2008). The following equation captures the relationship between the irradiance at the surface (E_s) and the irradiance at depth (E_d)

$$E_d = (E_s \cdot r)\exp(-K_d \cdot y)$$

where r is the reflection coefficient, K_d is the diffuse attenuation coefficient and y is the depth. The diffuse attenuation coefficient measures the exponential rate of decline of light levels with increasing depth

$$K_d = \log\left(\frac{E_s}{E_d}\right)/y$$

A K_d of 1 indicates that the light level decreases by 63% for every 1 m increase while a K_d of 2 indicates that the loss is 86% and a K_d of 3 indicates that the loss is 95%.

Following Davies-Colley and Nagels (2008), the diffuse attenuation coefficient was assumed to vary with turbidity (T), according to the following relationship

$$Kd = \exp(K_0 + K_T \cdot \log(T))$$

The above parameters were estimated from the surface light (E_s), light (E_d) at depth (y), and turbidity data (T) under the assumption that the residual variation in the hourly light at depth is log-normally distributed. The model accounted for autocorrelation by assuming that the expected light at depth at each individual site was randomly affected by the date.

2.4.1 Periphyton and Invertebrate Community Responses

Non-metric multidimensional scaling (NMDS) was used to explore variation in benthic and periphyton community composition at the genus and family levels. NMDS was first performed with 2010-2012 and 2017 data. Next, the NMDS analysis was conducted only at the genus level for the 2017 data. The Bray-Curtis dissimilarity index was used for both NMDS analyzes. This index is sensitive to the variation of species that have smaller abundances (Clarke and Warwick 1998). To visually explore differences in community compositions, the NMDS scores for every sample from all study years were plotted using the R package ggplot2 (Wickham 2009).

A permutational multivariate analysis of variance (PERMANOVA) was used to determine if there were significant differences in community compositions according to season/year, reach, depth (transect), site and reach. The amount of variability in community composition explained by each group, defined above, was determined by calculating the partial R^2 from a PERMANOVA. Both NMDS and PERMANOVAs do not make assumptions of the variable distributions and relationships (Anderson 2001; Clarke et al. 2006). The NMDS analysis and PERMANOVA used R package vegan (Oksanen et al. 2017). For both periphyton and invertebrates, the NMDS analysis was performed with rare taxa excluded. Rare taxa were defined as taxa that represented less than 5% of the total samples. To identify taxonomic differences between samples, taxa were related to the community differences by fitting them to the ordination plot as factors using Envfit (Oksanen et al. 2017). Only the taxa that were significant ($p<0.05$) and had R^2 greater than 0.1 were considered.

2.4.2 Periphyton and Invertebrate Productivity Responses

Response variables for periphyton and benthic invertebrates were calculated to describe production and community composition. These response variables along with mixed effects models were used to identify potential drivers of periphyton and benthic production in the Site C Reach and Downstream. The primary objective of these models is to better understand how physical factors (i.e. sediment deposition, velocity, flow fluctuations, light) affect benthic productivity including fish food organisms.

A subset of the physical variables described in Table 2-6 were used as explanatory variables for the invertebrate and periphyton production models because of success in similar models used for the Lower Columbia River, Middle Columbia River, and side channels of the Peace River. An indirect measure of water depth such as transect has been used as an explanatory variable in periphyton and benthic production models. However, this study was designed to explicitly measure water depth because of the importance of light availability due to the turbid waters of the Peace River (Schleppe et al. 2014). Samplers that have a moderate mean depth (0.5-1.0 m) over the deployment period are expected to be the most productive because these samplers receive adequate light and are submerged most of the time (Schleppe and Larratt, 2016). The mean water temperature over the deployment period is expected to be positively associated with invertebrate and periphyton production (Schleppe and Larratt, 2016).

Benthic and periphyton production are predicted to decrease with shorter submergence times. Frequent exposure of periphyton and invertebrate samplers results in the death of periphyton and a reduction in invertebrates, especially EPT taxa (Schleppe and Larratt, 2016; Kennedy et al. 2016). The periphyton and invertebrate community composition, measured by Simpson's Index, percent EPT, and good forage is also expected to change as a result of increased substrate dewatering. Samplers that are frequently dewatered are expected to have a less diverse community which have more tolerant taxa such as chironomids and diatoms (Hawes et al. 2014; Plewes et al. 2017).

The effect of velocity on invertebrate and periphyton production and community composition is dependent on the range of velocities in the study. Higher velocities cause a decrease in periphyton abundance and filamentous green taxa (Schleppe and Larratt, 2016). Moderate velocities provide ideal habitat for EPT taxa and as a result sites with higher velocities are often associated with higher invertebrate biomass and abundance (Schleppe et al. 2013; Hawes et al. 2014).

Depositional rate is expected to be negatively associated with periphyton and invertebrate production metrics (Schleppe et al. 2014). A shift in community composition is also expected in areas that experience high sediment deposition. Areas that experience high sediment deposition have an invertebrate community with more chironomids and less EPT. Periphyton communities with high rates of sediment deposition have more motile taxa such as Myxotrophic flagellated algae (Schleppe et al. 2014).

The response variables for periphyton and benthic invertebrates are described in Table 2-7 and Table 2-8. Response variables were log transformation to reduce heteroscedasticity and to further ensure that models met the assumption of normally distributed residuals, Cook's distance and residual plots were examined.

We used linear mixed-effects modeling (Zuur et al. 2009) and AICc model selection to evaluate the relative effects of the explanatory variables on each response variable. Methods described by Zuur et al. (2009) were employed to examine multi-collinearity among explanatory variables based on variance inflation factors (VIF) and correlation coefficients, avoiding inclusion of highly collinear variables (VIF > 5) together in descriptive models. We used the MuMln package in R (Barton 2012) to generate the model sets and rank them based on ΔAICc values and AICc weights (w_i), and to calculate multi-model averaged parameter estimates from 95% confidence sets for each response variable (Burnham and Anderson 2001; Grueber et al. 2011). Continuous explanatory variables were standardized by subtracting global means from each value (centering) and dividing by two times the SD (scaling), to compare among all parameters and interpret the main effects in conjunction with interaction terms (Gelman 2008; Schielzeth, 2010).We calculated relative variable importance (RVI), which is the sum of AICc weights from all models containing the variable of interest with variables having RVI values above 0.55 and confidence intervals that did not span zero.

Two different types of periphyton and benthic invertebrate models were run. Both types of models did not include any reservoir data. The first type of model included all 2017 samples. The second type of model included 2017 samples that were permanently submerged and had a submergence ratio of 0.95. For each response, Table 2-7 and Table 2-8 indicate the response variables considered. A detailed description of each explanatory variable is included in the methods (Table 2-6).

The explanatory variables in the full benthic invertebrate models included water velocity, total submergence time, mean water temperature while submerged, sediment depositional rate, and mean depth over deployment. The permanently submerged benthic invertebrate models included all the above explanatory variables except for total submergence time. Submergence ratio was included instead of total submergence time in the permanently submerged models. The number of plausible benthic invertebrate models (those with an AICc<3.0) ranged from 4 to 20 (Appendix O).

A suite of separate benthic invertebrate models were run on the benthic invertebrate Ekman samples for PR1-PR3, MD, and HD. These models included all 2017 sites and had the explanatory variables of water velocity, total submergence time, mean water temperature while submerged, sediment depositional rate, and mean depth over deployment. The number of plausible benthic invertebrate models (those with an AICc<3.0) ranged from six to seven (Appendix O).

The periphyton models excluded data collected from HD-4 and MD-0 from summer 2017 because the HD-4 plate was flipped and the MD-0 plate was exposed for ~99% of the summer deployment period. The explanatory variables in the full periphyton models included water velocity, total submergence time, mean water temperature while submerged, sediment depositional rate, and mean depth over deployment. The permanently submerged periphyton models included all of the above explanatory variables except for total submergence time. Submergence ratio and average light intensity were also included in the permanently submerged models. The number of plausible periphyton models (those with an AICc<3.0) ranged from 5 to 16 (Appendix N).

Table 2-7: Responses for Periphyton

Variable	Description
Total Abundance	Total Abundance across all species
Total Biovolume	Total Biovolume across all species
Chl-a	Total Chlorophyll-a
Simpsons Index	A measure of species richness that takes into account the abundance of each species
Percent Motile	The percentage of more motile taxa (resilient to deposition)*
Percent from Reservoir	The percentage of taxa that likely originated from upstream reservoir sources (imports)*
Percent Achnanthes	Percentage of *Achnanthes* spp. (resilient to scour)*
Species Richness	A count of the total number of unique species
Good Forage	An estimate of biomass considered to be good forage based upon a simple classification of periphyton taxa.

Table 2-8: Responses for Benthic Invertebrates

Variable	Description
Total Abundance	Total Abundance across all species
Total Biomass	Total Biomass across all species
Simpsons Index	A measure of species richness that takes into account the abundance of each species
Percent EPT	The percentage of Ephemeroptera, Plecoptera, and Trichoptera
Good Forage	Calculated by summing the biomasses of Ephemeroptera, Trichoptera and Plecoptera, and Dipteran species, all considered good fish forage

2.4.3 Ekman and Basket Benthic Invertebrate Comparison

The benthic invertebrate community compositions from Ekman and basket samples for Dinosaur Reservoir and the Site C reach were compared using NMDS at the genus level. The Bray-Curtis dissimilarity index was used for both NMDS analyses and rare taxa were excluded. The function Envfit was also used to help identify benthic invertebrate taxa that were more abundant in an Ekman or basket sampler.

Benthic invertebrate production (total biomass and abundance) was compared between samplers using an analysis of covariance (ANCOVA). An ANCOVA was used because depth of sampler was expected to be correlated to benthic invertebrate production. Mean depth over deployment was used as a covariate and both total biomass and abundance were log transformed. Residual plots were examined to ensure models met the assumptions of homoscedasticity, and models residuals were normally distributed.

2.4.4 Fish Stomach Contents

To better inform the testing of the availability of fish food organisms in the Peace River, stomach contents of fish sampled during the fish indexing program were analyzed. The relative abundances of consumed fish forage were plotted for Arctic Grayling, Mountain

Whitefish, and Rainbow Trout. Fish stomach content data was analyzed at the order level (i.e. EPT and D). Finally, NMDS at the family level was used to explore variation in benthic community composition in fish stomach contents collected from the Peace River. The same NMDS methods described in 2.4.1 were used for the fish stomach contents. A PERMANOVA was used to determine if there were significant differences in invertebrate community composition according to year, species, or site.

2.4.5 Zooplankton and Phytoplankton

Zooplankton and phytoplankton data for reservoirs were summarized according to dominant taxonomic group. Zooplankton densities were summarized and grouped by calanoid copepods, cyclopoid copepods, and Diplostraca, whereas phytoplankton biovolumes and abundances were summarized and grouped by cyanobacteria, diatoms, flagellates, dinoflagellates, and green algae.

2.5 Assumptions

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

The sampler frame was designed to trap deposited sediments so that we could sample the entire active, benthic substrate. We have assumed that sampler plates were not disproportionately affected by the retrieval and sample collection processes. It is possible that sampler plates retrieved from deeper areas may have experienced greater losses of sediment despite the baffle system, but this was not considered. Similarly, we have assumed that previous sampling years did not have disproportionately greater sediment loss than 2017 due to slight variations in sampler design or retrieval method.

The effects of foraging invertebrates were assumed to be randomly distributed over the artificial substrate within and among sites. We acknowledge that invertebrates may spend more time foraging along the edges of substrata and therefore disproportionately affect productivity along the perimeter of artificial samplers. Therefore, we avoided collecting samples from substrate edges unless no other viable alternative was available. Foraging intensity on Peace River samples is considered to be a small effect, reducing any potential data-skewing. Further, it is probable that invertebrate distributions around plates were clumped, reducing the potential for effects across multiple replicates.

Our analysis assumed that artificial substrates did not bias results toward a given algal taxa nor did they bias towards those taxa actively immigrating at the time and location of the sampler submergence. Although we made this assumption, the data suggests that artificial substrate types and natural substrates do respond differently (Schleppe et al, 2011). Future consideration may be required to accurately relate artificial samplers to natural substrates and determine if artificial substrates are indicative of actual riverine conditions, noting that currently a direct comparison is not feasible.

Sampler assessments were not intended to address immigration, sloughing, or any other temporal aspect of the periphyton or invertebrate community. For invertebrate analyses, this means we have not considered emigration or immigration from within or between sites and that specific operational patterns have not unduly affected any one community by changing densities of invertebrates. Artificial substrate samples that were obviously biased due to sloughing from rock flipping, etc. were excluded from collection. In cases where periphyton artificial substrates were damaged, but sufficient material was available for a sample, it was collected and treated the same as other samples. For invertebrates, damaged samplers were not analyzed as they were considered biased due to loss of rock within the basket. These field decisions were easy to make because large boulders rolling over artificial substrates, or those dragged upside down, left distinct trails of compressed Styrofoam or because sampling baskets were broken open. These field decisions reduced the available sample area, but we do not suspect that it biased the results. We acknowledge that substrate mobility and periphyton sloughing/drift and invertebrate drift are important components of periphyton and invertebrate production in the Peace River.

3.0 RESULTS

3.1 River and Reservoir Water Elevations

In 2017, the water elevation on the Peace River at Hudson's Hope (PR1, PR2 & PR3) within the Site C reach appeared lower and less variable than previous years of study, except for some notable peak flows. Moberly River flows peaked earlier and higher (>100 m^3/s) in 2017 compared to previous study years (Figure A19). Downstream of the Project, the Peace River (PD1 through PD5) water elevations were within the observable ranges occurring over the study period. In the Halfway River, flows peaked significantly higher in 2017 than in previous study years.

Water elevations in Dinosaur Reservoir were consistent with previous study years, ranging between 501.5 and 502.5 masl. Water elevations in Williston Reservoir were lower in May, when they were around 661 masl, peaking to 670 masl in August, declining to lower than average levels in November at 668 masl.

3.2 Physical Habitat Parameters of the Reservoirs

3.2.1 Physical Parameters

Williston Reservoir multimeter profiles and thermistor data from 2017 identified the thermocline at 10 m depth on July 14, 15 m on August 4 and >20 m on September 6. The mid-summer peak surface water temperature was 17°C on August 4 and the average epilimnion temperature was 15.2°C. These results are consistent with measurements collected in earlier studies on the Peace River system.

In contrast, thermocline development was limited in Dinosaur Reservoir by its rapid water exchange rates resulting in a retention time of only 5 days. Multimeter profiles and the thermistor data showed that <2°C separated the temperatures of the surface and bottom water for most of summer 2017. However, a shallow, transient thermocline was detected at 3-4 m on June 30/July 1 during hot weather. No other thermal layering was observed in 2017. Surface water temperatures reached 16.6°C and averaged just 12.4°C in the upper 10 m of the water column in summer 2017.

When all the data from Williston Reservoir PAR profiles and light loggers were assembled, the estimates of photic zone depth varied seasonally. Using 10 photons/m^2/sec as the minimum threshold for light required for most algae (Sigee, 2005), the photic zone in freshet was a very narrow 1.5 m in Dinosaur Reservoir, and a more typical 4.5 – 7.5 m in Williston Reservoir. The photic zones of both reservoirs expanded over the summer before tapering off again in October (Appendix I). The average thickness of the photic zone in Williston Reservoir during the 2017 growing season was 6.1 m with a range from 3.6 to 8.5m. The depth of the Dinosaur Reservoir photic zone was wider. It varied seasonally from 1.5 to 10 m. The average extent of the photic zone in Dinosaur Reservoir during the 2017 growing season was 7.3 m in the pelagic zone.

In these narrow littoral zones of Dinosaur Reservoir, the 2017 photic zone average estimate of 6.3 m suggests that 6 m defines the littoral zone, based on light available to support primary production, and agrees with the largest range of previous estimates.

Reservoir trophic status is always evaluated based on a range of factors (Table 3-1). Using the available metrics, both Williston and Dinosaur reservoirs were intermediate between oligotrophic (nutrient poor) and ultra-oligotrophic, as they were in earlier studies.

Table 3-1: Reservoir / Lake Classification by Trophic Status

Trophic Status	chlorophyll-a ug/L chl-a	Total phosphorus ug/L as P	Total Nitrogen ug/L as N	Secchi disc m	Primary production mg Carbon/m^2/day	TSI Index
Ultra-oligotrophic	<0.95	<4	< 75	>10	> 50	<30
Oligotrophic (low nutrients)	1 – 2	4 – 10	<100	6 -12	50 - 300	30 - 40
Mesotrophic (moderate)	2 – 5	10 – 20	100 – 500	3 – 6	250 – 1 000	40 - 50
Meso-eutrophic	5 - 7	20 - 35	500 - 900	2 - 3		50 - 60
Eutrophic (high nutrients)	7 - 25	35 - 100	900-1500	1 - 2.5	>1 000	60 - 70
Hyper-eutrophic	>25	>100	>1500	<1		70 - 80+
Williston Res. P	0.81	6.2 - 7.4	57 - 62	too turbid	10 - 347	
Dinosaur Res. P	0.63	5.7 - 5.9	208 - 262	too turbid		
Dinosaur Res. L	0.59	n/a	n/a	too turbid		

Stockner et al 2001; Harris et al 2005; Golder 2009a
(after Ashley 1983, Carlson 1983, Wetzel 2001, Carlson and Simpson 1996,Vollenweider and Kerekes, 1982, Kasprzac et al. 2008)

3.2.1 Reservoir Primary Productivity

Williston Reservoir monthly integrated photic zone samples from the pelagic zone during the 2017 growing season confirmed earlier results that Williston Reservoir has very low phytoplankton productivity (Harris et al. 2005; Stockner et al. 2005) consisting of:

- very low densities of typical reservoir diatoms (e.g., *Asterionella, Tabellaria, Fragilaria*) with dominance in June 2017 samples
- modest densities pico-cyanobacterial (*Synechocystis/Synechococcus, Anacystis*); and
- modest densities of flagellated phytoplankton that feed on picoplankton (e.g., *Dinobryon, Ceratium*, and the microflagellates *Cryptomonas, Chroomonas*) with an increase in October 2017 samples

Most of these phytoplankton taxa were also prevalent in Dinosaur Reservoir, in part from recruitment from Willison Reservoir (Stockner et al 2005). Dinosaur Reservoir's low nutrient concentrations and a hydraulic residence time of less than five days limits development of pelagic plankton biomass to very low but consistent phytoplankton production. Dinosaur phytoplankton was dominated by pico-cyanobacteria and photosynthetic bacteria, together with the flagellated taxa that forage them. This confirms earlier studies that found extremely low productivity that was driven largely by inputs from Williston Reservoir (Euchner, 2011; Golder 2009a).

One of the main reasons that littoral zones are critical to lake eco-functions is the periphyton development on shallow substrates. Littoral zone phytoplankton samples from Dinosaur Reservoir during 2017 captured this influence:

- very low densities of planktonic (e.g., *Fragilaria crotonensis, Aulacoseira*) as well as taxa that can be planktonic or periphyton (e.g., *Cyclotella, Synedra, Tabellaria*) that were likely torn off shoreline substrates by waves
- modest densities of cyanobacterial (*Synechocystis/Synechococcus, Anacystis* and periphyton *Lyngbya*)
- low densities of picoflagellates and low densities of large bacterivorous algae (e.g., *Dinobryon, Ceratium*); and
- high bacterial densities and a brief pulse in green algae densities (e.g., *Chlorella*) in August samples

Phytoplankton abundance among the 2017 growing season pelagic samples averaged 4282 cells/mL and 4160 cells/mL in Williston and Dinosaur reservoirs, respectively. Abundance at the D1 littoral site was similar at 4640 cells/mL, however it had significantly more biovolume than the pelagic sites at 0.43 x106 $\mu m^3/L$ versus 0.18 x106 $\mu m^3/L$ and 0.24 x106 $\mu m^3/L$ for Williston and Dinosaur reservoir pelagic samples.

The littoral samples collected during the growing season from Dinosaur Reservoir measure standing crop. The estimated turnover time for temperate littoral periphyton ranges from 10 to 20 days to replace the standing crop (Wetzel 2001).

Dinosaur Reservoir periphyton shared many dominant taxa with periphyton from Williston Reservoir. As expected, both periphytic communities were dominated by diatoms and micro-flagellates, and were subject to dominance shifts over the growing season in response to drawdowns and environmental conditions. Species richness was 10-32 taxa in D1 periphyton, very similar to earlier estimates (Golder 2009a). Simpson's index showed the community was diverse, with a mean of 0.81 – an identical value to the periphyton from riverine Site C reach and downstream sites (PR PD).

Although the reservoir littoral region was more productive and more diverse than the corresponding pelagic samples, the upper varial zone is subject to draw-downs. In 2017, this affected elevations spanning 500.0 masl to 502.8 masl during the 2017 deployment period. Drawdowns can dislodge periphyton and cause it to temporarily join the phytoplankton as the zone affected by waves shifts up and down the varial zone. The littoral photic vertical extent was 4-6 m, corresponding to a littoral area of ≈2.56 km^2 in Dinosaur Reservoir.

Dinosaur Reservoir periphyton biomass estimates were all substantially lower than the downstream riverine reaches (chlorophyll-a was 3-fold lower, abundance was 2.5-fold lower and biovolume was 3- to 4-fold lower) (Appendix I). Full estimates of areal biomass production will be calculated following the collection of data in 2018.

3.3 Physical Habitat Parameters of the Peace River

3.3.1 Depth

At each site, sampler elevations ranged from the upper varial zone (in the UV or transect position 0, partially exposed) to 3 to 5 m deep (DP or deep photic zone) (Appendix E). Samplers at position 0 were exposed most frequently, but still generally within the water / wetted areas, and the total time spent submerged varied depending upon site. The frequency of wetting was determined on an hourly basis for each sampler. Wetting frequency was variable, and depended upon site, flows, and season. Depths at each sampler plate increased by approximately 0.5 m with each position in the transect. Thus, at lower varial or position 1, samplers were positioned between 0.8 and 1.5 m, however depth varied over time depending on flows. Sampler depths were generally consistent with the target depths presented in Table 2-3.

3.3.2 Light

Light conditions at submerged sites on the Peace River were typical for a turbid river system, where suspended solids scatter and absorb sunlight. Throughout the Peace River, turbidity commonly exceeds 5-10 NTU, levels where primary productivity can be constrained by available light that is highly attenuated even at shallow depths. For example, at the PD sites, there was only approximately six weeks in the fall 2017 that had a lower turbidity than this threshold (Figure 3-2). Sites PR1 and PR2 in the future Site C reservoir, located immediately downstream of Dinosaur Reservoir, generally had higher light intensities due to lower turbidity than downstream areas at similar depths. Numerous spikes in turbidity were observed in downstream PD sites, commensurate with light attenuation at these sites during these periods. Throughout the Peace River, light decreased with increasing depth as expected, as did the variability of light intensity. Light intensities were markedly higher during substrate exposure, usually occurring in upper varial zones at transects 0 and 1. A summary of the average light conditions over a 24-hour day is presented in Appendix F.

Broader sampling transects were employed to span the full photosynthetically active zone in 2017 than in previous years, and this affects data comparisons with earlier years. For the turbid Peace River, the light loggers indicate a photic zone of only 0.8 to 2.2 m in highly depositional areas (e.g., PD2 & PR3) and 1.0 to 5.0 m in clear water areas and seasons (e.g., PR1 & PD5). The turbid mainstem results are similar to those observed in Peace River side-channels.

Light intensities in shallow water can exceed algal tolerances and cause photo-inhibition (Wetzel, 2001; Sigee 2005). This is universal in rivers with low turbidity, and 2017 data indicate that it may occur at times in the turbid Peace River. For example, light intensity was high enough to inhibit diatom growth at many “UV0” sampler positions and at the deeper “LV1” samplers at PD1 and PR1 in summer 2017. Some of this expected photo-inhibition may have occurred during sampler dewatering.

3.3.2.1 Light Modelling in Peace River

The diffuse light attenuation coefficient increased with increasing turbidity, meaning that light penetration to the riverbed is reduced as turbidity increases. At low turbidity (1 FNU) the attenuation coefficient was 0.31 (95% CL: 0.11 to 0.49) but increased to approximately 5 at 100 FNU. The light attenuation coefficient rapidly increased at low turbidities under 25 FNU, where the rate of increase with turbidity was less. Preliminary analyses suggest that only

19% of the light (95% CL: 13-27%) penetrated the surface at 1 FNU. The reflection coefficient of 0.18 is unrealistically low (Julian et al. 2008) and suggests that specific data collection is needed to determine this parameter with more accuracy.

The preliminary analysis of the light data suggests that light penetration to bed of the Peace River does not occur to any great extent beyond 2 to 2.5 m during periods of low turbidity and is dramatically reduced as turbidity increases because of the light attenuation occurs very rapidly from 0 to 25 FNU because the light attenuation coefficient increases rapidly in this turbidity range (Figure 3-1). This suggests that in situ productivity in the Peace River is limited to a very narrow band on the perimeter of the river, where light penetration is sufficient to allow growth to occur.

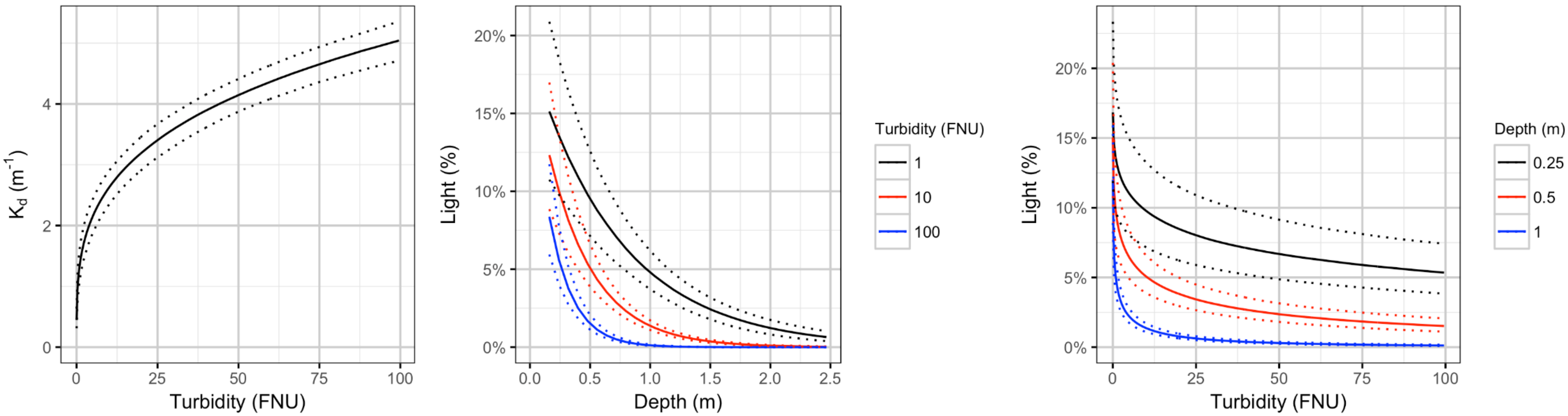

Figure 3-1: **The left figure shows the relationship between the diffuse light attenuation coefficient and the turbidity. The middle figure shows the relationship between the light attenuation and the depth at 1 FNU. The right figure identifies the relationship between the light attenuation at 0.2 m and the turbidity. Dotted lines represented 95% Confidence Limits (CLs).**

3.3.3 Turbidity

Turbidity at each downstream site in the Peace River was normally less than 100 FNU (Figure 3-2). Spikes in turbidity were observed at several sites, with the daily mean turbidity spikes ranging from 100 to 200 FNU. There were some instantaneous spikes observed that were greater than 500 FNU (PD2-2, Figure 3-2), and the magnitude of these spikes decreased as distance downstream increased, suggesting a localized effect that was reduced following mixing within the channel.

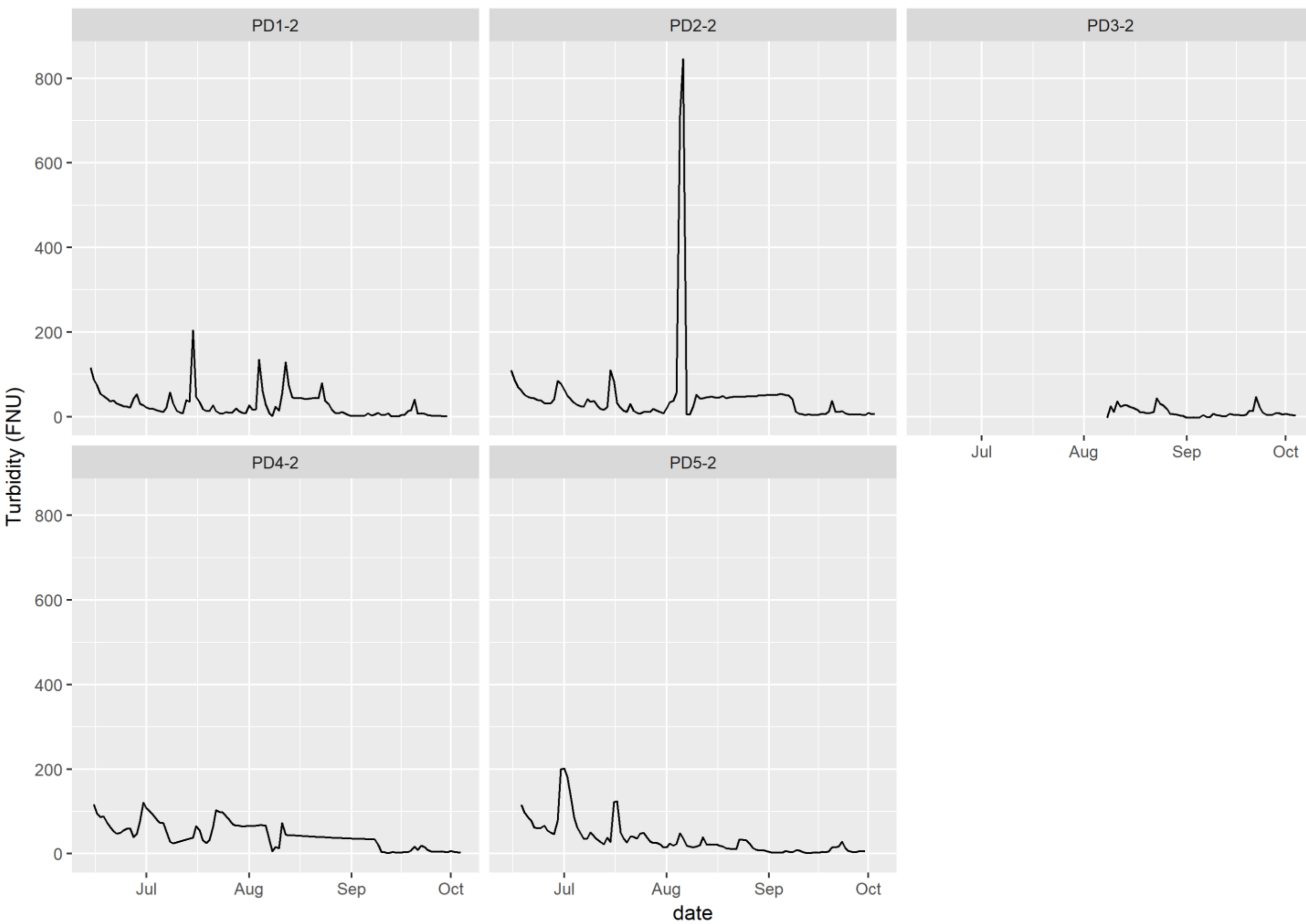

Figure 3-2: Average daily turbidity (FNU) at each downstream site in the Peace River over the duration of deployment.

3.3.4 Temperature

The temperatures at each Peace River site ranged from 10 or 11 ºC in June to a peak near 15 to 17 ºC in August, before declining to 11 or 12 ºC in October. Temperatures did not vary by transect, except during cases of exposure, but there was more observable variation among sites. Factors such as tributary inflow were important determinants of site-specific temperatures. The warmest sites were downstream sites PD4 and PD5, while the coolest were immediately downstream of Dinosaur (PR1 and PR2). A summary of mean daily temperatures is found in Appendix H.

3.4 Periphyton and Invertebrate Community Responses

3.4.1 Periphyton

The periphyton community structure was most similar within a given year and season (genus level: R^2= 0.32, F = 21.9. p < 0.01), with each year/season being unique. Community ordination plots, at both the genus and family level (R^2= 0.31, F = 20.7, p < 0.01), indicated that this seasonal variation is likely the most important determinant of the overall community structure (Figure 3-3). Since similar trends were observed at both the genus and family level, it is most likely that this trend exists despite different taxonomists between years. Other factors such as reach (R^2 = 0.03, F = 4.26. p <0.01) or site (R^2 = 0.14, F = 3.6. p <0.01) explained some of the variation, where the Dinosaur Reservoir community was distinctly different from those of downstream sites. Site level effects were observed because there were progressive shifts in the proportions of the dominant periphyton taxa. For example, the diatoms *Frustulia* and *Navicula* were less dominant at PD4 and PD5 than upstream sites in the summer, while in the fall, the large *Ceratium hirudinell*a numbers declined but the densities of diatoms *Synedra, Gyrosigma, Amphipleura, Cymbella* and *Navicula* all increased at PD5 (Figure 3-3).

Many river taxa were also found in Williston and Dinosaur reservoirs, confirming that reservoir recruitment is an important source of algal organic material to the Peace River. Halfway (HD) and Moberley (MD) samples were taxonomically distinct from the Peace River (PR) sites, partially explaining the effect of site on community ordination. Their samples contained proportionately more microflagellates than the mainstem sites, and a different suite of dominant diatoms including *Epithemia*, *Rhopalodia* and *Gomphonema*. The cyanobacteria *Synechocystis* was only prevalent in Fall samples, although high turbidity during freshet samples may have obscured its presence. The diatom *Cocconeis* was also correlated with MDS1 and was more abundant in the fall samples (MDS1 loading = -0.42, R^2 = 0.22).

A more transitional upper varial zone site (transect 0) was added in 2017. With this site added, depth increased in importance but was still not a strong factor affecting the periphyton community in mid elevation areas (2 through 4) (R^2 = 0.02, F = 2.4, p = 0.01).

At the mainstem PR sites, diatoms contributing the greatest biovolume included *Didymosphenia geminata* (Didymo), and representatives of common genera*, Synedra, Diatoma, Nitzschia* and *Achnanthidium*. Didymo was absent in the inflow tributary samples but was present in the Peace River in all studied years, in variable amounts. Didymo was prevalent in summer 2010, 2012 and 2017 sessions, often accounting for >20% of total diatom biovolume at PR1, PR2 and PR3. In the low flow fall 2017 session, Didymo accounted for 54% of PR1 biovolume and 28% of PR2 biovolume. It also inflated chlorophyll-a (chl-a) estimates where it occurred in dense mats.

Other "ecosystem engineering" taxa included the colonial cyanophyte *Aphanothece* that forms rubbery films and rarely, colonial cryptophyte *Hydrurus foetidus.* Didymo was the dominant biovolume contributor at all PD sites in both summer and fall 2010 sample sessions (Appendix I). Didymo was detected again in most 2017 PD samples, but at lower densities than 2010.

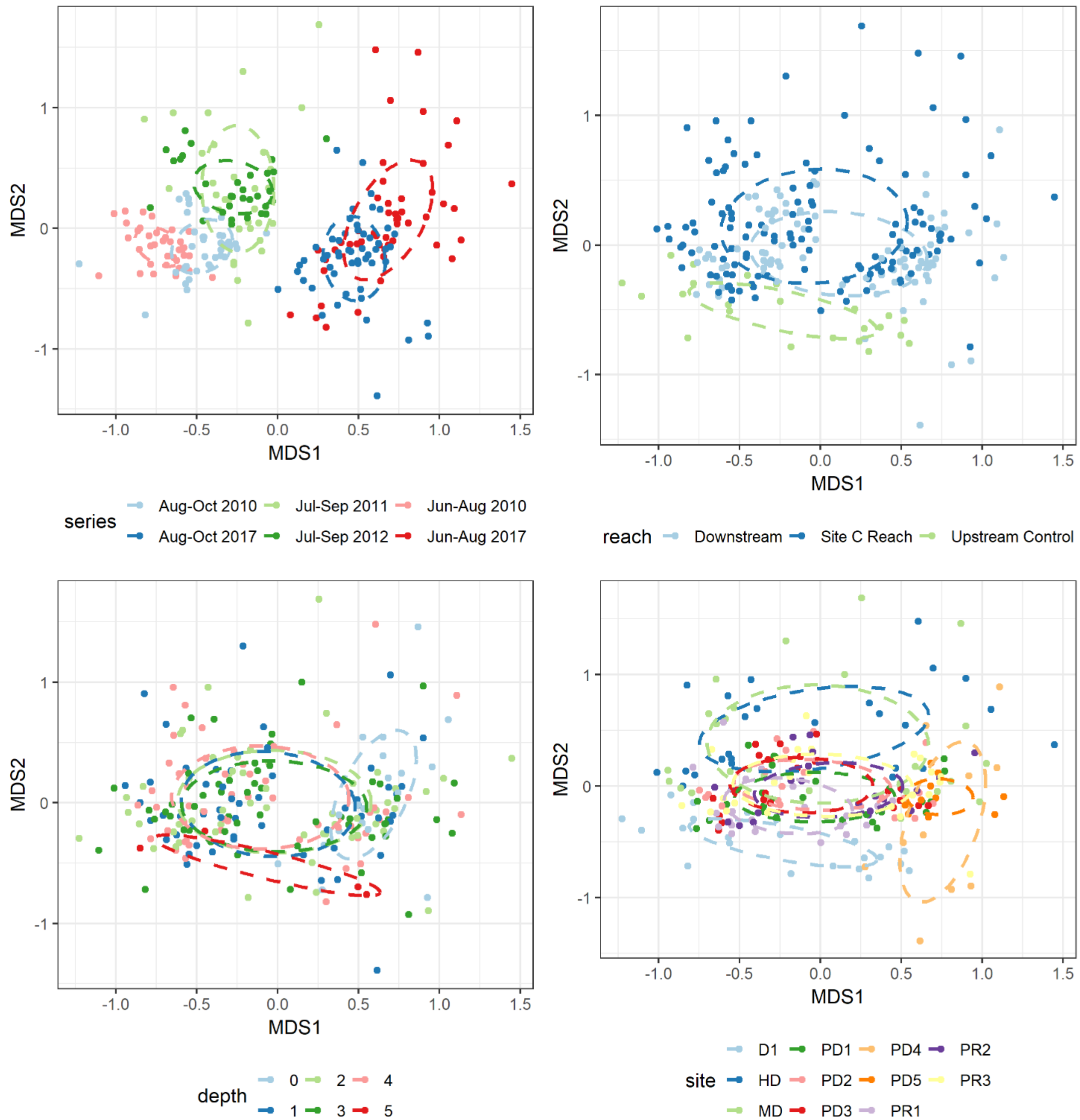

Figure 3-3: **NMDS of periphyton abundance at the genus level, grouped by sampling period (year/season), by general location (Site C Reach, Upstream Control, Downstream), by depth (transect position 0 (shallow) through 5 (deep), and by site for 2010 through 2017 data. Stress index was 0.22.**

3.4.2 Invertebrates

3.4.2.1 Ekman Samples

A distinct difference in community structure was expected between Ekman and invertebrate basket samplers, and differences were observed (Figure 3-4). In general, the community sampled using the Ekman resulted in a higher predominance of the bloodworm *Stictochironomus*, when compared with the basket samplers, which had a greater predominance of Heptageniidae (E) and Hydropsychidae (T) (method, $R^2 = 0.08$, $F = 8.05$, $p < 0.01$). There was a difference noted between sites, where samples collected from Dinosaur Reservoir were distinctly different from those sampled in riverine areas (site, $R^2 = 0.17$, $F = 3.65$, $p < 0.01$). Some distinction between the summer and fall sampling periods was observed, but it explained very little community variation (series, $R^2 = 0.02$, $F = 1.88$, $p = 0.023$). This suggests that each sampling method samples different communities, and consideration of data in this sense will allow comparison of pre- and post-flood invertebrate community types that transition from a riverine community to a reservoir community.

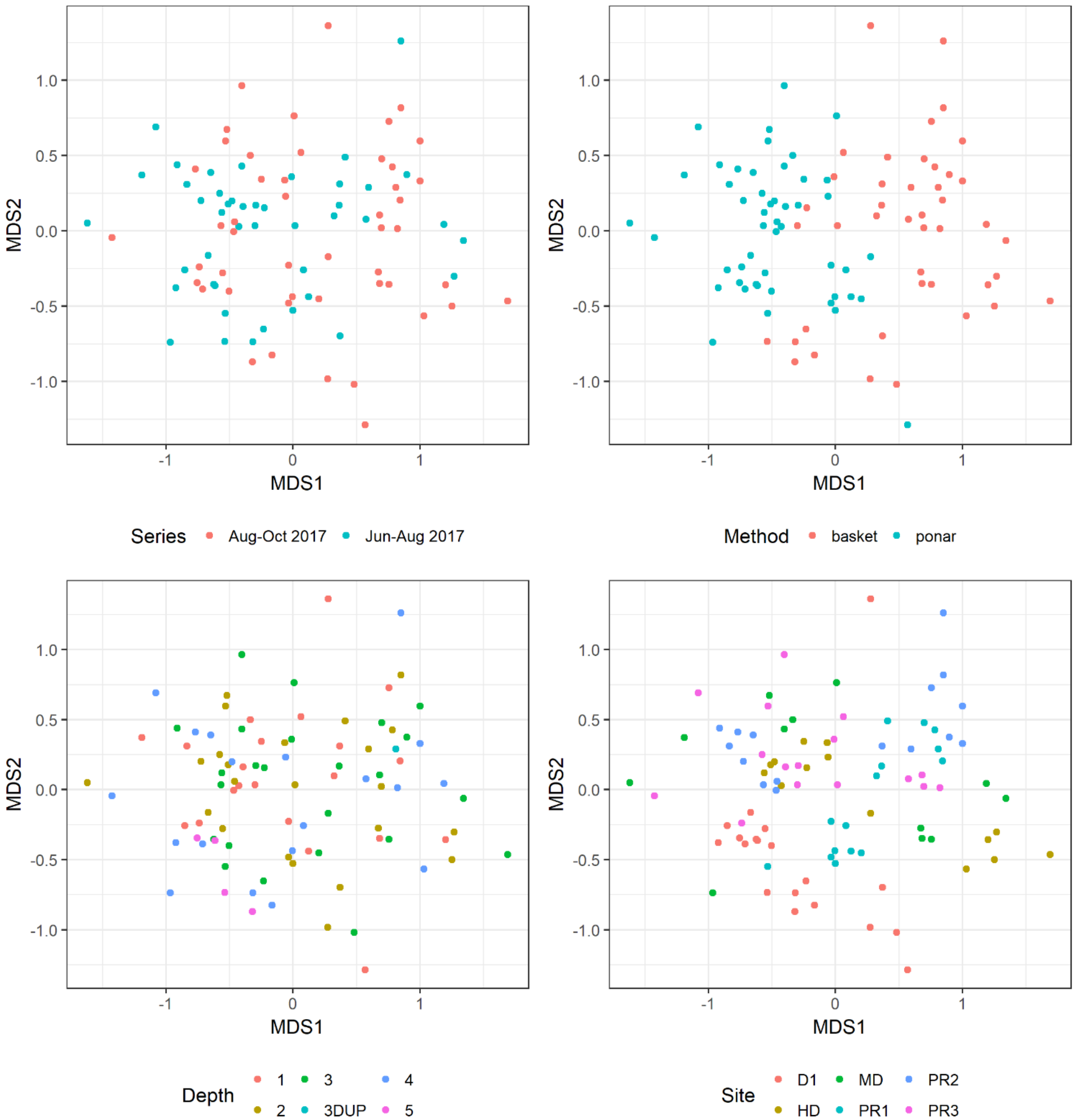

Figure 3-4: **NMDS of invertebrate abundance at the genus level, grouped by sampling period (year/season), by method (Ekman or Basket), Depth, and Site for 2017data. Stress index was 0.19.**

3.4.2.2 Rock Basket Samples

The invertebrate community structure varied most with the annual seasonal pattern of sampling (series, $R^2 = 0.18$, $F = 8.34$, $p < 0.01$). The invertebrate community at the rock basket sample sites were most similar within the reservoir and within riverine sites ($R^2 = 0.05$, $F = 5.43$, $p < 0.01$). At the genus level, the mayfly *Rithrogena* of the family Heptageniidae were important determinants of community structure. The effects of sampling series (season/year) and location (reservoir or river) were generally consistent at the genus (or lowest taxa) and the Family level, again suggesting that both trends exist independent of different taxonomists between years (Figure 3-5). At the Family level, members of the EPT taxa including Capniidae (P), Heptagenidae (E), Hydropsychidae (T) were important taxa in the NMDS. When considering only 2017 data with its additional transect locations, site ($R^2 = 0.25$, $F = 3.01$, $p < 0.01$) was the most important determinant, but both season (summer / fall) ($R^2 = 0.09$, $F = 9.8$, $p < 0.01$) and reach explained some of the similarity between samples ($R^2 = 0.08$, $F = 4.15$, $p < 0.01$).

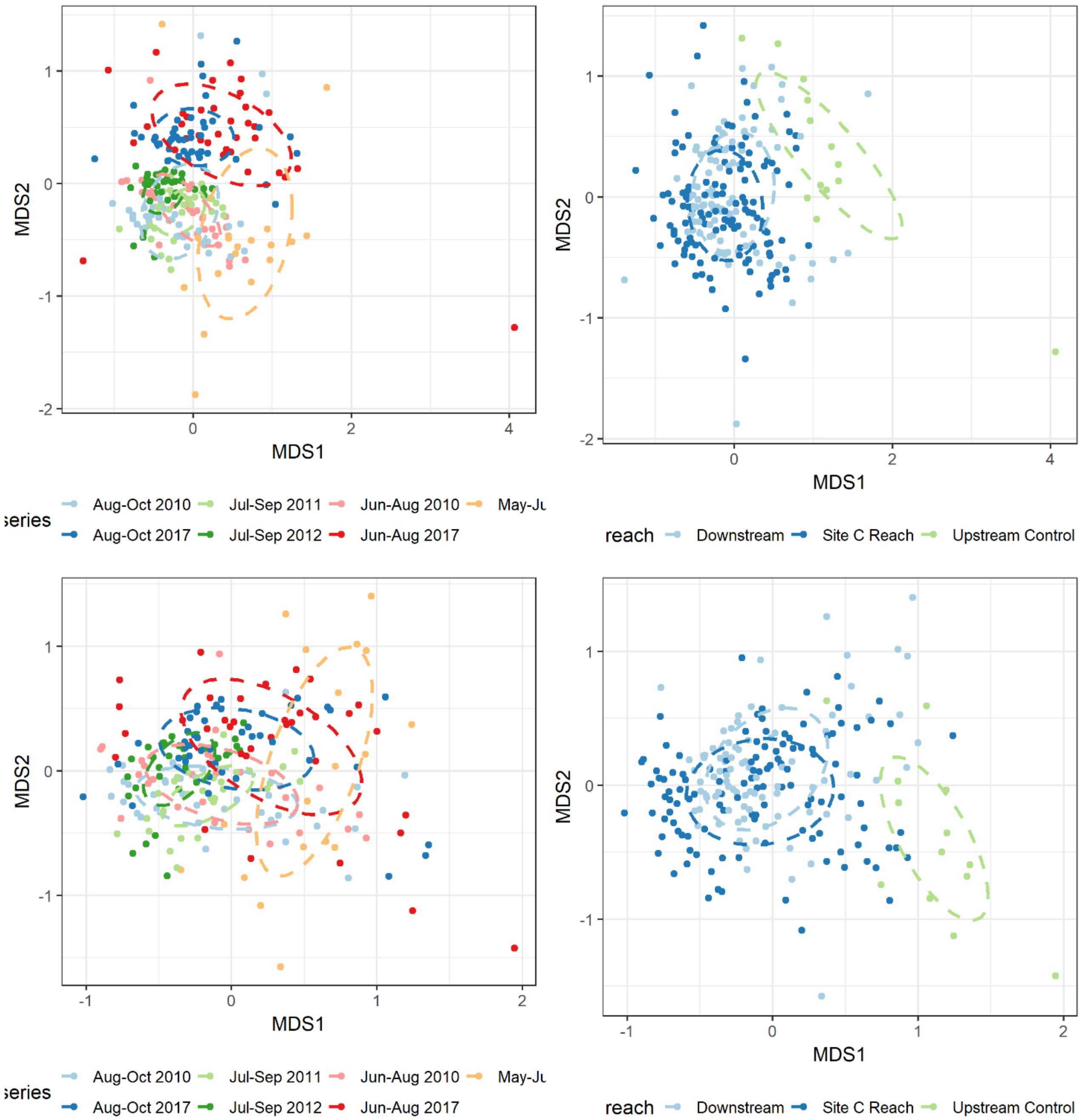

Figure 3-5: **NMDS of invertebrate abundance at the genus level (top) family level (middle), grouped by sampling period (year/season), by general location (Site C Reach, Upstream Control, Downstream) for 2010 through 2017 data. Stress index for both genus and family level were 0.23.**

3.5 Periphyton and Invertebrate Productivity Responses

3.5.1 Periphyton

Periphyton abundance was lower at most riverine sites in the 2017 early summer session (Jun-Aug) than in other sample sessions. Freshet processes most likely limited available light to the periphyton mat and altered deposition/scour throughout the system (Appendix I). Similarly, chlorophyll-a (chl-a) productivity was usually lower in the early summer session due to freshet processes such as deeper water and turbidity compared to samples collected during the late summer / fall (Aug-Oct). In the Site C reach, it was particularly pronounced during the 2011 and 2017 freshets. The additional "0" transect samples was frequently less productive due to dewatering, and the inclusion of these transects in 2017 should be considered when comparing estimates for the full transect among years.

Peace River chlorophyll-a was correlated with algal abundance and biovolume. This finding indicates that the main producers of chl-a in the periphyton are algae, while the contributions made to chl-a by photosynthetic bacteria were comparatively less important in the Site C reach. In the downstream PD reach, photosynthetic bacteria were more important chl-a producers, confirmed by the weaker correlation between chl-a and algal metrics.

PR1 and PR2 showed the highest chl-a of all sites due in part to reservoir recruitment and Didymo proliferation, but primarily resulting from higher light intensities compared to downstream sites with higher turbidities. These PR sites have shown high productivity across most years and most periphyton biomass metrics. Halfway and Moberly rivers showed much lower periphyton productivity relative to adjacent sites in the Peace River mainstem. Freshet flows were unusually high at these sites in 2017 and flows in the Halfway River increased rapidly following summer 2017 rain events. Compared to the adjacent PR sites, HD samples had 50% less the chl-a, abundance and biovolume, while MD samples had 75% less chl-a, and 50% less abundance and biovolume.

At the PD sites, the chl-a contribution made by photosynthetic bacteria was high during 2017, as indicated by the low algae counts and relatively high chl-a concentrations (Appendix I). The periphyton biomass metrics (chl-a, abundance, biovolume) were generally greater at PD1 through PD3 than they were at downstream PD4 and PD5.

Periphyton productivity was considered in two ways; firstly across the entire transect including upper varial zone areas, and secondly in areas that remained permanently submerged (submergence ratio of 0.95). A summary of the suite of productivity models considered for periphyton is found in Appendix N. Models for chl-a, abundance, biovolume, and species richness explained the most variation.

When all sites including the varial zone were compared, it was apparent that submergence time was the most important factor affecting periphyton productivity (Figure 3-6). Biovolume, abundance, and chl-a were all positively correlated with total time submerged. Velocity was also an important factor, with biovolume, abundance and chl-a all being negatively correlated. Chl-a and abundance were also negatively correlated with water depth while biovolume was positively associated with depositional rate. Depositional rate was also positively associated with percent motile taxa and negatively associated with Simpson's Index. However, the models of percent motile taxa and Simpson's Index explained minimal variation (pseudo-R^2= 0.11-0.13). Peak production generally occurred within the upper varial zone that occurs in shallow water with some exposure (transect 0 or transect 1 locations), likely because light penetration to the substrates is greatest in this region.

When only continuously submerged locations along the Peace River mainstem are considered, velocity was the most important factor determining the periphyton community, where chl-a, biovolume and abundance decreased with increasing velocity (Figure 3-7). Similar, to the full transect models percent motile taxa was positively associated with depositional rate and Simpson's index was negatively associated with depositional rate.

Many production indices were assessed for data collected from 2010 to 2017 mainstem periphyton. The following were important observations:

- Percent *Achnanthes* (shear stress index) increased during freshet seasons
- Percent motile taxa (siltation index) was one of the few indices to exceed previous years during 2017, particularly at PD1
- Percent-from-reservoir accounted for a much higher percentage of the periphyton in 2017 than in the previous sampled years, particularly in the samples spanning the freshet period. Reservoir contributions at PR1, PR2 and MD, located downstream of Dinosaur Reservoir and Moberly Lake, exceeded those of the other riverine sites.

However, statistical models for these indices explained limited variation as measured by pseudo-R^2, and these algal indices are not being considered for inclusion in the spatial model.

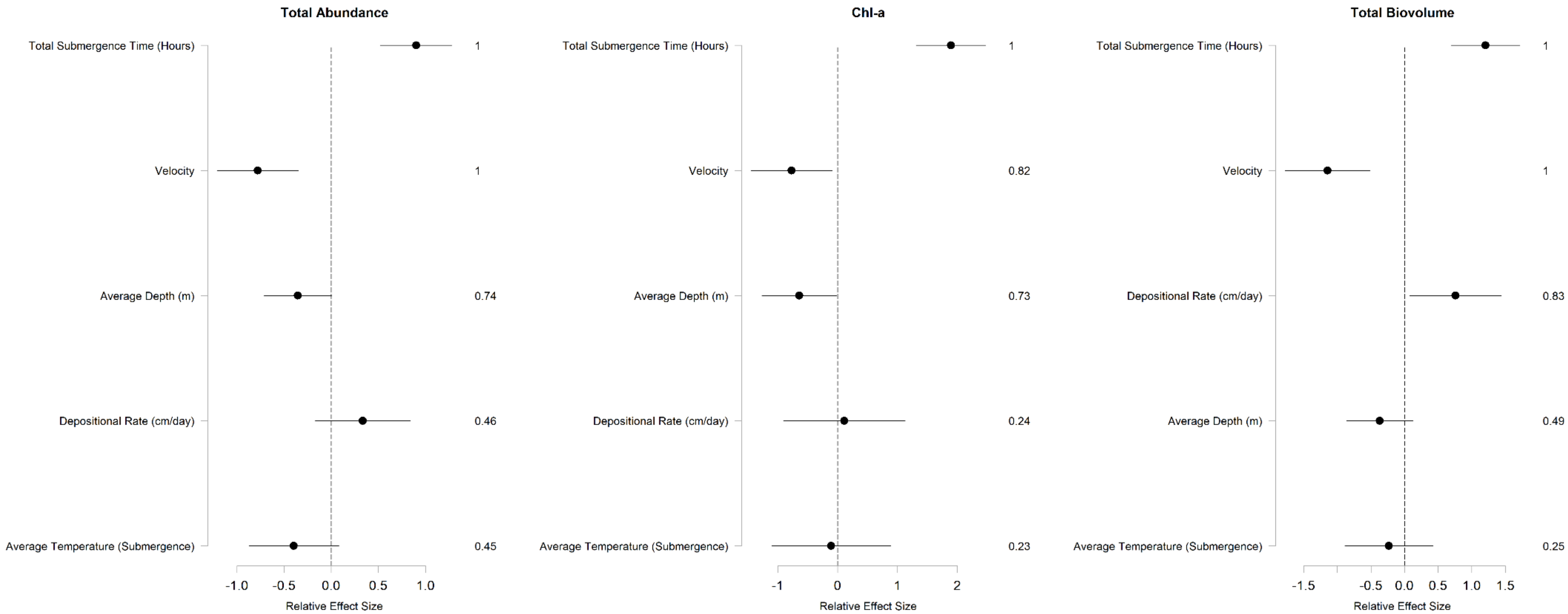

Figure 3-6: The coefficients and their 95% CLs of standardized explanatory variables of periphyton production in the Peace River considering the full varial zone (transect 0 to 4). Periphyton responses included abundance, chlorophyll-a and biovolume. Explanatory variables included mean temperature, submergence time, water velocity, sediment deposition rates, and average depth. Coefficients were standardized to allow comparisons of the direction and size of effects, noting that variables with CLs that do not cross zero have an effect on the response variable. Key explanatory variables are those that have a relative variable importance (RVI) >0.6-0.7 and the RVI is shown on the right-hand side of each panel.

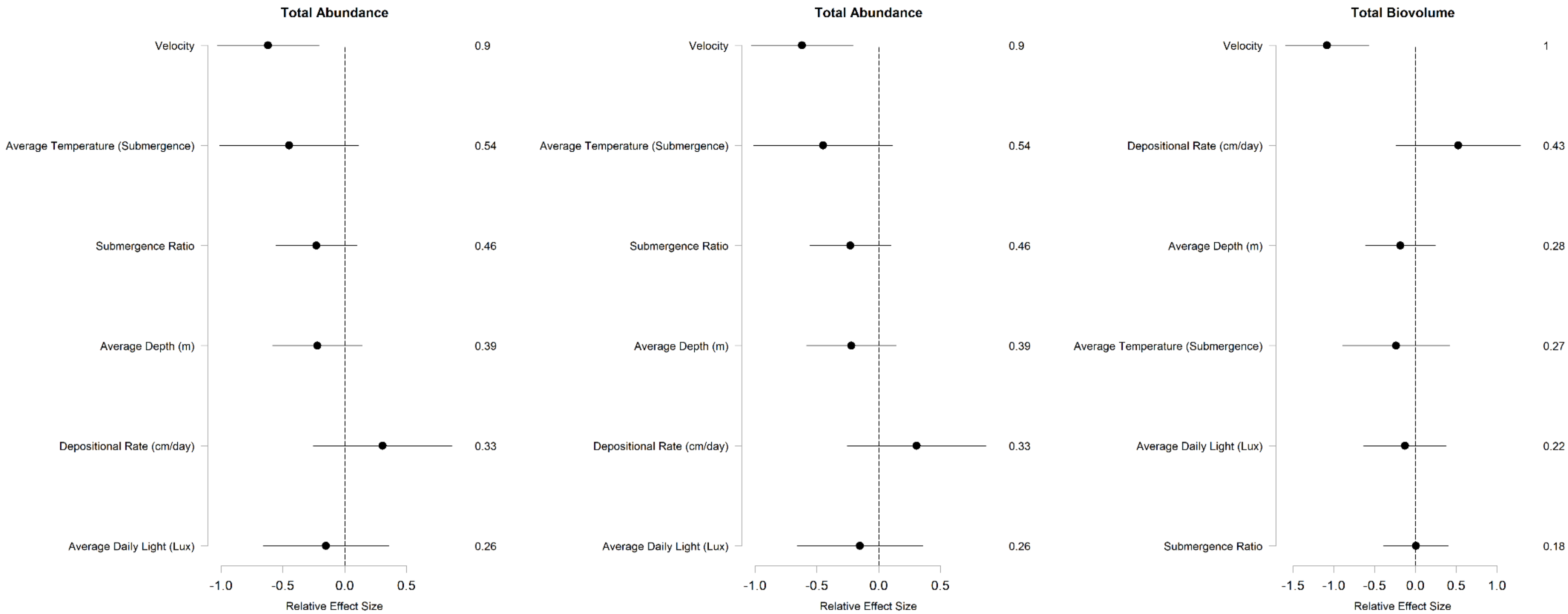

Figure 3-7: **The coefficients and their 95% CLs of standardized explanatory variables of periphyton production in Peace River considering permanently submerged sites only with a submergence ratio of 0.95 (approximately transect 1-2 to 4). Periphyton responses included abundance, chl-a and biovolume. Explanatory variables included mean temperature, submergence time, water velocity, sediment deposition rates, and average depth. Coefficients were standardized to allow comparisons of the direction and size of effects, noting that variables with CLs that do not cross zero have an effect on the response variable. Key explanatory variables are those that have a relative variable importance (RVI) of greater than 0.6-0.7 and the RVI is shown on the right-hand side of each figure.**

3.5.2 Invertebrates

3.5.2.1 Ekman Samples

Ekman samples for PR sites were modelled to understand what physical processes may affect natural invertebrate communities in depositional areas. A summary of the full suite of models considered for each response is found in Appendix O. Invertebrate models for abundance and biomass explained more variance than models for diversity or good forage which had lower pseudo-R^2.

When the full transect was considered, biomass and abundance models described a reasonable amount of variation, but no specific predictor appeared to be highly important (Figure 3-8). While the relationship was not strong (pseudo-R^2 = ~0.26[1]), good forage was positively correlated with velocity, suggesting that as velocity increases, more valuable forage is present. Sediment deposition rate was negatively associated with good forage, whereas Simpson's Index was negatively associated with depth. The percent EPT model explained minimal variation and had no significant predictors.

[1] The pseudo-R^2 is approximate because each model has a different R^2.

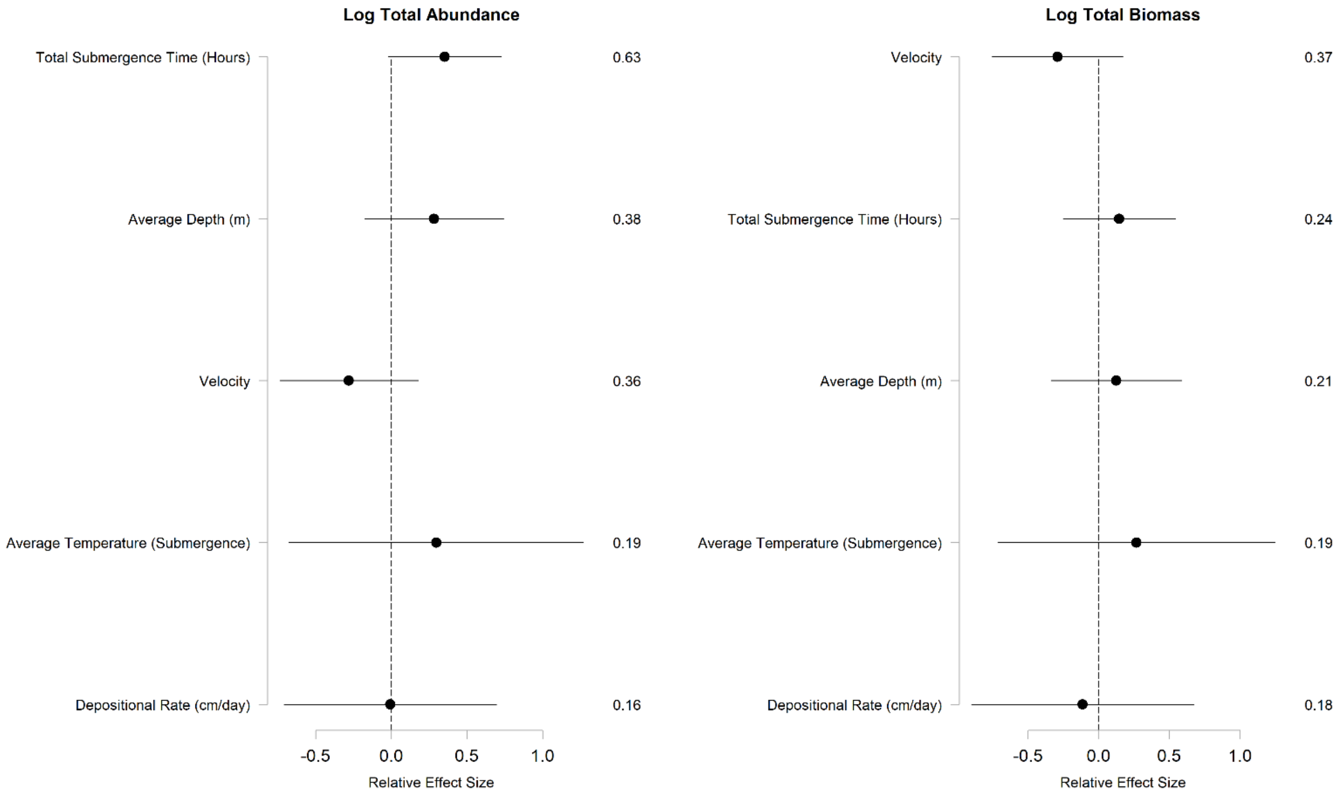

Figure 3-8: The coefficients and their 95% CLs of standardized explanatory variables of invertebrate production in Peace River from Ekman samplers considering the full transect (transect 1 to 4). Invertebrate responses included abundance, biomass, and quantity of food for fish organisms (sum of EPT and Dipterans). Explanatory variables included mean temperature, submergence time, water velocity, sediment deposition rates, and average depth. Coefficients were standardized to allow comparisons of the direction and size of effects, noting that variables with CLs that do not cross zero have an effect on the response variable. Key explanatory variables are those that have a relative variable importance (RVI) of greater than 0.6-0.7 and the RVI is shown on the right-hand side of each figure.

3.5.2.2 Rock Basket Samples

The reservoir site in Dinosaur Reservoir had a similar percentage of Chironomidae as the riverine sites. However, the percentage of EPT taxa was considerably lower, where riverine sites were usually greater than 25% EPT and the reservoir site was typically less than 25% EPT. The percent Chironomidae were less than 20% in both the reservoir and the river. Percent Chironomidae and percent EPT did not appear to show any trend between sample years. When all years of data were considered, percent Chironomidae in reservoir areas were greatest at shallow sites, but in riverine areas, no clear trends were observed. In four years of data spanning 2010–2017, percent EPT appeared to increase from PR1 to PR2, and subsequently stabilize at downstream sites. A full suite of summary statistics can be found in Appendix K, where data is broken down graphically for each response variable.

Invertebrate productivity was considered in two ways, across the full transect and within only permanently submerged areas (baskets with a submergence ratio of 0.95). A summary of the full suite of models considered for each productivity response is found in Appendix O. Invertebrate models for abundance and biomass explained more variance than models for diversity or good forage which had lower pseudo-R^2. Metrics with higher pseudo-R^2 are more valuable for assessing invertebrate productivity at a reach scale because they better relate physical processes in the river to invertebrate productivity.

When considering the full transect, abundance and biomass were negatively correlated with temperature (Figure 3-10). Abundance and biomass were positively correlated with velocity, indicating that as velocity increased so did these metrics. Food for fish (sum of EPT and Dipteran), percent EPT, and Simpson's Index had no significant associations with any predictor (Figure 3-10).

When only permanently submerged sites were considered, similar trends emerged (Figure 3-10). Specifically, the relationships between abundance and biomass were negatively associated with temperature. Biomass was positively associated with velocity. Although, good forage was negatively associated with velocity, the association explains limited variation (pseudo-R^2=0.07-0.16). The models for Simpson's Index and percent EPT also explained minimal variation (pseudo-R^2=0.00-0.16) and had no significant associations with predictors.

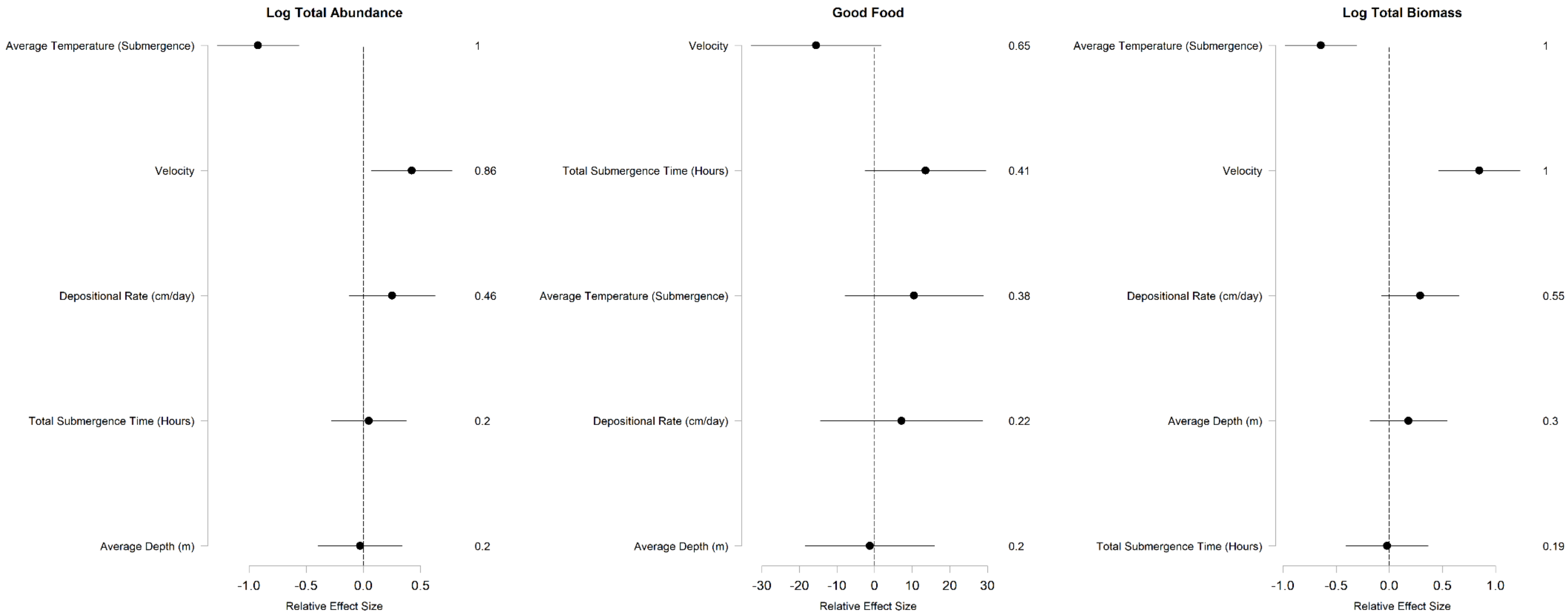

Figure 3-9: The coefficients and their 95% CLs of standardized explanatory variables of invertebrate production in Peace River considering the full transect (transect 1 to 4). Invertebrate responses included abundance, biomass, and quantity of food for fish organisms (sum of EPT and Dipterans). Explanatory variables included mean temperature, submergence time, water velocity, sediment deposition rates, and average depth. Coefficients were standardized to allow comparisons of the direction and size of effects, noting that variables with CLs that do not cross zero have an effect on the response variable. Key explanatory variables are those that have a relative variable importance (RVI) of greater than 0.6-0.7 and the RVI is shown on the right-hand side of each figure.

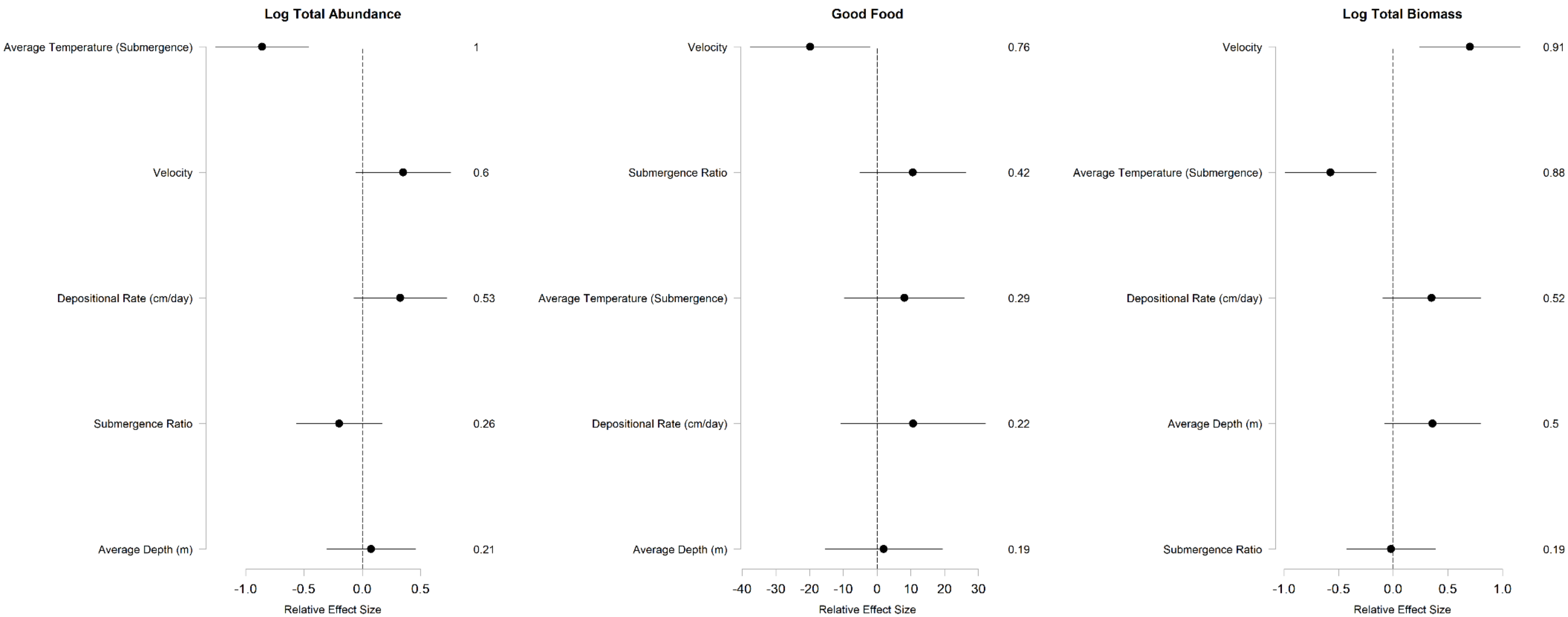

Figure 3-10: The coefficients and their 95% CLs of standardized explanatory variables of invertebrate production in Peace River considering the permanently submerged area only (transect 1 or 2 to 4). Invertebrate responses included abundance, biomass, and quantity of food for fish organisms (sum of EPT and Dipterans). Explanatory variables included mean temperature, submergence time, water velocity, sediment deposition rates, and average depth. Coefficients were standardized to allow comparisons of the direction and size of effects, noting that variables with CLs that do not cross zero have an effect on the response variable. Key explanatory variables are those that have a relative variable importance (RVI) of greater than 0.6-0.7 and the RVI is shown on the right-hand side of each figure.

3.5.2.3 Method Comparison

We compared the differences in the abundance and biomass of invertebrates sampled using the Ekman and the invertebrate basket. We found no significant differences in areal abundance (density) (ANCOVA: F= 6.11, df=70, p = 0.50) between the Ekman and basket samples. However, the Ekman and basket samplers had significantly different areal biomass (F=17.6, df=70, p <0.001). In fall of 2017, the basket sampler at PR1 had higher invertebrate biomass compared to the Ekman sampler (Figure 3-11). Both ANCOVA's for density and biomass suggested that densities are greater as water depth increases (depth was significant as a covariate) (Appendix P). These differences are subject to the method chosen to convert density or "#/basket" to aerial density or "#/m^2" of river bottom sampled. Thus, appropriate consideration is needed when directly comparing the two methods because of the influence of correction factors to adjust samples to represent a physical area of riverbed.

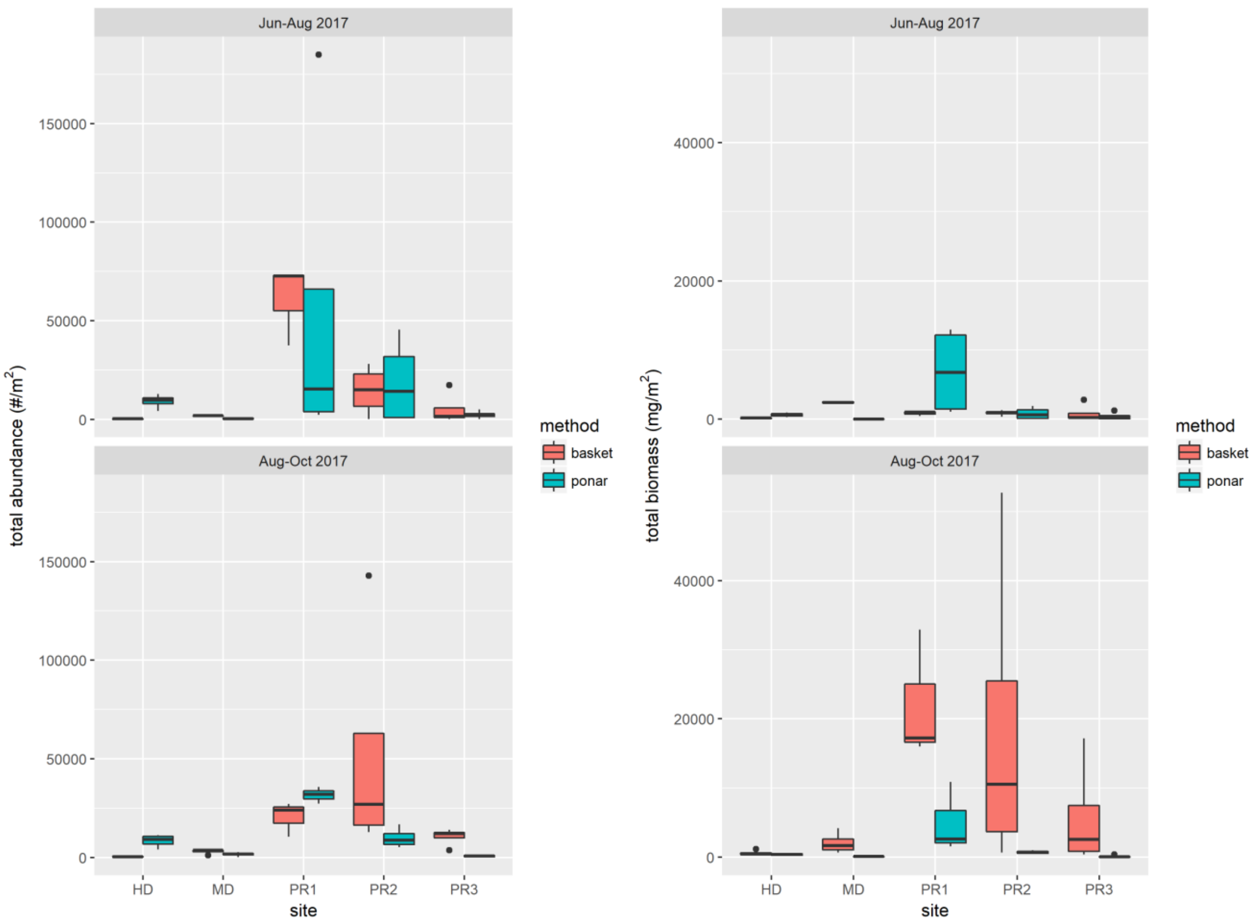

Figure 3-11: Total abundance (#/m^2) and biomass (mg/m^2) of invertebrates sampled using rock baskets and a Ekman Dredge in the Peace River at different sites in the summer and fall, 2017.

3.6 Zooplankton

In previous studies, 15 zooplankton species were found in Williston and Dinosaur reservoirs (Golder 2009a), 14 of which were common to both reservoirs. In 2017, 17 zooplankter taxa were captured in 150 µm plankton vertical hauls from D1-littoral, 16 from D1-pelagic and 21 from W1-pelagic ,17 of which were found in both reservoirs. Identified species included:

- **Calanoid copepods** *Epischura nevadensis, Leptodiaptomus pribilofensis, and Leptodiaptomus ashlandi, Heterocope septentrionalis Skistodiaptomus oregonensis*
- **Cyclopoid copepods** *Cyclops bicuspidatus thomasi Cyclops scutifer*,
- **Diplostraca** *Eubosmina longispina, Diaphanosoma leuchtenbergianum, Diaphanosoma bergei Chydorus sphaericus, Leptodora kindtii, Ceriodaphnia sp., Daphnia longiremis, Daphnia galeata mendotae, Daphnia pulex, Daphnia rosea Daphnia thorata, Daphnia pulicaria Simocephalus vetulus,* and *Holopedium gibberum*.
- **Rotifers** *Kellicottia sp Keratella spp. Polyarthra sp., Asplanchna sp., Bosmina sp., Conochilus sp (from 80 micron net)*

The grazing calanoid copepods typically account for >70% of the zooplankton biomass in both reservoirs, with a peak in mid-summer (Stockner et al. 2001; Golder 2009a). In the 2017 abundance results, they accounted for 63% in D1-L, 54% in D1-P and 64% in W1-P samples (Appendix J). The predatory cyclopoid copepods accounted for 26 to 39% of the 2017 reservoir samples. Cladocerans accounted for only 6 - 7% of Dinosaur Reservoir samples, but accounted for 10% of the Williston Reservoir samples, where they peaked in mid-summer 2017. Total 2017 zooplankton densities ranged from 3 to 16 individuals/L in Dinosaur Reservoir and from 5 to 34 individuals/L in Williston Reservoir, confirming that Williston Reservoir is a more productive reservoir (Golder, 2009a).

Rotifers are small zooplankters that are not captured by a 150 µm zooplankton net. They can be numerous with rapid reproduction and are an important link between pico/nano-plankton and invertebrates. Five rotifer taxa were identified from 2017 80 µm plankton tow samples, and although small rotifers can still escape this net, these results indicate that the rotifer communities are important to invertebrate biomass production. Rotifer communities can be used as indicators of a reservoir's trophic state, with increasing nutrients marked by increased rotifer biomass, specifically increased occurrence of *Keratella cochlearis* in summer and increased abundance of small bacterivorous rotifers (Yoshida et al. 2003, May and O'Hare 2005).

Dinosaur Reservoir habitats supported the highest zooplankton numbers in early summer, while Williston Reservoir supported more zooplankton in late summer (Aug, Sept). The Peace River sites are not suitable zooplankton rearing habitat, thus the individuals occurring at PR1, PR2 and PR3 were exported from upstream reservoirs. This explains the progressive decline in zooplankton density from 1-4 to 1-0.5 individuals/L as water moved downstream through the Site C reach. Additionally, the pulses in Dinosaur Reservoir zooplankton density were mirrored in the exported zooplankters measured at the PR sites (Appendix J). These pulses of recruitment would enhance zooplankton production in Site C reservoir.

Zooplankton were not measured in the littoral water column in 2010 to 2012 because it was assumed that it would be nil, given the shallow depths (<6 m). However, in 2017, littoral plankton hauls identified low to moderate zooplankton numbers with similar class proportions as the pelagic plankton hauls. D1-Littoral samples often held more zooplankton than D1-Pelagic, indicating that this is important zooplankter habitat, as is often the case (Yoshida et al. 2003; Wetzel 2001).

Total zooplankton biomass fluctuated with phytoplankton densities, both between seasons and among years. Areal biomass estimates of zooplankton production will be prepared following the 2018 field season.

No invasive mussel veligers were detected in the 2017 zooplankton, phytoplankton or periphyton samples from the reservoirs or the Site C.

3.7 Fish Stomachs

Ephemeroptera, Plecoptera, Trichoptera, and Dipterans were important forage for fish, consisting of at least 75% of the taxa in the stomach contents of Arctic Grayling, Mountain Whitefish, and Rainbow Trout (Figure 3-12). Data from all years indicates that Dipterans are important forage items in upstream reservoirs, consisting of a greater overall percentage of the Mountain Whitefish and Rainbow Trout forage than all other taxa. More Ephemeroptera were consumed in Peace River than the upstream reservoir, again because of available abundances most likely associated with habitat preferences. The quantity of Plecoptera and Trichoptera consumed by fish was more consistent between reaches and the upstream reservoirs, suggesting similar availability or preference by Arctic Grayling, Mountain Whitefish, and Rainbow Trout. Since EPT and Dipteran taxa represent over 75% of the food consumed, these taxa provide a reasonable index for understanding fish forage.

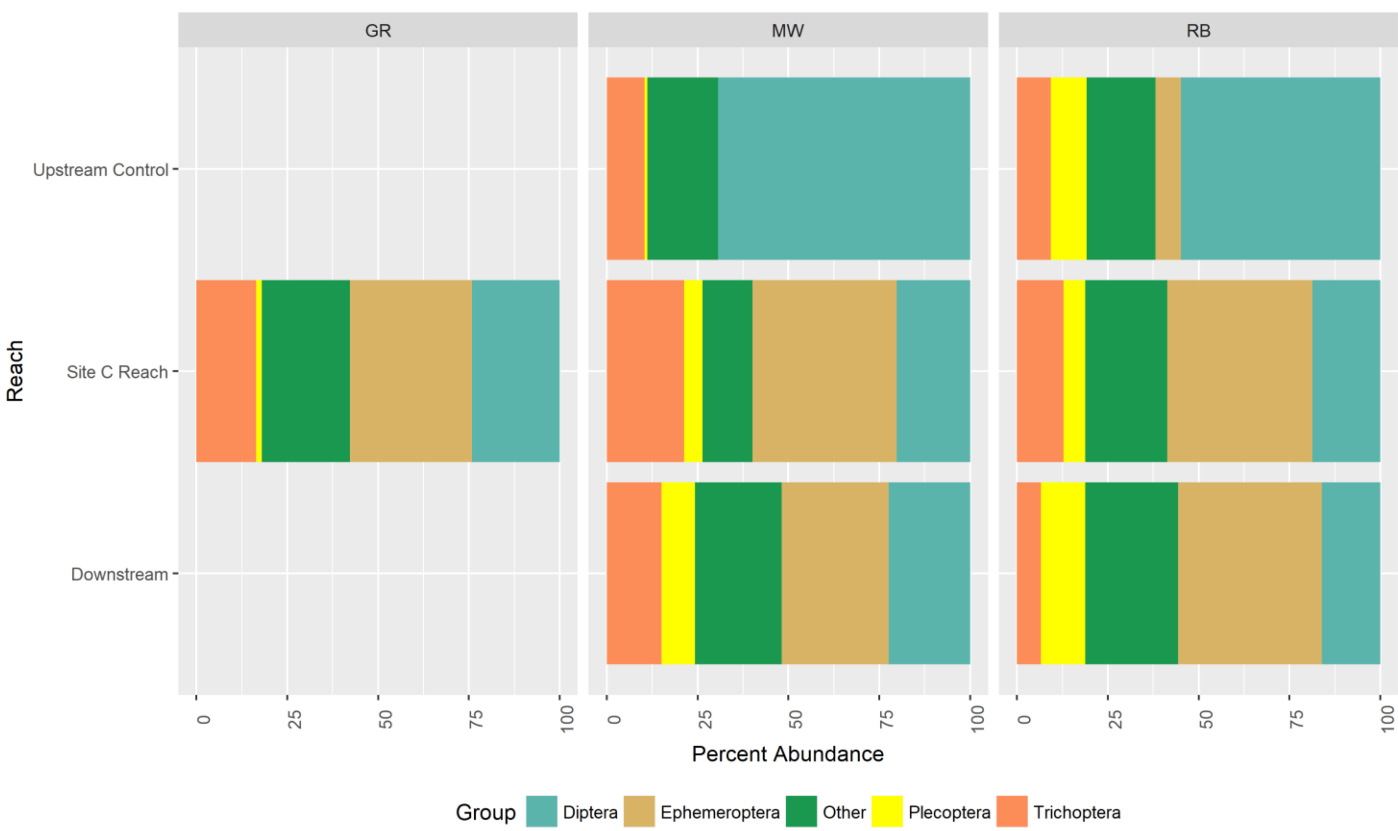

Figure 3-12: Relative abundance of Diptera, Ephemeroptera, Plecoptera, and Trichoptera in Arctic Grayling (GR), Mountain Whitefish (MW), and Rainbow Trout (RB).

We observed a distinct difference in community structure of invertebrates foraged by fish (Figure 3-13). Factors such as reach (Downstream, Site C, Upstream Control, $R^2 = 0.10$, $F = 12.3$, $p < 0.001$), site ($R^2 = 0.13$, $F = 5.43$, $p < 0.01$), fish species ($R^2 = 0.05$, $F = 6.63$, $p < 0.001$), and year ($R^2 = 0.03$, $F = 7.05$, $p < 0.01$) all influenced what was consumed by these three species. Thus, there are many factors that influence what fish forage on. The emergence patterns of invertebrates likely affect what and when different invertebrates are preferred by fish species, which may partially explain the effect of year on community structure. Forage items between the Site C reach and downstream reaches were more similar than the upstream reservoir control, explained by increased preference or greater relative abundance of Dipterans consumed (Figure 3-12).

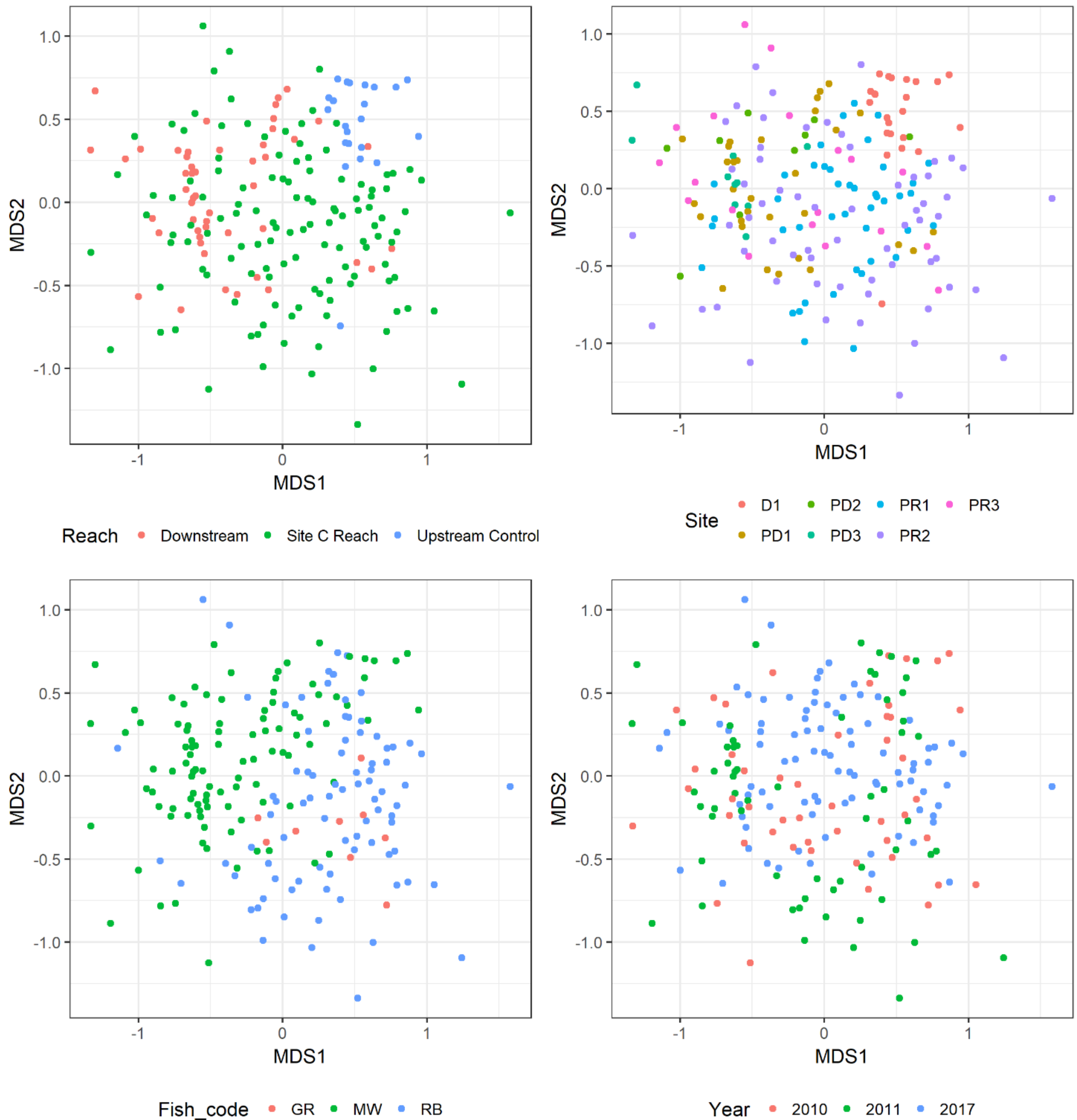

Figure 3-13: NMDS plots of benthic invertebrates consumed by fish in upstream reservoirs, Site C Reach, and downstream areas with a stress index of 0.20. Data is considered by Reach, Site, Species, and Year. GR= Arctic Grayling, MW= Mountain Whitefish, and RB= Rainbow Trout.

4.0 DISCUSSION

Assessing the influences of the Site C Project on the Peace River involves many co-ordinating monitoring programs. The objectives of the monitoring programs covered in this report are to:

Mon-6: understand and compare food for fish and the underlying processes that support benthos productivity in the Site C reach, pre- and post-flooding, and to compare the Site C reach against reference sites in Williston and Dinosaur reservoirs in a BACI study design.

Mon-7: investigate the effects of dam construction and operations on the biomass and production of invertebrates, including fish food organisms, downstream of the Project to Many Islands in Alberta.

Mon-17: investigate the effects of water level fluctuations on the catchability of Peace River fish and benthos biomass and production, from the Project to Many Islands in Alberta, by providing insights into the causal links between Project-related hydrological effects and the resultant changes in the trophic structure.

4.1 Reservoir

4.1.1 Physical Parameters

In addition to size, morphometry and nutrient concentrations, thermal and light profiles are key to understanding reservoir primary productivity. Thermal layering affects water temperatures and directs inflow and outflow layers, while light penetration controls the zone suitable for primary productivity.

The summer 2017 thermocline was centered on 10 to 15 m in Williston Reservoir, while only transient stratification was detected in Dinosaur Reservoir, consistent with other years of study (Harris et al. 2005; Stockner et al. 2001). These year-round studies identified Williston as dimictic with full water column mixing in late October as the surface water cools, and again following ice-off in early May. Lack of stratification increases the overall heat budget of a reservoir, but continual mixing maintains cooler surface water (Wetzel, 2001).

One of the main reasons that littoral zones are critical to lake eco-functions is the periphyton development on well-lit shallow substrates within the photic zone. A reservoir photic zone is highly dynamic, depending on water turbidity, transparency, color, cloud cover, waves, and algal production. The depth of the reservoir photic zone varied seasonally from 3.6 to 8.5 m at W1 and from 1.5 to 10 m in D1 pelagic measurements. The average photic zone extent measured in 2017 was ~7 m in Dinosaur Reservoir and ~6 m in Williston Reservoir pelagic zones. In the Dinosaur Reservoir littoral zone, the photic zone was estimated at ~6.3 m, slightly lower than the pelagic estimate. The width of the littoral zone in Dinosaur Reservoir has been defined as 3, 4 to as much as 6 m depth at high water (Blackman and Leering 2006; Harris et al., 2005; Golder 2009a; Golder 2012). We would therefore agree with the estimated extent of the littoral zone to 6 m of water depth, since this extent will provide sufficient light to the substrates to support primary production for most of the growing season.

Using the available metrics and data up to 2017, both Williston and Dinosaur reservoir pelagic areas would be classified as ultra-oligotrophic to oligotrophic. This agrees with previous assessments (AIM 2000, Stockner et al. 2001, 2005, Harris et al. 2005, Euchner 2011). The Dinosaur Reservoir littoral area was slightly more productive than the pelagic zone, perhaps due to entrainment of periphyton into phytoplankton by turbulence, and it was classified as oligotrophic. This confirms earlier studies that found extremely low productivity that was driven largely by inputs from Williston Reservoir (Euchner, 2011; Golder 2009a). Dinosaur Reservoir's low nutrient concentrations and a hydraulic residence time of less than five days limits development of plankton biomass (Golder, 2009a). Although nutrients are lost from the reservoirs as plankton exports from reservoirs, they are important inputs to the river below. Based on 2017 productivity results, these may be of greater importance than in-situ riverine periphyton production during freshet or other flood events.

4.1.2 Periphyton

Periphyton in the littoral zone provides a significant portion of the overall primary production in most lakes (Table 4-1; Wetzel, 2001). All littoral productivity measurements to date for Williston and Dinosaur reservoirs confirm the importance of the littoral zones, despite water level fluctuations in the growing season and large >10 m winter draw-downs in the Williston Reservoir (Harris et al. 2005). Harris et al. (2005) concluded that the littoral embayments of Williston Reservoir were still more productive than the main pelagic region.

Dinosaur Reservoir periphyton was diverse but areal productivity metrics were 2.5 to 4 times lower than the Peace River sites. Samples from 2017 confirmed that periphyton of the littoral region was more productive and more diverse than the corresponding pelagic samples.

Table 4-1: Reservoir Comparison

	Chlorophyll-a	Primary Productivity	
	(mg chl-a/m^2)	(mg carbon/m^2/day)	(algae cells/mL)
Williston embayments	10.3	33	3500 – 4800
Williston pelagic	7.6	25 - 34	n/a
Williston pelagic 2017	8.1	n/a	2950 - 5050
Dinosaur pelagic 2017	6.3	n/a	3150 - 4750
Dinosaur littoral 2017	5.9	n/a	3900 - 6550
Slocan Lake	26.3	59	n/a
Okanagan Lake, N. basin	22.2	80 - 165	2659 ± 2415
Okanagan Lake, S. basin	32.2	64	4144 ± 6144
Kalamalka Lake pelagic	0.7 - 2.1 µg/L	n/a	1200 - 2400
Vaseux Lake	0.9 - 4.2 µg/L	n/a	2067 ± 1743
Kootenay Reservoir, N Arm	58.9	368	n/a
Kootenay Reservoir, S Arm	44.1	239	n/a
Arrow Lakes Res. upper	55.4	261	n/a
Arrow Lakes Res. lower	42.1	263	n/a

after Harris et al. 2005 * Mean of June through September

Depth-integrated chl-a drawn from entire photic zone considered

4.1.3 Phytoplankton

In Williston and Dinosaur reservoirs, the smaller phytoplankton of <3 microns usually account for the greatest proportion of primary productivity. In a 2005 study of Williston Reservoir, the shallower embayments were dominated by small nanoplankton (2.0 – 20 microns) while the open water pelagic regions were dominated by tiny picoplankton (0.2 – 2.0 microns) consisting of cyanobacteria and photosynthetic bacteria (Harris et al. 2005). We classified Williston Reservoir as ultra-oligotrophic, that is, the standing stock of biomass at all trophic levels in the reservoir areas were very low, as were the rates of primary production. Harris et al. (2005) determined that light and the major nutrients phosphorus and nitrogen co-limited Williston Reservoir.

Phytoplankton samples from both Williston and Dinosaur reservoirs in 2017 showed very low productivity that was numerically dominated by pico-cyanobacteria with brief pulses of diatoms, flagellates and green algae. Most of these phytoplankton taxa were also prevalent in Dinosaur Reservoir, in part from recruitment from Williston Reservoir (Stockner et al 2005). Littoral zone phytoplankton samples from Dinosaur Reservoir during 2017 captured the influence of periphyton dislodged from shallow substrates.

Picoplankton communities often dominate oligotrophic lakes (Shortreed and Stockner, 1981) because their high surface area to volume ratio allows them to scavenge nutrients efficiently and their simple structures allow rapid reproduction rates. As expected, we found numeric dominance by these tiny bacteria-sized algae in both Williston and Dinosaur reservoirs in 2017.

4.1.4 Reservoir Invertebrates

The Dinosaur Reservoir sample site had a higher predominance of Chironomids and fewer EPT taxa compared to riverine sites, as expected. These results confirm the conclusions of the EIS - sites in the Site C reach are expected to transition from lotic or riverine with greater predominance of EPT taxa to lentic or reservoir with a greater predominance of Chironomidae after flooding.

4.1.5 Zooplankton

Total zooplankton biomass fluctuated with phytoplankton densities, both between seasons and among years. Twenty-one zooplankton taxa were found in Williston and Dinosaur reservoirs in 2017, 17 of which were common to both reservoirs. The grazing calanoid copepods accounted for >50 to 70% of the zooplankton abundance in both reservoirs while the predatory cyclopoid copepods accounted for 25 to 30%. Cladoceran abundance accounted for only 6 to 7%, and the rotifers accounted for a very small percentage of the Williston and Dinosaur reservoir zooplankton standing crops. Williston Reservoir usually generates higher zooplankton densities than Dinosaur Reservoir (Harris et al. 2005), and 2017 was no exception.

Bacteria-sized particles are too small for large, herbivorous zooplankton to consume and instead, they are consumed by micro-grazers such as ciliates and rotifers that are in turn consumed by the larger zooplankton. This extra step in the food chain reduces the efficiency of the reservoir’s food chain (Harris et al. 2005), but rotifers do provide an important link between bacteria and predatory benthic invertebrates.

4.2 River

4.2.1 Physical Habitat Parameters

The growing season temperatures at each mainstem site ranged from 10 to 11ºC in June to a peak near 15ºC in August. This cool temperature range affects benthos community composition and reproduction rates (Wetzel, 2001).

Light restriction of periphyton production is an over-arching factor affecting the entire Peace system (Schleppe et al. 2013; Stockner et al 2001; Harris et al. 2005). Light effects can also be masked by depth and by settlement of algal cells imported from upstream sources, and possibly confounded by photo-inhibition. The Peace River system is frequently turbid (NTU>5 to 10), with significant peaks exceeding 100 NTU during the ascending limb of high flow events. Turbidity as low as 5 to 10 NTU is known to reduce periphyton productivity, with progressively larger reductions as turbidity increases (Parkhill and Gulliver 2002). For the turbid Peace River, secchi depth and the light loggers indicate a photic zone of only 0.8 to 2.2 m in downstream depositional areas, which is confirmed by light modelling. These results suggest that no more than 2.5% of the light available at the surface can be found deeper than 2.0 m depth at 1 FNU turbidity. Further, light modelling data suggest that light is less than 10% of that available at the surface at 0.2 m depth when the river is 100 NTU. This is consistent with our general observations on the Peace River, where peaks in all periphyton metrics are often observed at areas with intermediate to high light intensities in shallow water. Under low light availability, thin biofilms with low biomass are expected (Wagner et al. 2015; Adlboller 2013; Ceola et al. 2013), but in the Peace River, periphyton production in these locations was augmented by deposition of algal productivity from either upstream periphyton or from upstream reservoir phytoplankton.

Light, depth, and turbidity were variable over time at each site. Each of these factors affected light intensity at the river bed and affected the area available at each site where in situ photosynthesis can occur. It was also apparent that natural sediment loads in tributary plumes, or even localized sedimentation processes, can impact turbidity, and therefore light conditions in the Peace River mainstem. Understanding both the wetted history, temperature, and light conditions at the sites is necessary to understand end points in productivity because the area where growth occurs is likely restricted to the shallow perimeters of the river margins, bars and islands. Interestingly, we did not find a relationship between depth, light, turbidity, and food for fish productivity metrics (primarily periphyton). A variety of reasons for this response are provided in Section 4.2.1. Future years of data collection will provide additional data to confirm whether these physical factors predict productivity.

4.2.1 Periphyton

Photosynthesis of even the most resilient organisms is prevented after light is reduced to <1% of the light available at the water surface. Consequently, only the periphery of the channel bed will be suitable for active periphyton growth, where light penetration reaches the substrate at appropriate intensities. A broader sampling span was employed in 2017 than in previous years to ensure that the entire photic zone was sampled. Conversely, light intensities in shallow water can exceed algal tolerances and cause photo-inhibition (Wetzel, 2001; Sigee 2005). This is universal in rivers with low turbidity, and 2017 data indicate that it may occur at times in the turbid Peace River.

Like other river systems, the area of productive habitat in the Peace River was limited by the wetting patterns associated with both hydropower operations and natural variation in tributary flows (Schleppe et al. 2011). The extent of the upper varial zone (transect position 0) contributions to the overall productivity of the Peace River were dependent on frequency and duration of substrate exposures/submergences.

Community analysis indicated that annual and seasonal variation is likely the most important determinant of the overall periphyton community structure. Many algae associated with the river periphyton taxa were also found in Williston and Dinosaur reservoirs, confirming that reservoir recruitment is an important source of algal organic material to the Peace River. Zooplankton and phytoplankton drift from Dinosaur Reservoir and from Moberly Lake represent taxa and nutrient imports to the Site C reach. Taxonomic indices of shear, depositional rates, and reservoir recruitment all indicated that the Peace River is a turbid, dynamic system subject to high flows.

The main producers of chlorophyll-a in the Peace River periphyton were algae, while the contributions made by photosynthetic bacteria were small in the Site C reach and more important at the downstream PD sites. Halfway and Moberly rivers showed much lower periphyton productivity compared to sites in the adjacent Peace River mainstem. At the PD sites, the chl-a contribution made by photosynthetic bacteria was high during 2017, as indicated by the low algae counts and relatively high chl-a concentrations. This finding is important to understanding carbon cycling in this nutrient-limited system.

PR1 and PR2 showed the highest periphyton production of all sites – due in part to reservoir recruitment and Didymo proliferation. It was found at these sites in the 2010 - 2012 studies as well (Golder 2012). Didymo is important because it is a large diatom that can form extensive mats of its attachment stalks that cover river substrates, while at other times, its growth is moderate and beneficial (Kilroy and Bothwell 2011). Didymo growth varies annually but generally does best with controlled, moderate flows and high light conditions (Kilroy and Bothwell 2011).

High turbidity in the Peace River reduced light penetration to the river bed, and ultimately reduced production from primary producers. While the relationship had limited predictive capability, chl-a appeared to decrease with increasing depth, supporting the idea that growth occurred in narrow bands that were limited by submergence at the upper boundary and by light penetration to the substrates at the lower boundary. Prevalent periphyton species that grew in situ included those that were tolerant of low light conditions, and motile taxa that can travel up through deposited sediment. Taxonomic data indicate that phytoplankton/ periphyton exports from upstream reservoirs are important to the overall productivity of the Peace River mainstem, supported by the importance of sediment deposition in the models. In regulated rivers, the contribution to in situ periphyton production made by reservoir algae imports into the river is often significant (Larratt et al. 2013).

As expected, substrate submergence was the most important factor governing productivity followed by water velocity. Similar to the Middle Columbia River, samplers with longer periods of submergence have higher levels of periphyton production (Schleppe and Larratt, 2016). Results from submerged samplers in 2017 identified water velocity as a key factor contributing to periphyton productivity, more so than light, depth, or other factors, where periphyton production decreased with increasing water velocity. Higher water velocities result in an increase of shear stress which causes filamentous green algae to be dislodged and also causes suspension of fines which cause periphyton loss through abrasion (Flinders and Hartz 2009; Luce et al. 2010; Schleppe and Larratt, 2016). Velocity is a key predictor of periphyton production in the Lower Columbia River especially during high flow periods such as freshet (Plewes et al. 2017).

Light was not identified as a critical determinant of periphyton productivity in the submerged sampler models. In contrast, other studies in the Peace River identified as a critical determinant of periphyton production (Schleppe et al, 2013; Harris et al. 2005). This is an interesting result, and likely occurred because as velocity decreased, deposition increased. Since the areas of suitable light penetration on the river are confined to narrow bands of lower varial zone, settlement of algal production originating from in-situ or upstream production areas may augment productivity in depositional areas that have lower velocity. This has been previously observed in the Peace River as part of GMSMON-5 (Schleppe et al. 2014). Our statistical models did not detect the effects of light restrictions, perhaps because light effects can be masked at depth by the settlement of algal cells imported from upstream sources or perhaps because sampler positions did not overlap consistently with the highly productive bands.

As expected, areas with high depositional rates had a less diverse periphyton community because these areas favour motile taxa (Schleppe et al. 2014). The positive association between periphyton biovolume and depositional rate was likely a result of burial of algae cells originating from upstream areas.

Production metrics at sites in the Peace River mainstem were lower than those typical in mainstems of regulated rivers, likely due to its turbid waters and high sediment deposition rates (Table 4-2). Water velocity and substrate submergence were also the most important predictors of the periphyton community. Turbid Peace River water is suspected to hinder photosynthesis, particularly during high flows when turbidity is greater.

Table 4-2: Riverine Comparison

Metric	Oligotrophic or stressed	Typical large rivers*	Eutrophic or productive	PR Site C Reach	PD down stream
Taxa richness(live & dead)	<20 – 40	25 – 60	variable	17 - 21	8 – 20
Chlorophyll-a ug/cm^2	<2	2 – 5	>5–10 (30+)	2.0 – 3.6	1.4 – 3.8
Algae density cells/cm^2	<0.2 x10^6	1 - 4 x10^6	>10 x10^6	0.9– 1.8 x10^6	0.2–1.5 x10^6
Algae biovolume cm^3/m^2	<0.5	0.5 – 5	20 - 80	2.9 - 6.7	3.0 – 6.5
Diatom density frustules/cm^2	<0.15 x10^6	1 – 2-5 x10^6	>10 x10^6	0.0032-6.95x10^6	0.037-6.75x10^6
Biomass – AFDW mg/cm^2	<0.5	0.5 – 2	>3	n/a	n/a
Biomass –dry wt mg/cm^2	<1	1 – 5	>10	n/a	n/a
Bacteria count, HTPC CFU/cm^2	<4 -10 x10^6	0.4–50 ×10^6	>50×10^6 – >10^{10}	n/a	n/a
Accrual chl-a ug/cm^2/d	<0.1	0.1 – 0.6	>0.6	n/a	n/a

Comparison data obtained from Flinders and Hartz 2009; Biggs 1996; Peterson and Porter 2002; Freese et al. 2006; Durr and Thomason 2009; Romani 2001; Biggs and Close 1989. (ug/cm^2 = 0.1 x mg/m^2)

*Rivers include Jackson River, Colorado; New Zealand Rivers (Canterbury); Yellowstone River; River Warnow, Germany; Riera Major, northeastern Spain

In summary, time spent submerged is probably the most important determinant of productivity in the Peace River, as it is in the MCR (Schleppe et al. 2011). Bands of in situ production probably occur along the river margins and along bars where light penetration is sufficient to result in periphyton growth. Like other river systems, velocity appears to be important, with high velocity locations having lower overall productivity. Sediment deposition rates may also be important, with greater biovolume likely in areas where deposition is more rapid. In these areas, the periphyton also consists of more motile species that can migrate up through deposited sediment.

4.2.2 Invertebrates

Like periphyton, the invertebrate community structure varied most with the series of sampling (year and season combined). Invertebrate communities from reservoir areas and from riverine sites were distinct, with reservoir areas dominated by Chironomidae and riverine areas having a higher predominance of EPT taxa. In the 2017 data, with two additional transect locations, site was the most important determinant of community similarity, but both season and reach were also important. The differences in benthic invertebrate community composition between sites was also observed by Golder (2012).

Water velocity and water temperature were the most important factors affecting invertebrate production in the Peace River, where abundance and biomass increased with increasing velocity, and decreased with increasing temperature. The relationship with velocity is common and has been observed in the Lower Columbia River (Plewes et al. 2017; Hawes et al. 2014). The observed relationship is likely a result of incomplete sampling of all velocity conditions may be relevant because at some point, velocity can act to limit invertebrate production.

The negative association between water temperature and invertebrate productivity has not been found in other studies. Warmer water temperatures usually result in an increase of invertebrate production (Schleppe and Larratt, 2016). Water temperature may be confounding for other factors. For example, in 2017 the sites on Moberly and Halfway River had warmer water temperatures and lower invertebrate productive compared to sites on the Peace River. In the summer of 2017, MD and HD samplers experienced frequent dewatering (i.e. exposure) and this likely resulted in lower invertebrate abundance and biomass.

Water temperature, submergence, water depth, and depositional rate explained little variability in percent EPT and good forage of the basket samplers. Interestingly, in the Lower Columbia River some variability in percent EPT is explained by velocity and substrate size (Hawes et al. 2014; Plewes et al. 2017). The Lower Columbia River ecological productivity study is a multi-year dataset. Hence, associations between percent EPT and good forage may emerge next year when additional data is added to the models. The Ekman samples supported the Lower Columbia River findings, as velocity was positively associated with good forage.

Depositional habitat models sampled by the Ekman sampler had different associations than the basket samplers. Areas of higher sediment deposition in depositional habitats were associated with lower quality fish food. Previous work on the Peace River as part of GMSMON-5 produced similar results, where the invertebrate community had increasing quantities of Chironomidae over EPT taxa in areas with increased sediment deposition (Schleppe et al. 2014). Samplers that were deeper during deployment had invertebrate community that were less diverse. The lower invertebrate diversities may be a result of EPT taxa that lay their eggs at the river’s edge being less abundant at deeper sites (Kennedy et al. 2016).

Sedimentation patterns may also affect the benthic communities. For instance, many of the important species that created “similarity between” sites were either members of the Chironomidae or Ephemeroptera / Plecoptera / Trichoptera (EPT) species. Each group is usually associated with different habitat types, where Chironomidae are much more common in fine sediments than mayflies because the later prefer coarser substrate. Previous work on the Peace River as part of GMSMON-5 produced similar results, where the community had increasing quantities of Chironomidae over EPT taxa in areas with increased sediment deposition. Invertebrate production appeared to slightly increase with greater sedimentation rates, possibly because biomass settlement in these areas increased overall production compared to light-limited, higher velocity areas. Ephemeroptera, Plecoptera, Trichoptera, and Dipterans were important forage for fish, consisting of at least 75% of the taxa sampled in the stomachs of Arctic Grayling, Mountain Whitefish, and Rainbow Trout. The fish stomach contents of Mountain Whitefish and Rainbow Trout in the Lower Columbia River also had high abundances of EPT and Dipterans (Plewes et al. 2017). The invertebrate taxa found in the stomachs of Arctic Grayling, Mountain Whitefish, and Rainbow Trout suggest fish forage preferences. There are many other factors such as food availability, fish species, and habitat preferences that can cause differences in the stomach contents of fish. However, despite these differences all fish stomachs had a high percentage of EPT and Dipteran taxa, which supports the use of these taxa as an index for understanding fish forage.

4.3 Management Hypotheses

The focus of the data analysis herein was to understand physical processes that affect productivity of periphyton and invertebrates in the Site C reach (currently lotic, future reservoir), the downstream riverine sites (PD), and in upstream control reservoirs (Dinosaur and Williston reservoirs). Initially, the analysis focused on the merging of the 2017 data with previous study years, and subsequently using analyses to consider physical factors that influence invertebrate, periphyton, and zooplankton productivity in the Peace River above, within, and below the Project. Once these physical processes are understood, models can parameterize factors for a spatial model that can predict the area of productive habitat in the Peace River pre- and post-flood of the Site C reservoir. These models can be used to subsequently address Mon-6, Mon-7, and Mon-17 management questions.

4.3.1 Mon-6 Management Hypotheses

Riverine areas of the Site C reach will ultimately become reservoir areas following the construction of the Project. Data for the Site C reach from 2010 to 2017 was combined with Peace River downstream sites to increase sample size and allow a better understanding of the physical processes that influence productivity in riverine areas. Data collected to date suggest that submergence and water velocity are likely the most influential factors affecting periphyton and invertebrate productivity in the Peace River. Similarly, modelling of light intensity at the riverbed indicates that light penetration of sufficient intensity to support photosynthesis (PAR) only occurs in shallow water due to factors such as turbidity and depth. It is likely that narrow bands of in situ growth establish along the river on shallow substrates where light intensities are sufficient. This productive band is bound on the upper end by patterns of submergence that create the upper varial zone and on the lower end by available light. Our current sampling transects may partially overlap with this narrow band during turbid events or time periods when light attenuation is high.

Within the reservoirs, sampling indicated that the productive photic zones are dynamic and averaged 6 m deep in Williston Reservoir and 7 m deep in Dinosaur Reservoir. In 2017, benthic production differed between the littoral zones and the pelagic zones of Dinosaur Reservoir and warrant further consideration. All invertebrate production data suggests that the Site C reach will transition from a riverine community dominated by EPT and Dipteran taxa to a reservoir community type dominated by Chironomidae. This is supported by the comparison of Ekman invertebrate samples from Dinosaur Reservoir with Ekman and rock basket samples from riverine areas which document a similar shift to Chironomidae and Oligochaetes. BC Hydro (2013) predicted this invertebrate community shift in the EIS (BC Hydro 2013).

In future years, once predictive spatial models have been developed, the aerial production (density or mass/m^2) and reach-wide biomass (rate or mass-km^2/yr) of key invertebrate fish food items will be modelled to answer the management questions. Data collected in 2018 will be used to help further develop and parameterize a spatial model of productivity to determine how and if productivity changes pre- and post-flood in the areas of the future Site C reservoir.

4.3.2 Mon-7 Management Hypotheses

Currently, Mon-6 and Mon-7 data are best combined to address the Mon-7 management questions. The combined dataset indicates that submergence and water velocity are the most important determinants of periphyton and invertebrate productivity in riverine areas. Continued data collection in 2018 will allow for a better understanding other physical factors, such as light intensity, that can affect productivity in downstream areas and are expected to be important. Ultimately, additional data collection will allow for the development of a more accurate spatial model to better estimate productivity of the study area at a reach scale.

Similar to Mon-6, predictive spatial models will be developed and used to answer management questions regarding the aerial production (density or mass/m^2) and reach-wide biomass (rate or mass-km^2/yr) of key invertebrate fish food items. Data from 2018 will be used to help further develop and parameterize a spatial model of productivity to determine how and if productivity changes in areas downstream of the future Site C reservoir.

4.3.3 Mon-17 Management Hypotheses

Like other large river systems, greater substrate submergence increased periphyton and invertebrate production. This relationship was not as apparent on the Peace River compared to the MCR, likely because the varial zone is smaller due to flow fluctuations, but a similar pattern and observation of reduced productivity was still observed. This supports the inclusion of submergence time as a necessary factor in a spatial model of productivity. Previous work by BC Hydro and the Columbia Power Corporation on the Columbia River found that benthic and periphyton death rates occur very quickly after exposure (likely within hours for invertebrates and within 24 hours for periphyton during dry, warm conditions), meaning that use of hour as the lowest denominator of time is necessary to assess how operations affect wetted habitat and subsequently productivity of the Peace River (Schleppe et al. 2011, Schleppe et al 2013). To address the Mon-17 management question, a spatial model will be used to predict productivity pre- and post-flood of the Site C reservoir in an hourly dataset[2], which will be used to extrapolate how operations of the Project may affect invertebrate and periphyton productivity. Data collected in 2017 indicated that light penetration limits productivity to narrow bands along the margins of the river during turbid flows, and yet daily or hourly variation in water levels likely dewater these same areas of the river which are typically concentrated in water less than 1 m deep (depending on turbidity). Future years of data collection will focus on identifying more specifically how light affects productivity to better predict productivity along the river margins, which are also subject to dewatering. When all data were considered in the development of a spatial model of productivity, it currently appears that inclusion of, at minimum, submergence, velocity and possibly temperature should occur. Future years will determine the most appropriate way to include light in spatial models. If temperature is to be used in the spatial model, further analysis is necessary to better understand the response.

Invertebrate abundance and biomass are the best candidate responses to consider in a spatial model because the physical factors influencing these productivity metrics are better understood than other invertebrate responses such as percent EPT (models described more variability, see Table A25 and Table A27). Periphyton, biovolume, abundance, and chlorophyll-a are all metrics that could be considered for use in the spatial model. Interestingly, metrics of "good forage" for both periphyton and invertebrates were not useful responses to consider for the spatial model because these they could not be accurately

[2] As feasible depending upon data or computing limitations.

predicted using only physical factors collected in this study (i.e., they had lower pseudo-R^2 and described less variability in the response variables).

Future years of the study will focus on the overall importance of each of these variables, consider other expected important variables such as light, and determine how best to include them and parameterize them as predictors in a spatial model of productivity.

Table 4-3: Mon-6, Mon-7 and Mon-17 Status of Objectives, Management Questions and Hypotheses After Construction Year 3 (2017)

Mon-6 Management Questions and Hypotheses	**Construction Year 3 (2017) Summary**
Q1. What is the change in areal biomass (mass/m^2) and reach-wide biomass (mass-km^2/yr) of fish food organisms in the Site C reach between years before and after construction of the Project? H1. Reach-wide biomass of invertebrates in the Site C reach will be the same between years before and after reservoir formation.	2017 was the fourth year of pre-flood sampling, following 3 years of sampling during the approval process. Since all sampling to date is considered "pre" flood, a comparison of pre and post is not yet possible. Therefore, the focus of 2017 was to collect and understand physical factors that may influence periphyton, zooplankton and invertebrate productivity using all four years of data. Management questions will be addressed by developing a spatial model of fish food or productivity for the study area. Within the reservoirs, sampling suggests that turbidity-limited light penetration is important in defining the shallow photic zone, and subsequently defining productive habitat. Differences in invertebrate and periphyton productivity were noted between the littoral zone and the pelagic zones of Dinosaur Reservoir and warrant further consideration. In riverine areas, estimates of productivity also appeared to vary between years, but patterns were less consistent. Key factors affecting fish food organisms were related to submergence and velocity, where in areas of reduced velocity, deposition of sediments and algal slough may increase the productivity metrics, particularly in light limited sites. Light modelling and physical data collection suggest light penetration is limited in the turbid Peace system. For this reason, it is suspected that in situ productivity in the Peace system is derived largely from narrow bands along river margins, where light intensity is sufficient to result in growth, and submergence is sufficiently long to maintain a productive community. The upper varial zone is confined by the wetting frequency resulting from hydro operations which can vary on an hourly basis. While modelling does suggest a weak correlation with depth, factors such as light intensity were not identified to be as important as other physical mechanisms in Site C reach. In future years, we continue to consider physical processes and subsequently use data models to develop a spatial model of productivity for the Peace River to determine the effects of Site C construction on reach-wide biomass of fish food organisms within, above at control sites, and downstream of the Site C site. Changes in fish food organism production will be determined by parameterizing a spatial model that can be run at any time following completion of the Site C dam. To develop the spatial model, invertebrate abundance and biomass, and periphyton abundance, biovolume, and chl-a are the best responses to consider reach-wide biomass because the effects of physical processes like velocity and submergence on these responses are understood. Areal and reach-wide biomass estimates of productivity will be developed following the last year of pre-flood data collection (2018). In future years, after predictive spatial models have been developed, the area and density of key invertebrate fish food items will be modelled to answer the management questions. Data collected next year (2018) will be used to help further develop and parameterize a spatial model of productivity to determine how, or if, production of fish food organisms in Site C Reach will be affected pre and post flood of the Site C Reservoir.
Q2. What is the change in production of fish food organisms in the Site C reach between years before and after construction of the Project? H2. The production of fish food organisms in the Site C reach will be the same between years before and after reservoir formation.	Since data for Mon-6 and Mon-7 were collected from primarily riverine sites in 2017 (with the exception of upstream reservoir control sites), the summary above for Mon-6 Q1 is directly applicable.
Mon-7 Management Questions	**Construction Year 3 (2017) Summary**

Q1. What is the change in areal biomass of fish food organisms in the Peace River between years, before, during and after construction of the Project? H1. Reach-wide biomass of invertebrates in the Peace River between the Project and the Many Islands area in Alberta will remain the same over time before, during, and after the construction of the Project.	Since data for Mon-6 and Mon-7 were collected from primarily riverine areas in 2017 (with the exception of upstream reservoir control sites), the above summary for Mon-6 is directly applicable.
Q2. What is the change in production of fish food organisms in the Peace River between years before, during and after construction of the Project? H2. The production of fish food organisms in the Peace River between the Project and the Many Islands area in Alberta will remain the same over time before, during, and after the development of the Project.	Since data for Mon-6 and Mon-7 were collected from primarily riverine areas in 2017, the Mon-6 summary is directly applicable.

Mon-17 Management Questions	Construction Year 3 (2017) Summary
How do changes in the hydrologic regime affect estimates of catchability used in the Peace River Fish Community Monitoring Program (Mon-2)? How do changes in the hydrological regime affect fish and fish habitat of the Peace River? H_2: Periphyton production among and within sites in the Peace River is independent of the magnitude and timing of flow fluctuations. H_3: Biomass of invertebrates (benthos) among and within sites in the Peace River is independent of the magnitude and timing of flow fluctuations.	Invertebrate and periphyton productivity are affected by the magnitude and timing of flows on the Peace River. The magnitude of flows determines the area of wetted habitat that create areas of periphyton and invertebrate growth or productivity. Work on other BC river systems was confirmed on the Peace - periphyton and invertebrates respond quickly to exposure. Only short durations of up to 24 hours in warm, dry conditions may cause significant reductions in the biomass or availability of food for fish. For this reason, the study design has used one hour intervals has to assess the effects of timing and magnitude of flows on periphyton and invertebrate productivity in the Peace River, pre and post flood. For invertebrates, abundance and biomass are the preferred responses for use to model productivity as it relates to flow timing and duration because the physical factors influencing productivity are better understood when compared to other metrics. For periphyton, abundance, biomass, chl-a and species richness are all possible candidate metrics to assess productivity because physical factors appeared to explain considerable variation when compared to other metrics. We will continue to investigate these physical factors that can influence productivity, and they will be subsequently used to develop a spatial model of productivity to answer Mon-17 management questions and hypotheses.

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Appendix A Detailed Site Maps

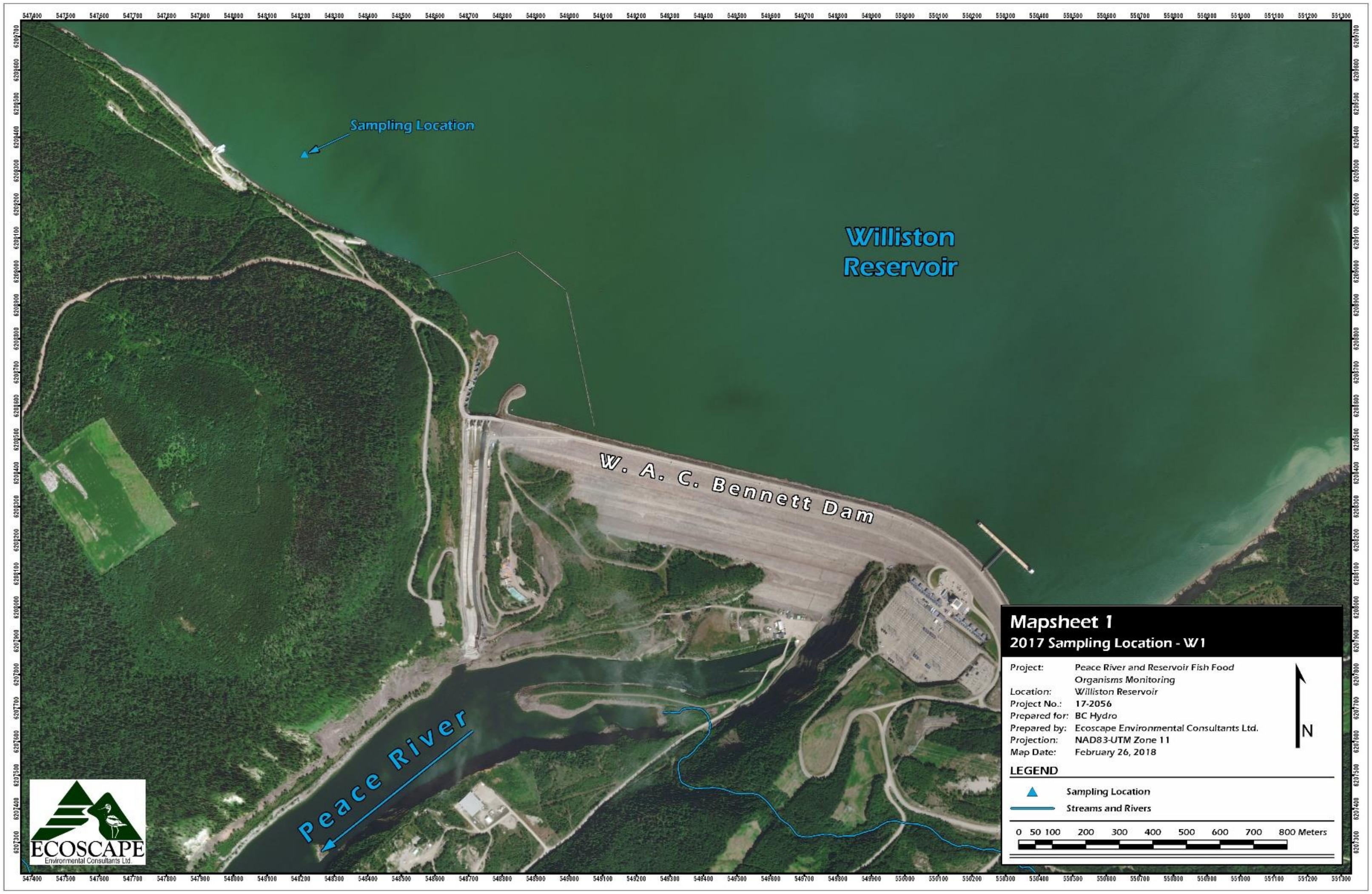


Figure A1 **Detailed Williston Site Location Map.**

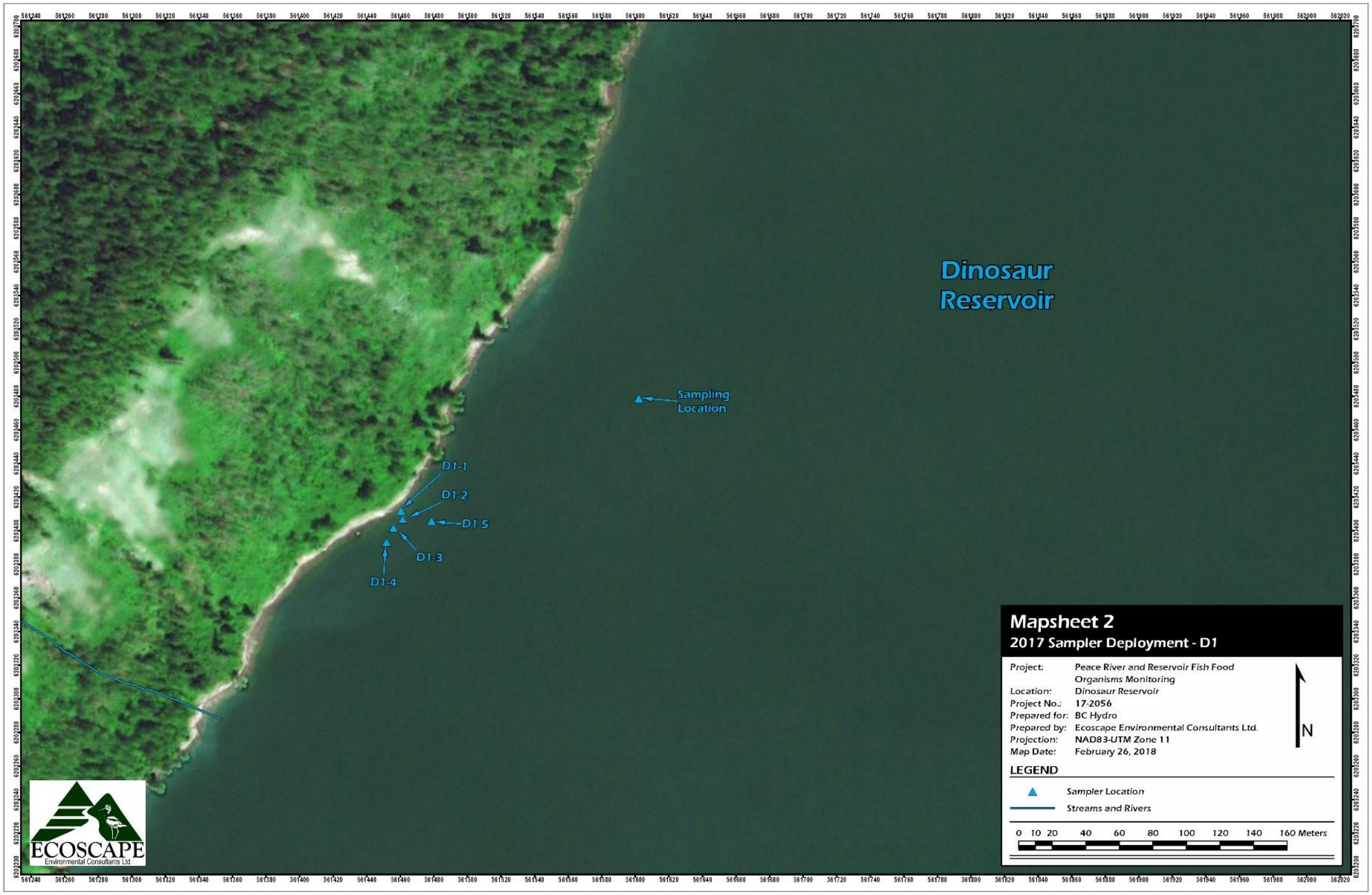


Figure A2 **Detailed Dinosaur Site Location Map.**

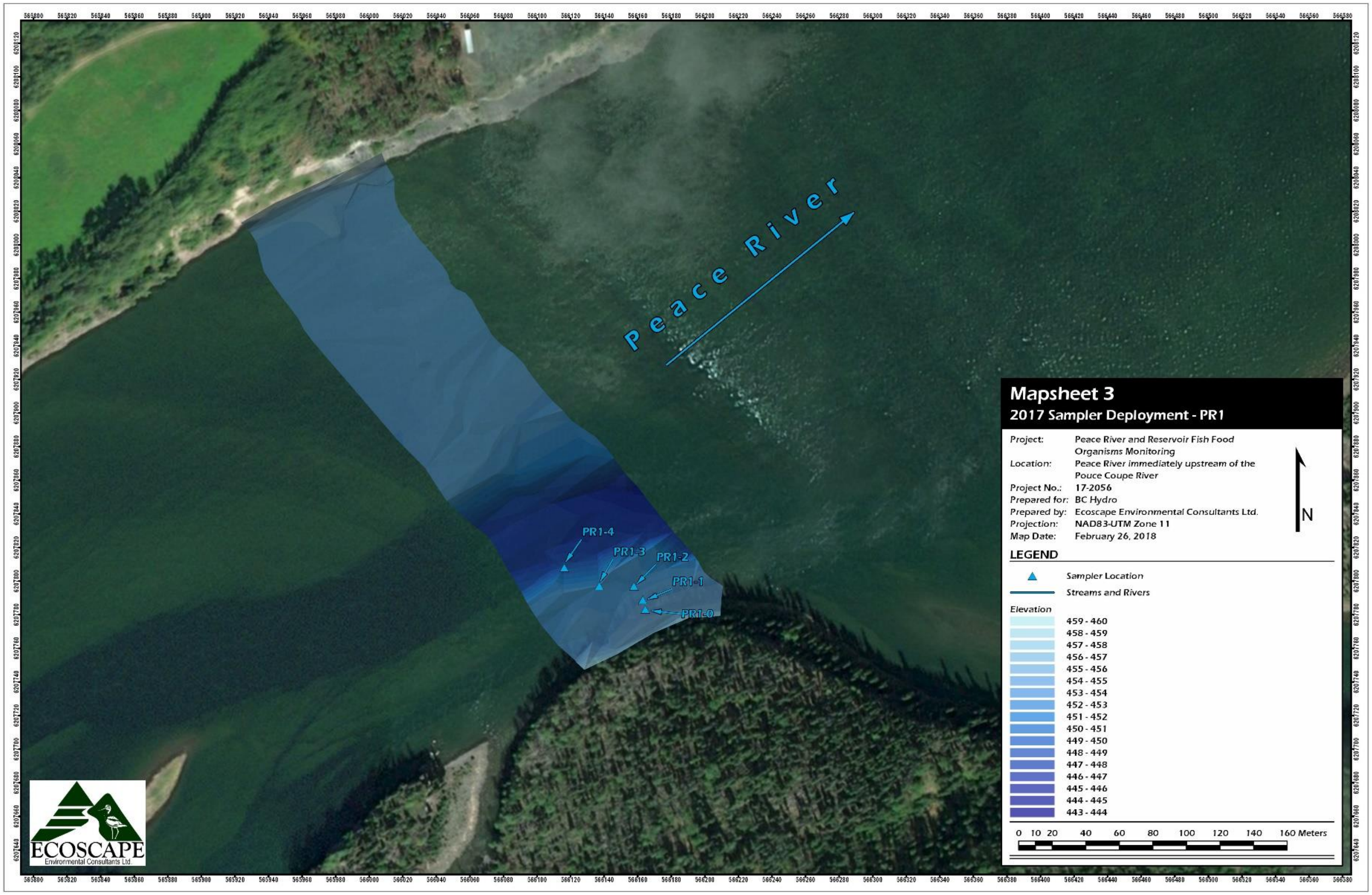


Figure A3 **Detailed PR1 Site Location Map.**

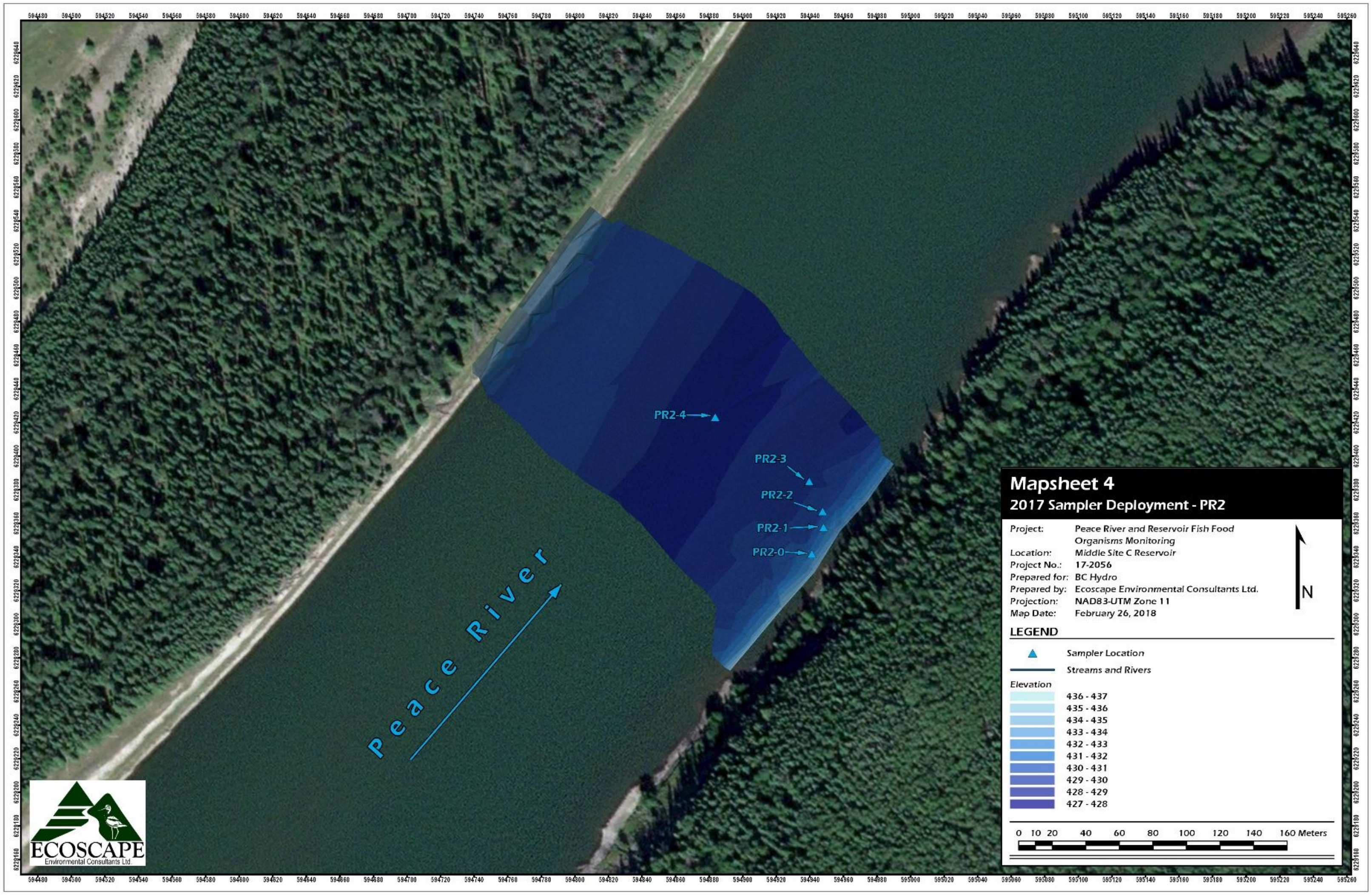


Figure A4 **Detailed PR2 Site Location Map.**

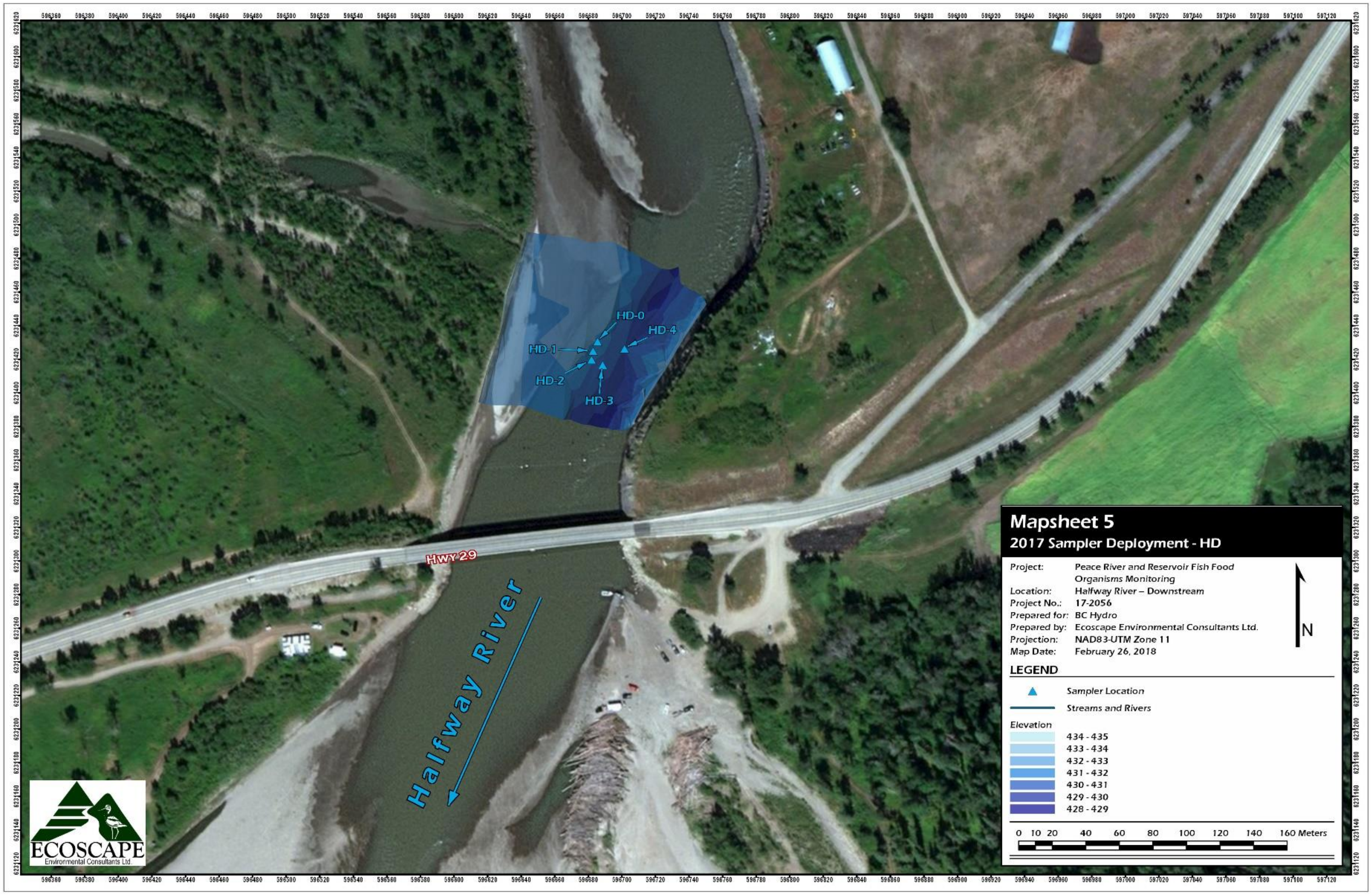


Figure A5 **Detailed HD Site Location Map.**

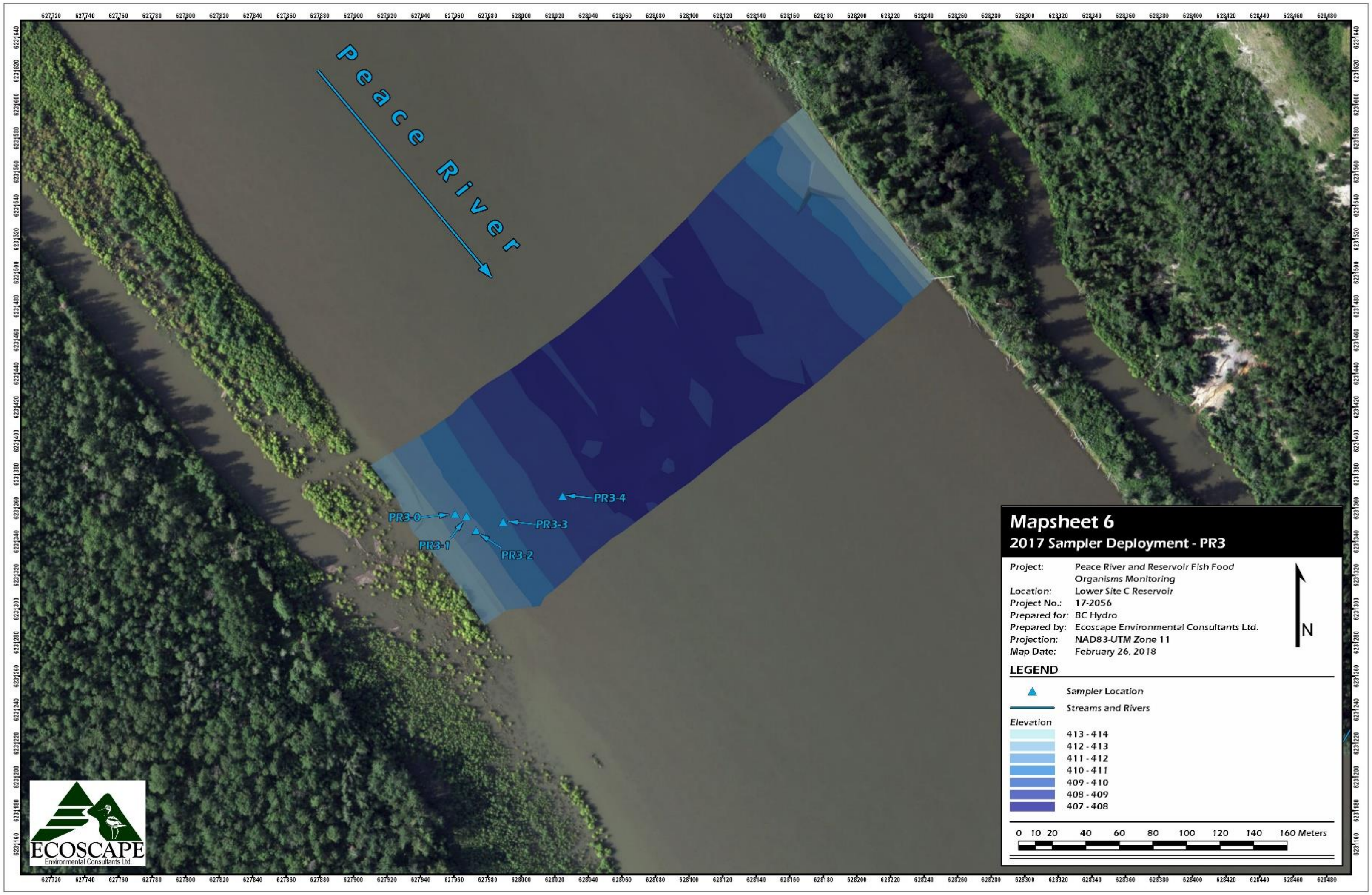


Figure A6 **Detailed PR3 Site Location Map.**

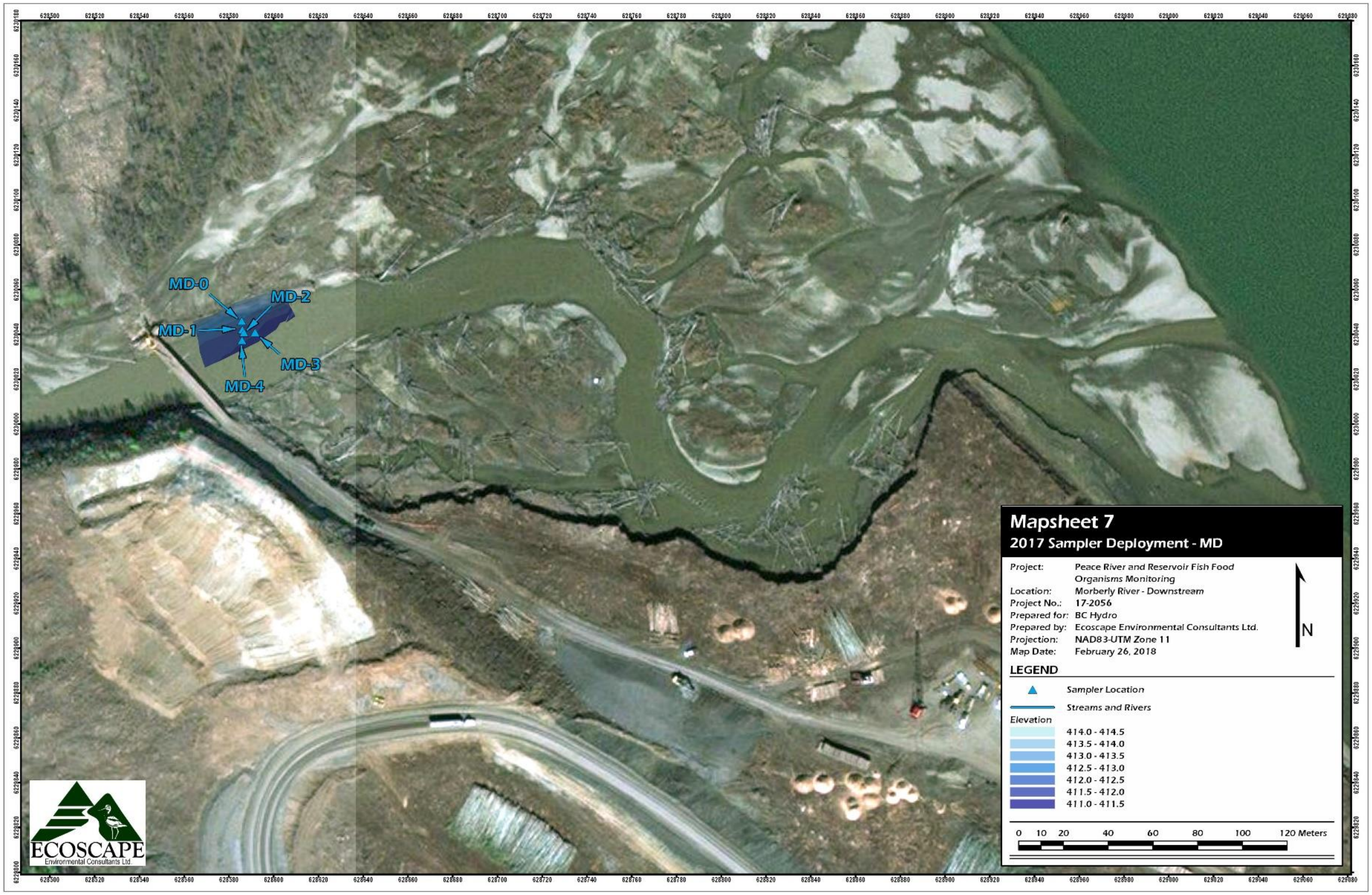


Figure A7 **Detailed MD Site Location Map.**

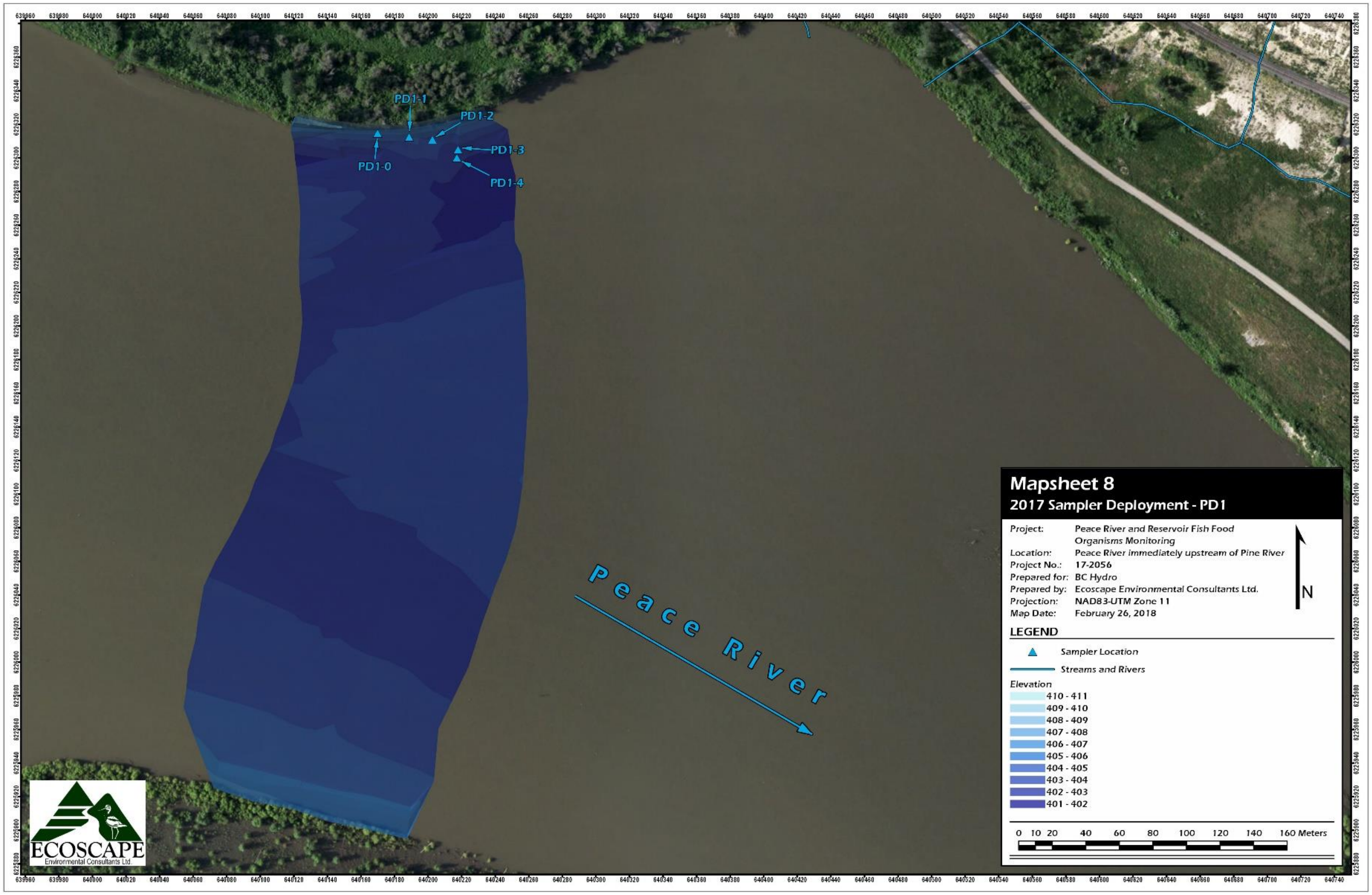


Figure A8 **Detailed PD1 Site Location Map.**

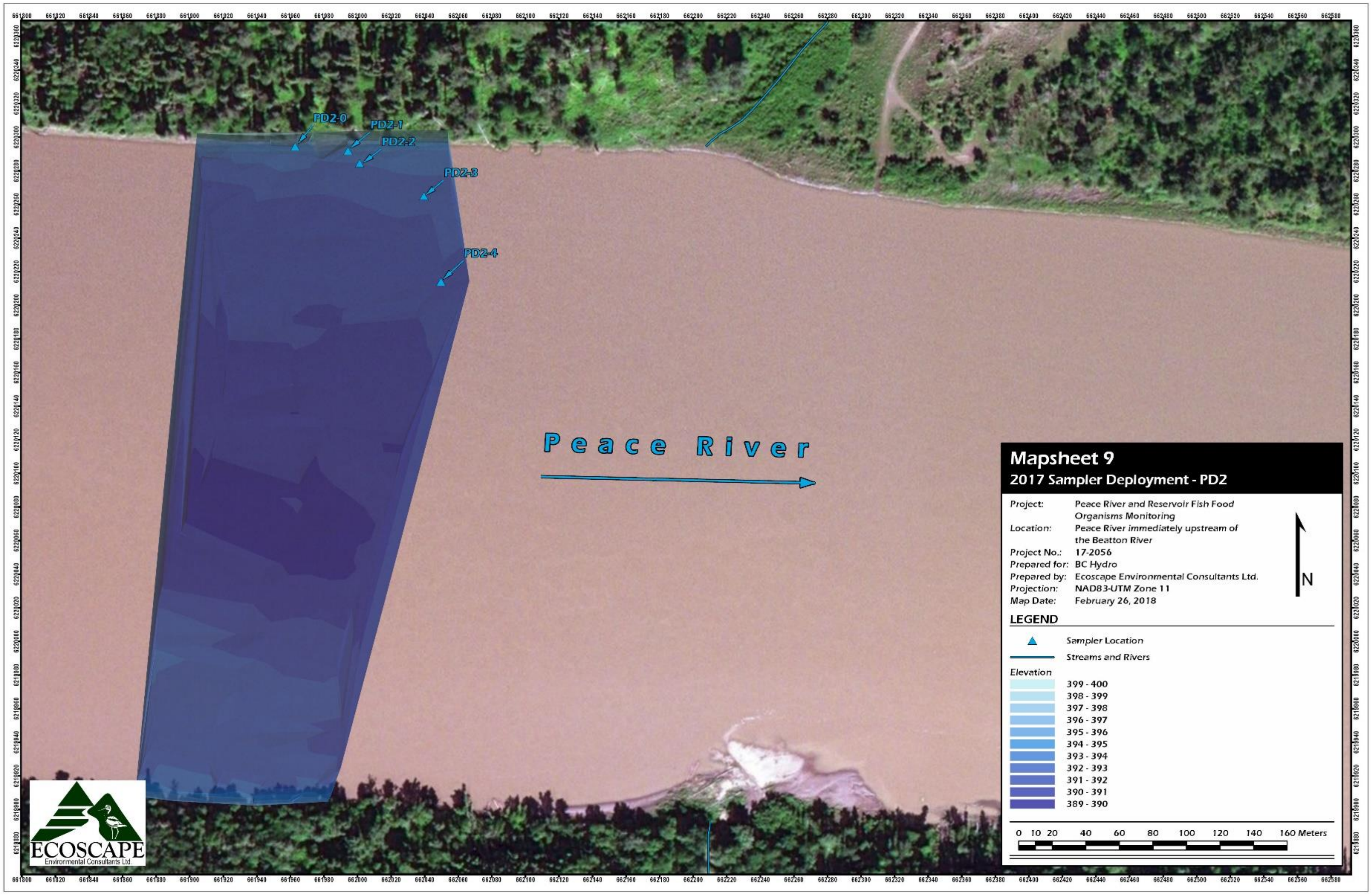


Figure A9 **Detailed PD2 Site Location Map.**

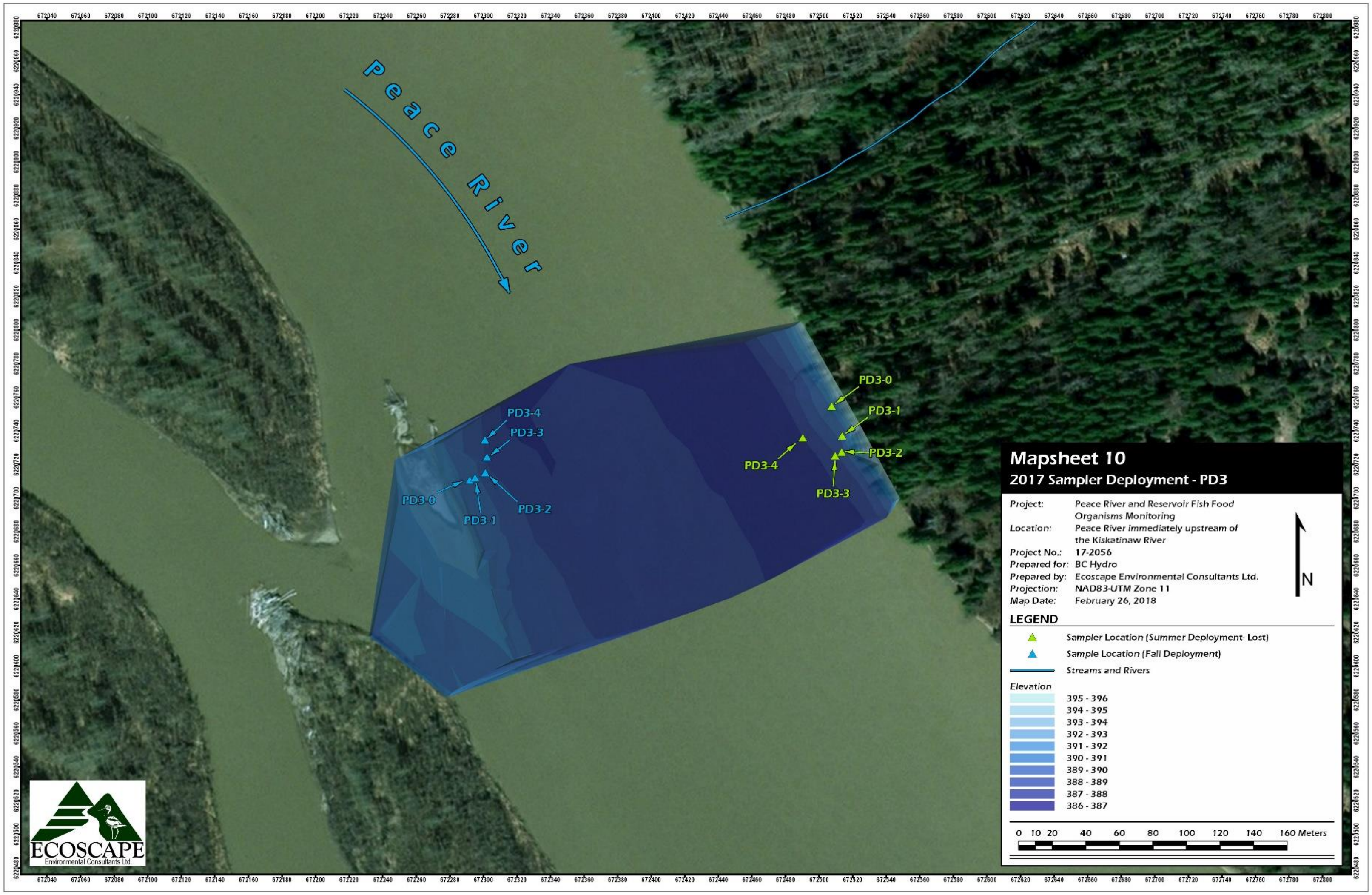


Figure A10 Detailed PD3 Site Location Map.

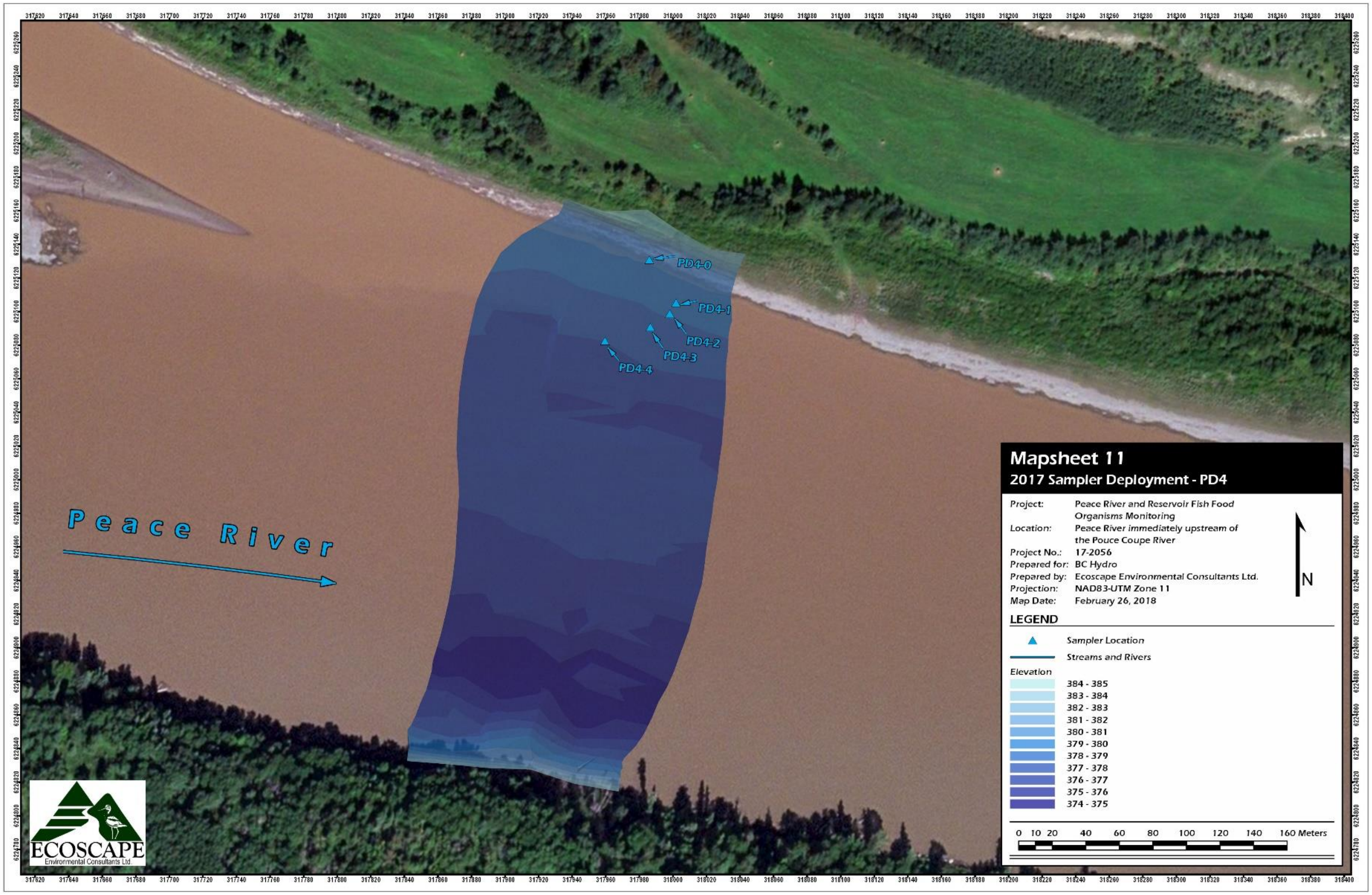


Figure A11 **Detailed PD4 Site Location Map.**

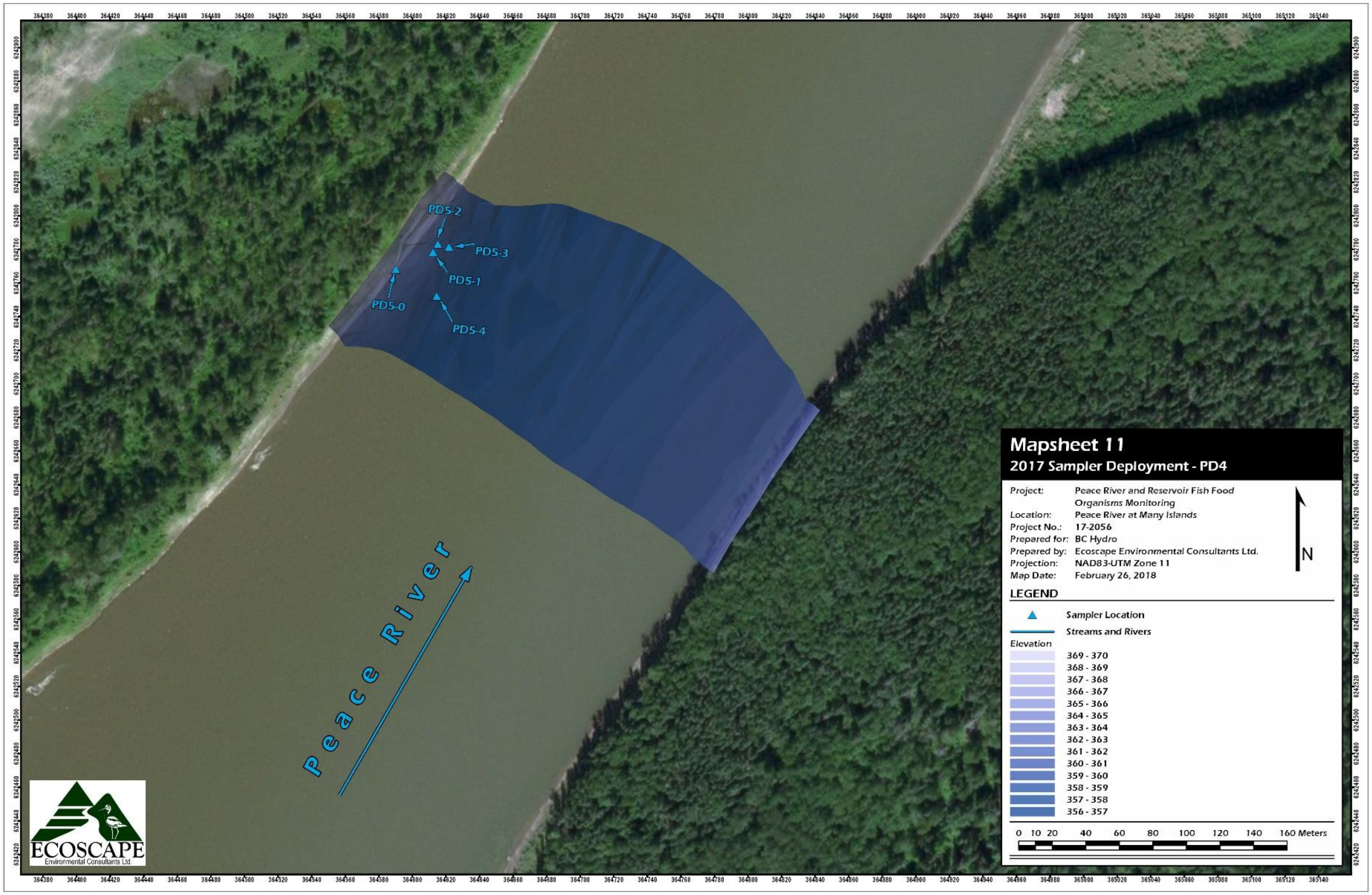


Figure A12 Detailed PD5 Site Location Map.

Appendix B Detailed Sampling Methods

Phytoplankton Sampling (Taxonomy and Chlorophyll-a)

A preferred method of determining reservoir productivity involves collecting a composite sample with a Van Dorn water sampler. Water samples were collected from three depths above the thermocline at the pelagic site in Willison Reservoir and at both the littoral and pelagic sites in Dinosaur Reservoir. Composite samples were collected from each site monthly between June and October 2017. The Van Dorn was used to collect three water samples from (1) 1 m depth, (2) the lower extent of the photic zone (field estimated as 1.7 times the Secchi depth) and (3) mid-way between these depths. These three samples were evenly (by volume) combined and mixed in a 4 L plastic bottle that was pre-marked to delineate the three volumes. Once the three samples were combined, the 4 L bottle was capped and inverted several times to thoroughly mix the water. One (1) litre of the sample was subsequently poured off into a 1 L plastic bottle for analysis. The bottle was labelled with the site name and date of collection. It was stored in the dark and chilled on ice until the end of the field day, when approximately half of the sample was filtered through a 0.45µm nitrocellulose filter. The volume of the filtered sample was recorded and the filter was folded into an aluminum foil cover to exclude light and stored on ice until submission to the laboratory for chlorophyll-a analysis. The remainder of the 1 L sample was fixed with Lugal's solution prior to storage at 4°C until it could be delivered to Larratt Aquatic for taxonomic identification, and biovolume / density determination.

Phytoplankton Vertical Hauls (Taxonomy)

Reservoir productivity was also determined using phytoplankton vertical hauls. Composite samples were collected from the pelagic site in Willison Reservoir and at both the littoral and pelagic sites in Dinosaur Reservoir monthly between June and October 2017. A 80 µm phytoplankton net was lowered to 1.7times the Secchi depth and pulled through the water at a speed of less than 1 m/second. The contents of the net were then rinsed into a 300 mL plastic container. The phytoplankton haul was repeated two more times with the contents of the additional pulls placed in the same container. The composite sample was fixed with Lugal's solution prior to storage at 4°C until it could be delivered to Larratt Aquatic for taxonomic identification, and biovolume / density determination. The phytoplankton hauls were useful to determine rare species and were also used as a backup for zooplankton taxonomy.

Zooplankton Vertical Hauls (Taxonomy and Biomass)

Reservoir zooplankton communities were sampled using a plankton net with a 500 mm diameter frame opening and a mesh size of 153 µm. Composite samples were collected from the pelagic site in Willison Reservoir and at both the littoral and pelagic sites in Dinosaur Reservoir monthly between June and October 2017. The wetted depth at each sample location was determined using the on-board depth sounder. The zooplankton net was then lowered to 2 m above the reservoir bed and slowly pulled vertically through the water column at a rate of 0.5 m/second. The contents of the net were placed into a 1 L plastic bottle. Three hauls were collected at each site and the contents combined as a composite. Once all three hauls were complete, the sample was fixed with 70% reagent alcohol. Organisms/m^3 was subsequently calculated (*total depth of the hauls • area of frame opening mouth*).

Artificial Substrates (Rock Baskets) for Benthic Invertebrate Community Analysis and Biomass

Benthic invertebrate communities were assessed using artificial substrate samplers (rock baskets). Rock baskets (planar area = 0.038m^2) were filled with pebble-sized rock (32-64 mm). Samplers were deployed for between 49 to 54 days in the summer and 52 to 58 days in the fall. Upon retrieval, the rock baskets were transferred immediately into a pre-labelled bucket of clean filtered river water. The baskets were opened in the bucket and all the rocks were individually scrubbed using a soft bristle brush to release clinging invertebrates. Washed rocks were then rinsed in the sample water and placed back in the basket and stored for future use. The contents from each bucket were captured on a 397 µm sieve, and rinsed into pre-labeled 500 mL plastic containers and preserved in 70% reagent alcohol prior to transport to Cordillera Consulting for taxonomic identification and community metrics.

Natural Substrate Sampling (Benthic Invertebrate Taxonomy and Biomass)

Natural depositional substrates were sampled using an Ekman dredge. This was done to allow consistent and paired sampling of riverine and future Site C reservoir conditions at sites PR1, PR2, PR3, HD, and MD. Samples were also collected from D1 littoral areas for comparison. Where possible, a composite of three sub-samples was batched into every sample analyzed, to account for variable sample size due to small sample volumes. The invertebrate samples were sieved in a wash bucket with a 250 micron mesh and transferred to a labeled sample bottle and preserved with 70% reagent alcohol.

Turbidity and Total Suspended Solids (TSS)

Turbidity loggers (YSI EXO Sonde by Xylem (Yellowsprings, OH, USA)) were deployed on the mid-depth samplers at the five sites downstream of the Project. Data were downloaded from loggers during the mid-deployment maintenance schedule, and the sondes/sensors were cleaned of sediment and recalibrated using turbidity standards. In-situ turbidity was also measured, using a Hach 2100P Turbidimeter (Loveland, CO, USA), at mid-sampler depth locations at all the riverine sites as well as in Williston and Dinosaur reservoir pelagic and littoral sites. Furthermore, turbidity was measured from cross-channel composite samples to compare spatial differences in turbidity across the river. The cross channel composite water sample was also retained (1 L) and submitted for analysis of total suspended solids (TSS).

Reservoir PAR Profiles

Photosynthetically active radiation was profiled in the pelagic and littoral reservoir sites as well as the thalweg of the Peace River at each of the riverine sample sites. The sensor was affixed to a cannonball and downrigger containing a fin to maintain the vertical aspect of the sensor in current and drift. In the reservoir, PAR readings were measured at the water surface and at 1 m depth intervals whereas 0.5 m intervals were measured in the river.

Reservoir Temperature Thermistor Profiles

Two thermistor lines with six light/temperature loggers each were constructed to inform the temperature/light profiles of the Williston and Dinosaur reservoirs. Each thermistor line was deployed in approximately 20 m depth and constantly they recorded data from June through

October. The thermistors were concentrated in the photic zone depths, with one thermistor at mid-depth and one near the 20 m depth on each line.

Detailed Classification of Reservoirs

The following table provides an overview of ranges in productivity for comparison of the upstream control reservoirs and for the future Site C reservoir, in relation to other BC lakes.

Table A1 General Estimates of reservoir annual primary productivity

Trophic status productivity	Production of organic carbon
Productive – eutrophic cold	0.15 – 0.5 kg C/m²/yr (1500 – 5000 kg C/ha/yr)
phytoplankton	200 - 2000 kg C/ha/yr
periphyton	20 - 1000 kg C/ha/yr
aquatic macrophytes	1170 kg C/ha/yr
riparian vegetation	not available
Mesotrophic - typical BC lake	0.05 - 0.15 kg C/m²/yr (500 - 1500 kg C/ha/yr)
phytoplankton	100 - 400 kg C/ha/yr
periphyton	1000 kg C/ha/yr
aquatic macrophytes	500 kg C/ha/yr
riparian vegetation	not available
Oligotrophic – D1 W1 sites	0.01 – 0.05 kg C/m²/yr (100 – 500 kg C/ha/yr)
phytoplankton	47 - 80 kg C/ha/yr
periphyton	400 kg C/ha/yr
aquatic macrophytes	180 kg C/ha/yr
riparian vegetation	not available

Wetzel 2001, Table 19-7 – 10 convert kg C to kg organic matter (OM = 46.5% C)

Appendix C Proposed Spatial Productivity Model

Since invertebrates and periphyton are affected by as little as a few hours of exposure during dry weather, the spatial model will use hour as the lowest time increment, allowing it to consider short-term deviations in operations. Eventually, it is possible that with ongoing investment, this spatial model could be developed to the point where decisions about consequences of flow augmentation are considered in real time. Key features of the proposed conceptual model include:

1. Light intensity on the river bed can be used as a predictor in the spatial productivity model, using a combination of turbidity and depth. Recent works by Davies-Colley and Nagels (2008) provide a useful method to correlate turbidity with light penetration. By collecting in situ turbidity data, field point samples for PAR, depth data at each site, and using light data from sensors on the deployment plates, we plan to model this parameter and include it as a key variable in the spatial model. Understanding the relationship between light, depth, turbidity, and productivity was a main focus in 2017.
2. Velocity is another potential predictor to consider in the spatial productivity model. Velocity is frequently identified as an important factor influencing periphyton and invertebrate productivity. Recent works by Ateia *et al.* (2016) provide a nonlinear model that links the effects of near-bed velocities and periphyton growth, where we can use growth/accrual data collected in these works to modify these curves as necessary. Using a combination of river elevations models, we believe we can determine a reasonable estimate for velocities under different flows. If contracted, we would discuss the best approach on how to integrate existing BC Hydro velocity/flow data for project efficiency. In 2017, we focused on how velocity could be added to a spatial model of productivity.
3. Seasonal productivity is related to temperature, which is a direct measure of growing conditions for which continuous data will be collected.

The following presents our preliminary spatial productivity model. The base model consists of a logistic growth curve, with the base model supported by works on the Columbia River, and in other papers of periphyton and invertebrate growth. In constant environments, periphyton growth can be modelled using the simple logistic model (Ateia et al. 2016; Schleppe et al. 2015).

$$\frac{dP}{dt} = \mu_{max} \cdot P\left(1 - \frac{P}{P_{max}}\right)$$

where P is the periphyton at time t, dP/dt is the net rate of growth, μ_{max} is the maximum growth rate at the reference conditions, and P_{max} is the carrying capacity.

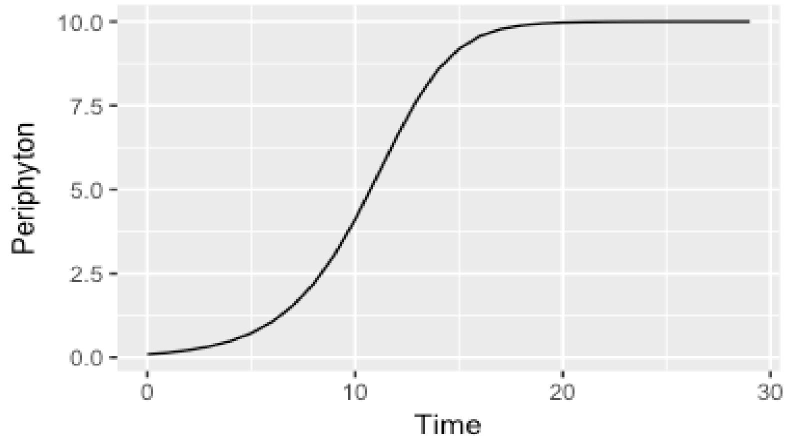


Figure A13 Conceptual logistic growth curve with $\mu_{max} = 0.5$ and $P_{max} = 10$

A death curve, resulting from substrate exposure to air, is an exponential decay function and was generating using data from the Columbia River. (Schleppe et al. 2015). Schleppe et al. (2015) accounted for the effect of exposure to air by collecting data and using literature summaries to understand how mortality occurs in the varial zone. In this work, and supporting work on the middle Columbia River, substrate exposure to air was deemed to be the most important determinant of periphyton and invertebrate biomass in regulated rivers. The function to be used for Mon-17 will be similar to the following:

$$\frac{dP}{dt} = -\lambda_A \cdot P.$$

In the case of the Peace River, we propose to incorporate density, light (I) and water temperature (T) dependent growth components from Uehlinger et al. (1996) with the velocity-based (υ) growth dependency from Ateia et al. (2016) and the exponential decay from Schleppe et al. (2015) to produce the following model:

$$\frac{dP}{dt} = P \begin{cases} \mu_{max} \cdot \dfrac{1}{1 + k_{P,inv}.P} \cdot \dfrac{I}{I + k_I} \cdot exp(\beta_T(T - T_0)) \cdot \dfrac{\upsilon}{1 + upsilon}, & \text{if } D > 0 \\ -\lambda_A, & \text{if } D = 0 \end{cases}$$

where

$$I = exp(-\lambda_D \cdot D \cdot N)$$

and

$$\upsilon = exp(\beta_{V1} V + \beta_{V2} V^2)$$

and D is the depth, N is the turbidity and V is the velocity.

If indicated by data from the Peace River, we will incorporate losses due to scour at high velocities. The model will also examine whether additional factors not captured by the physical parameters of water temperature, depth, velocity, light and turbidity are also affecting growth. We will test for the effects of channel type and season.

The water temperature (T), surface light (S) and turbidity (N) data will be continuously monitored (hourly) at fixed stations while the velocity (V) and depth (D) at the substrate will be estimated from the discharge using the HEC RAS or River2D model outputs. Discrete measurements of the light across a range of depths and turbidities will also be collected.

The parameters μ_{max}, $k_{P,inv}$, k_I, β_T, β_{V1}, β_{V2}, λ_D and λ_A will be estimated from the data using maximum likelihood and/or Bayesian models as appropriate based on the amount of data, existing uncertainties and missing values. The parameters will be estimated separately for three different periphyton metrics: abundance, chlorophyll-a and biovolume.

The result will be a model(s) which allows the hourly productivity (in terms of periphyton abundance, chlorophyll-a or biovolume) and invertebrate productivity (abundance or biomass) to be estimated through time for a patch of river under any discharge regime, like those constructed by Ecoscape for the Columbia Power Corporation (Schleppe et al. 2015). Due to the fine temporal and spatial scales, estimation of depths and velocities and predictions of productivity will require substantial computational resources.

Appendix D River Station Elevation Plots

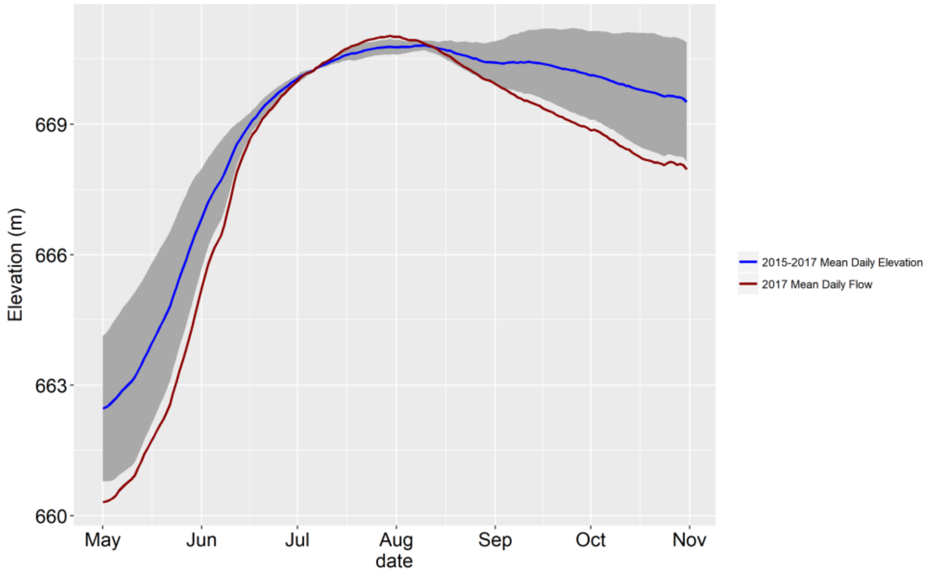


Figure A14 Water Elevations in Williston Reservoir at Williston Forebay 1.

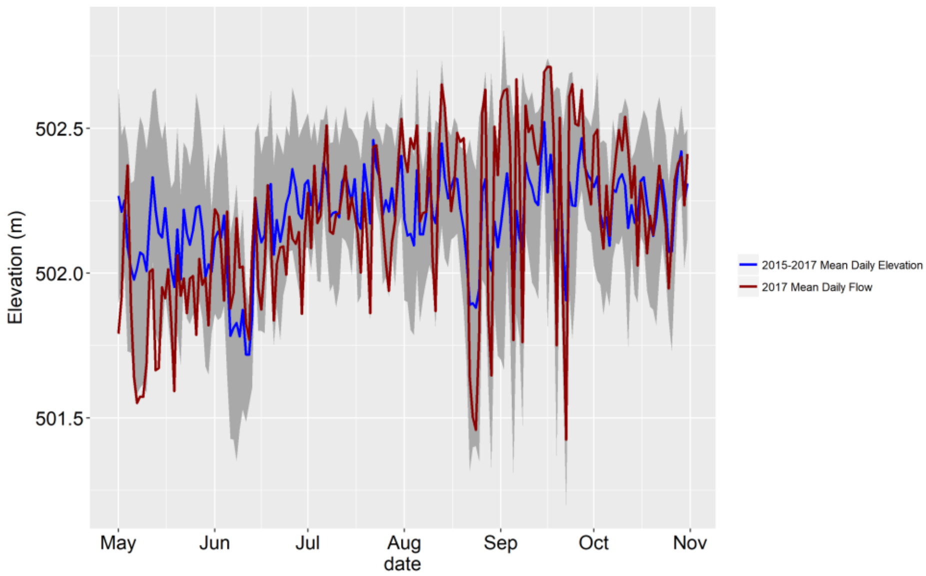


Figure A15 Water Elevations in Dinosaur Reservoir at Dam Forebay.

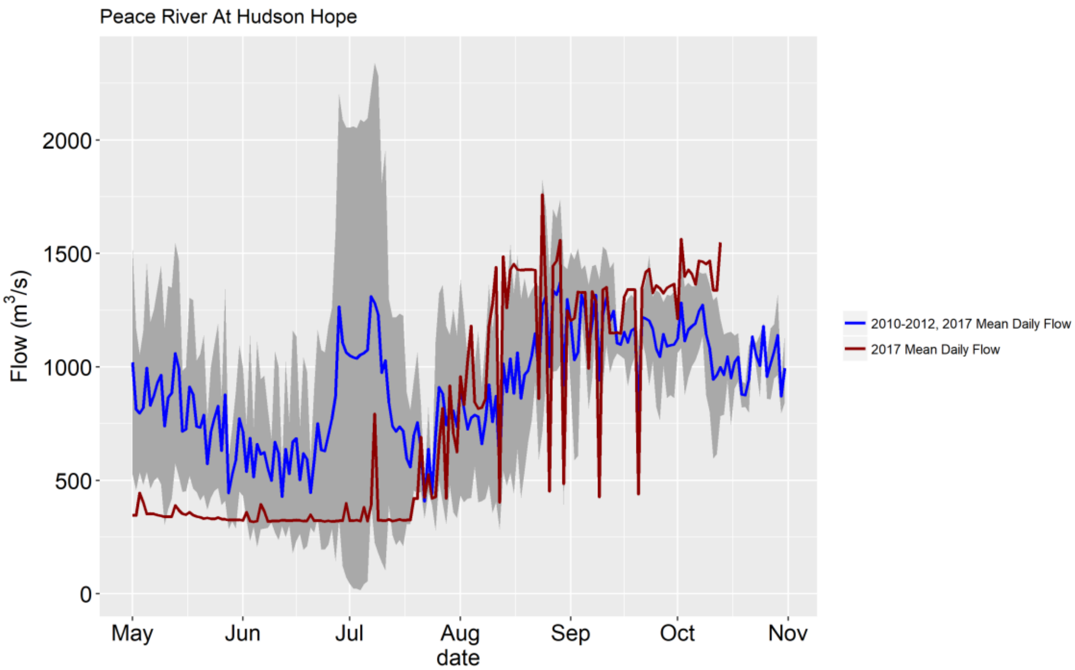


Figure A16 Flows in Peace River at Hudson's Hope (07EF001).

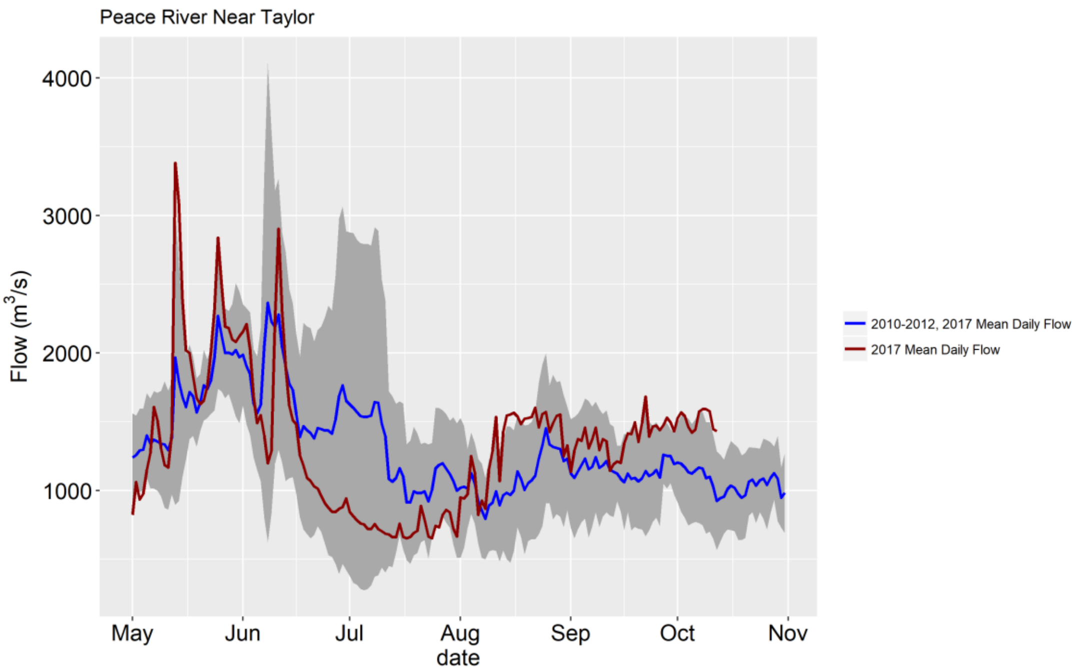


Figure A17 Flows in Peace River near Taylor (07FD002).

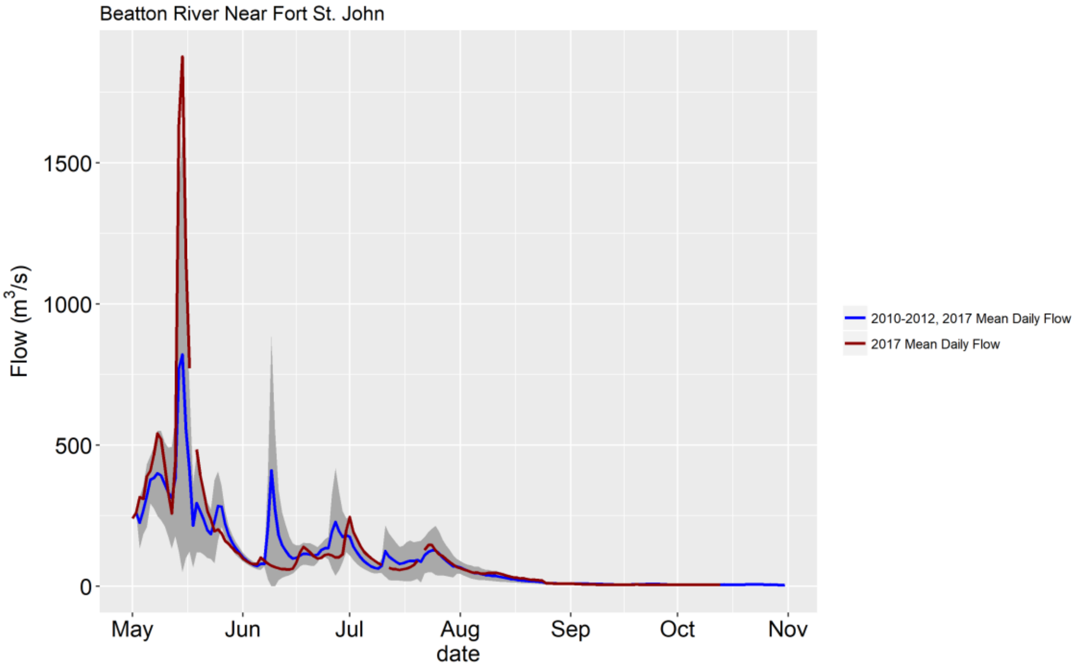


Figure A18 Flows in the Beatton River near Fort St. John (07FC001).

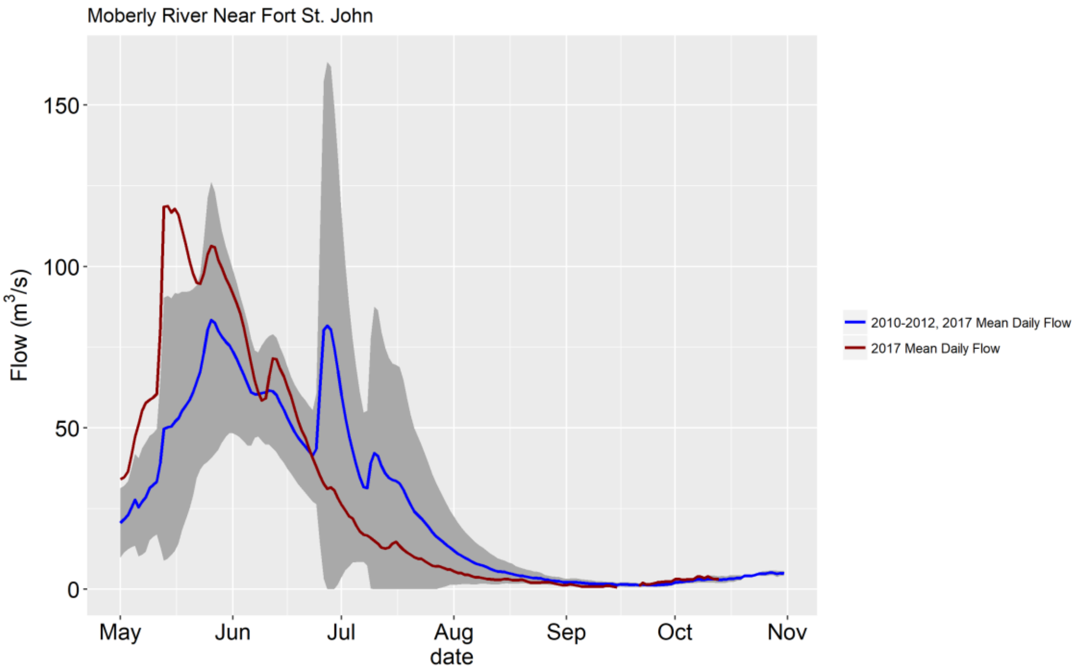


Figure A19 Flows in Moberly River near Fort St. John (07FB008).

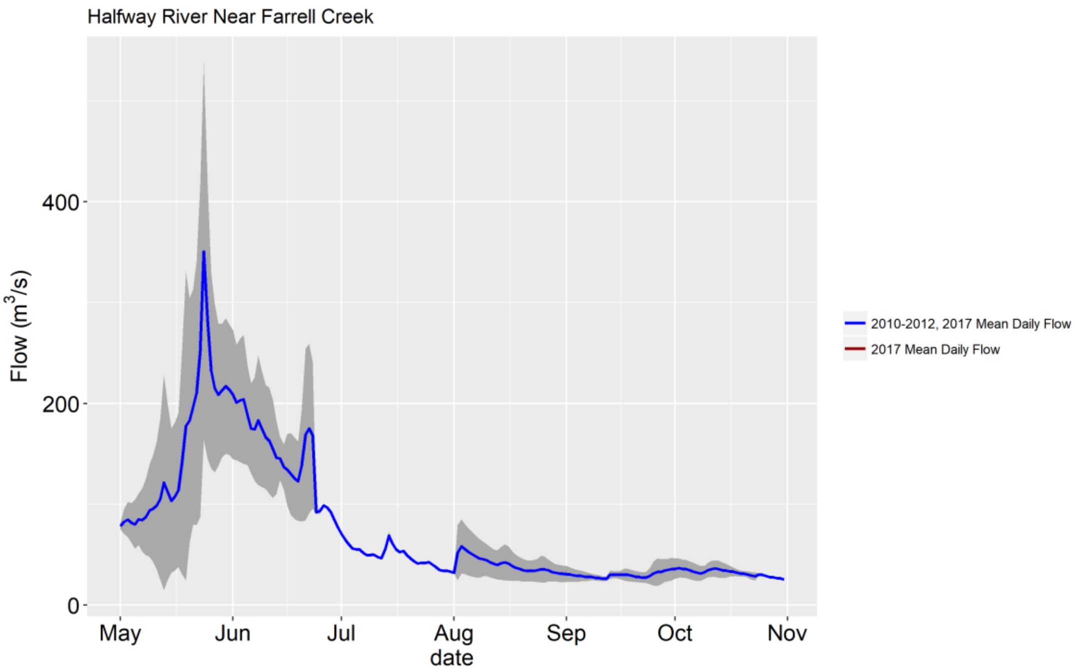


Figure A20 Flows in Halfway River near Farrell Creek (07FA006).

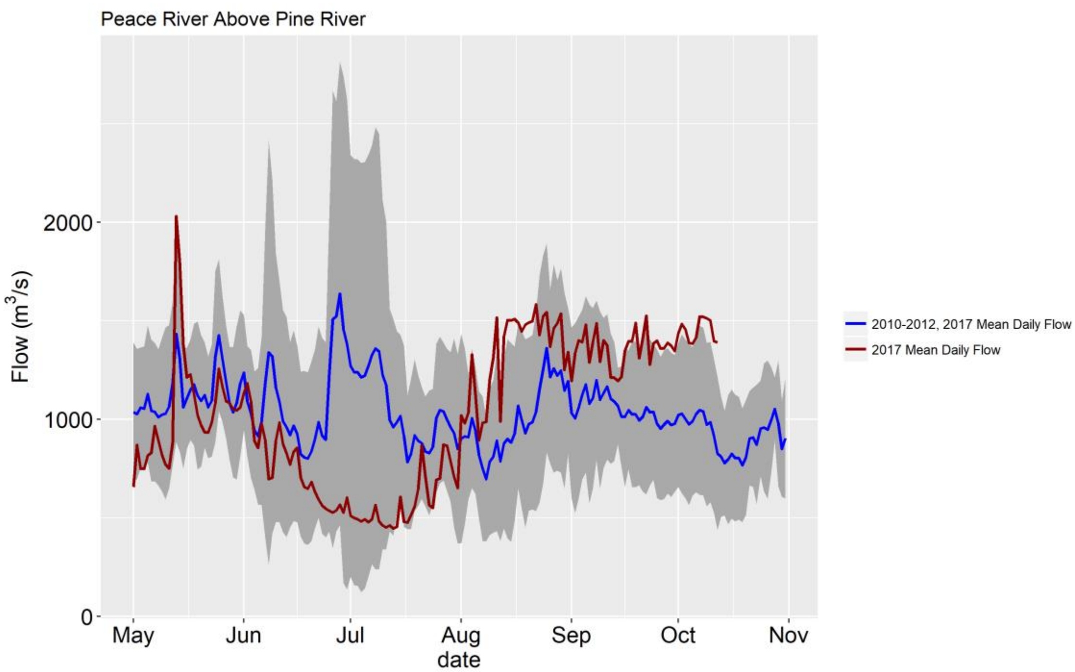


Figure A21 Flows in Peace River above Pine River (07FA004).

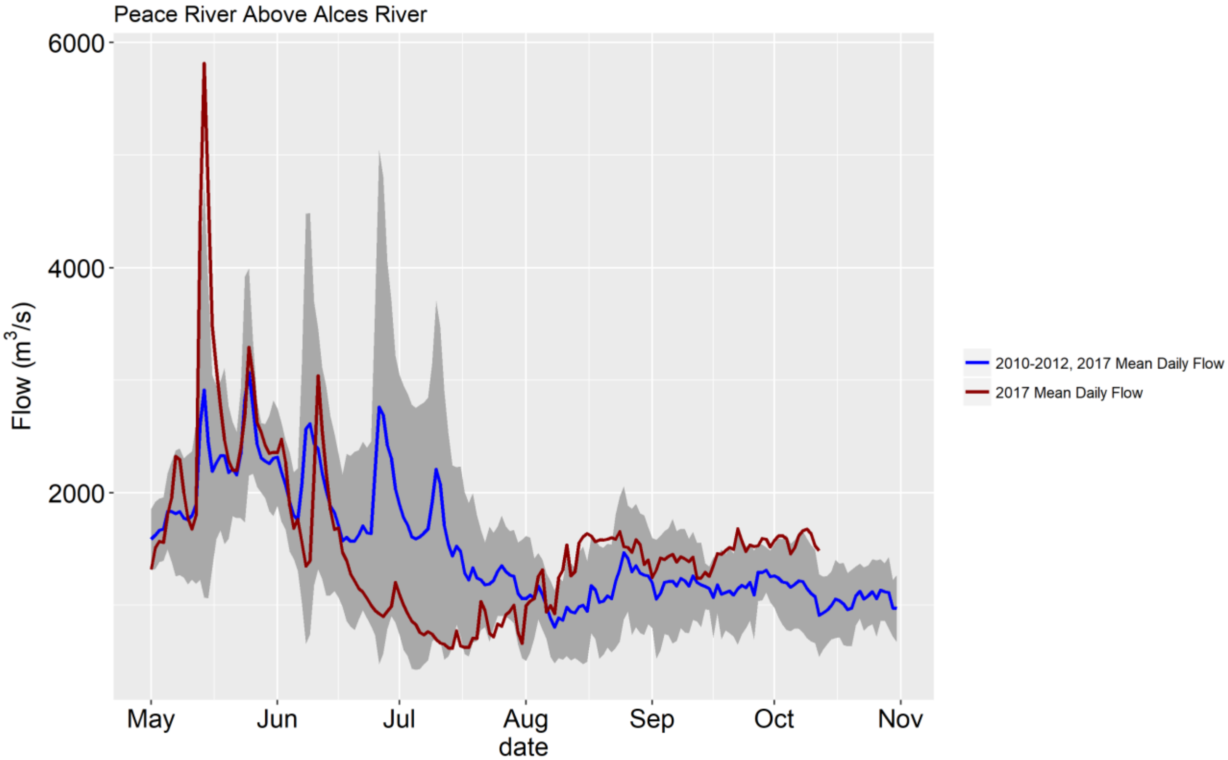


Figure A22 Flows in Peace River above Alces River (07FD010).

Appendix E Site Depth Plots

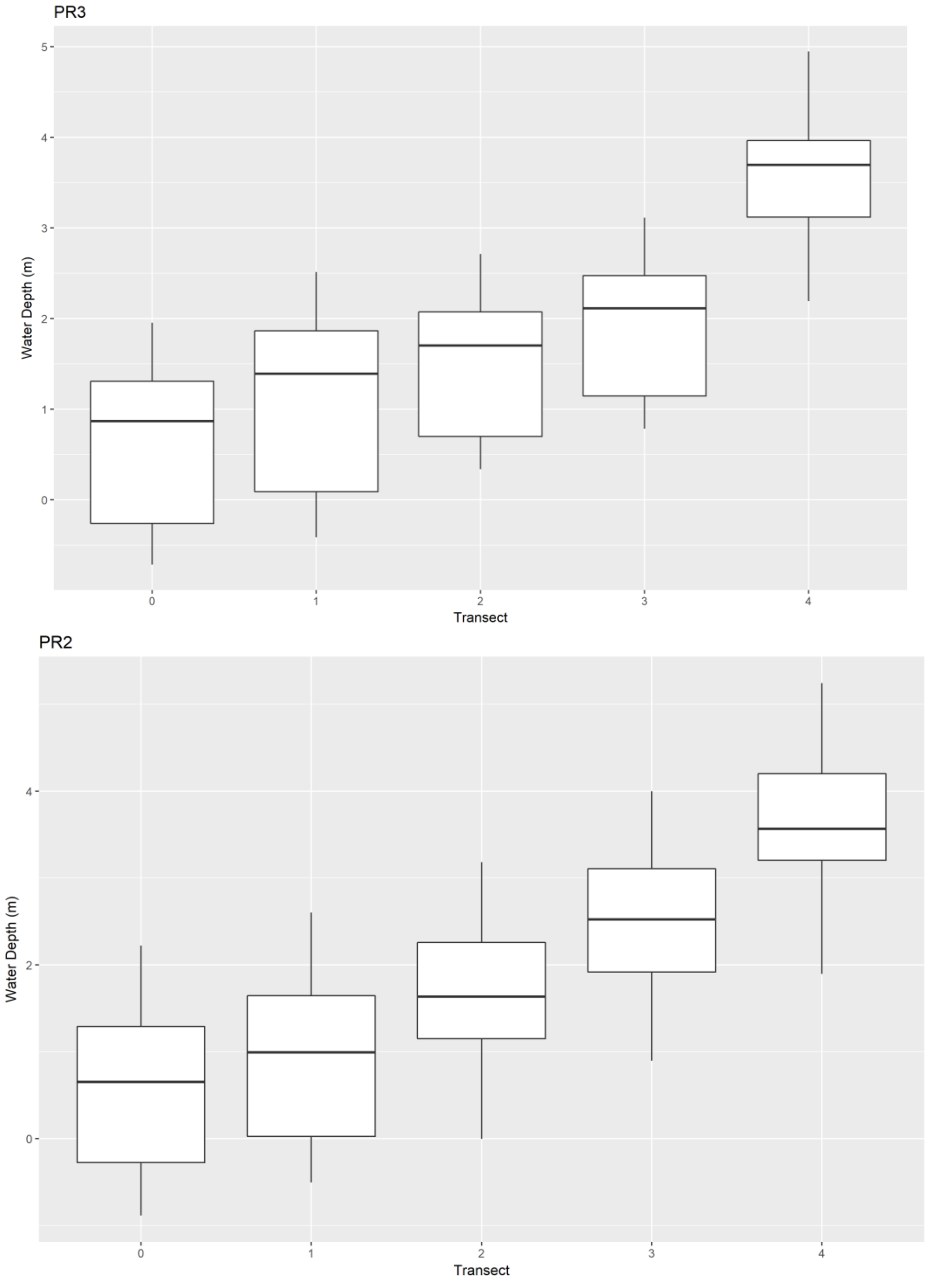


Figure A23 Boxplots of mean daily water depth for summer and fall 2017 sampling periods at each transect position in PR2 and PR3

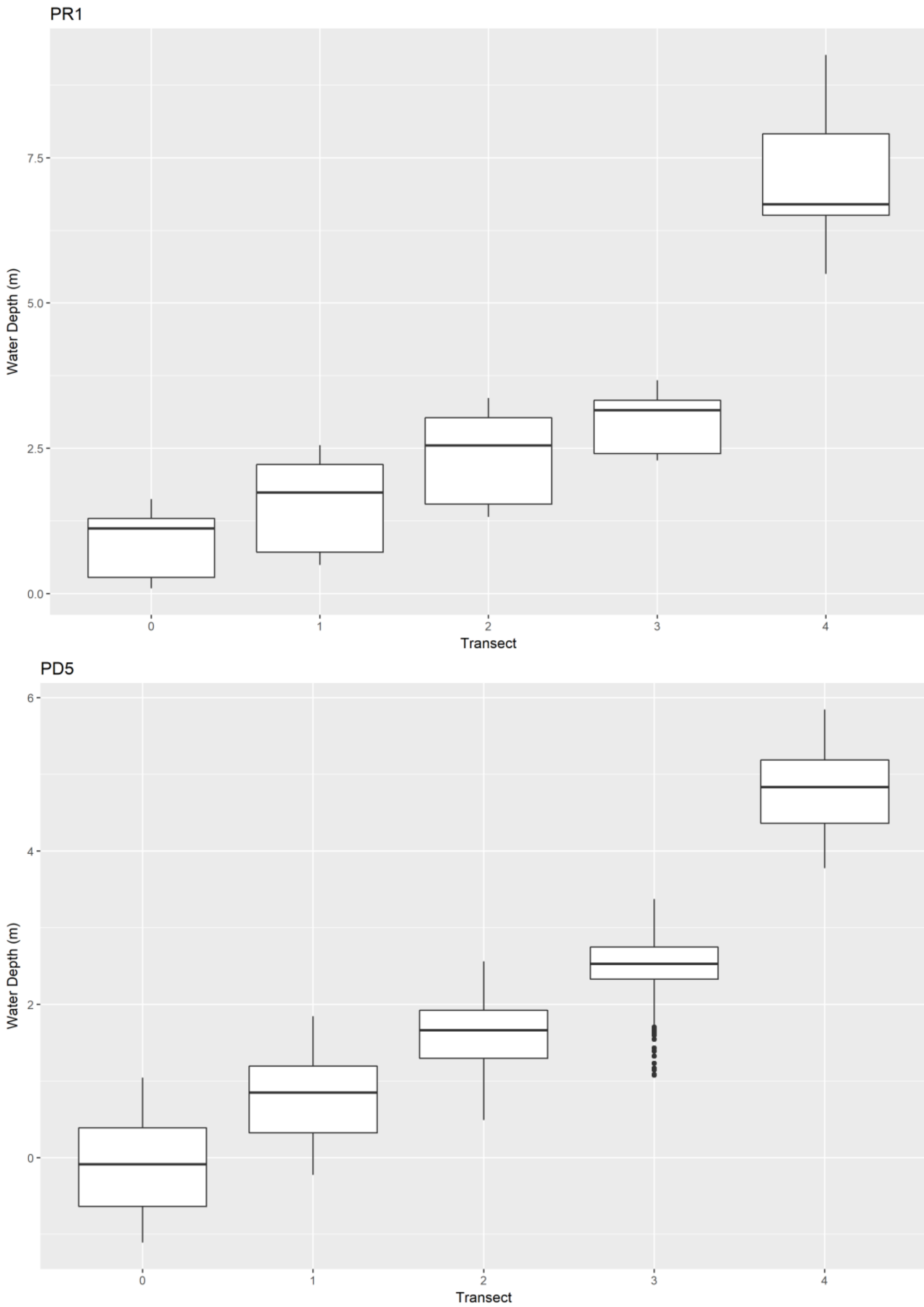
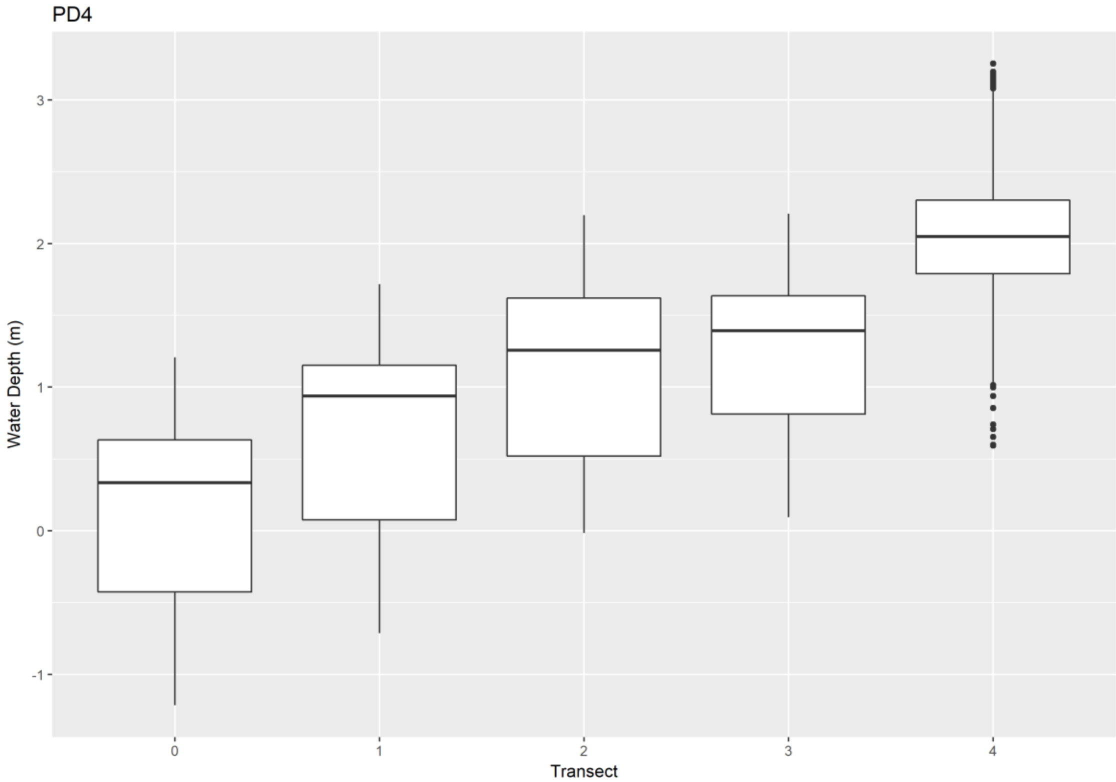


Figure A24 Boxplots of mean daily water depth for summer and fall 2017 sampling periods at each transect position in PD5 and PR1.



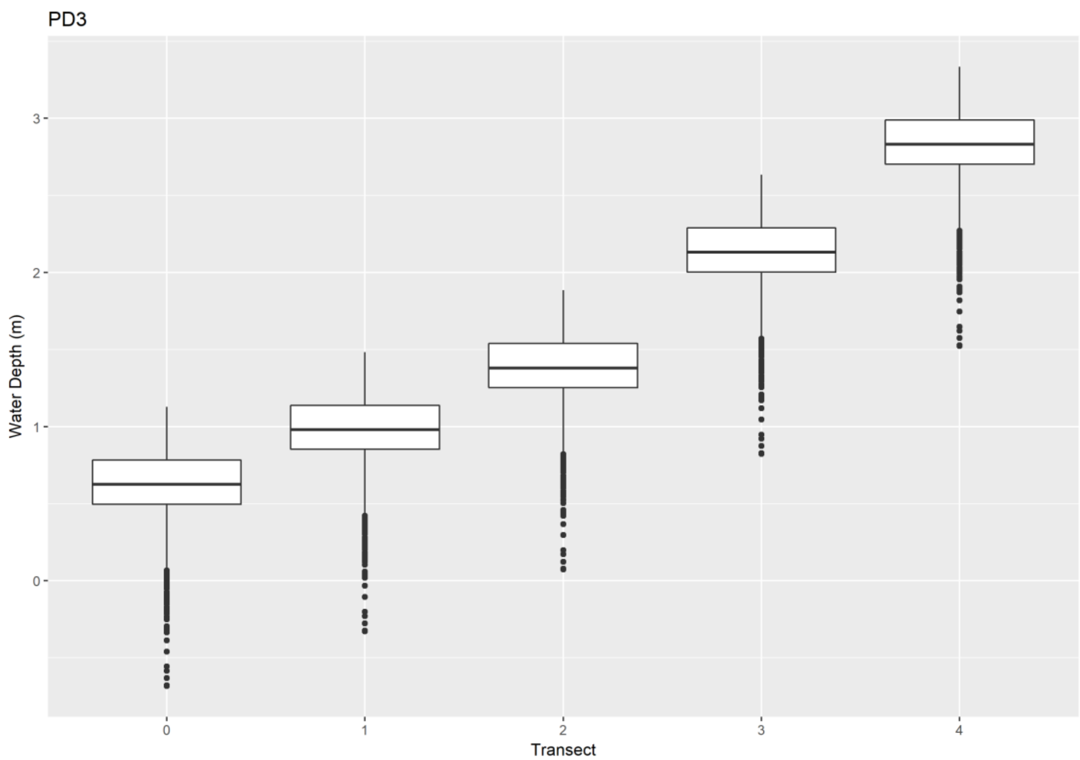
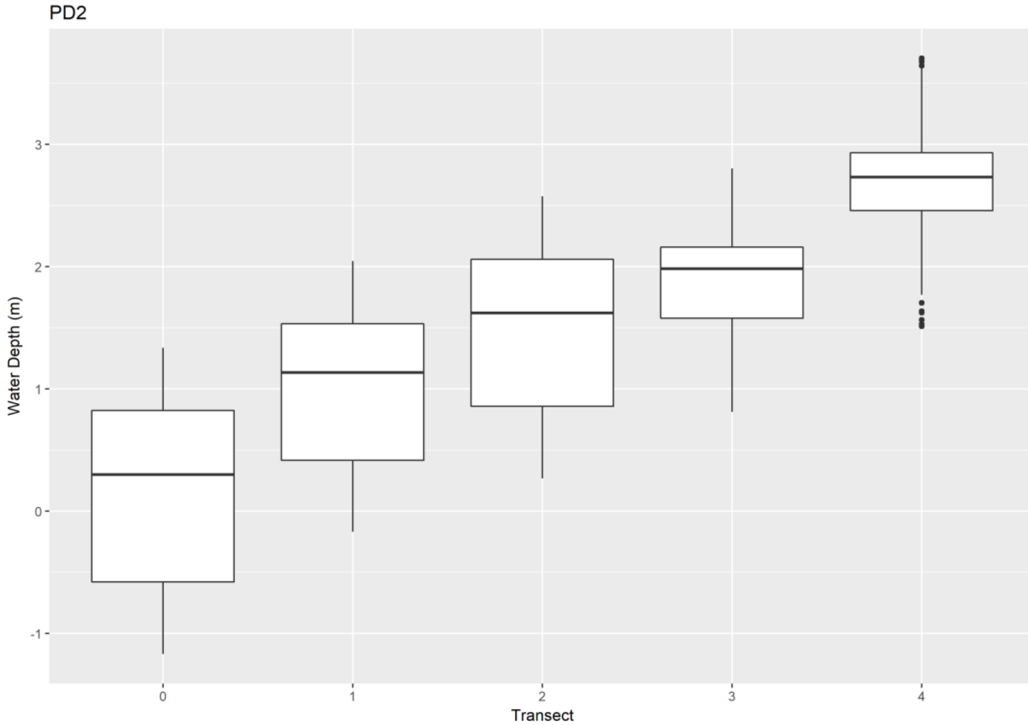


Figure A25 Boxplots of mean daily water depth for summer and fall 2017 sampling periods at each transect position in PD3 and PD4.



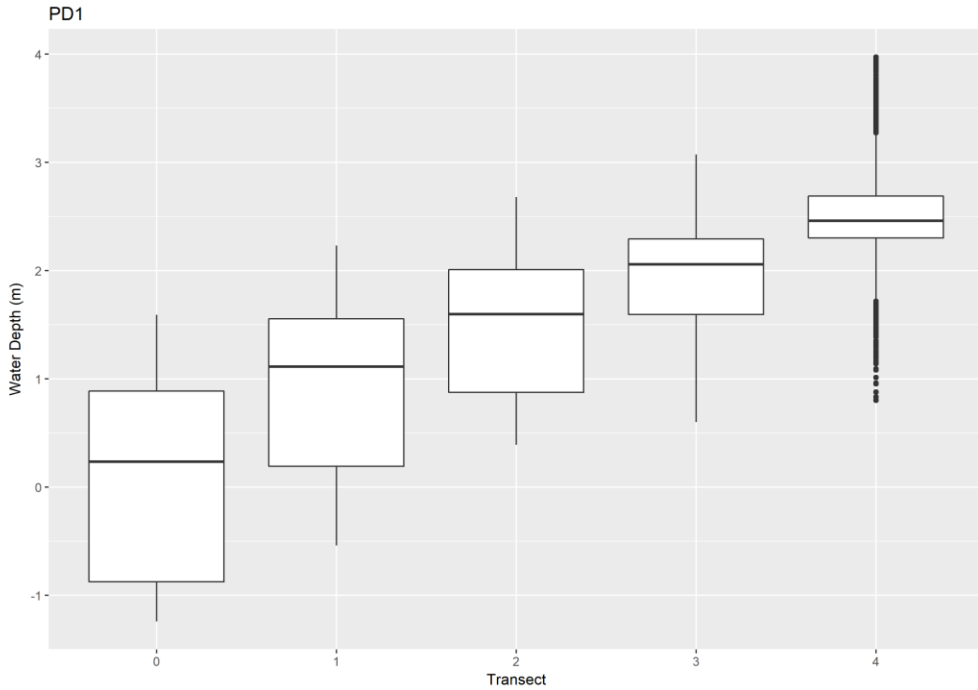


Figure A26 **Boxplots of mean daily water depth for summer and fall 2017 sampling periods at each transect position in PD1 and PD2.**

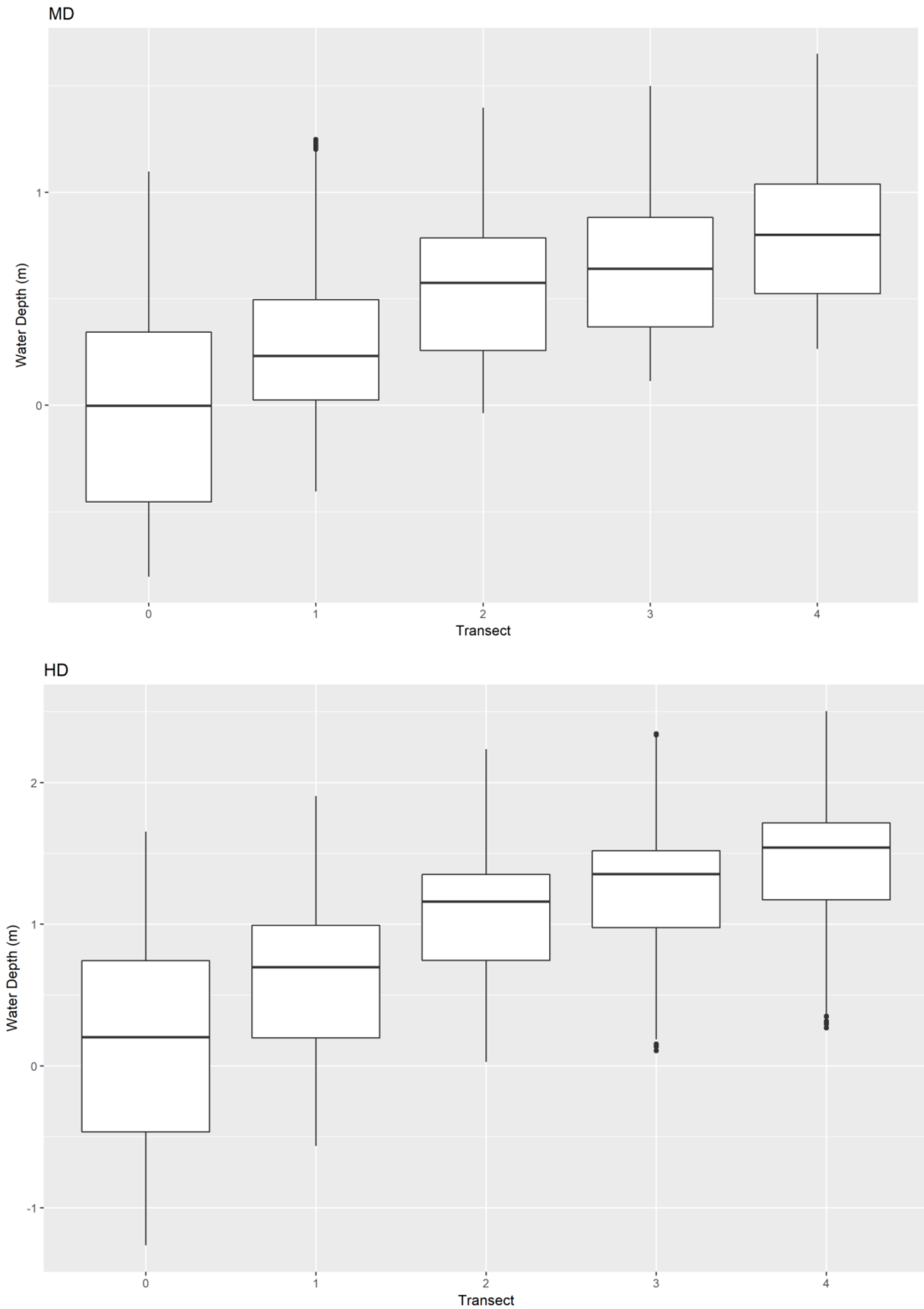


Figure A27 **Boxplots of mean daily water depth for summer and fall 2017 sampling periods at each transect position in HD and MD.**

Appendix F Light Plots

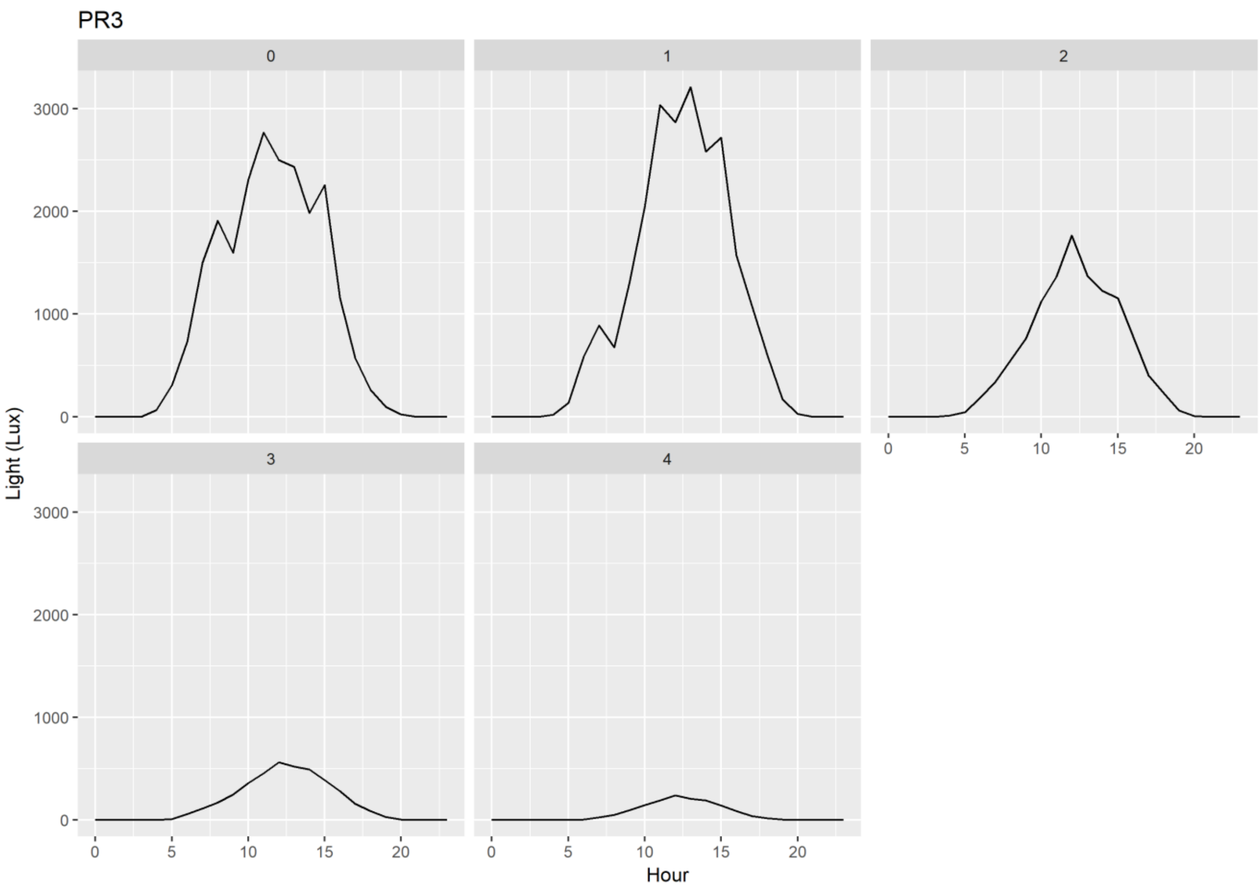


Figure A28 Average daily light intensity at PR3 over the duration of deployment.

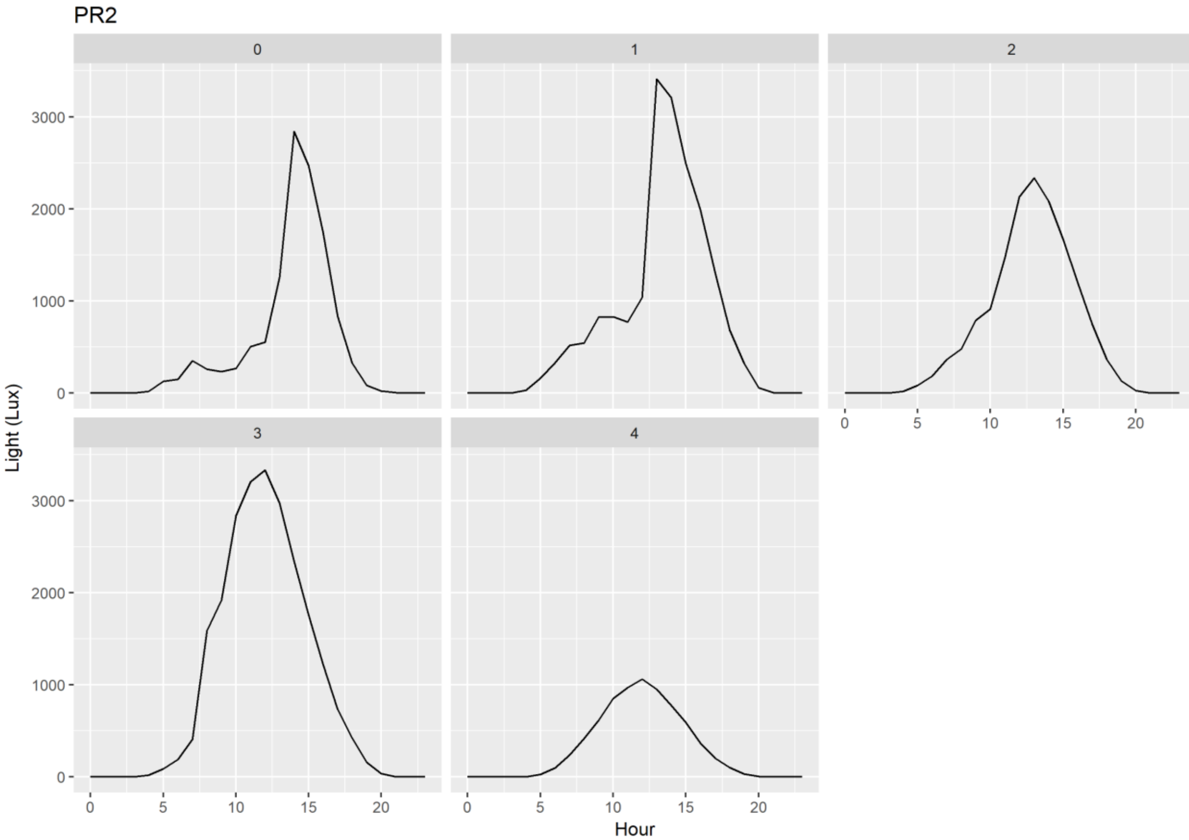


Figure A29 Average daily light intensity at PR2 over the duration of deployment.

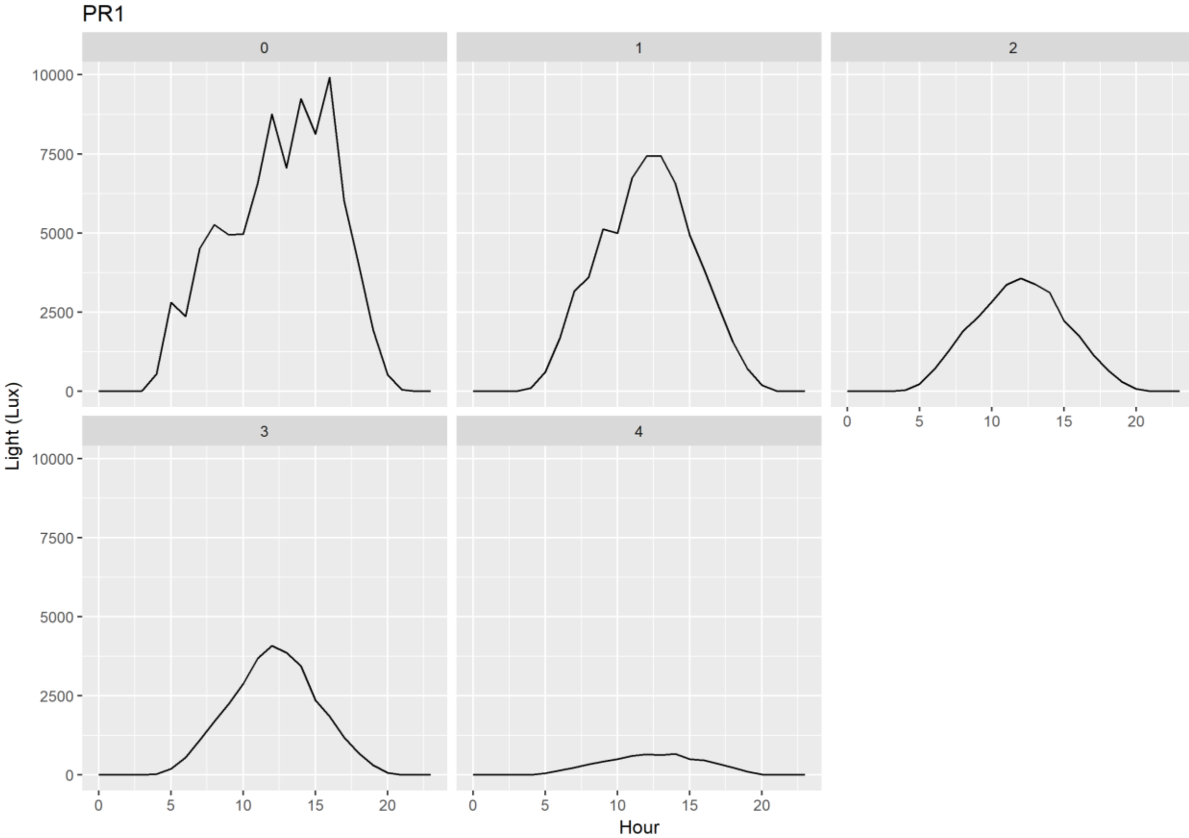


Figure A30 Average daily light intensity at PR1 over the duration of deployment.

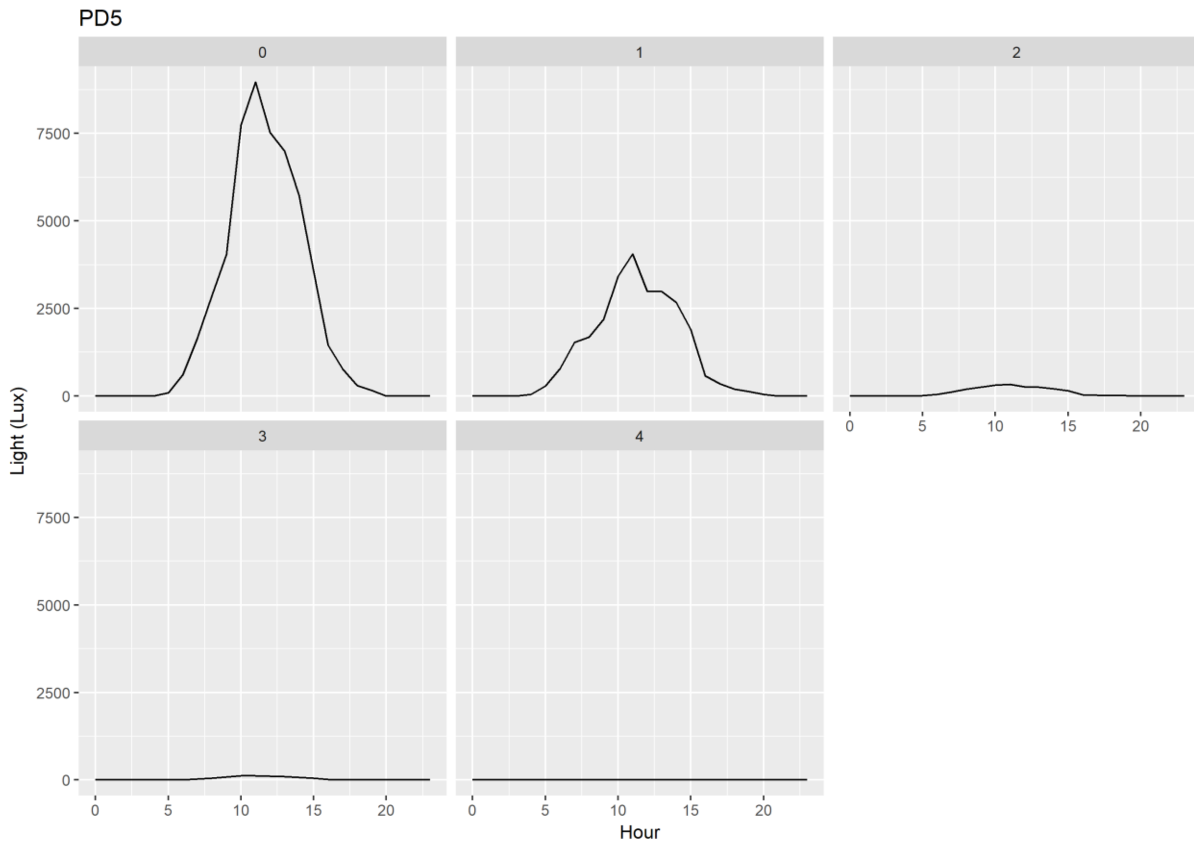


Figure A31 Average daily light intensity at PD5 over the duration of deployment.

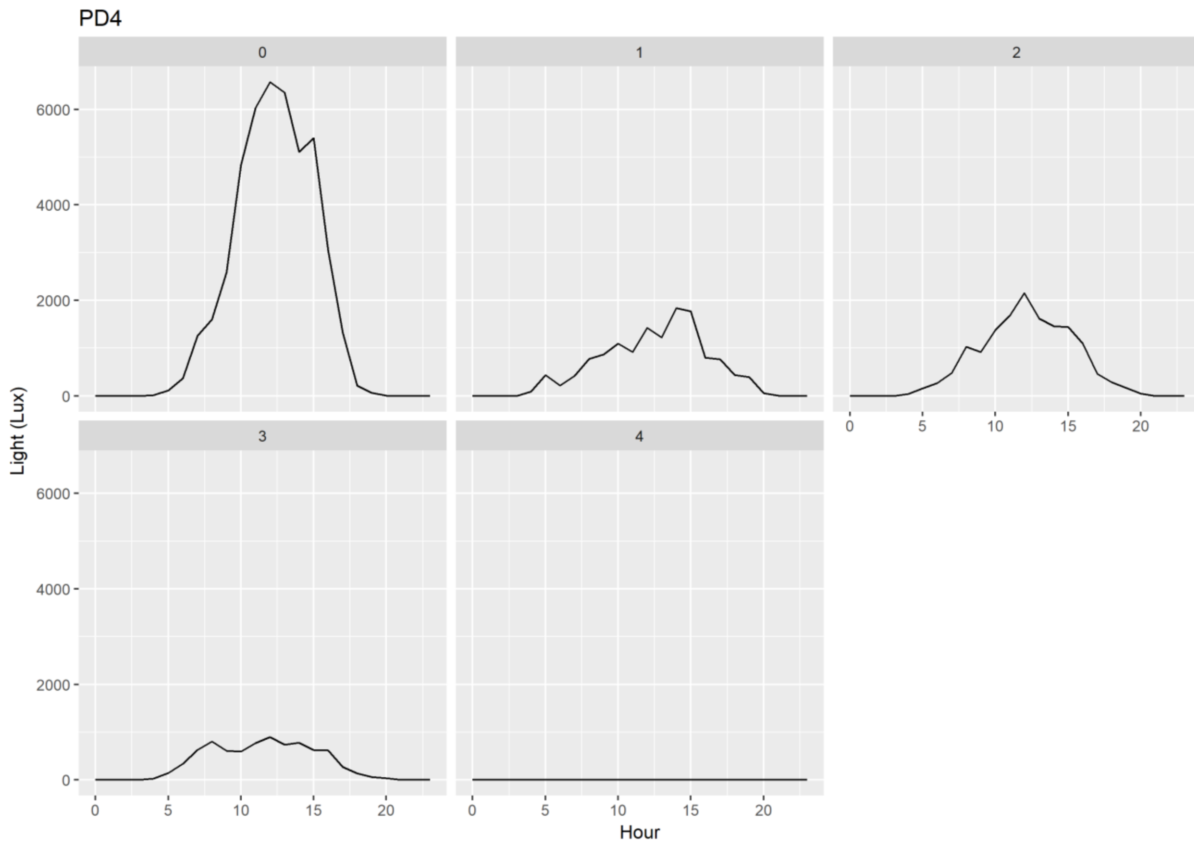


Figure A32 Average daily light intensity at PD4 over the duration of deployment.

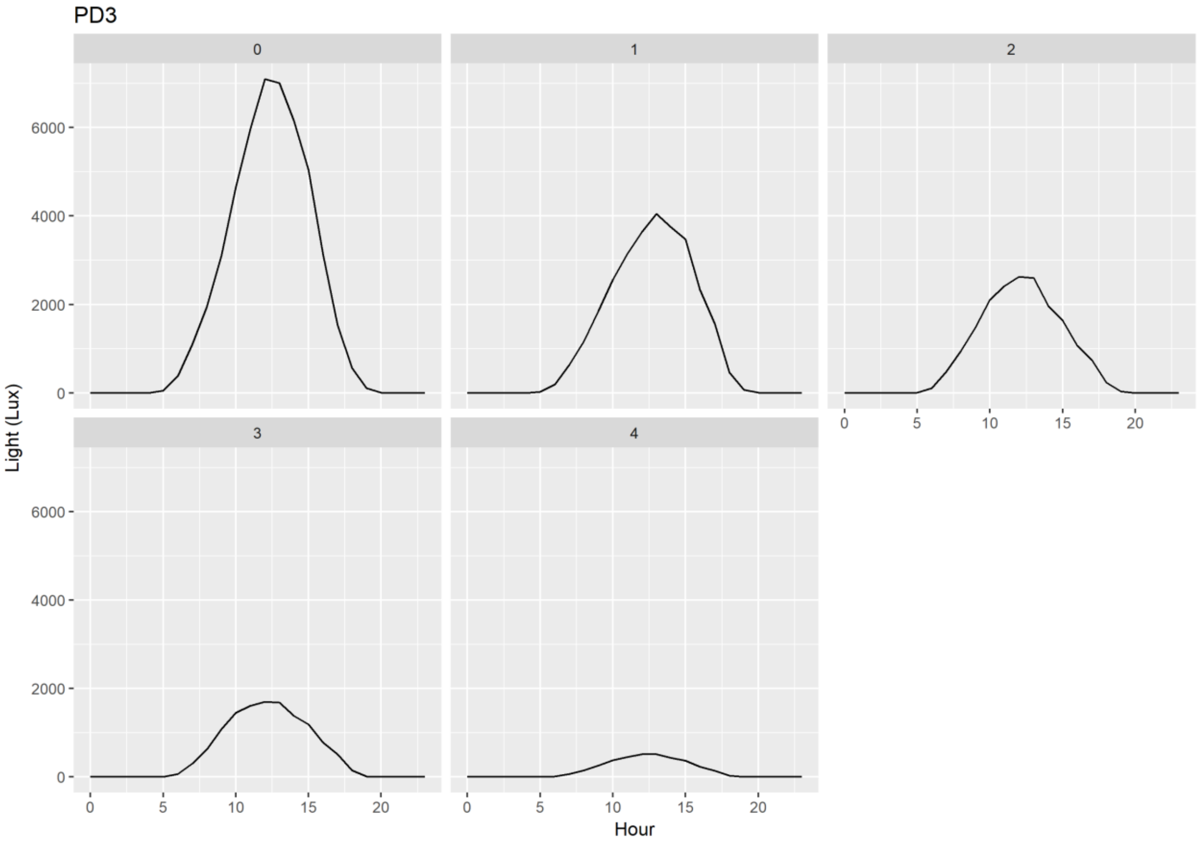


Figure A33 Average daily light intensity at PD3 over the duration of deployment.

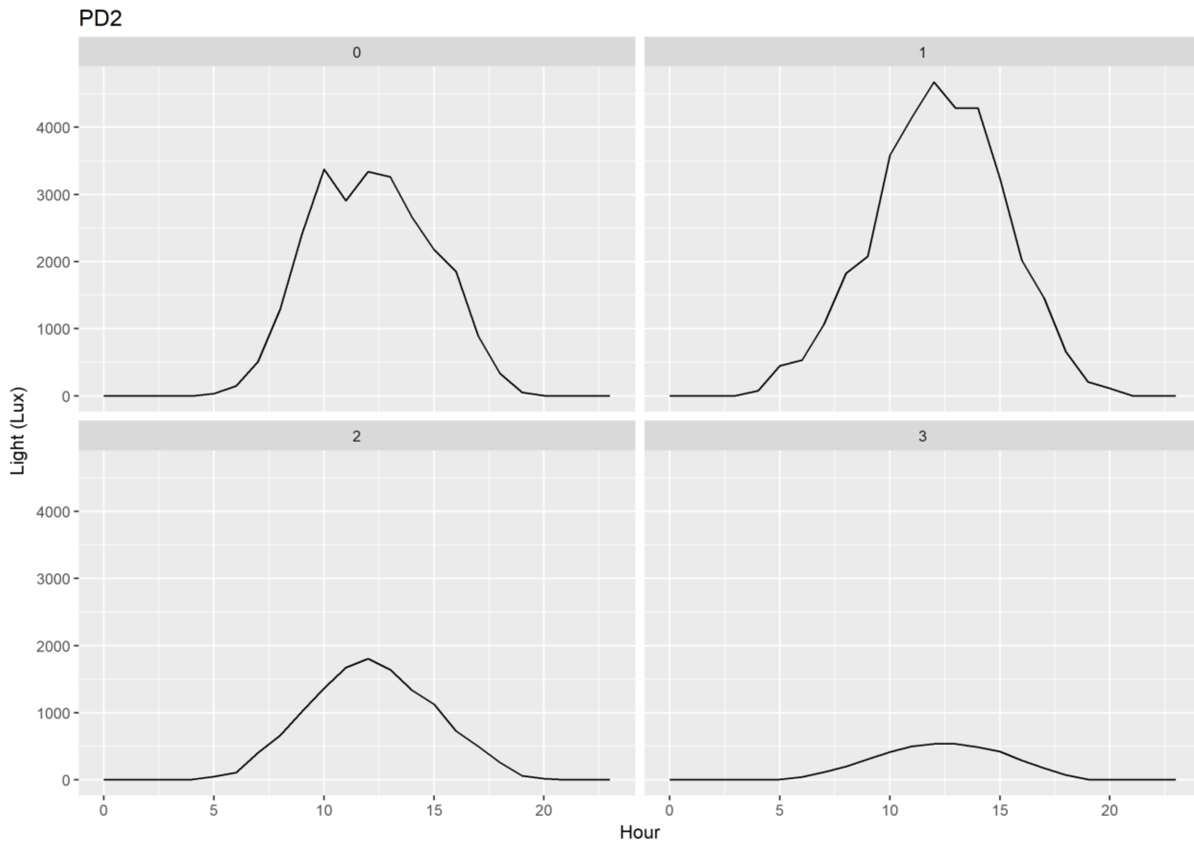


Figure A34 Average daily light intensity at PD2 over the duration of deployment.

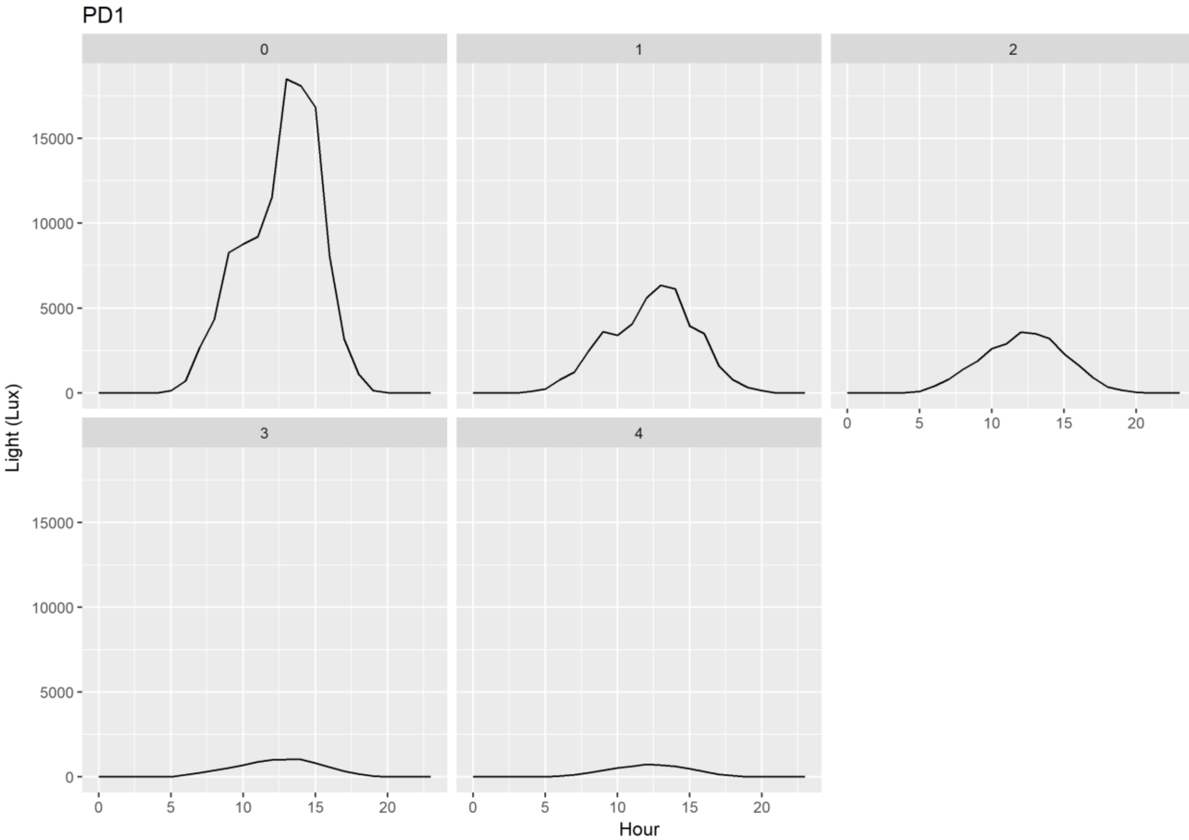


Figure A35 Average daily light intensity at PD1 over the duration of deployment.

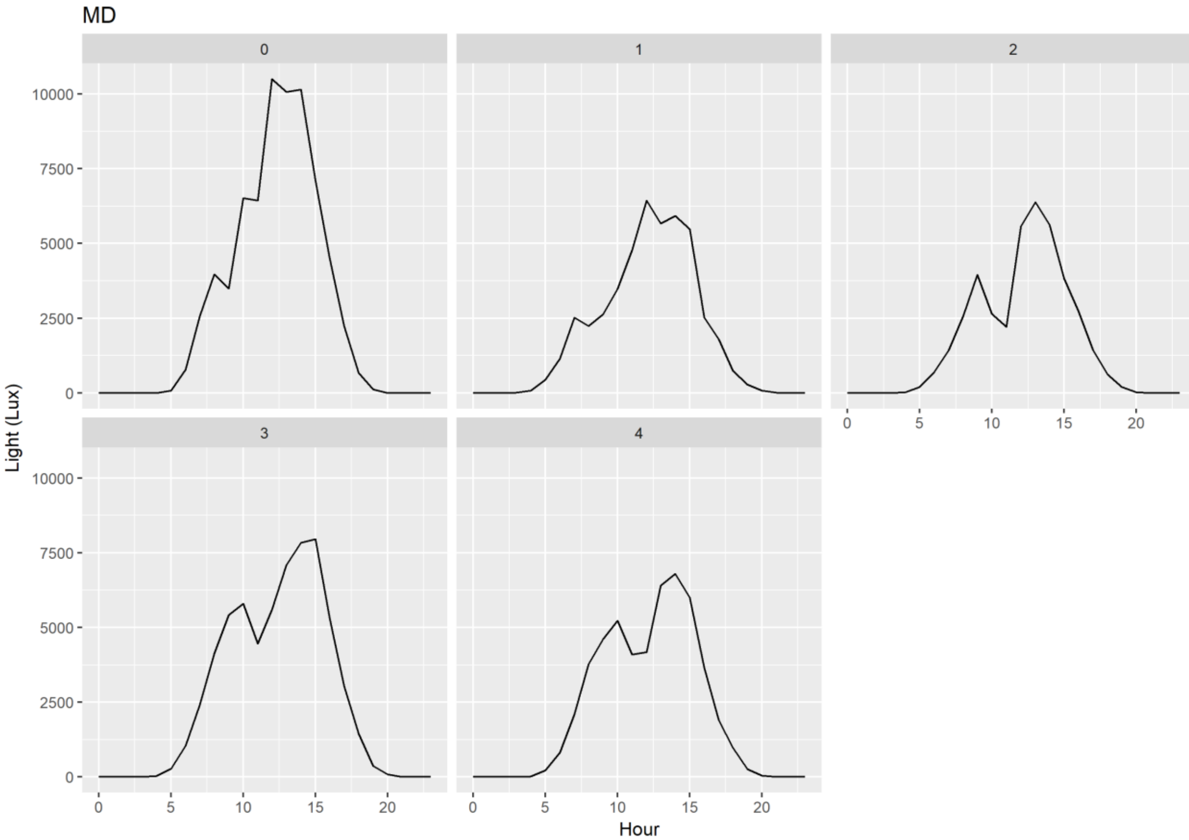


Figure A36 Average daily light intensity at MD over the duration of deployment.

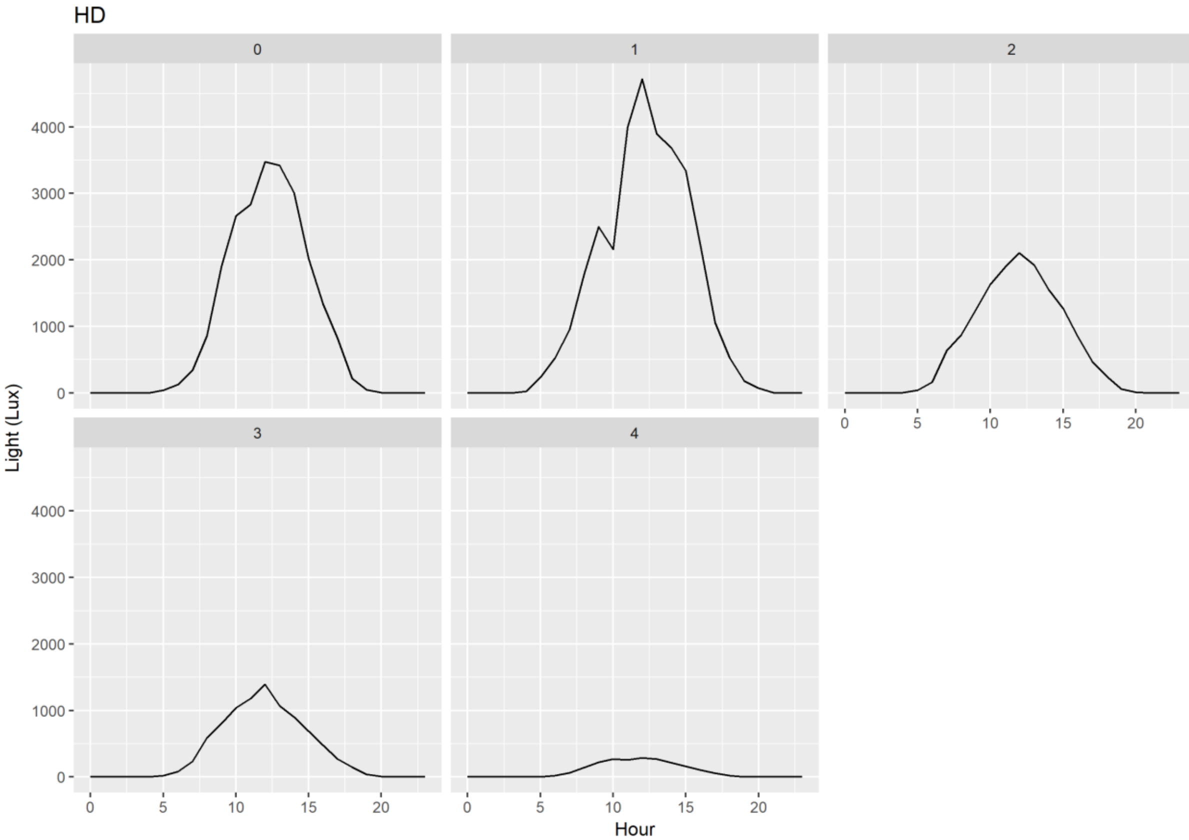


Figure A37 Average daily light intensity at HD over the duration of deployment.

Appendix G Light Model Results

```
data {
      int nObs;
      real Light[nObs];
      real Surface[nObs];
      real Depth[nObs];
      real Turbidity[nObs];
      int nSite;
      int Site[nObs];
      int nDay;
      int Day[nObs];
  }
  parameters {
      real bR;

      real sSiteDay;
      matrix[nSite,nDay] bSiteDay;

      real bKd;
      real bKdTurbidity;
      real sLight;
  }
  model {
      vector[nObs] eKd;
      vector[nObs] elog_Light;

      bR ~ uniform(0, 1);
      bKd ~ normal(0, 1);
      bKdTurbidity ~ normal(0, 1);
      sLight ~ uniform(0, 5);

      sSiteDay ~ uniform(0, 5);
      for(i in 1:nSite) {
        for(j in 1:nDay) {
          bSiteDay[i,j] ~ normal(0, sSiteDay);
        }
      }

      for (i in 1:nObs) {
          eKd[i] = exp(bKd + bKdTurbidity * log(Turbidity[i]));
          elog_Light[i] = log(Surface[i] * bR) - eKd[i] * Depth[i] + bSiteDay[
Site[i],Day[i]];
          Light[i] ~ lognormal(elog_Light[i], sLight);
      }
  }
```

Figure A38 Description of the light model and the R code used.

Table A2 Parameter descriptions

Parameter	Description
`bKd`	The diffuse attenuation coefficient (K_d) at a `Turbidity` of 1 in m^{-1}
`bKdTurbidity`	The effect of `log(Turbidity)` on `bKd`
`bR`	The reflection coefficient (r)
`Depth`	The depth (y) in m
`Light`	The irradiance at depth (E_d) in lx
`sLight`	The SD of the residual variation in `Light`
`Surface`	The irradiance at the surface (E_s) in lx
`Turbidity`	The turbidity (T) in *FNU*

Table A3 Model coefficients

term	estimate	sd	zscore	lower	upper	pvalue
bKd	0.3096482	0.1016103	3.028491	0.1032940	0.4947023	0.0027
bKdTurbidity	0.2842869	0.0220974	12.876475	0.2431494	0.3291792	0.0007
bR	0.1882057	0.0352608	5.421153	0.1311017	0.2688625	0.0007
sLight	0.5206322	0.0112388	46.324846	0.4997354	0.5437715	0.0007
sSiteDay	1.4695596	0.0792211	18.596866	1.3255816	1.6434700	0.0007

Table A4 Model summary

n	K	nchains	niters	nthin	ess	rhat	converged
1333	5	3	500	10	600	1.007	TRUE

Appendix H Temperature Plots

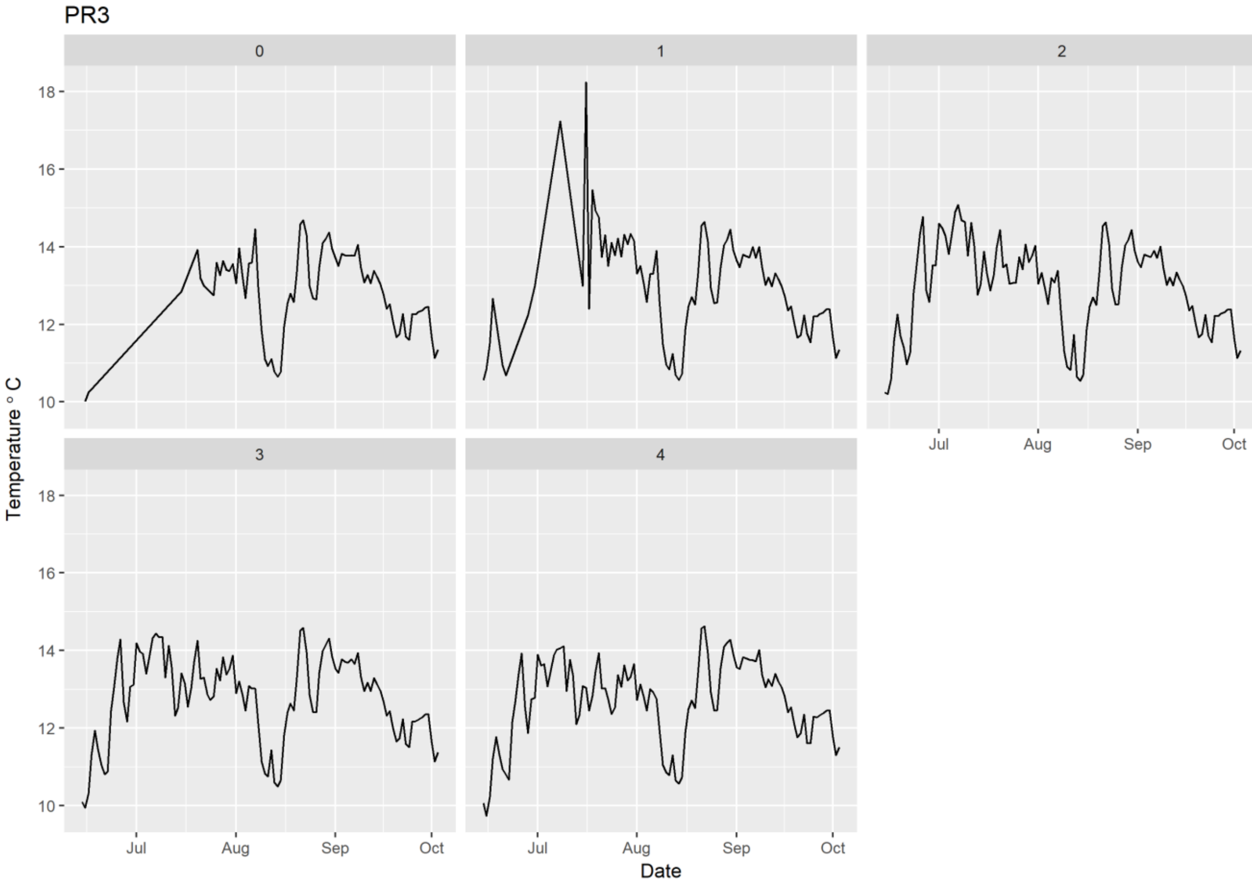


Figure A39 Average daily temperature at PR3 over the duration of deployment.

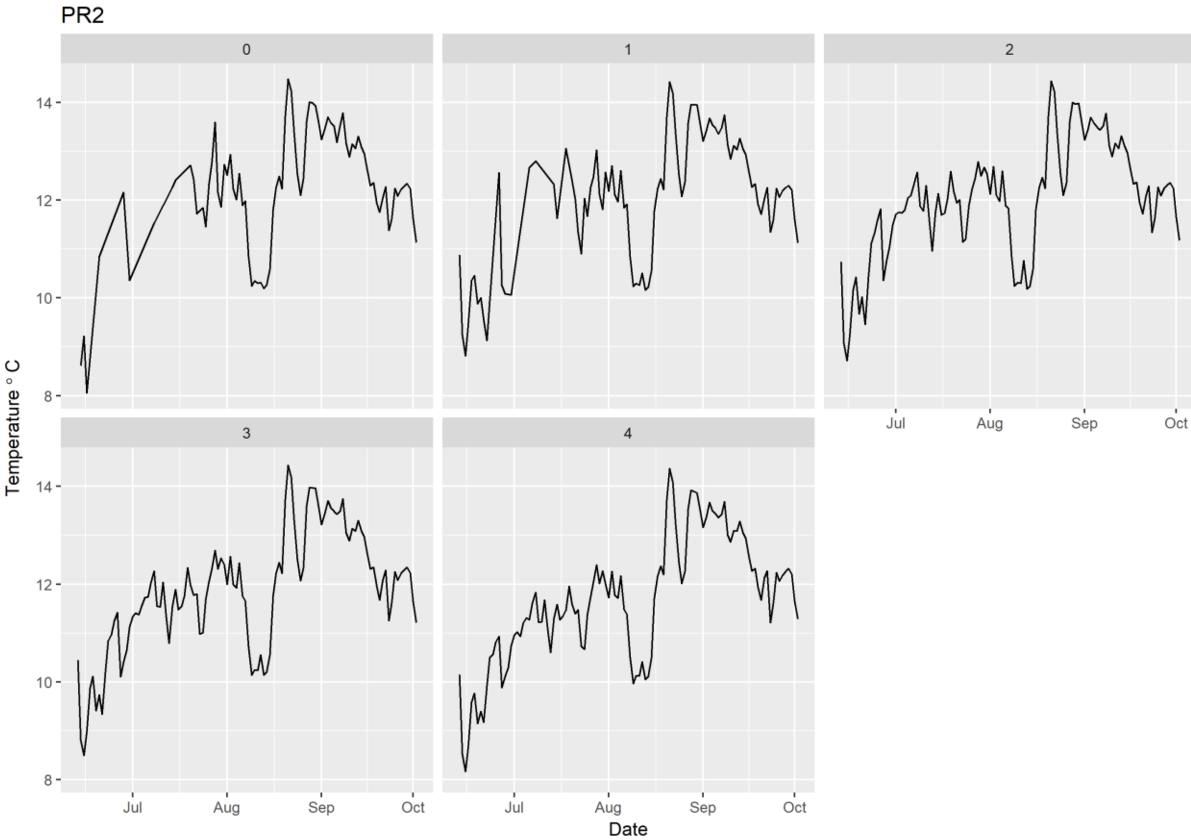


Figure A40 Average daily temperature at PR2 over the duration of deployment.

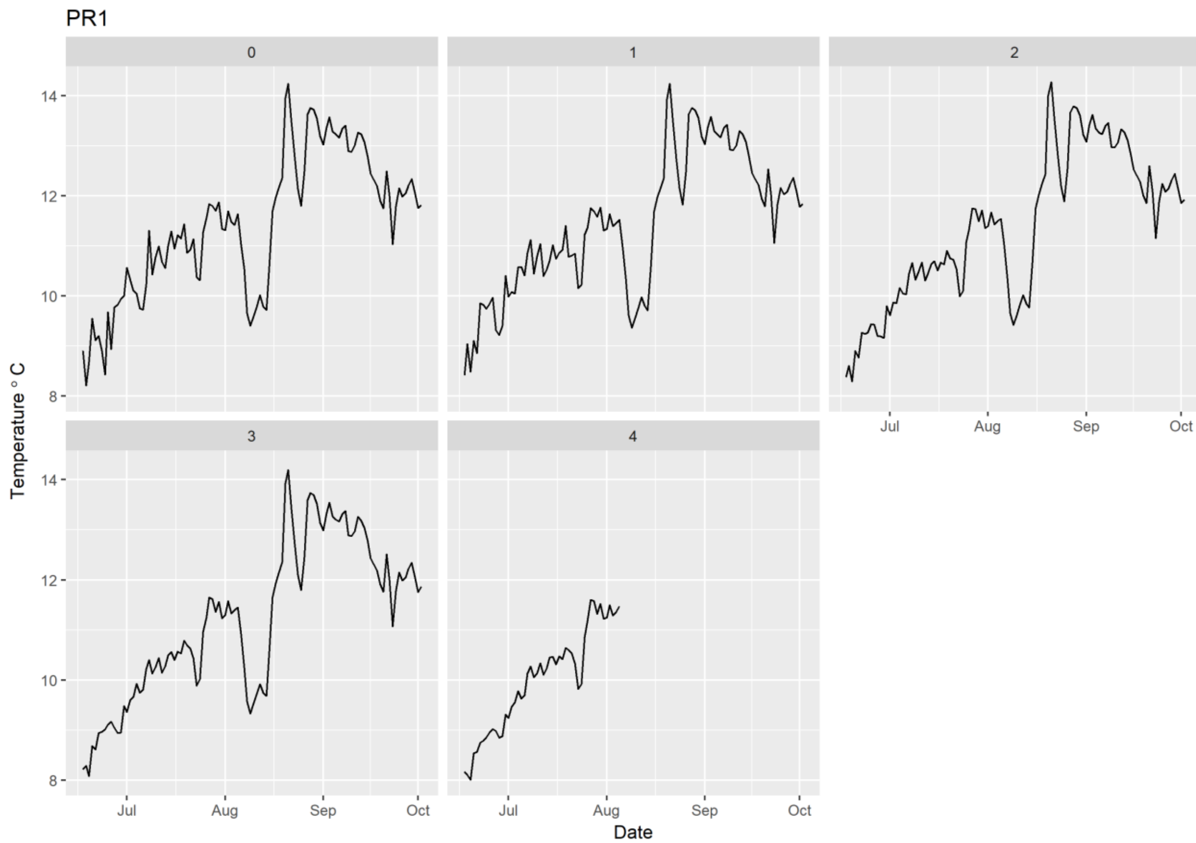


Figure A41 Average daily temperature at PR1 over the duration of deployment.

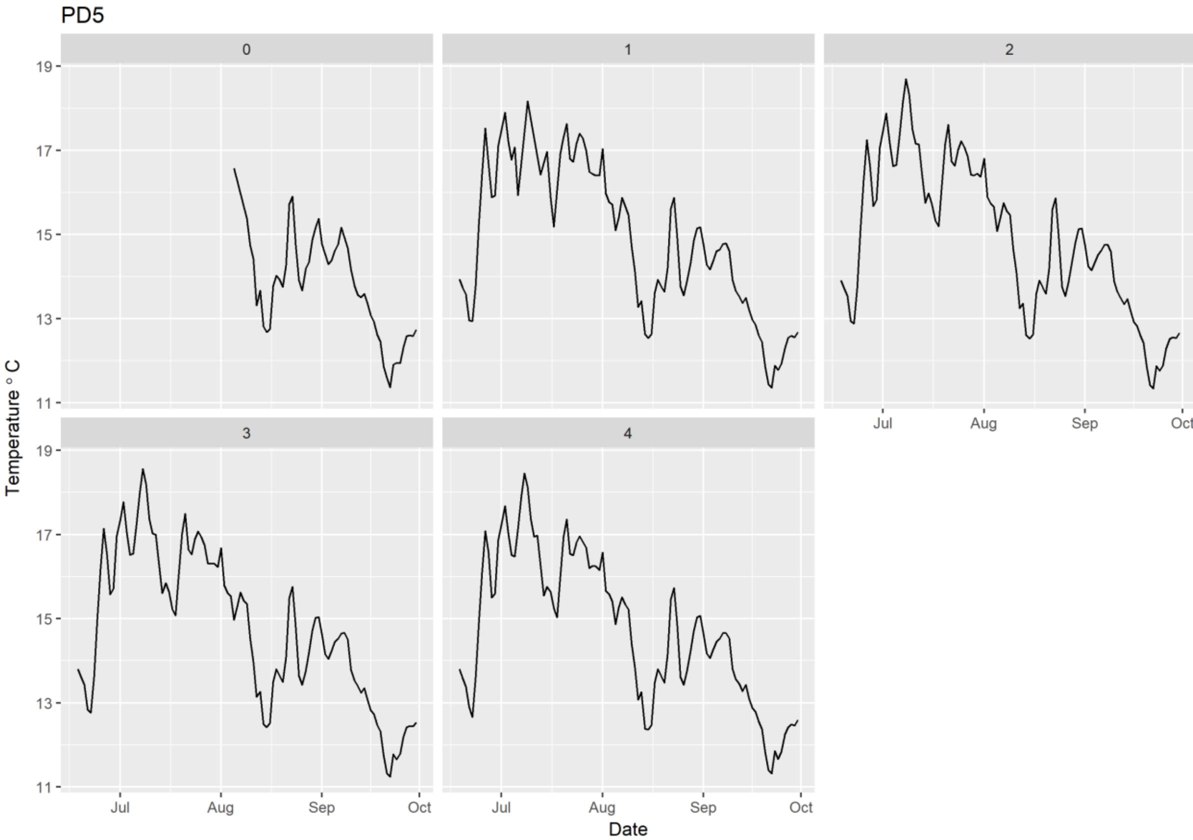


Figure A42 Average daily temperature at PD5 over the duration of deployment.

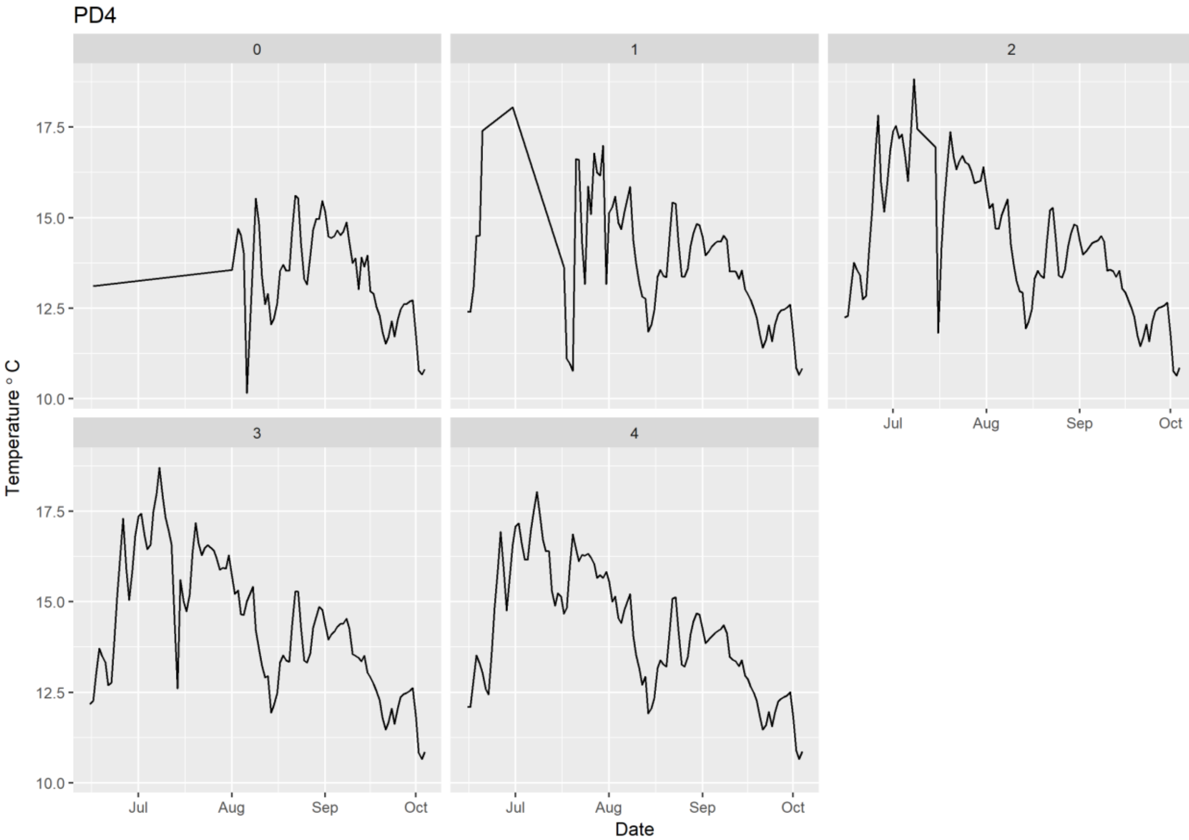


Figure A43 Average daily temperature at PD4 over the duration of deployment.

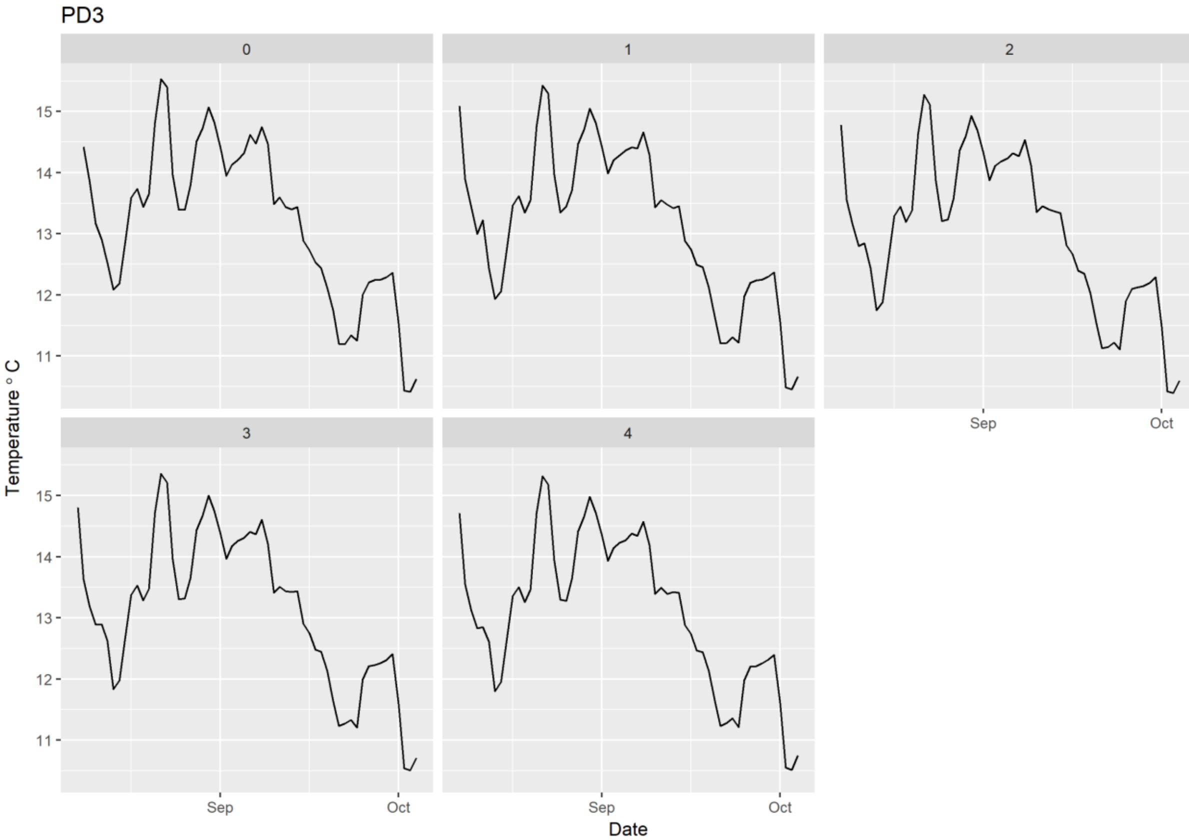


Figure A44 Average daily temperature at PD3 over the duration of deployment.

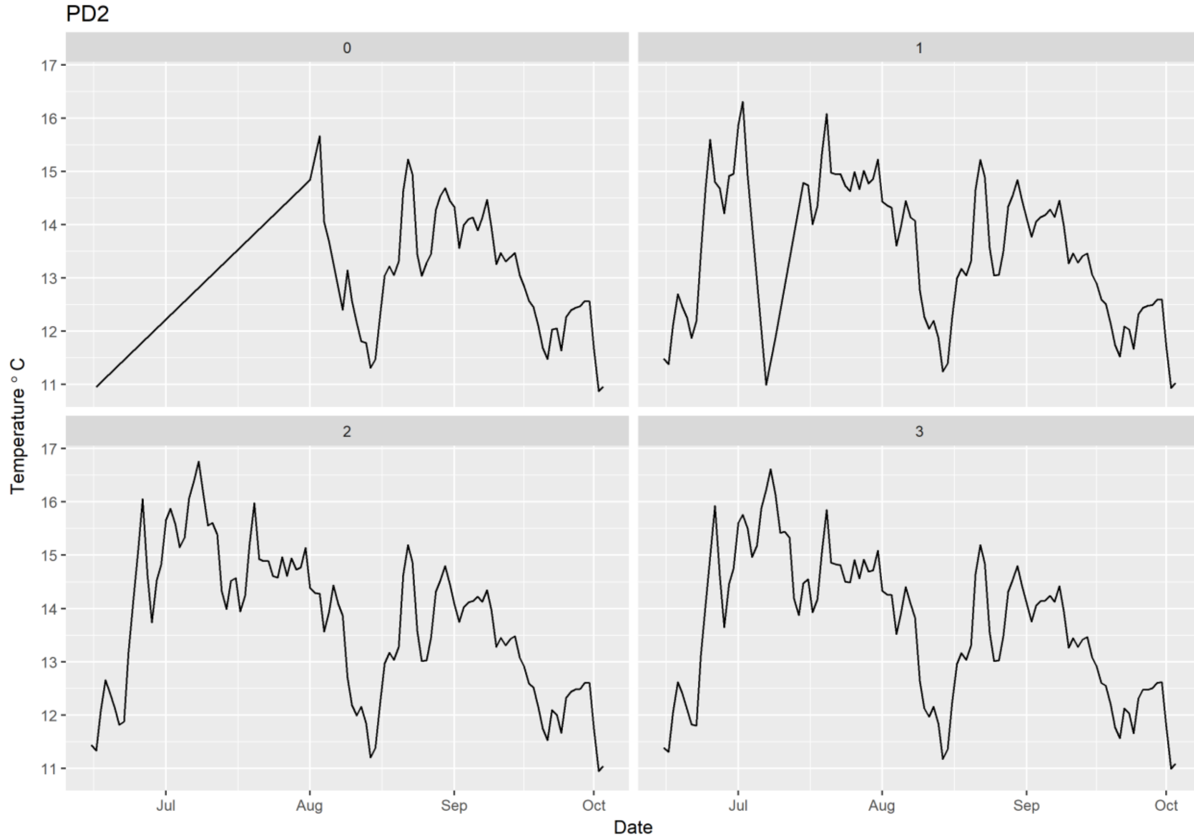


Figure A45 Average daily temperature at PD2 over the duration of deployment.

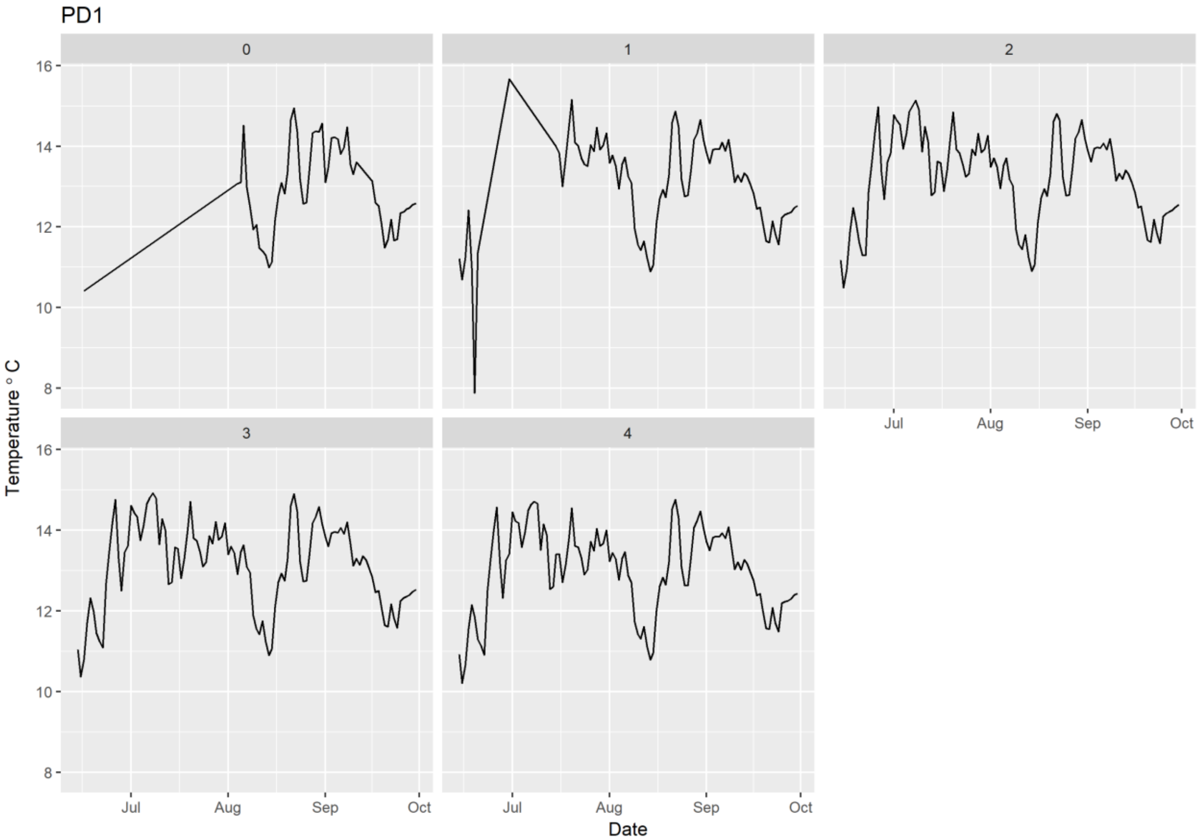


Figure A46 **Average daily temperature at PD1 over the duration of deployment.**

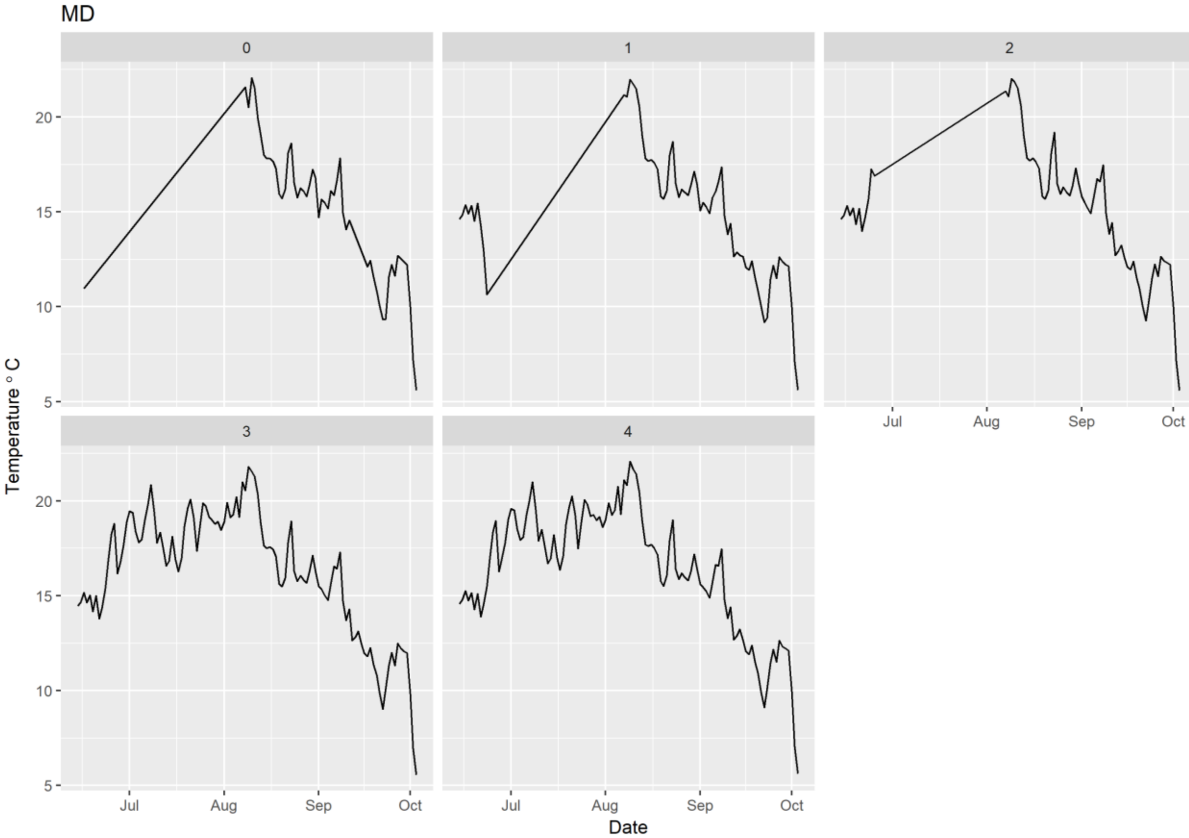


Figure A47 Average daily temperature at MD over the duration of deployment.

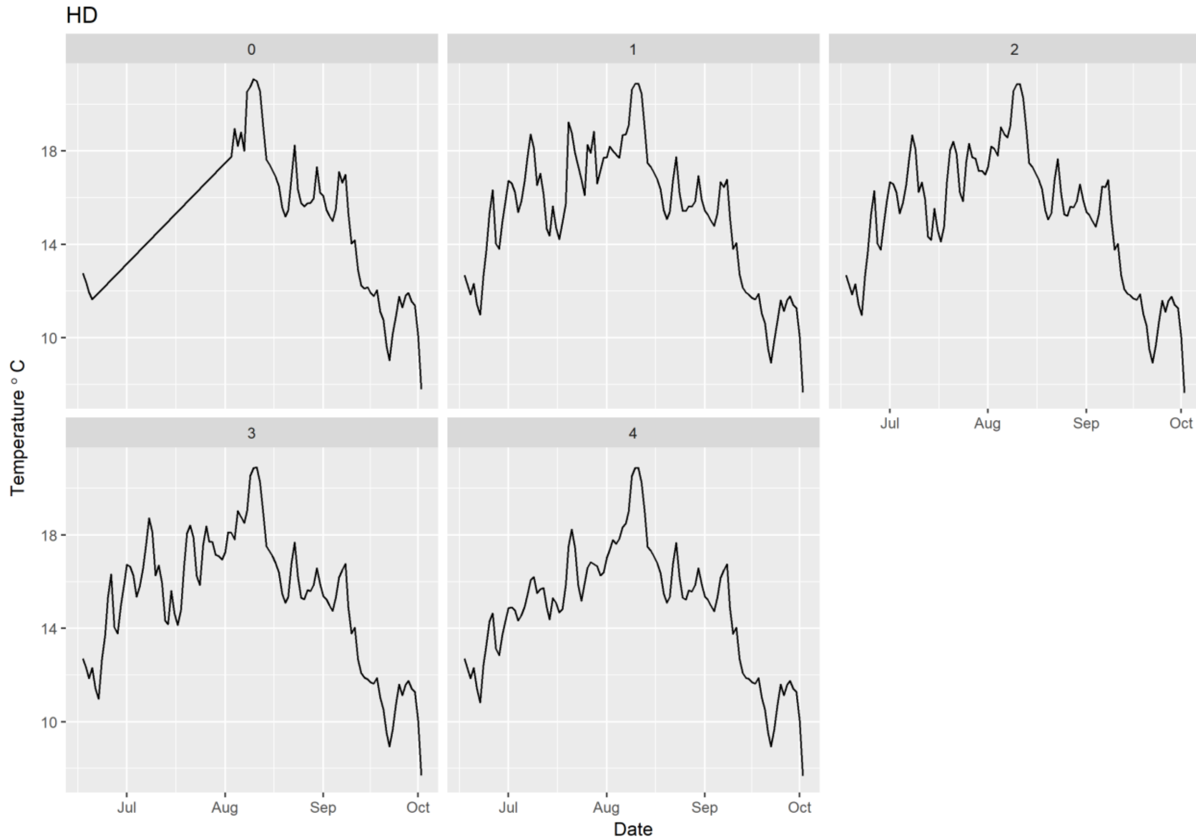


Figure A48 Average daily temperature at HD over the duration of deployment.

Appendix I Periphyton Summary Stats and Figures

Table A5 Periphyton productivity and community composition metrics summarized by site for 2010-2017 data.

PERIPHYTON	RESERVOIR			SITE C REACH						DOWNSTREAM RIVERINE		
2010 - 2017	Dinosaur	PR1	PR2	PR3	HD	MD	Combined	PD1	PD2	PD3	PD4	PD5	Combined
Chl-a mg/m^2													
mean	9.01	36.02	35.09	20.09	18.12	8.02	**23.27**	38.15	20.44	35.06	13.74	24.65	**28.46**
St Deviation	7.58	38.97	27.80	9.21	16.07	8.25	**24.95**	40.39	14.72	20.56	15.08	21.22	**26.93**
median	8.57	26.36	32.29	20.65	14.04	5.12	**19.06**	32.55	16.20	31.75	6.65	20.45	**25.00**
min	0.09	5.24	5.18	1.11	0.12	0.01	**0.01**	0.12	1.49	2.33	0.13	0.64	**0.12**
max	25.4	192.00	141.00	36.23	51.30	30.49	**192.00**	210.59	56.70	82.90	38.20	62.60	**210.59**
Abundance cells/cm^2													
mean ± SD	450390	1547869	1820921	924895	713324	639925	**1100329**	1408078	1352615	1447214	332986	192864	**1151230**
St Deviation	479748	1263976	1965414	777613	648764	493659	**1196314**	1552776	1719677	1200025	211519	162868	**1403159**
median	265024	1162871	1004119	636925	576930	672577	**775909**	933593	781351	1201130	314880	158752	**648006**
min	4247	3622	39360	81344	92365	10496	**45437**	73472	47232	176788	94464	36736	**36736**
max	2311338	4899271	6787336	2773249	2349913	1515346	**6787336**	6299772	6410505	5651600	682240	545792	**6410505**
Biovolume cm^3/m^2													
mean ± SD	1.36	5.96	6.74	2.90	2.83	3.44	**4.25**	6.45	6.31	5.24	3.43	2.95	**5.40**
St Deviation	0.94	4.17	4.66	2.19	2.68	2.66	**3.65**	6.93	5.59	4.86	4.14	2.41	**5.50**
median	1.21	5.23	4.90	2.16	2.36	2.95	**3.19**	3.67	3.90	3.76	1.48	1.99	**3.67**
min	0.01	0.01	0.76	0.72	0.46	0.12	**0.41**	0.42	0.32	0.42	0.28	0.13	**0.13**
max	4.08	16.86	16.28	8.87	10.33	11.35	**16.86**	28.64	20.90	21.88	11.48	6.95	**28.64**
Species Richness (# species)													
mean ± SD	18	21	17	17	12	14	**16**	19	18	20	8	8	**17**
St Deviation	6	5	6	8	6	6	**7**	7	6	6	4	2	**7**
median	16	21	16	17	13	16	**16**	20	19	22	6	9	**17**
min	10	13	6	7	5	2	**7**	7	6	12	3	5	**3**
max	32	30	29	33	22	24	**33**	29	29	30	17	11	**30**
Simpson's index													
mean ± SD	0.81	0.82	0.83	0.82	0.79	0.81	**0.81**	0.81	0.85	0.82	0.68	0.80	**0.81**
St Deviation	0.10	0.06	0.05	0.07	0.13	0.12	**0.09**	0.06	0.04	0.07	0.16	0.05	**0.09**
median	0.84	0.84	0.84	0.83	0.84	0.85	**0.84**	0.82	0.86	0.83	0.74	0.81	**0.83**
min	0.56	0.65	0.68	0.61	0.44	0.38	**0.38**	0.59	0.76	0.60	0.35	0.69	**0.35**
max	0.91	0.89	0.90	0.91	1.00	0.91	**1.00**	0.90	0.91	0.92	0.91	0.85	**0.92**
BI forage value (%)													
mean ± SD	43.60	56.10	53.28	55.04	58.98	48.27	**54.31**	55.38	52.63	62.09	34.20	29.55	**51.11**
St Deviation	15.43	21.21	23.79	21.58	25.63	26.22	**23.68**	26.14	25.08	17.99	31.04	14.82	**25.60**
median	45.58	57.58	52.84	60.10	66.65	47.38	**57.60**	52.67	59.03	61.98	25.04	27.93	**53.66**
min	10.10	19.09	9.08	6.09	15.47	5.75	**5.75**	19.20	11.22	25.21	2.53	8.33	**2.53**
max	71.76	89.70	97.21	90.92	100.00	100.00	**100.00**	96.87	100.00	90.27	100.00	56.70	**100.00**
from reservoirs or lakes													
mean ± SD	8.95	8.16	9.15	4.45	1.23	10.26	**6.63**	4.66	3.25	2.07	8.77	11.02	**4.81**
St Deviation	10.70	11.08	18.27	15.04	4.10	27.43	**17.18**	10.53	8.29	5.01	26.98	18.85	**13.03**
median	4.41	3.53	1.89	0.65	0.00	0.35	**0.73**	0.65	0.69	0.28	0.00	0.00	**0.43**
min	0.00	0.25	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	**0.00**
max	41.10	37.35	80.81	77.06	20.73	88.71	**88.71**	38.31	36.97	21.54	85.55	50.93	**85.55**

Table A6 **Top five periphyton taxa for each site, year, and season by percent biovolume.**

D1 Jun-Aug 2010	D1
Eucocconeis	17.4
Achnanthidium	15.6
Chroomonas	13.6
Synedra	8.2
Peridinium	5.7

D1 Aug-Oct 2010	D1
Synedra	20
Tabellaria	17.6
Staurosira	8.4
Chroomonas	6.9
Diatoma	6.8

D1 Jul-Sep 2011	D1
Synedra	20
Nitzschia	18.3
Diatoma	12.1
Euglena	11.3
Aphanothece	11

D1 Jun-Aug 2017	D1
Synedra	32.9
Frustulia	8.2
Cladophora	8.1
Navicula	6.6
Amphora	6.4

D1 Aug-Oct 2017	D1
Pinnularia	29.1
Synedra	12.7
Surirella	7.3
Cymbella	7.1
Navicula	7

Site C R Jun-Aug 2010	HD	MD	PR1	PR2	PR3
Didymosphenia	0	0	12.4	30.2	23.8
Synedra	0	14.9	9.6	11.4	12.1
Achnanthidium	8	0	7.6	13	18.7
Diatoma	0	0	34	0	0
Encyonema	20.9	0	0	7.1	5.6
Chroomonas	17.1	14.1	0	0	0

Site C R Aug-Oct 2010	HD	MD	PR1	PR2	PR3
Synedra	0	12.2	10.6	11.7	20.4
Rhopalodia	13.7	22.1	0	0	0
Chilomonas	17.1	17	0	0	0
Tabellaria	0	0	16.5	16.3	0
Didymosphenia	0	0	11.6	11	9.1
Asterionella	0	0	17.8	12	0
Encyonema	15.5	8	0	0	0

Site C R Jul-Sep 2011	HD	MD	PR1	PR2	PR3
Aphanothece	30.6	16.8	0	28.2	0
Encyonema	0	4.4	17.3	15.7	25.1
Nitzschia	5.4	18.1	11.3	11.3	14.6
Chroomonas	0	34.7	0	0	0
Gomphonema	0	0	22.8	0	5.7
Cryptomonas	25.9	0	0	0	0
Asterionella	0	0	13.1	0	12.4

Site C R Jul-Sep 2012	HD	MD	PR1	PR2	PR3
Cryptomonas	37.2	46.6	0	0	19.3
Diatoma	11.6	0	14	47.6	15.8
Didymosphenia	0	0	17.3	21.2	14.2
Encyonema	0	0	9.9	6.7	7.5
Epithemia	21.3	0	0	0	0
Chroomonas	9	10	0	0	0

Site C R Jun-Aug 2017	HD	MD	PR1	PR2	PR3
Cymbella	6.1	83.5	24.8	33.1	18
Diatoma	56.1	3.4	24.5	12.9	13
Synedra	5.9	0	16.2	15.8	30.9
Navicula	0	3.4	6	8.4	11.5
Didymosphenia	0	0	12.1	8.1	8.9

Site C R Aug-Oct 2017	HD	MD	PR1	PR2	PR3
Synedra	28.7	16.9	4.1	23	24.8
Didymosphenia	0	0	64.2	28.4	0
Rhopalodia	17	25.1	0	0	0
Frustulia	0	0	0	6.8	26.7
Encyonema	0	0	5.8	13.2	11.3
Gomphonema	11.2	12.6	0	0	0

PD Jun-Aug 2010	PD1	PD2	PD3
Didymosphenia	17.2	43.8	24.5
Synedra	13.7	10.2	13.7
Achnanthidium	15.5	0	13.2
Eucocconeis	7.2	4.4	8.3
Encyonema	0	5	6.3

PD Aug-Oct 2010	PD1	PD2	PD3
Didymosphenia	48.8	11.6	0
Synedra	11	18.2	19.6
Diatoma	7	11	9.1
Encyonema	3.9	0	12.5
Staurosira	0	8	7.7

PD Jul-Sep 2011	PD1	PD2	PD3
Nitzschia	27.6	16.8	10.8
Didymosphenia	18.9	29.3	0
Cryptomonas	0	21.9	19.4
Gomphonema	7.4	0	13.8
Encyonema	14.9	0	0

PD Jul-Sep 2012	PD1	PD2	PD3
Cryptomonas	38.9	27.6	27.7
Diatoma	17.3	11.3	26.6
Nitzschia	4.7	16.7	13.3
Chroomonas	10	11.2	0
Encyonema	5.7	6	6.7

PD Jun-Aug 2017	PD1	PD2	PD3	PD4	PD5
Cymbella	25.4	14.7	22.9	66.7	21.3
Synedra	15.7	17	21.4	10.5	18
Frustulia	21.7	20.9	24.5	0	10.5
Amphipleura	0	0	4.7	5.4	17.2
Navicula	14.4	10.3	14.7	9.2	0
Didymosphenia	0	14.1	0	0	17

PD Aug-Oct 2017	PD1	PD2	PD3	PD4	PD5
Ceratium	48.3	55	28.7	24.5	0
Frustulia	7.8	15.7	16.6	17.7	0
Synedra	5.3	6.1	8.8	17.4	18.8
Encyonema	15.5	6.8	8.8	0	0
Gyrosigma	0	0	0	10.5	19
Didymosphenia	6.1	0	0	13	0
Amphipleura	0	0	0	0	15.8
Cymbella	0	3.6	0	0	8.7
Navicula	0	0	0	0	12

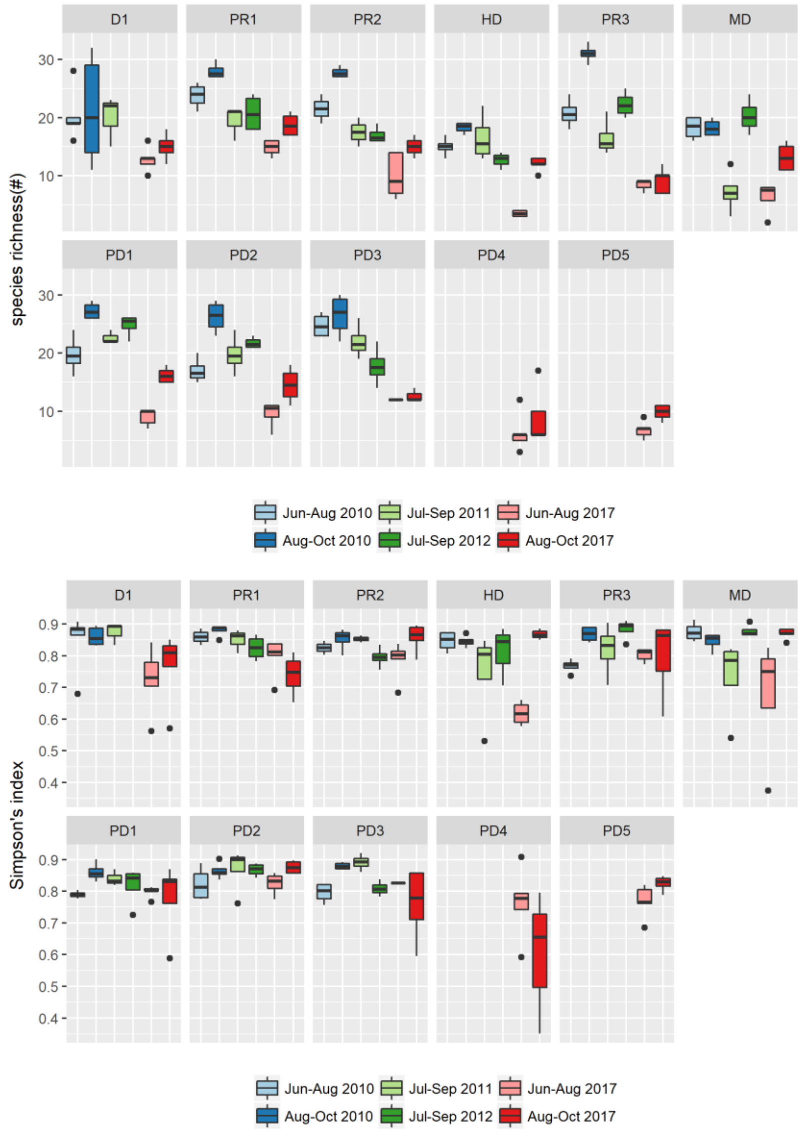
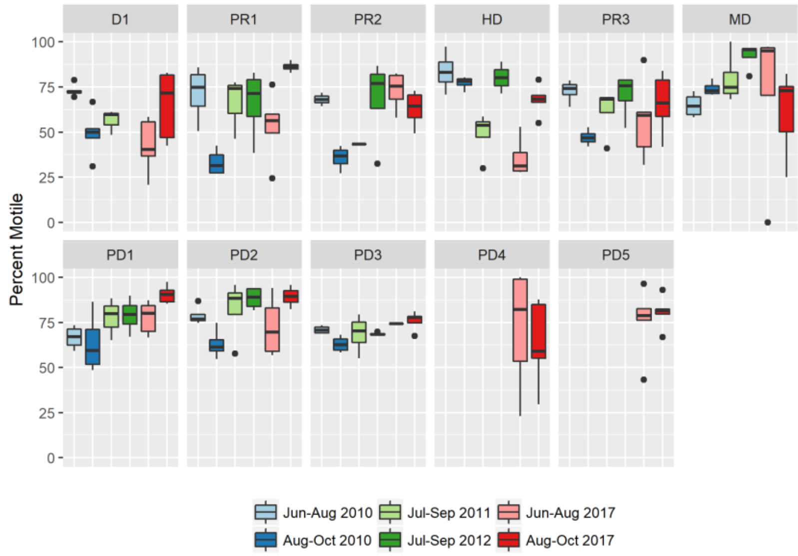


Figure A49 **Periphyton species richness and Simpson's index (diversity) for 2010-2012 and 2017.**



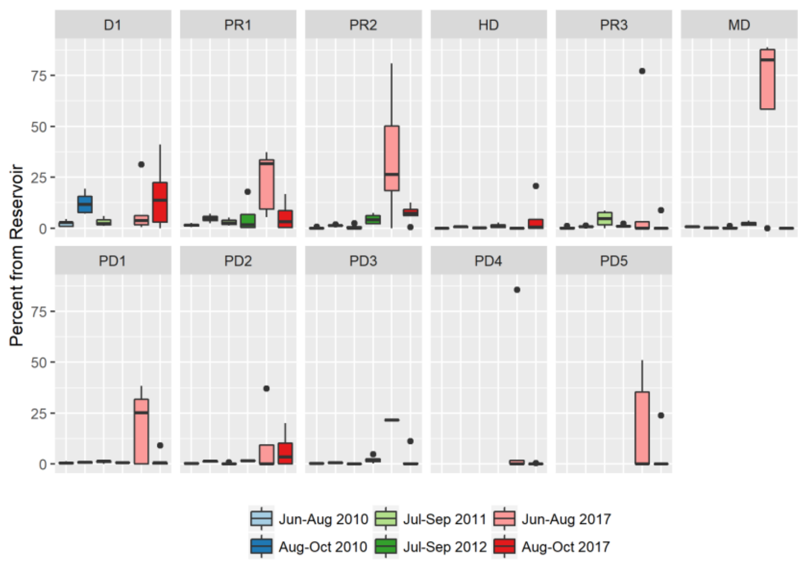
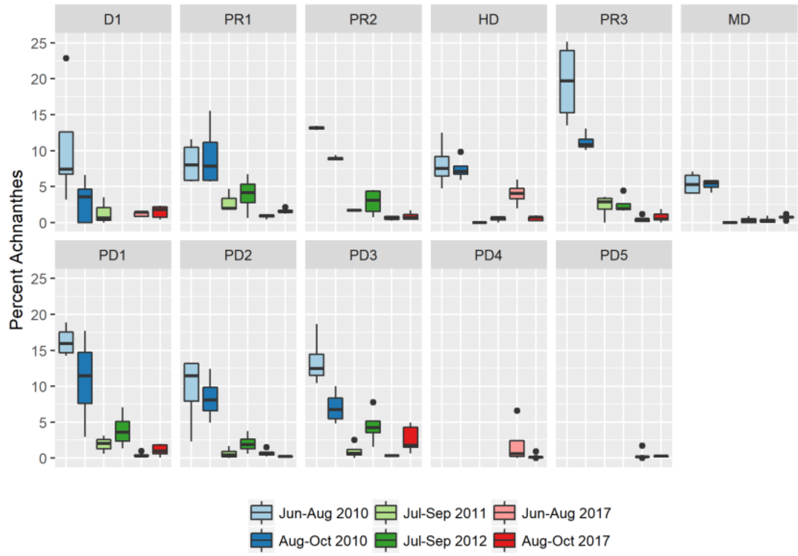


Figure A50 Periphyton percent motile and percent from reservoir for 2010-2012 and 2017.



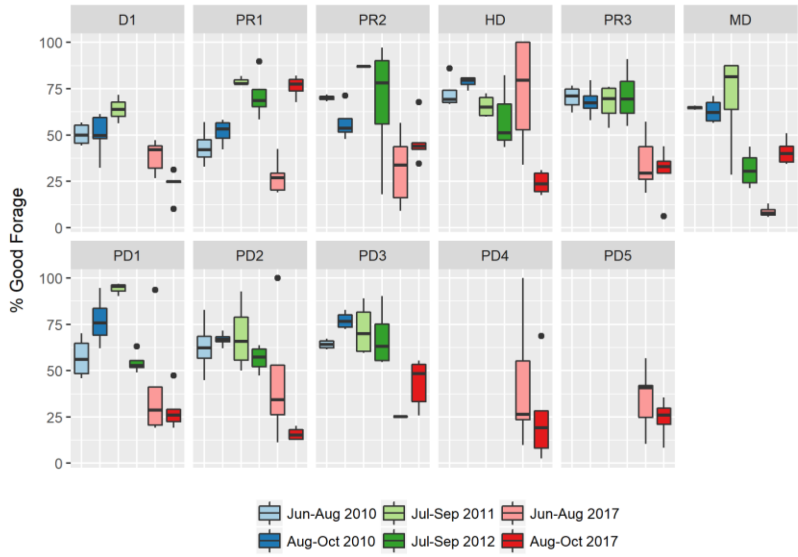


Figure A51 **Periphyton percent Achnanthes and percent from good forage for 2010-2012 and 2017.**

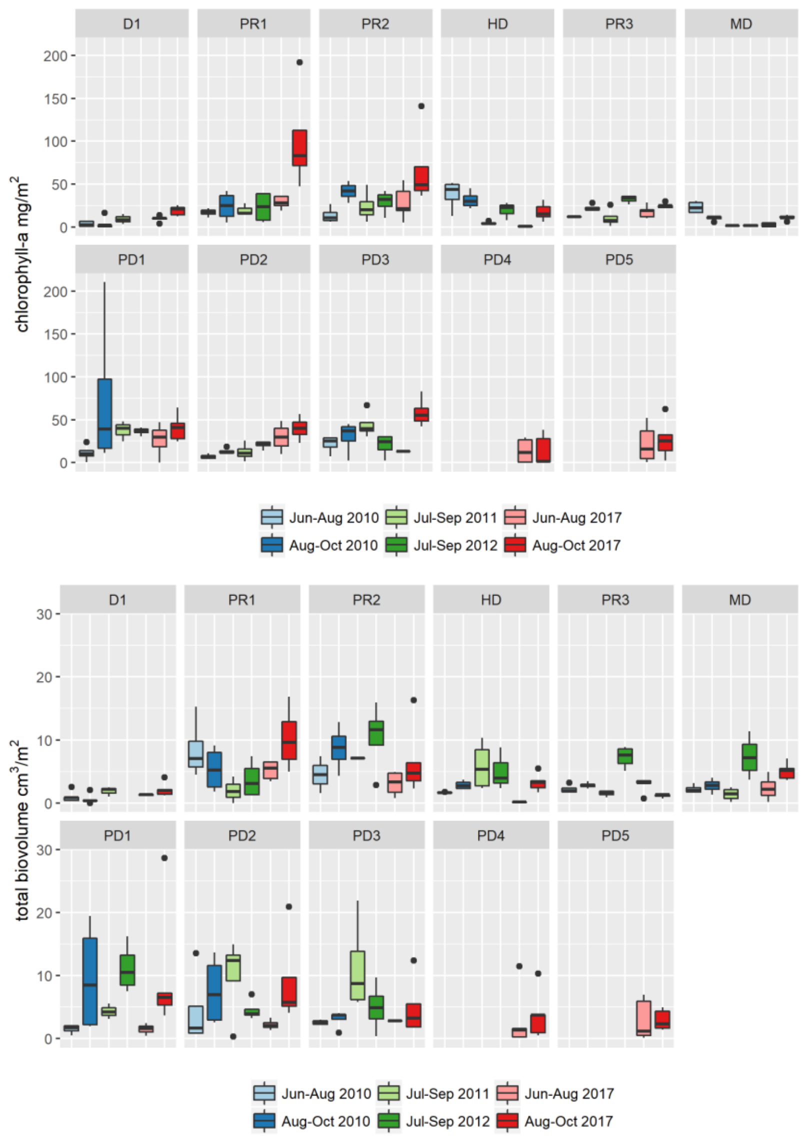


Figure A52 Periphyton chlorophyll-a and total biovolume for 2010-2012 and 2017.

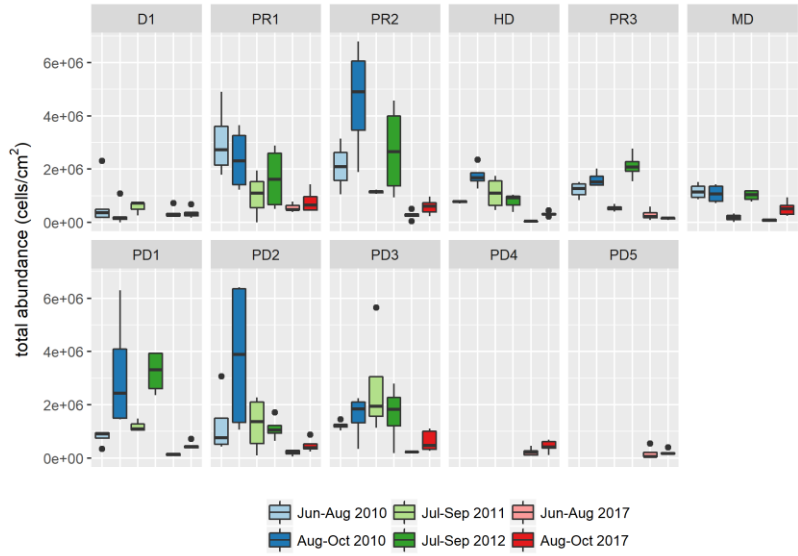


Figure A53 Periphyton total abundance for 2010-2012 and 2017.

Appendix J Zooplankton Summary

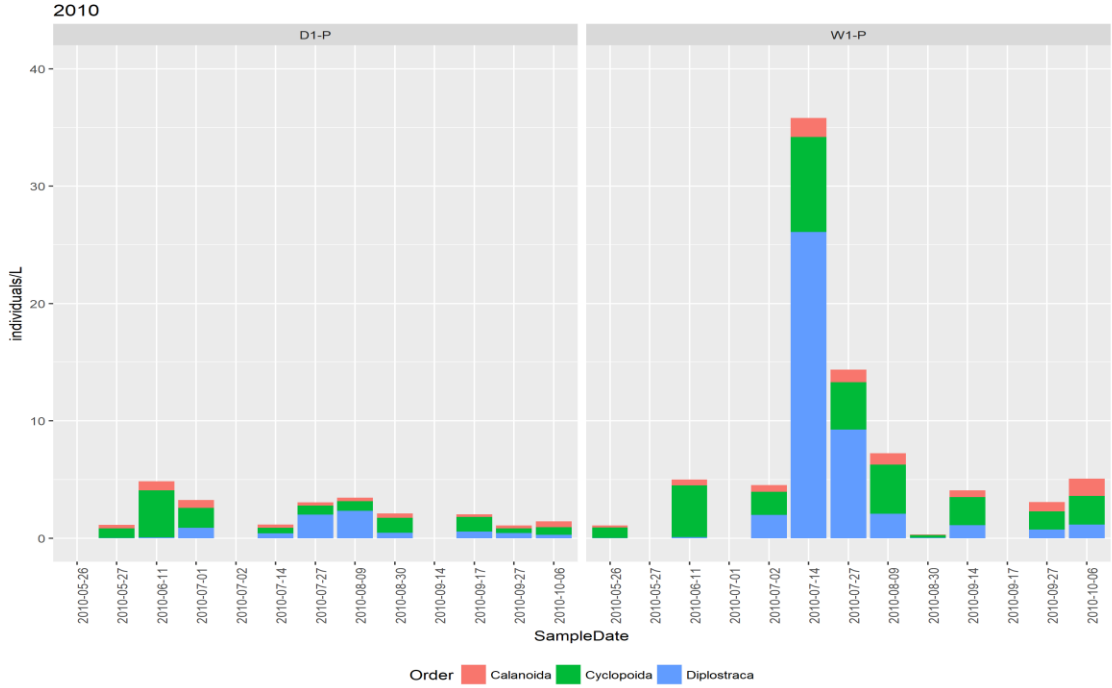


Figure A54 Zooplankton densities in Dinosaur and Williston reservoirs in 2010

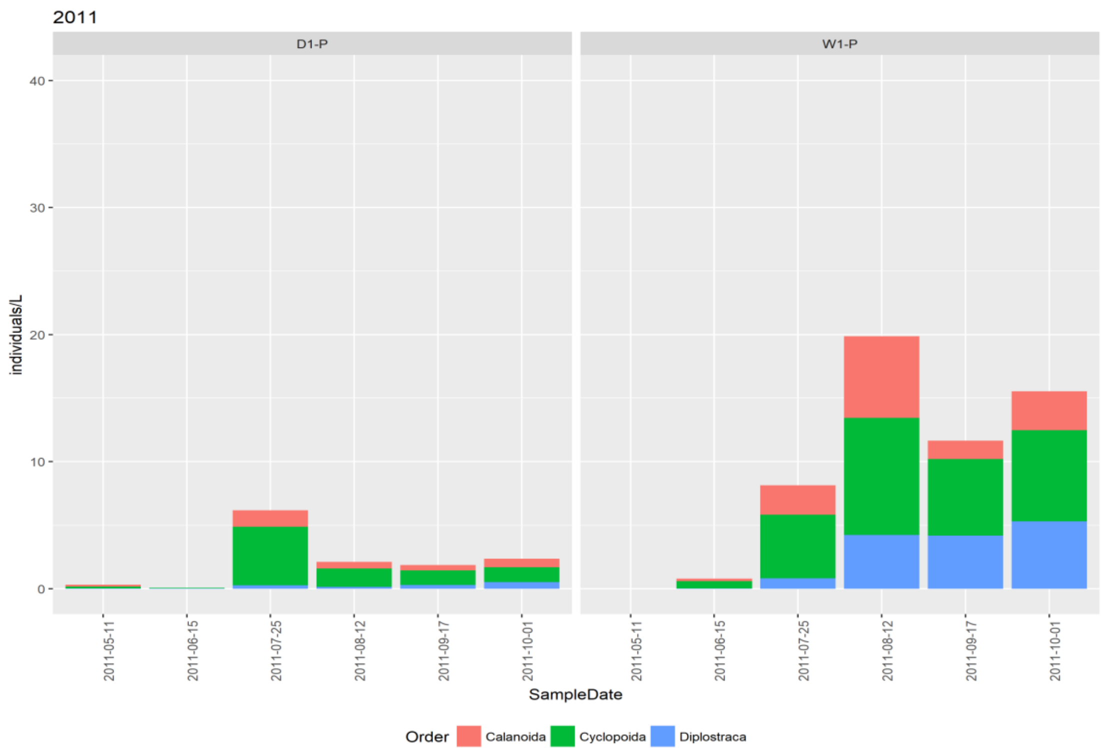


Figure A55 Zooplankton densities in Dinosaur and Williston reservoirs in 2011

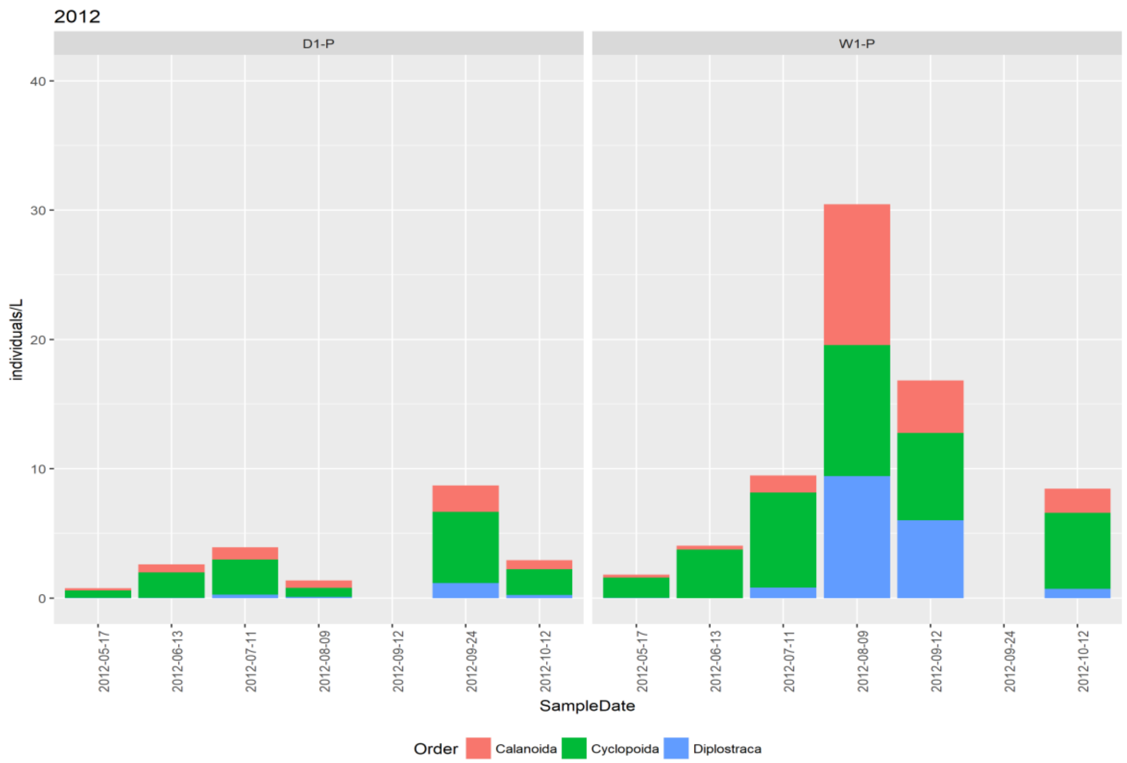


Figure A56 Zooplankton densities in Dinosaur and Williston reservoirs in 2012

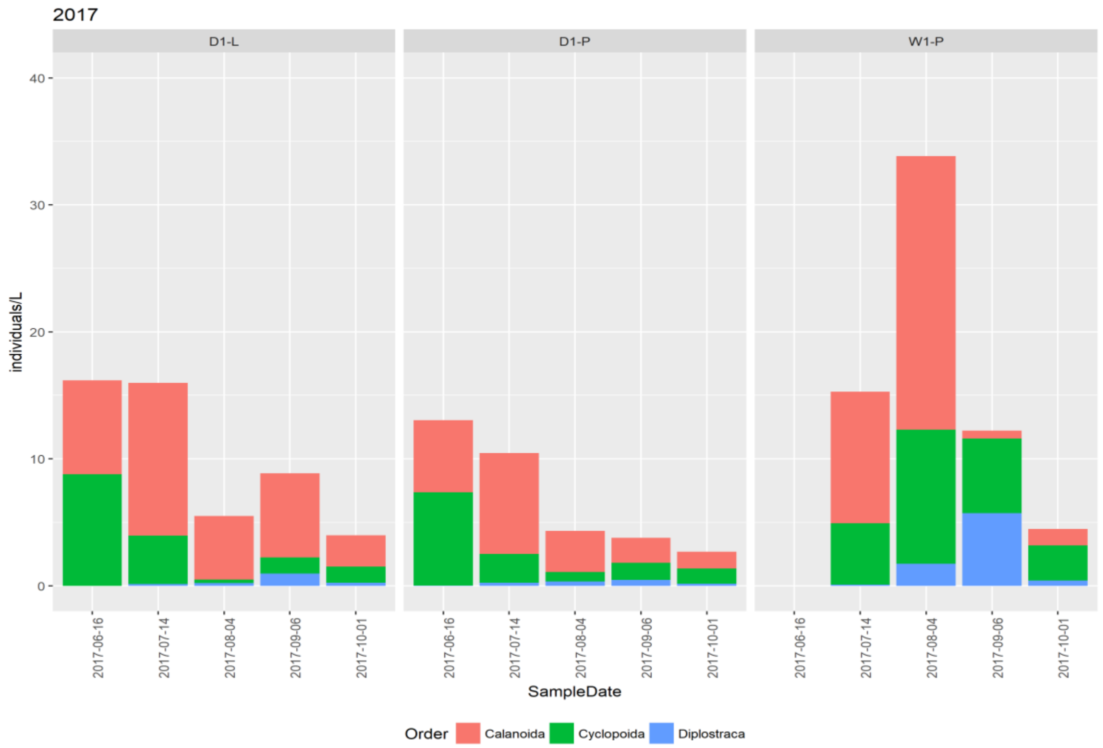


Figure A57 Zooplankton densities in Dinosaur and Williston reservoirs in 2017

Appendix K Invertebrate Summary Stats

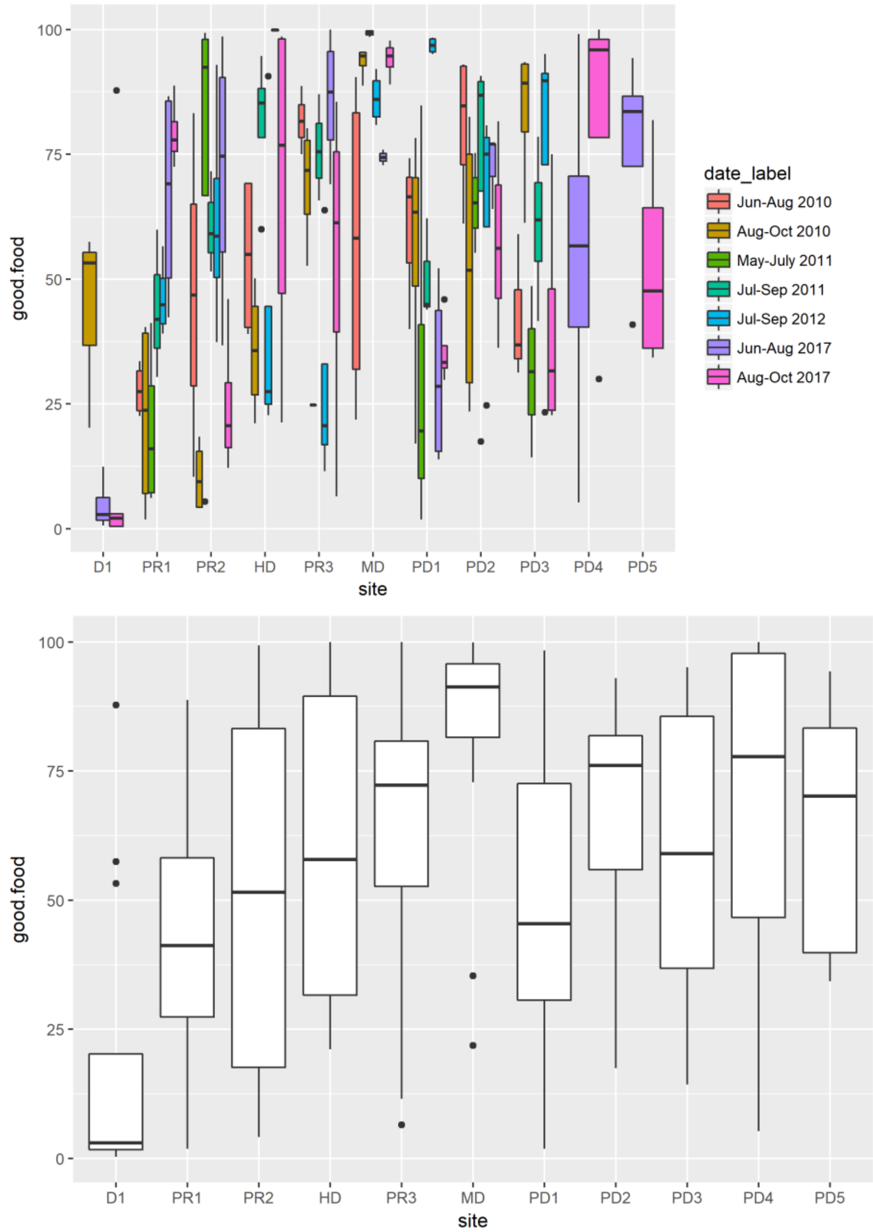


Figure A58 Percent good food benthic invertebrates grouped by site and year/season.

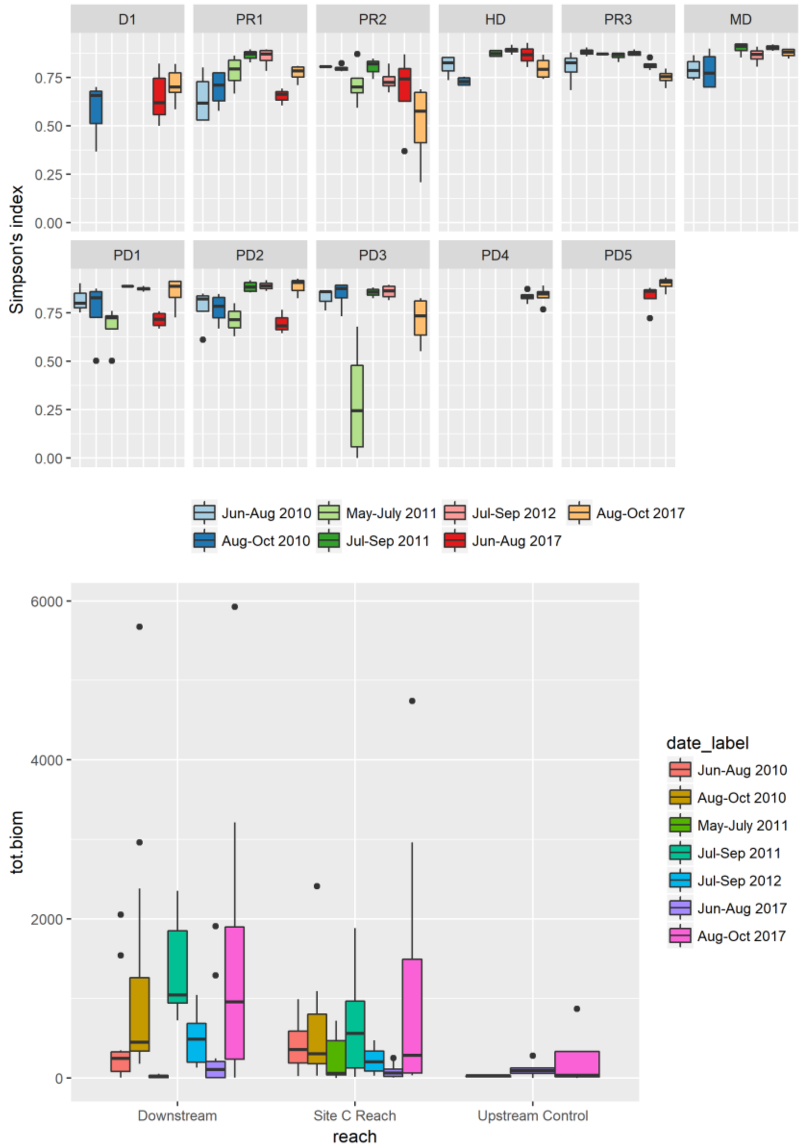


Figure A59 Benthic invertebrates Simpson's index and total biomass.

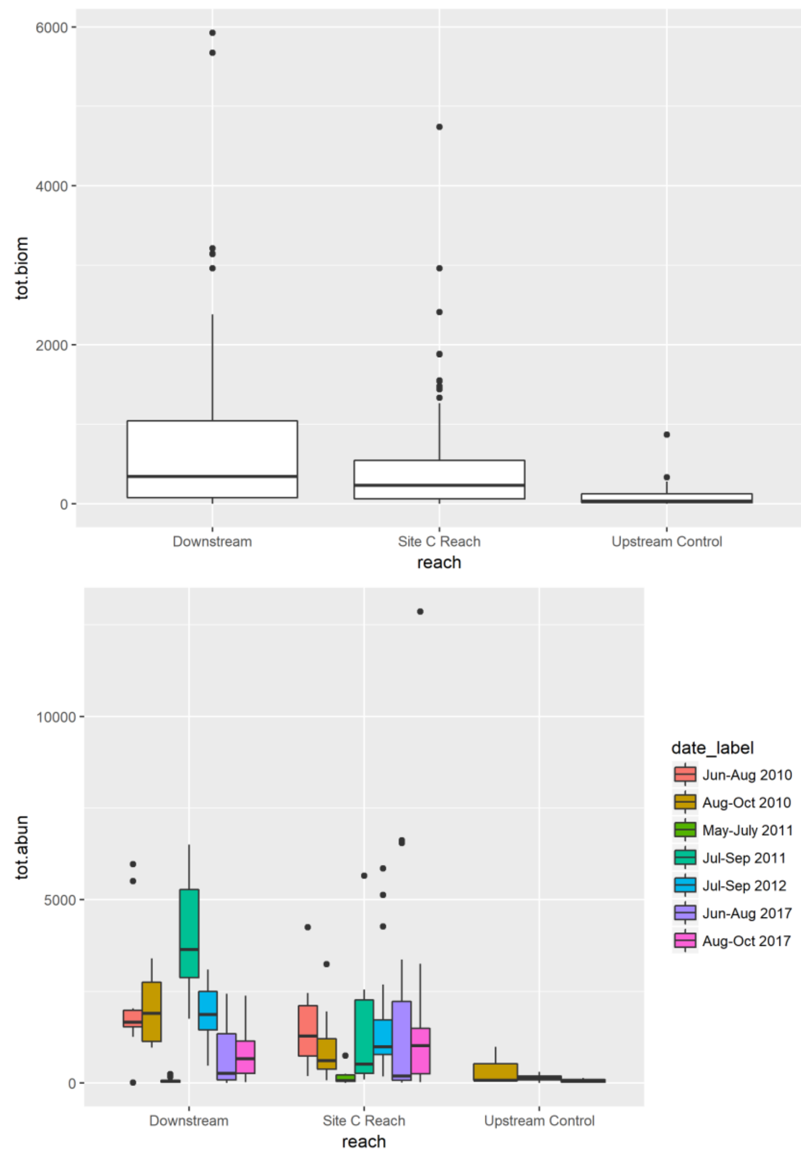


Figure A60 Benthic invertebrates total biomass and abundance.

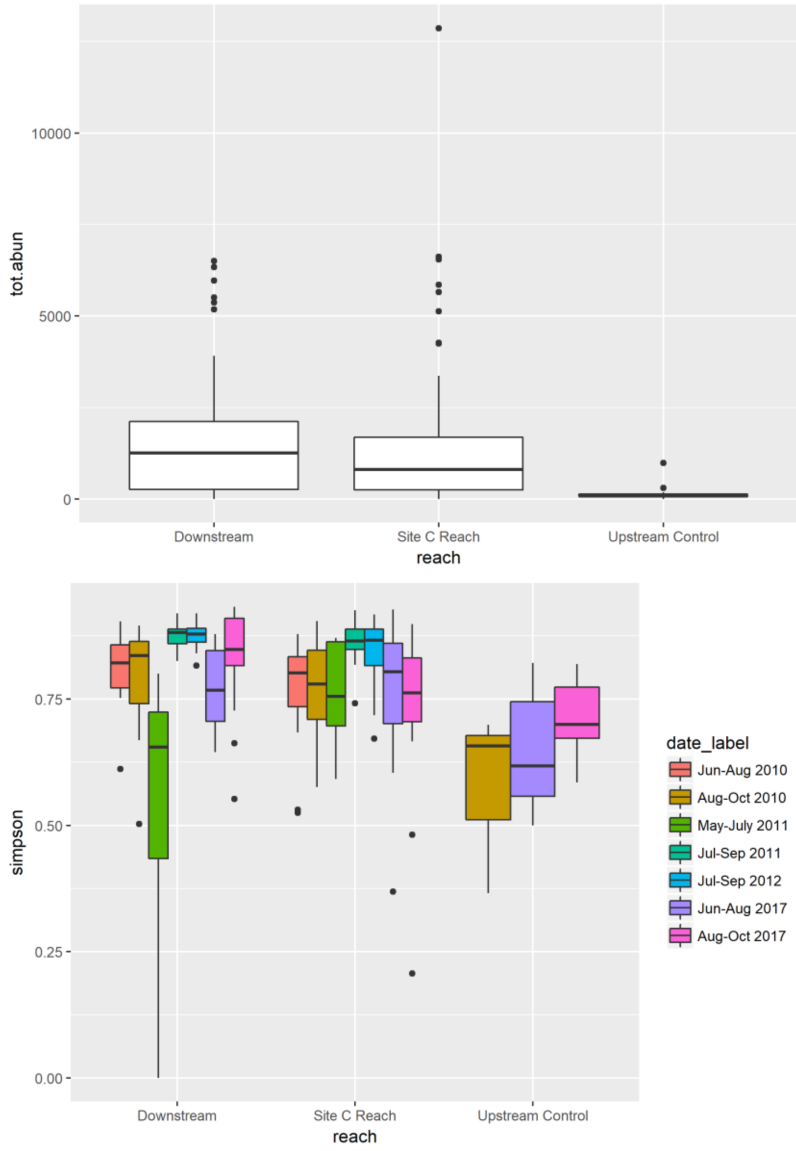


Figure A61 Benthic invertebrates total abundance and Simpson's index.

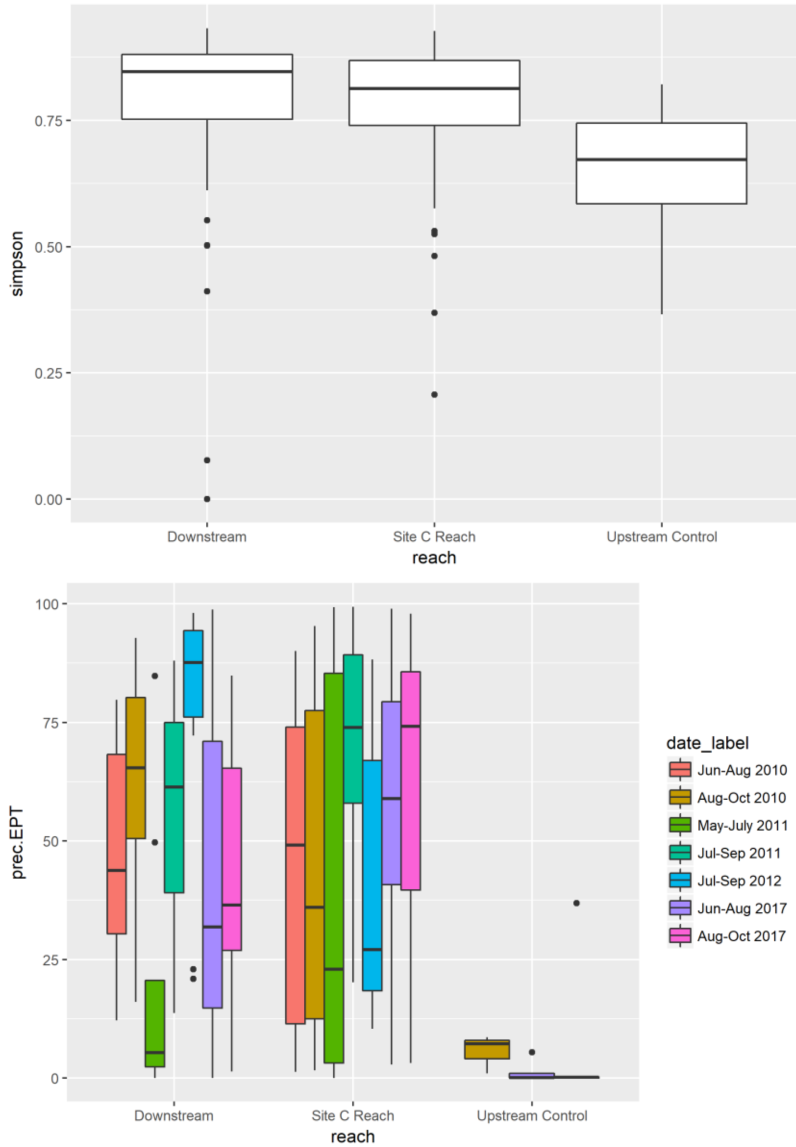


Figure A62 Benthic invertebrates Simpson's index and percent EPT.

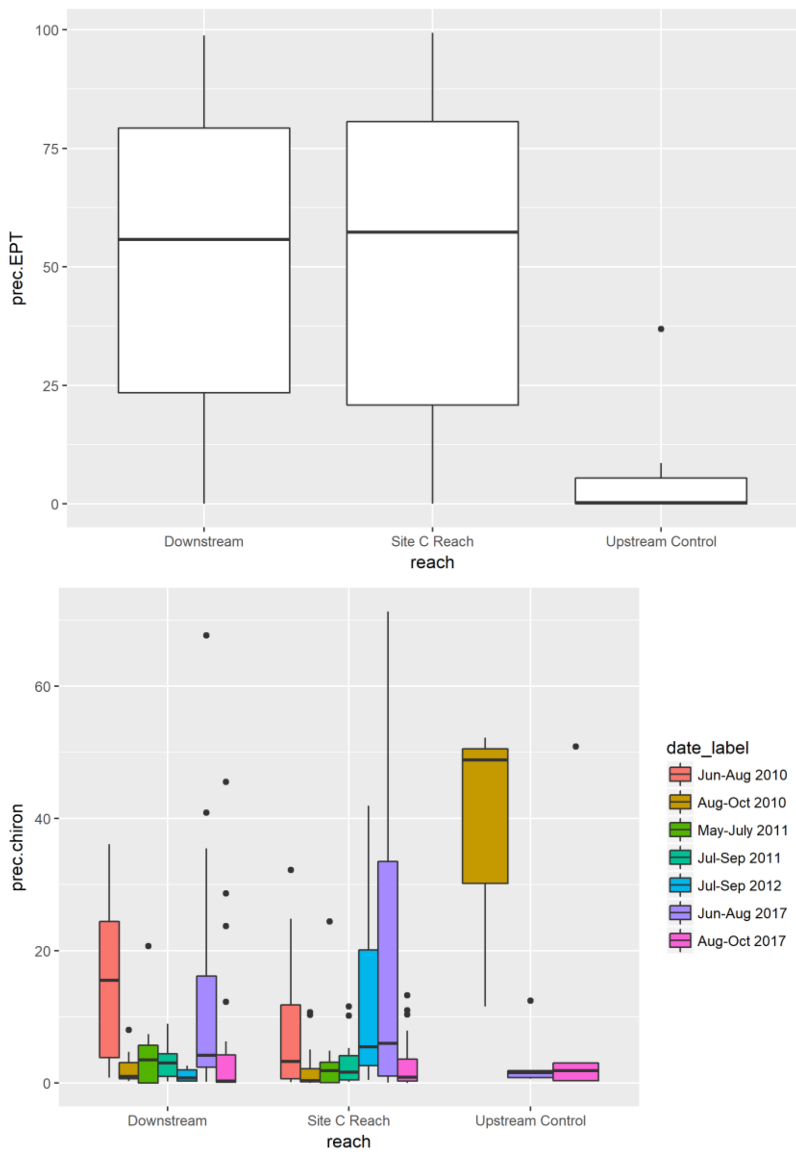


Figure A63 Benthic invertebrate's percent EPT and percent Chironomidae.

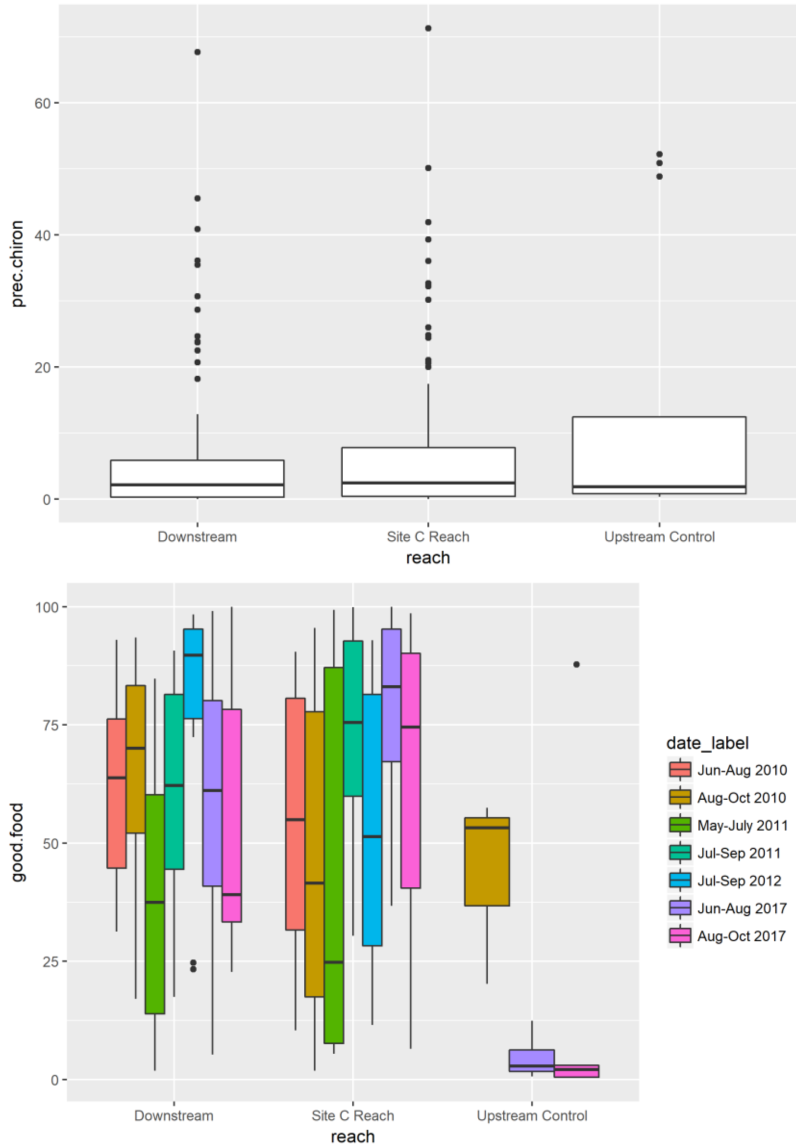


Figure A64 Benthic invertebrate's percent Chironomidae and percent good food.

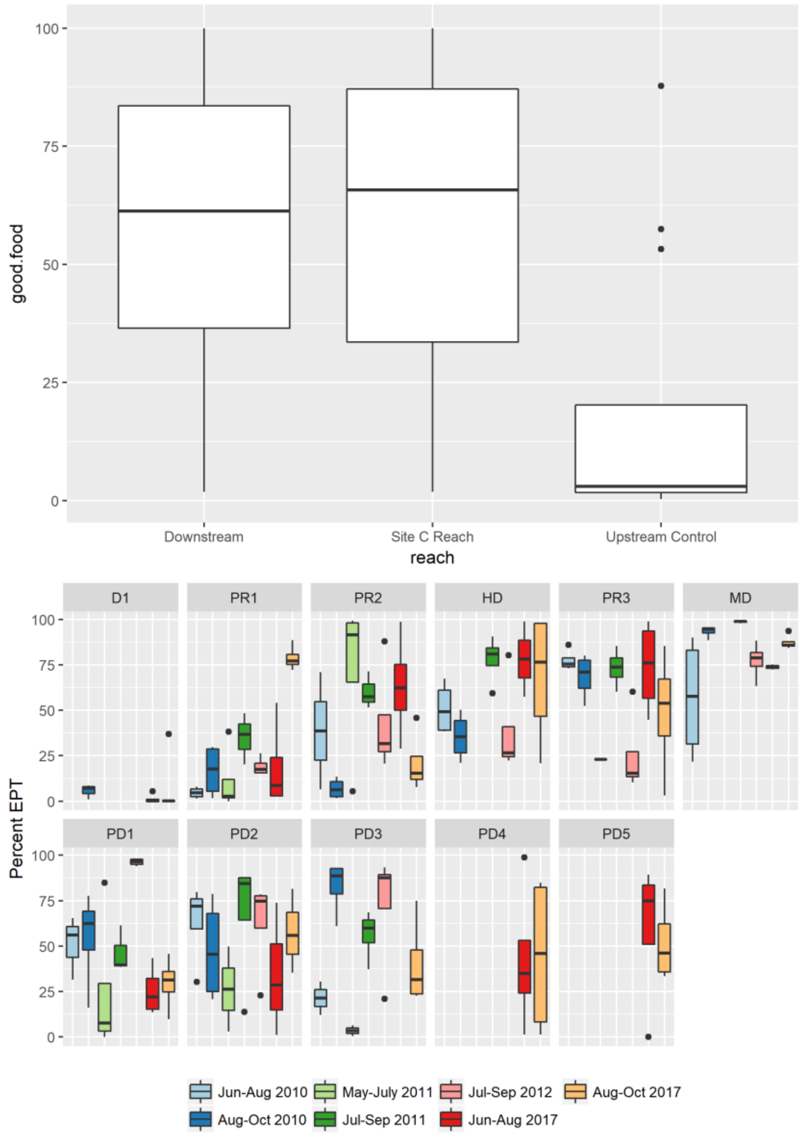
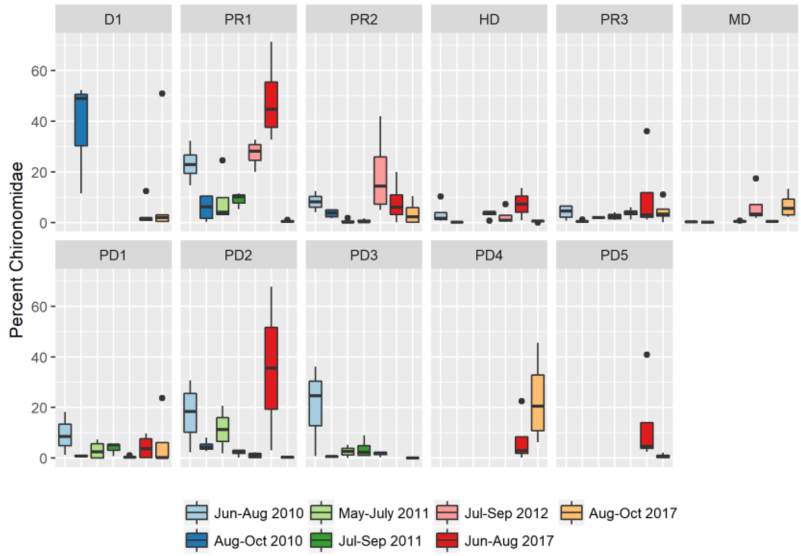


Figure A65 Benthic invertebrate's percent good food and percent EPT.



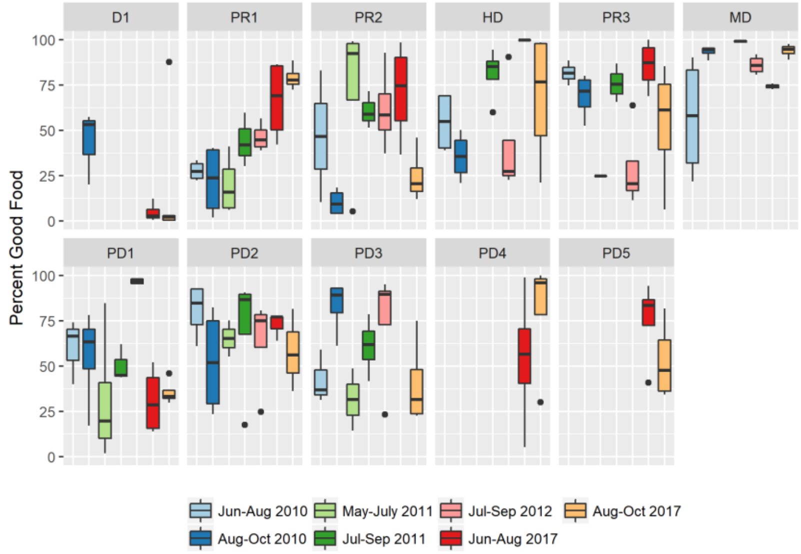


Figure A66 Benthic invertebrate's percent good food and percent EPT.

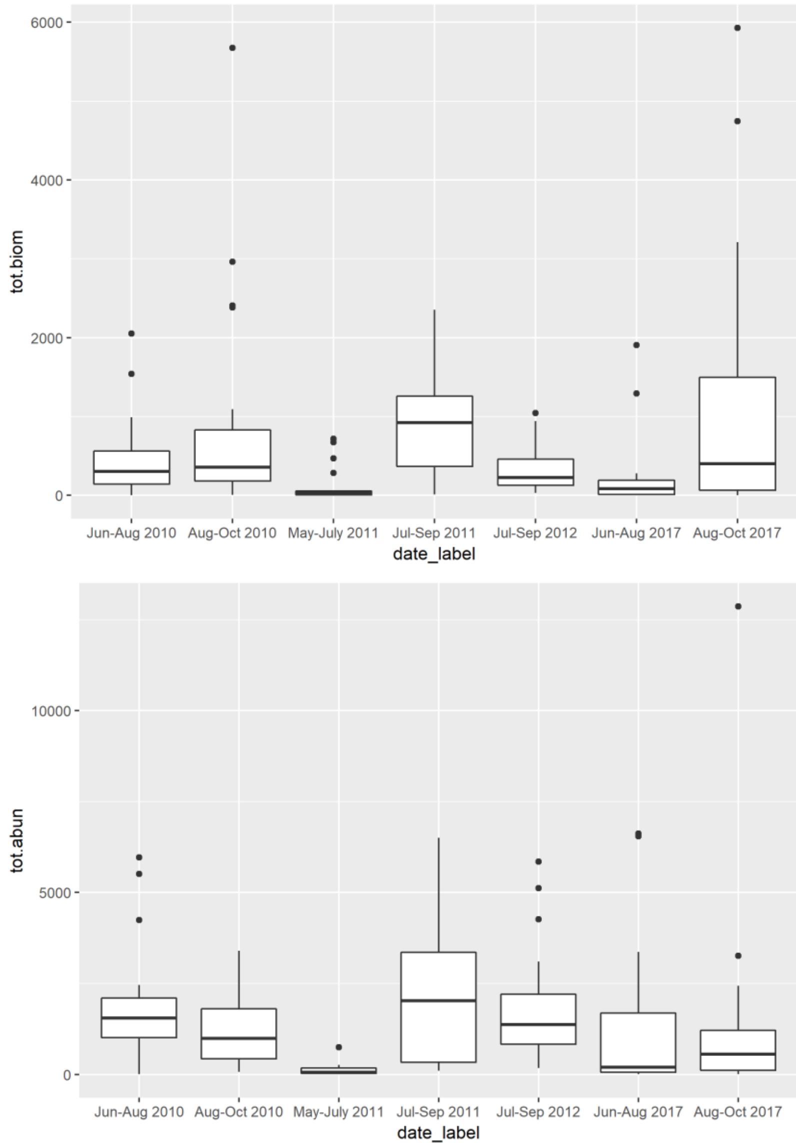


Figure A67 Benthic invertebrate's total biomass and abundance from basket samplers.

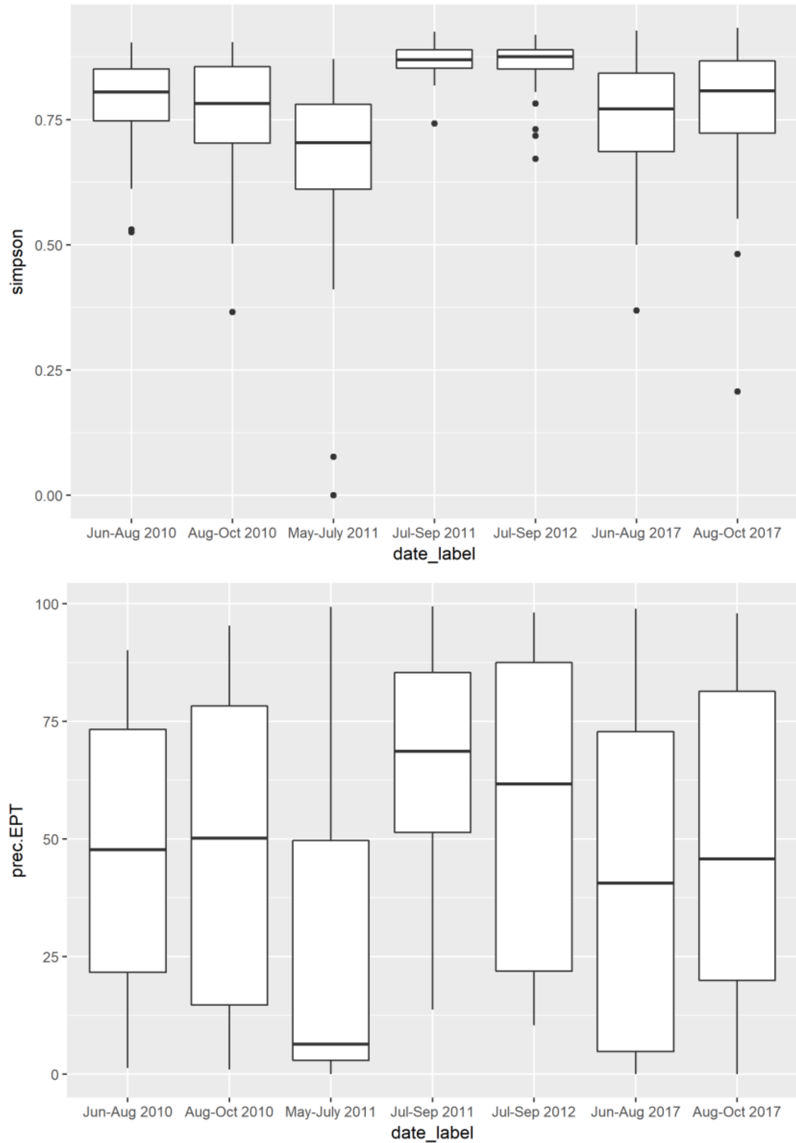


Figure A68 Benthic invertebrate's Simpson's index and percent EPT from basket samplers.

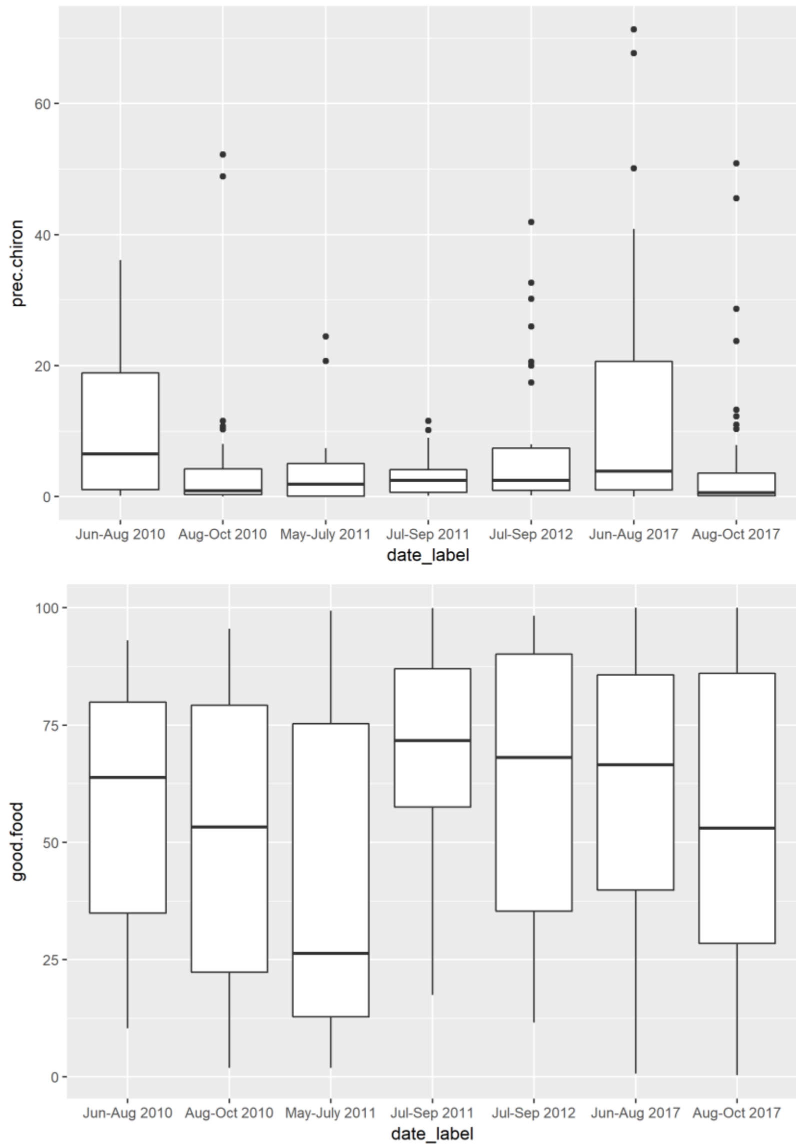


Figure A69 Benthic invertebrate’s percent Chironomidae and percent good food from basket samplers.

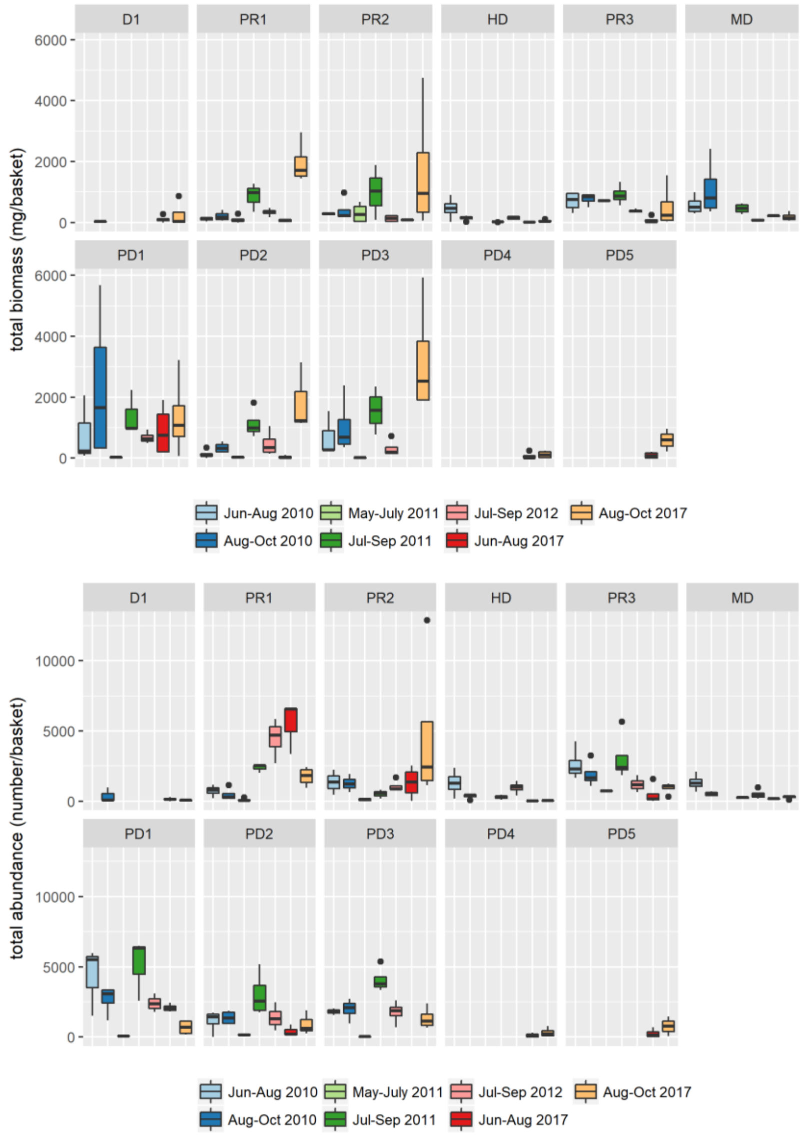


Figure A70 Benthic invertebrate's total abundance and biomass from basket samplers.

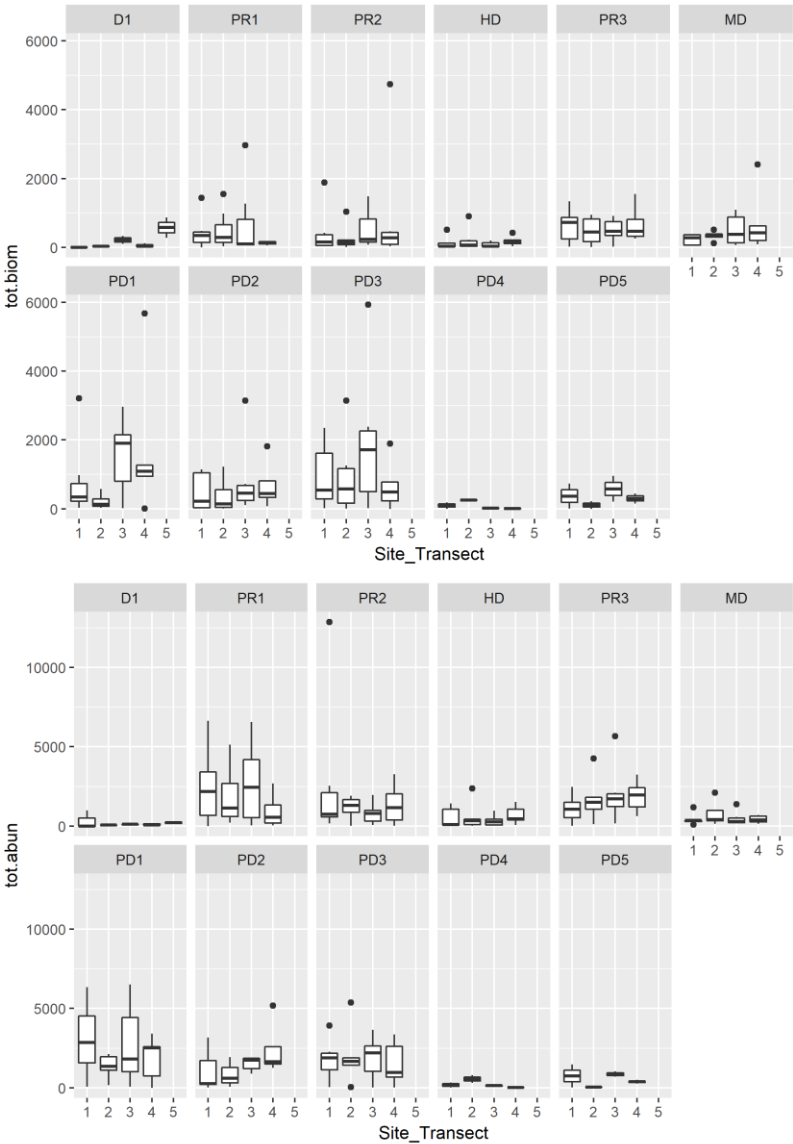
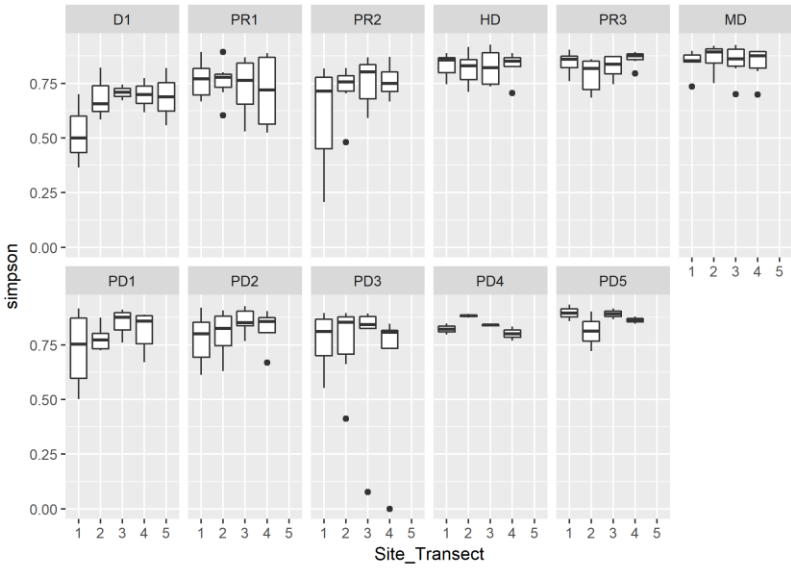


Figure A71 Benthic invertebrate's total biomass and abundance from basket samplers.



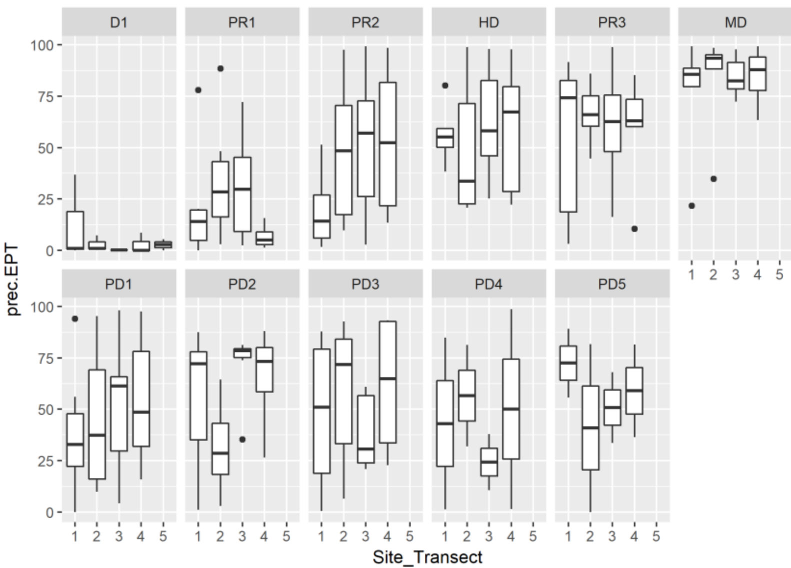


Figure A72 Benthic invertebrate's Simpson's index and percent EPT from basket samplers.

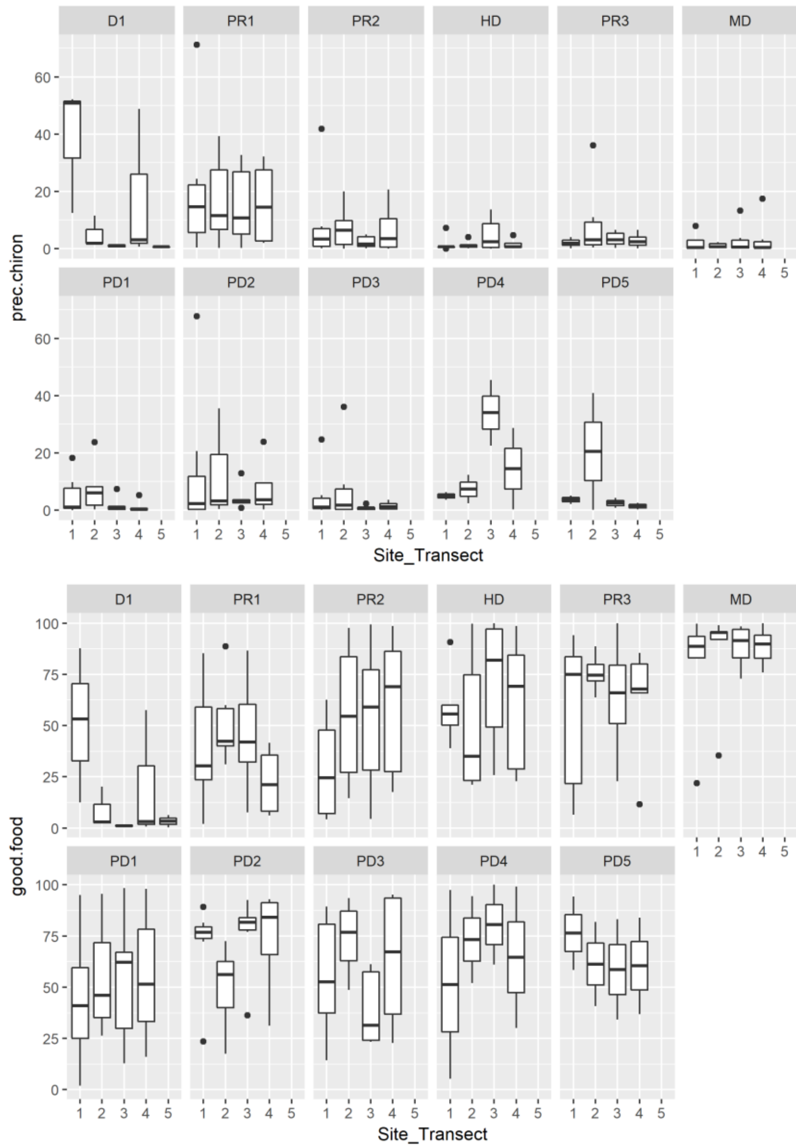
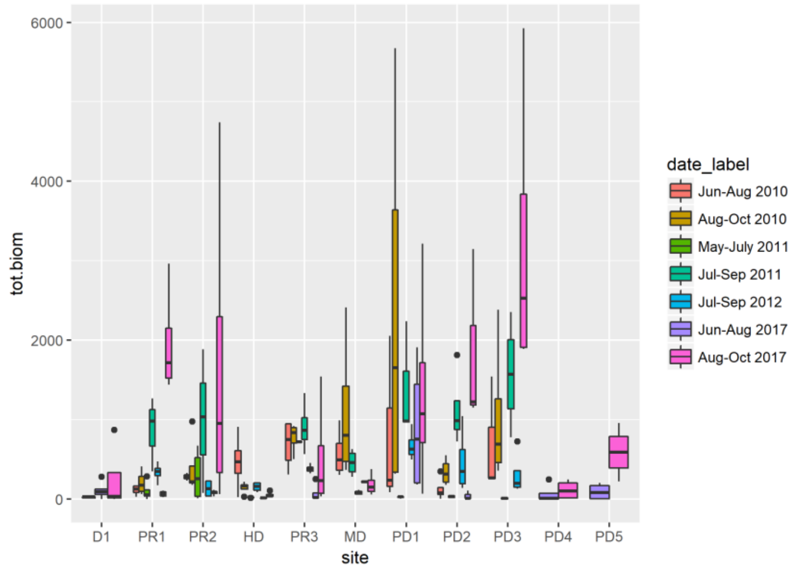


Figure A73 **Benthic invertebrate's percent Chironomidae and percent good food from basket samplers.**



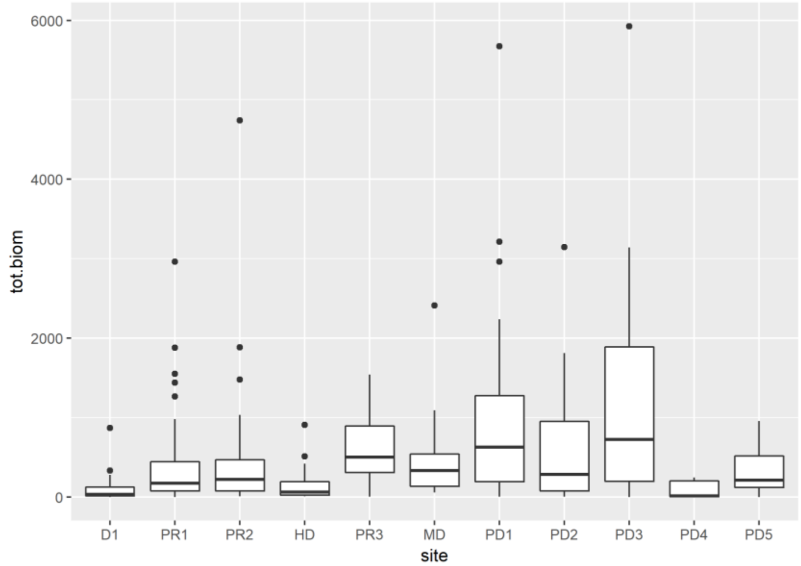


Figure A74 Benthic invertebrate's total biomass from basket samplers.

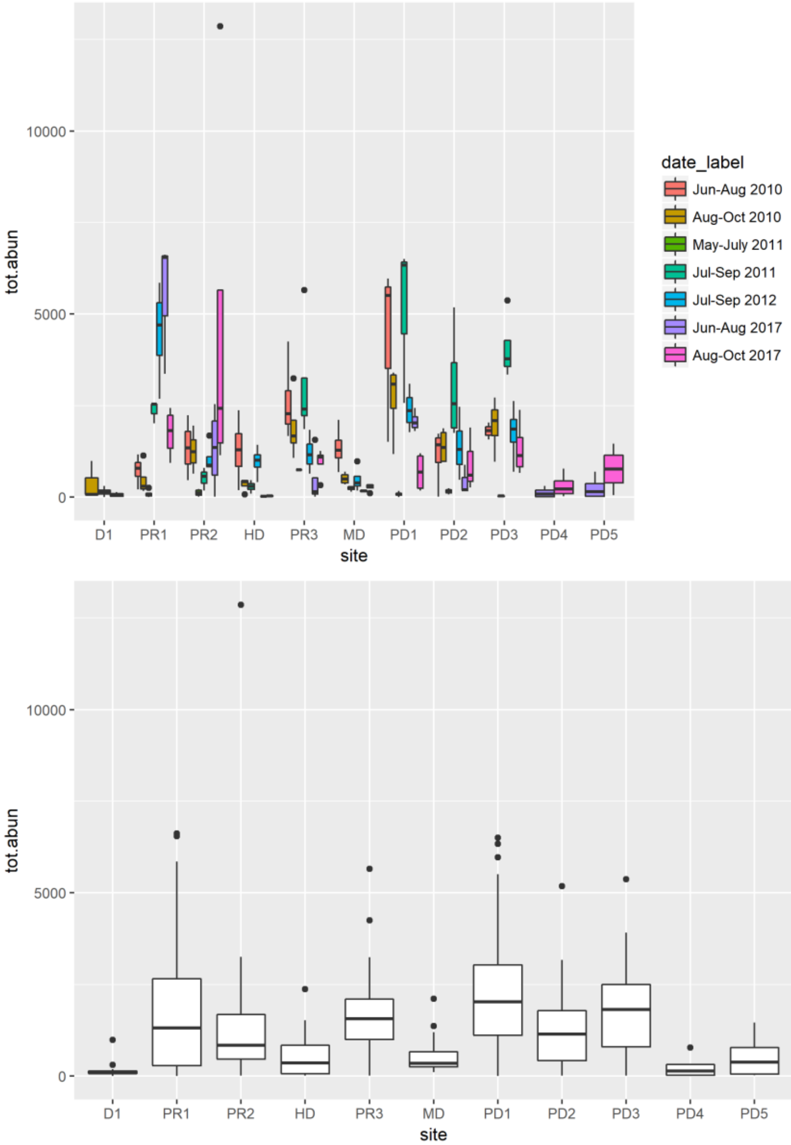
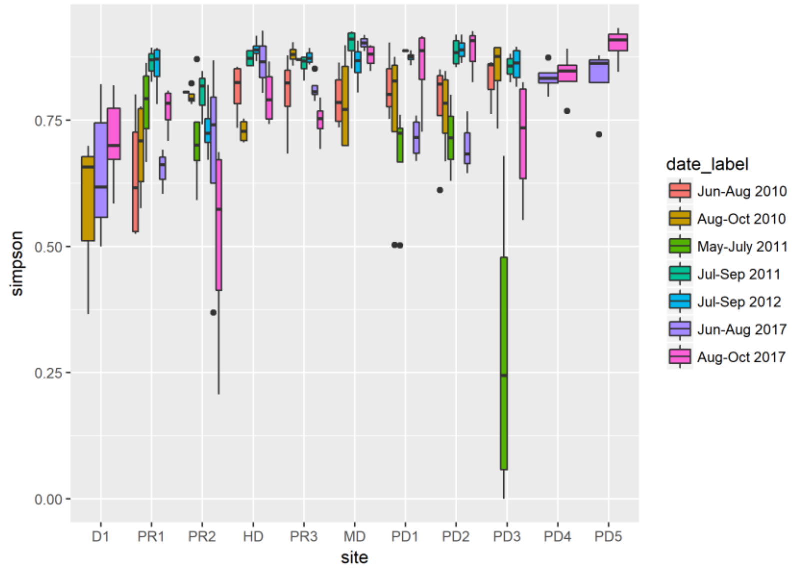


Figure A75 Benthic invertebrate's total abundance from basket samplers.



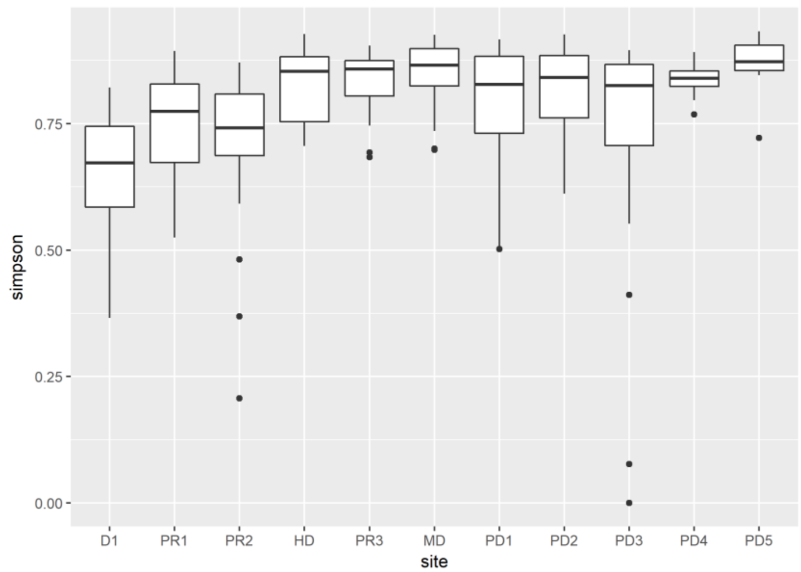


Figure A76 Benthic invertebrate's Simpson's index from basket samplers.

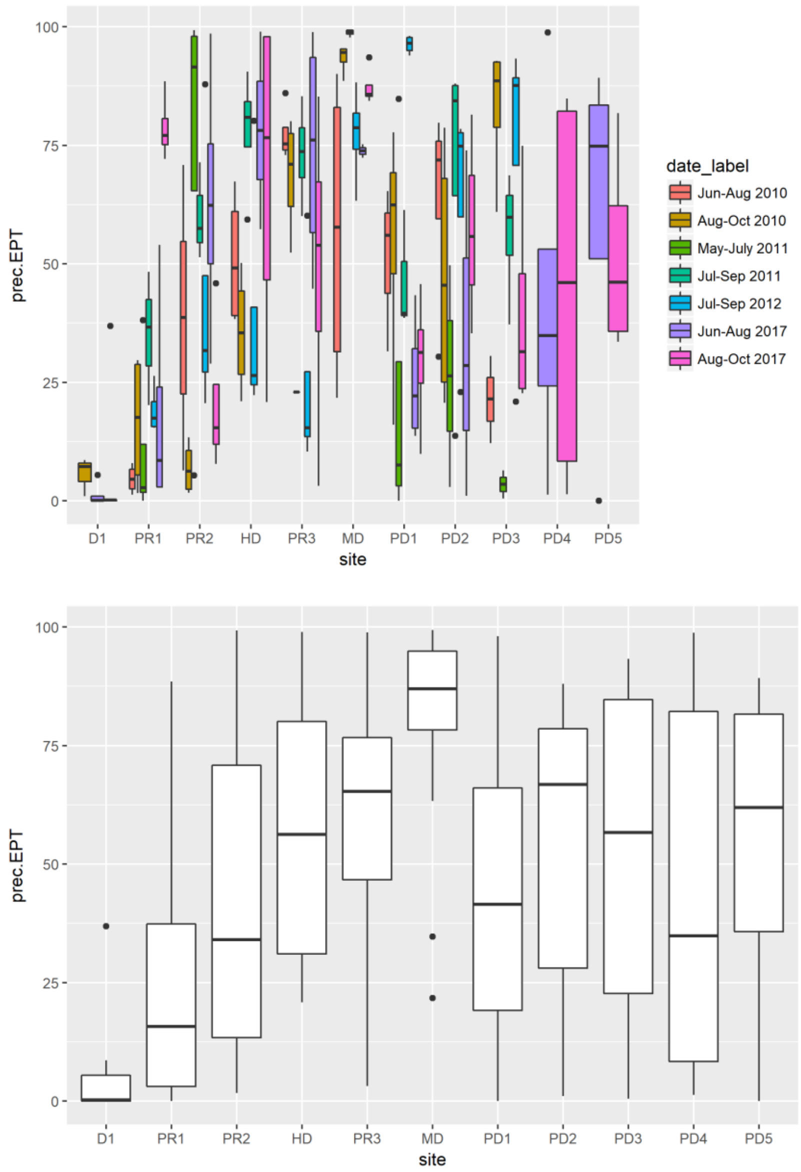
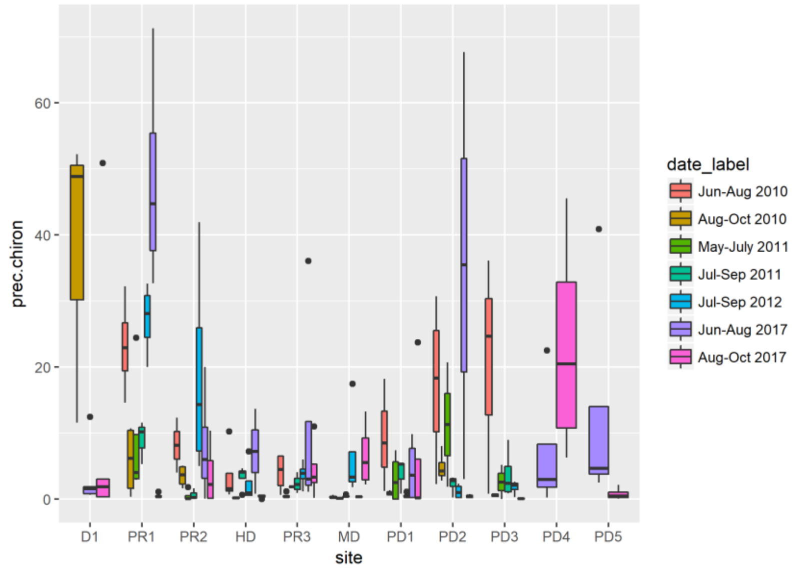


Figure A77 Benthic invertebrate's percent EPT from basket samplers.



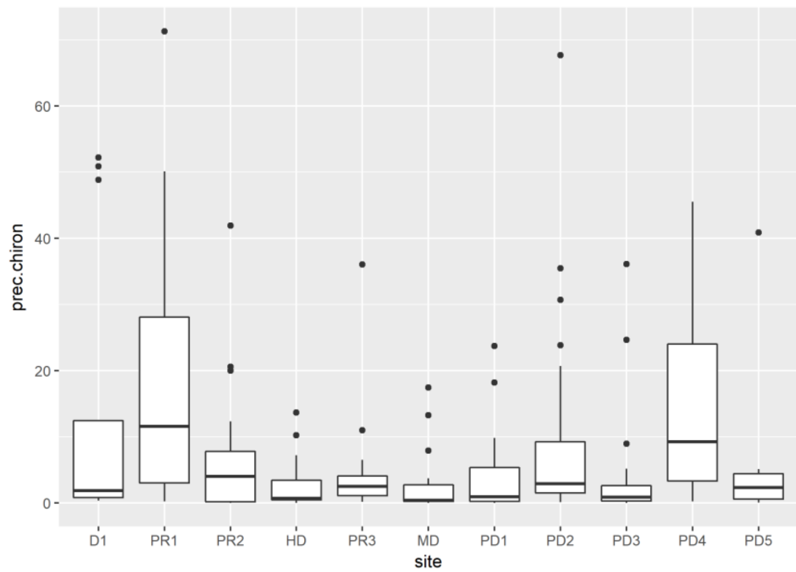


Figure A78 Benthic invertebrate's percent Chironomidae from basket samplers.

Appendix L NMDS Periphyton Results

Table A7 NMDS Periphyton Results for Genus Level analysis without rares

group	R_stat	Fstat	p_val
series	0.321849	21.92642	<0.001
reach	0.03515	4.262411	<0.001
depth	0.005868	1.387031	0.127
site	0.137601	3.605963	<0.001

Table A8 NMDS Periphyton Species Loadings for Genus Level analysis without rares

Species	NMDS1	NMDS2	pval	r2
Achnanthidium	-0.38056	-0.1826	0.001	0.178165
Ankistrodesmus	-0.36894	0.156031	0.001	0.160461
Chilomonas	-0.27703	0.254731	0.001	0.141632
Chroomonas	-0.46439	0.064721	0.001	0.219851
Cryptomonas	-0.27171	0.277317	0.001	0.150729
Cymbella	0.438004	-0.24242	0.001	0.250613
Eucocconeis	-0.39692	-0.20959	0.001	0.201468
Fragilariforma	-0.15964	-0.29987	0.001	0.115405
Frustulia	0.29607	-0.33113	0.001	0.197306
Peridinium	-0.35874	-0.03505	0.001	0.129921
Pseudanabaena	-0.34251	0.092195	0.001	0.125812
Staurosira	-0.32056	-0.15843	0.001	0.127859
Synechocystis	0.19396	-0.35598	0.001	0.164342

Table A9 NMDS Periphyton Results for Family Level analysis without rares

group	R_stat	Fstat	p_val
series	0.309538	20.7117	<0.001
reach	0.038218	4.649209	<0.001
depth	0.005883	1.390752	0.144
site	0.154012	4.114323	<0.001

Table A10 NMDS Periphyton Species Loadings for Family Level analysis without rares

Species	NMDS1	NMDS2	pval	r2
Achnanthaceae	-0.34394	-0.22548	0.001	0.169138
Chroomonadaceae	-0.37008	-0.25664	0.001	0.202823
Cryptomonadaceae	-0.40014	0.115614	0.001	0.17348
Cyanobacteriaceae	-0.20929	0.270388	0.001	0.11691
Fragilariaceae	-0.32301	-0.06325	0.001	0.108338
Merismopediaceae	0.331227	0.08904	0.001	0.11764
Nitzschiaceae	0.02996	0.321581	0.001	0.104312
Nostocaceae	-0.31744	0.051873	0.001	0.103461
Oocystaceae	-0.38768	0.149721	0.001	0.17271
Peridiniaceae	-0.33753	-0.18213	0.001	0.147099
Pseudanabaenaceae	-0.40751	0.147182	0.001	0.187731

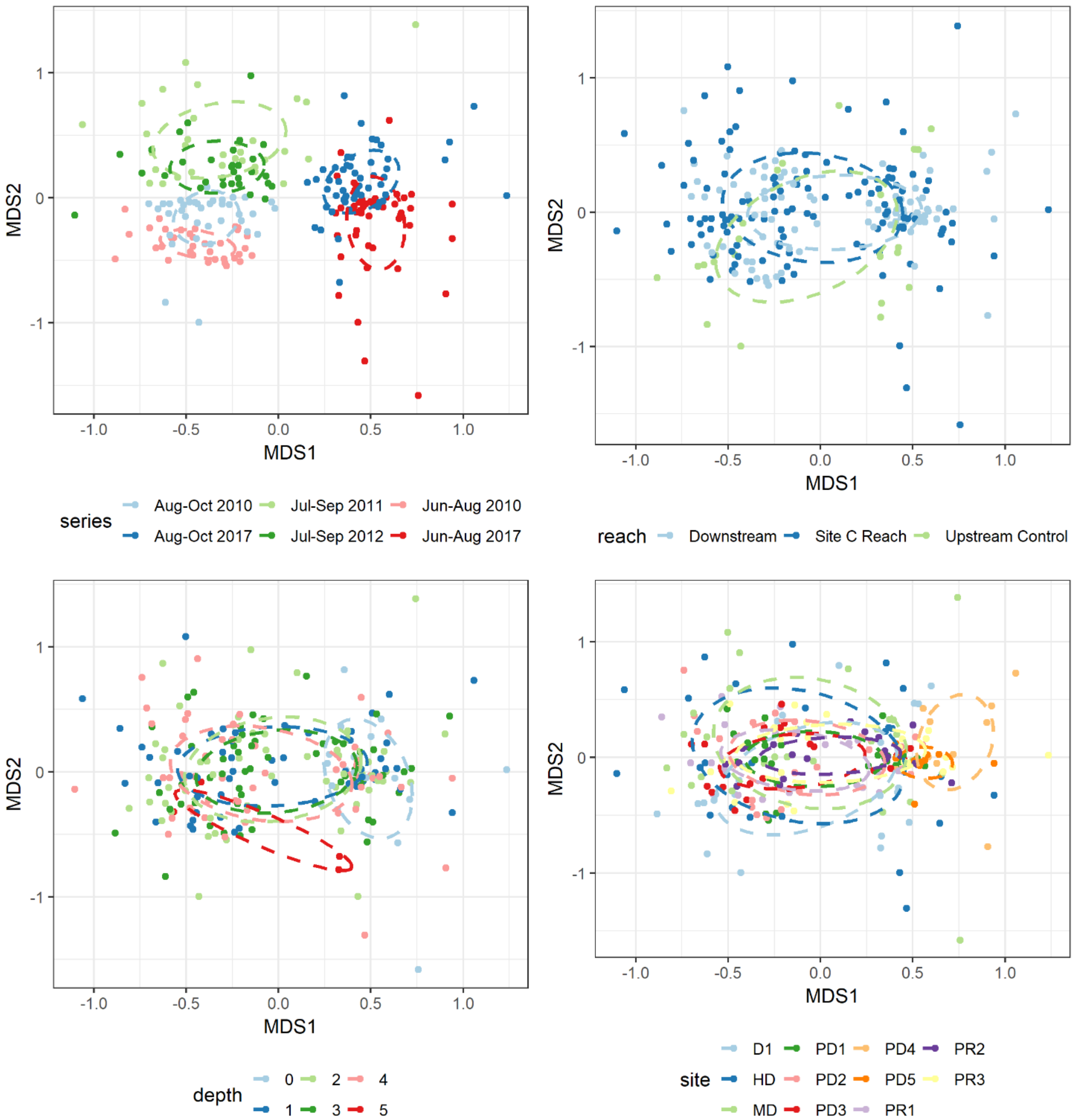


Figure A79 NMDS plots at the Family level.

Table A11 NMDS Periphyton Results for Genus Level analysis without rares for 2017 data only

group	R_stat	Fstat	p_val
series	0.088502	9.806551	<0.001
reach	0.076624	4.149127	<0.001
depth	0.023308	2.410261	0.012
site	0.250635	3.077055	<0.001

Table A12 NMDS Periphyton Species Loadings for Genus Level analysis without rares for 2017

Species	NMDS1	NMDS2	pval	r2
Achnanthidium	-0.309220031	-0.250821728	0.001	0.158528567
Amphora	-0.377562512	-0.370569895	0.001	0.279875498
Cocconeis	-0.425507349	-0.184353641	0.001	0.21504277
Cyclotella	-0.341509536	-0.181066311	0.001	0.149413772
Didymosphenia	-0.274169139	-0.174956149	0.012	0.10577837
Encyonema	-0.342667202	-0.044488208	0.002	0.119400012
Fragilaria	-0.361447517	-0.111391973	0.001	0.143052479
Fragilariforma	-0.27276937	0.188880212	0.007	0.110078864
Frustulia	-0.270835267	0.164504475	0.009	0.100413464
Oscillatoria	-0.234014092	0.276764115	0.004	0.13136097
Planktolyngbya	-0.268349861	-0.318990332	0.001	0.173766479
Synechocystis	-0.236290151	0.483889775	0.001	0.28998235
Synedra	-0.318269715	0.074995086	0.007	0.106919874
Tabellaria	-0.315553436	-0.230132061	0.003	0.152534737

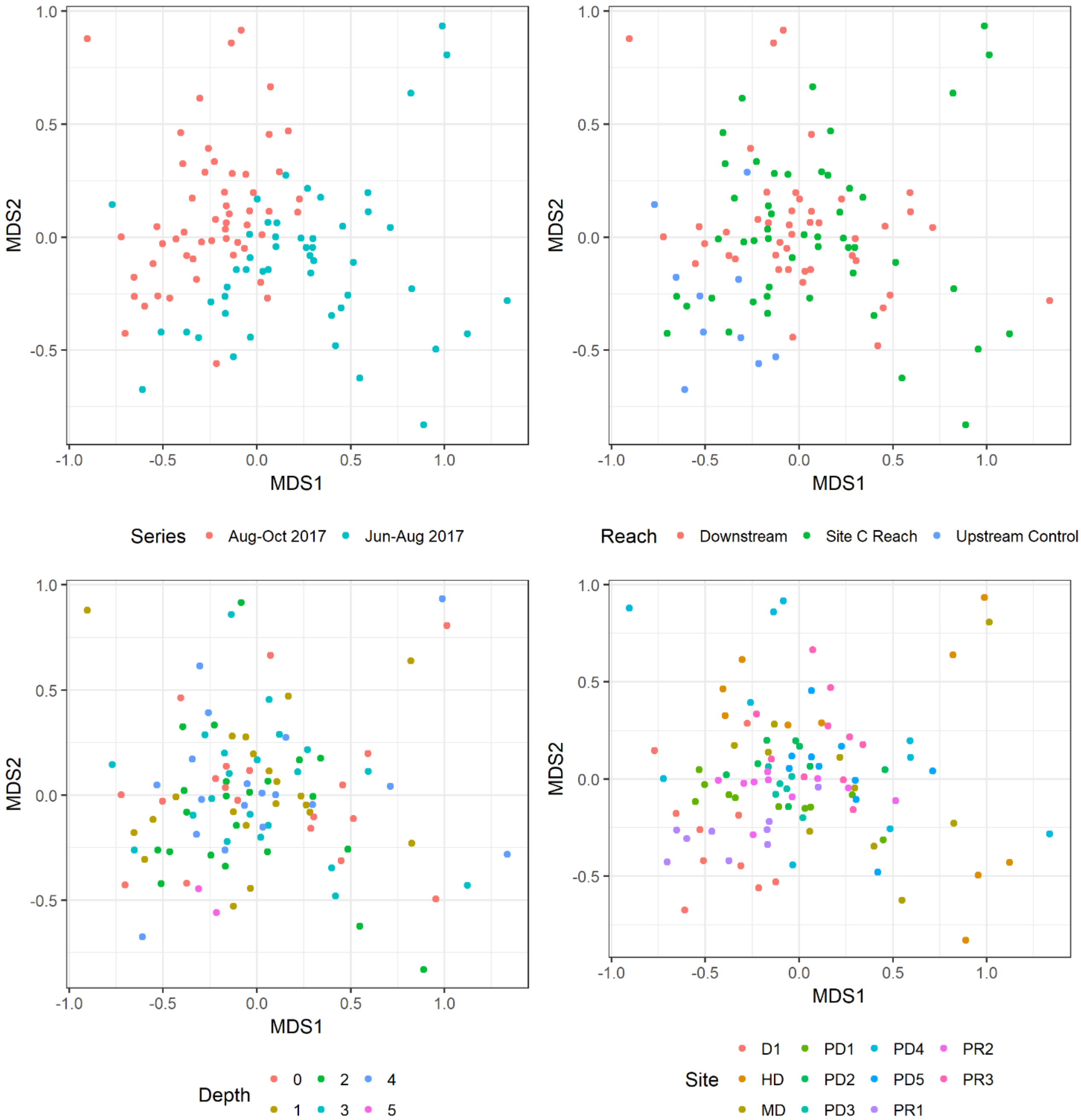


Figure A80 **NMDS plots at the Genus level considering only 2017 data.**

Appendix M NMDS Invertebrate Results

Table A13 NMDS Invertebrate Results for Genus Level analysis without rares

group	R_stat	Fstat	p_val
series	0.188929	8.34692	<0.001
reach	0.04721	5.425601	<0.001

Table A14 NMDS Invertebrate Species Loadings for Genus Level analysis without rares

Species	NMDS1	NMDS2	pval	r2
Rhithrogena	-0.299730965	-0.18774574	0.001	0.125087114

Table A15 NMDS Invertebrate Results for Family Level analysis without rares

group	R_stat	Fstat	p_val
series	0.157717	6.709756	<0.001
reach	0.06312	7.377316	<0.001

Table A16 NMDS Invertebrate Species Loadings for Family Level analysis without rares

Species	NMDS1	NMDS2	pval	r2
Capniidae	-0.245617247	-0.200819544	0.001	0.100656322
Heptageniidae	-0.397248823	-0.155347442	0.001	0.181939456
Hydropsychidae	-0.342580022	0.119486651	0.001	0.131638131
Lymnaeidae	0.283659957	-0.333107247	0.001	0.191423409

Table A17 NMDS Invertebrate Results for Genus Level analysis without rares for 2017

group	R_stat	Fstat	p_val
series	0.041399	3.282171	<0.001
reach	0.091502	3.776918	<0.001
depth	0.068222	1.05433	0.32
site	0.366945	3.883591	<0.001

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Table A18 NMDS Invertebrate Results for Genus Level analysis without rares for 2017

Species	NMDS1	NMDS2	pval	r2
Arctopsyche	0.199703116	0.251247015	0.023	0.103006397
Fossaria	-0.325492588	-0.130077664	0.002	0.122865624
Heptageniidae	0.300527896	-0.292860155	0.001	0.176084087
Psectrocladius	-0.482408179	0.033958356	0.001	0.233870821
Rhithrogena	0.123891813	-0.321395224	0.013	0.118644072
Stagnicola	-0.211770284	-0.37852049	0.001	0.188124415
Stictochironomus	-0.292058066	-0.296768757	0.002	0.173369609
Taeniopteryx	0.174235378	-0.289450884	0.009	0.114139781

Table A19 NMDS Fish Stomach Invertebrate Results for Family Level analysis

group	R_stat	Fstat	p_val
reach	0.096255	12.30159	<0.001
site	0.125479	5.428451	<0.001
fish_code	0.054288	6.630249	<0.001
year	0.029506	7.053609	<0.001

Table A20 NMDS Fish Stomach Invertebrate Species Loadings for Family Level analysis

Species	NMDS1	NMDS2	pval	r2
Chironomidae	0.122031	0.381383	0.001	0.160345
Glossosomatidae	-0.3264	0.159893	0.001	0.1321
Heptageniidae	-0.24231	-0.2073	0.001	0.101689

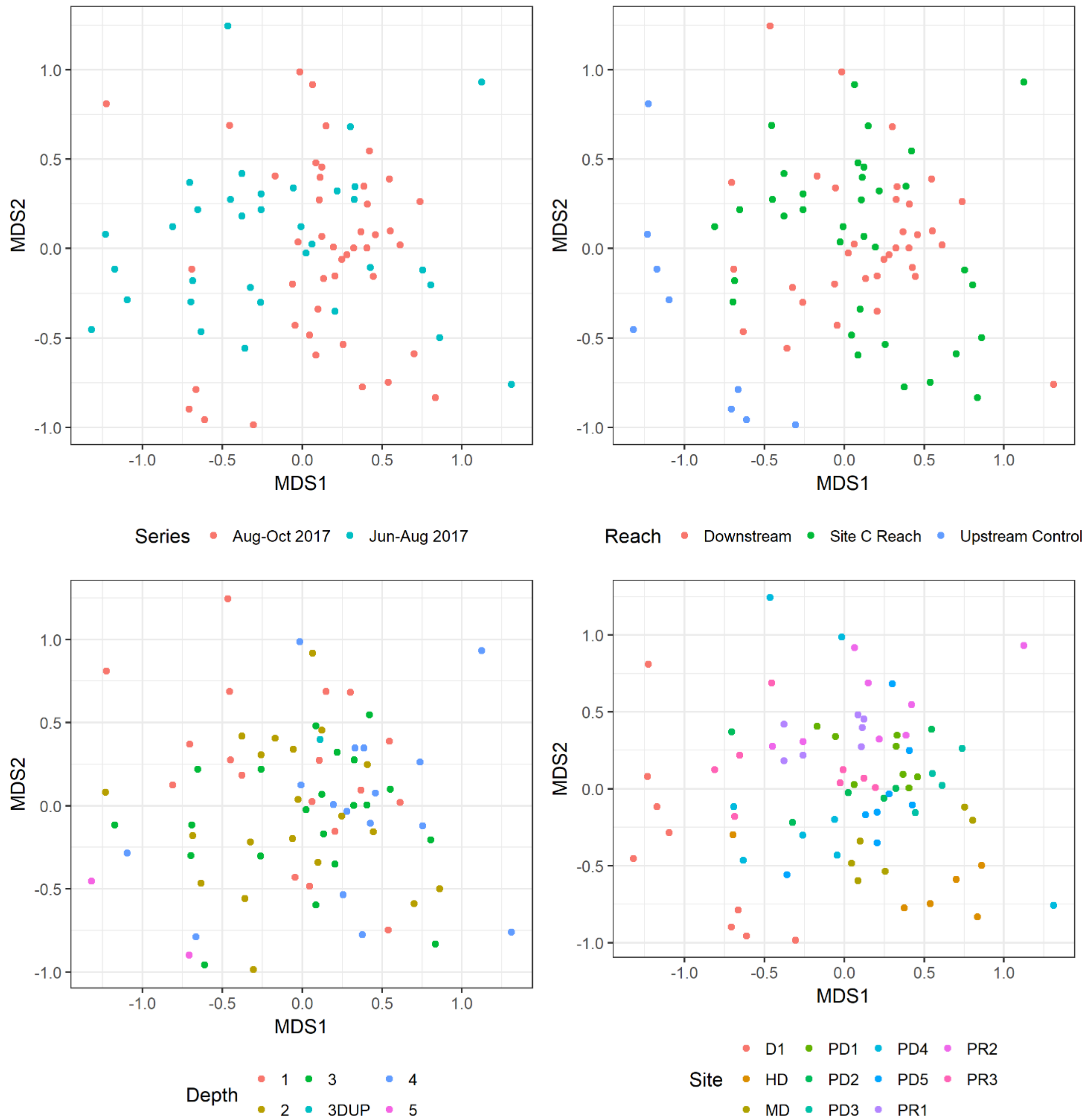

Figure A81 **NMDS plots at the Genus level considering only 2017 data.**

Appendix N Periphyton Production Model Results

Table A21 Summary of the number of plausible models identified using model averaging (those with a ∆AIC <3) and the range of pseudo-R^2 values for selected models for samplers across all transects

# of plausible models (AIC<3)	minr2	maxr2	Production Metric
5	0.44	0.47	Chlorophyll-a
11	0	0.05	Percent Achnanthes
6	0.07	0.07	Percent from Reservoir
11	0	0.04	Percent Good Forage
5	0.13	0.13	Percent Motile
8	0.1	0.12	Simpsons Index
7	0.52	0.55	Species Richness
6	0.46	0.51	Total Abundance
6	0.35	0.4	Total Biovolume

Table A22 Model average summaries of periphyton models for all transects. The explanatory variables have standardized coefficients with 95% CLs.

response	variable	Estimate	Std.Error	lower.CI	upper.CI	rvi
Chl-a	Total Submergence Time (Hours)	1.89	0.29	1.31	2.48	1.00
Chl-a	Velocity	-0.77	0.34	-1.45	-0.09	0.82
Chl-a	Average Depth (m)	-0.64	0.32	-1.27	-0.01	0.73
Chl-a	Depositional Rate (cm/day)	0.11	0.51	-0.91	1.13	0.24
Chl-a	Average Temperature (Submergence)	-0.11	0.50	-1.10	0.89	0.23
Chl-a	(Intercept)	2.74	0.33	2.09	3.39	NA
Percent Achnanthes	Average Temperature (Submergence)	-5.23	3.83	-12.83	2.37	0.47
Percent Achnanthes	Average Depth (m)	-3.65	3.95	-11.50	4.19	0.32
Percent Achnanthes	Total Submergence Time (Hours)	-3.50	3.54	-10.53	3.53	0.31
Percent Achnanthes	Velocity	2.73	3.94	-5.09	10.55	0.28
Percent Achnanthes	Depositional Rate (cm/day)	0.90	3.76	-6.57	8.37	0.20
Percent Achnanthes	(Intercept)	-3.82	1.83	-7.46	-0.17	NA
Percent from Reservoir	Depositional Rate (cm/day)	5.70	10.85	-15.87	27.27	0.24
Percent from Reservoir	Average Depth (m)	1.30	8.70	-15.99	18.59	0.23
Percent from Reservoir	Total Submergence Time (Hours)	4.83	8.49	-12.05	21.71	0.22
Percent from Reservoir	Velocity	1.81	9.36	-16.80	20.43	0.21
Percent from Reservoir	Average Temperature (Submergence)	-1.27	10.91	-22.95	20.42	0.21
Percent from Reservoir	(Intercept)	-37.97	6.76	-51.40	-24.54	NA
Percent Good Forage	Total Submergence Time (Hours)	-0.21	0.17	-0.54	0.13	0.40
Percent Good Forage	Average Temperature (Submergence)	-0.16	0.16	-0.48	0.16	0.32
Percent Good Forage	Velocity	0.14	0.17	-0.19	0.48	0.29
Percent Good Forage	Average Depth (m)	0.15	0.18	-0.21	0.50	0.28
Percent Good Forage	Depositional Rate (cm/day)	0.00	0.16	-0.32	0.33	0.21
Percent Good Forage	(Intercept)	3.40	0.08	3.25	3.55	NA
Percent Motile	Depositional Rate (cm/day)	1933.09	662.00	617.93	3248.24	1.00
Percent Motile	Velocity	-656.02	689.54	-2025.98	713.95	0.30
Percent Motile	Average Depth (m)	398.33	582.79	-759.34	1556.00	0.27
Percent Motile	Average Temperature (Submergence)	502.79	670.09	-828.57	1834.16	0.26
Percent Motile	Total Submergence Time (Hours)	323.64	540.31	-750.31	1397.60	0.25
Percent Motile	(Intercept)	5322.17	343.99	4638.10	6006.25	NA
Simpsons Index	Depositional Rate (cm/day)	-0.09	0.03	-0.15	-0.03	0.88
Simpsons Index	Average Depth (m)	0.03	0.02	-0.02	0.07	0.41
Simpsons Index	Velocity	0.00	0.03	-0.06	0.06	0.25
Simpsons Index	Total Submergence Time (Hours)	0.01	0.02	-0.04	0.05	0.24
Simpsons Index	Average Temperature (Submergence)	0.02	0.03	-0.04	0.08	0.22
Simpsons Index	(Intercept)	0.79	0.03	0.73	0.84	NA
Species Richness	Total Submergence Time (Hours)	1.25	0.74	-0.22	2.73	0.61
Species Richness	Velocity	-1.30	0.81	-2.90	0.30	0.57

response	variable	Estimate	Std.Error	lower.CI	upper.CI	rvi
Species Richness	Average Depth (m)	0.28	0.71	-1.12	1.68	0.24
Species Richness	Depositional Rate (cm/day)	0.16	1.25	-2.31	2.63	0.23
Species Richness	Average Temperature (Submergence)	-0.16	1.05	-2.24	1.92	0.23
Species Richness	(Intercept)	10.74	2.29	6.20	15.29	NA
Total Abundance	Total Submergence Time (Hours)	0.90	0.19	0.52	1.28	1.00
Total Abundance	Velocity	-0.78	0.22	-1.21	-0.35	1.00
Total Abundance	Average Depth (m)	-0.35	0.18	-0.71	0.00	0.74
Total Abundance	Depositional Rate (cm/day)	0.34	0.25	-0.17	0.84	0.46
Total Abundance	Average Temperature (Submergence)	-0.40	0.24	-0.87	0.08	0.45
Total Abundance	(Intercept)	12.42	0.27	11.88	12.95	NA
Total Biovolume	Total Submergence Time (Hours)	1.21	0.26	0.69	1.72	1.00
Total Biovolume	Velocity	-1.15	0.32	-1.78	-0.51	1.00
Total Biovolume	Depositional Rate (cm/day)	0.76	0.34	0.08	1.44	0.83
Total Biovolume	Average Depth (m)	-0.37	0.25	-0.86	0.13	0.49
Total Biovolume	Average Temperature (Submergence)	-0.23	0.33	-0.89	0.42	0.25
Total Biovolume	(Intercept)	0.91	0.26	0.39	1.43	NA

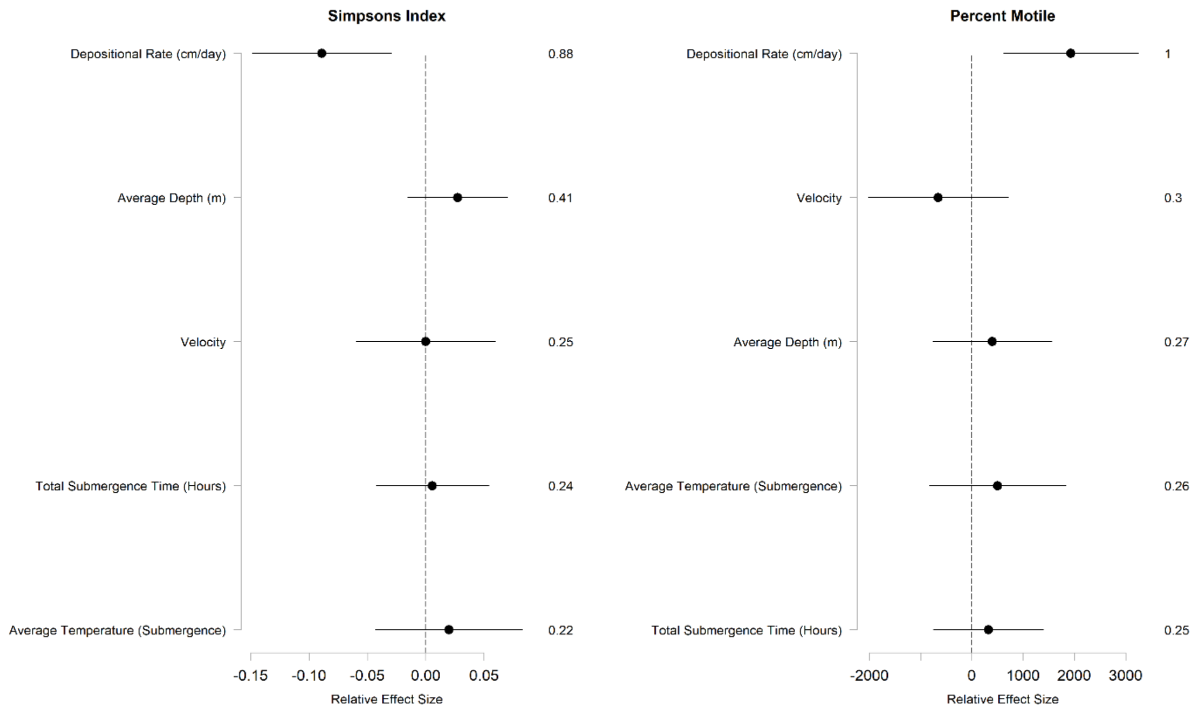

Figure A82 **The coefficients and their 95% CLs of standardized explanatory variables of periphyton production in Peace River considering the full varial zone (transect 0 to 4). Periphyton responses included Simpson's Index and Percent Motile. Explanatory variables included mean temperature, submergence time, water velocity, sediment deposition rates, and average depth. Coefficients were standardized to allow comparisons of the direction and size of effects, noting that variables with CLs that do not cross zero have an effect on the response variable. Key explanatory variables are those that have a relative variable importance (RVI) of greater than 0.6-0.7 and the RVI is shown on the right-hand side of each figure.**

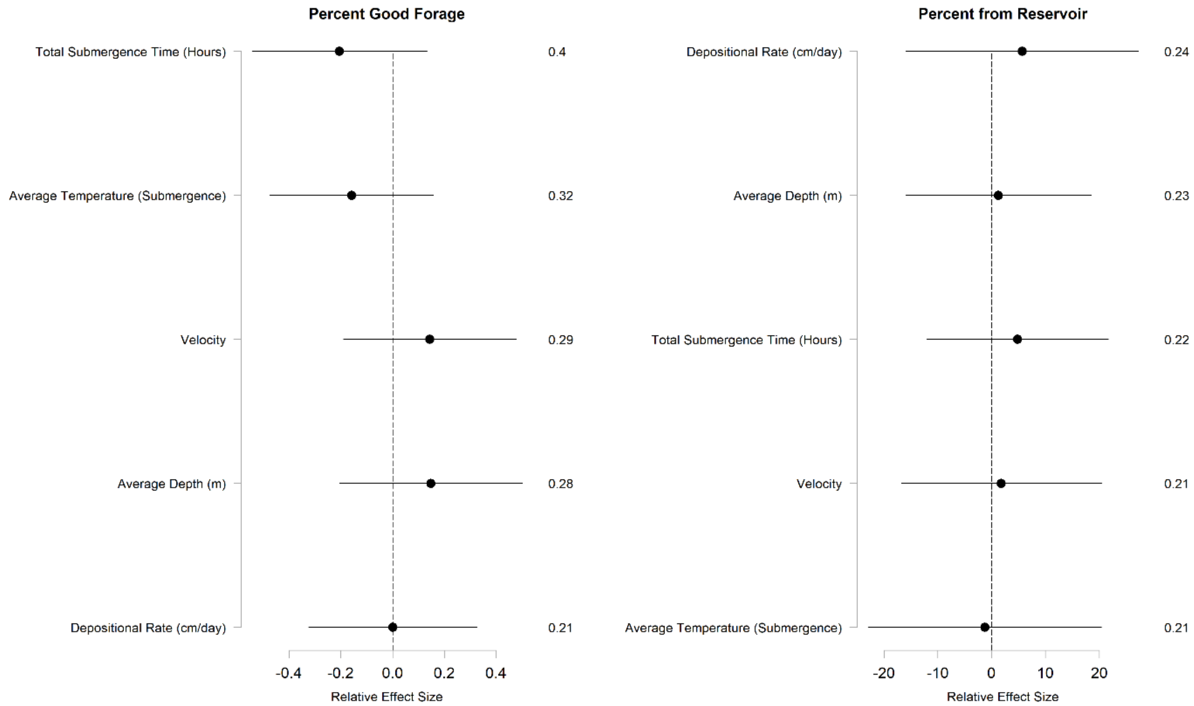

Figure A83 **The coefficients and their 95% CLs of standardized explanatory variables of periphyton production in Peace River considering the full varial zone (transect 0 to 4). Periphyton responses included Percent Good Forage and Percent from Reservoir. Explanatory variables included mean temperature, submergence time, water velocity, sediment deposition rates, and average depth. Coefficients were standardized to allow comparisons of the direction and size of effects, noting that variables with CLs that do not cross zero have an effect on the response variable. Key explanatory variables are those that have a relative variable importance (RVI) of greater than 0.6-0.7 and the RVI is shown on the right-hand side of each figure.**

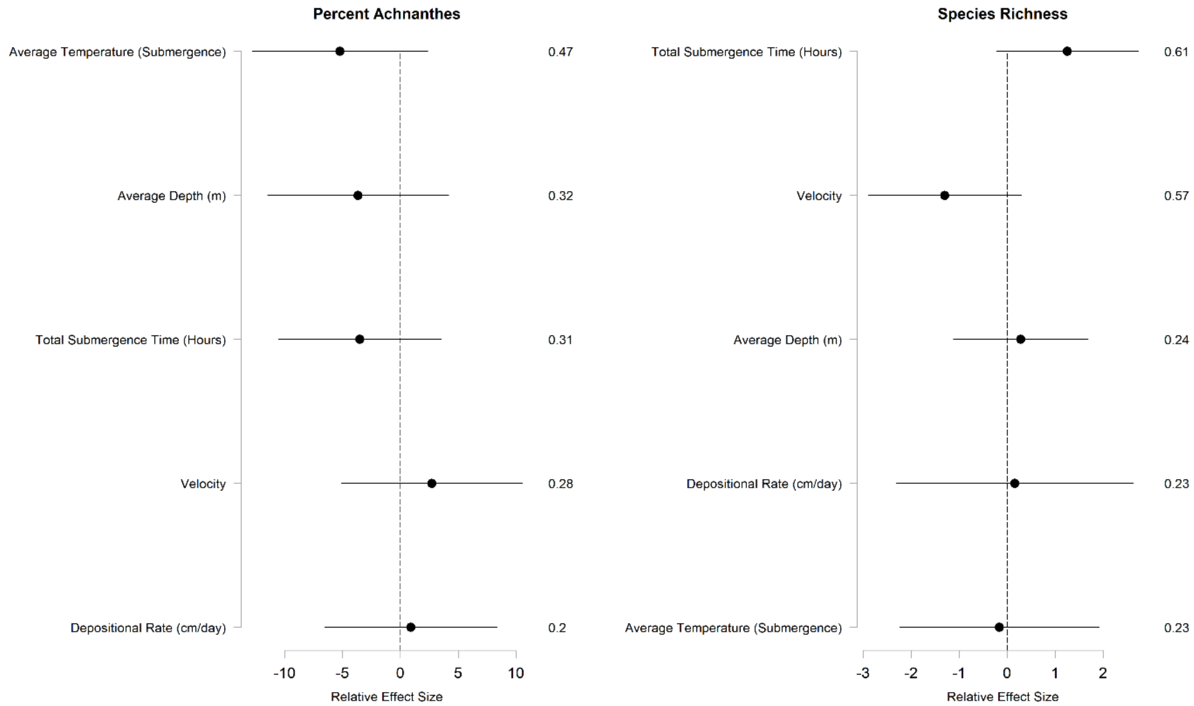

Figure A84 **The coefficients and their 95% CLs of standardized explanatory variables of periphyton production in Peace River considering the full varial zone (transect 0 to 4). Periphyton responses included Percent Achnanthes and Species Richness. Explanatory variables included mean temperature, submergence time, water velocity, sediment deposition rates, and average depth. Coefficients were standardized to allow comparisons of the direction and size of effects, noting that variables with CLs that do not cross zero have an effect on the response variable. Key explanatory variables are those that have a relative variable importance (RVI) of greater than 0.6-0.7 and the RVI is shown on the right-hand side of each figure.**

Table A23 Summary of the number of plausible models identified using model averaging (those with a ΔAIC <3) and the range of pseudo-R^2 values for selected models for samplers across all permanently submerged transects.

# of plausible models (AIC<3)	minr2	maxr2	Production Metric
7	0.47	0.49	Chlorophyll-a
14	0	0.1	Percent Achnanthes
8	0.12	0.15	Percent from Reservoir
8	0.01	0.09	Percent Good Forage
6	0.23	0.3	Percent Motile
11	0.19	0.29	Simpsons Index
16	0.64	0.66	Species Richness
13	0.49	0.53	Total Abundance
8	0.41	0.44	Total Biovolume

Table A24 Model average summaries of periphyton models for all permanently submerged transects. The explanatory variables have standardized coefficients with 95% CLs.

response	variable	Estimate	Std.Error	lower.CI	upper.CI	rvi
Chl-a	Velocity	-0.99	0.33	-1.65	-0.32	0.95
Chl-a	Average Depth (m)	-0.32	0.28	-0.89	0.24	0.36
Chl-a	Average Daily Light (Lux)	-0.26	0.35	-0.96	0.45	0.26
Chl-a	Average Temperature (Submergence)	0.25	0.43	-0.62	1.12	0.23
Chl-a	Depositional Rate (cm/day)	0.21	0.57	-0.93	1.36	0.22
Chl-a	Submergence Ratio	-0.03	0.27	-0.57	0.51	0.21
Chl-a	(Intercept)	2.88	0.66	1.55	4.20	NA
Percent Achnanthes	Submergence Ratio	7.93	5.00	-2.09	17.95	0.53
Percent Achnanthes	Average Temperature (Submergence)	-6.11	4.89	-15.91	3.68	0.39
Percent Achnanthes	Average Daily Light (Lux)	4.18	5.55	-6.91	15.28	0.27
Percent Achnanthes	Average Depth (m)	-4.13	5.35	-14.83	6.57	0.26
Percent Achnanthes	Velocity	2.81	4.89	-7.00	12.62	0.23
Percent Achnanthes	Depositional Rate (cm/day)	-2.21	4.89	-12.01	7.60	0.21
Percent Achnanthes	(Intercept)	-4.34	2.22	-8.80	0.11	NA
Percent from Reservoir	Velocity	-12.73	12.18	-37.14	11.69	0.32
Percent from Reservoir	Submergence Ratio	9.21	10.47	-11.77	30.19	0.29
Percent from Reservoir	Average Daily Light (Lux)	7.63	12.05	-16.49	31.74	0.25
Percent from Reservoir	Average Depth (m)	4.51	10.66	-16.86	25.87	0.22
Percent from Reservoir	Depositional Rate (cm/day)	-4.61	14.29	-33.26	24.03	0.20
Percent from Reservoir	Average Temperature (Submergence)	-3.12	13.51	-30.21	23.97	0.20
Percent from Reservoir	(Intercept)	-37.39	8.45	-54.34	-20.45	NA
Percent Good Forage	Velocity	0.41	0.21	-0.01	0.83	0.63
Percent Good Forage	Submergence Ratio	0.20	0.19	-0.19	0.58	0.31
Percent Good Forage	Average Temperature (Submergence)	0.42	0.26	-0.10	0.93	0.29
Percent Good Forage	Average Depth (m)	0.05	0.20	-0.35	0.44	0.21
Percent Good Forage	Depositional Rate (cm/day)	0.13	0.27	-0.42	0.68	0.19
Percent Good Forage	Average Daily Light (Lux)	-0.13	0.21	-0.55	0.30	0.19
Percent Good Forage	(Intercept)	3.42	0.14	3.13	3.72	NA
Percent Motile	Depositional Rate (cm/day)	2075.59	671.92	727.84	3423.34	0.99
Percent Motile	Average Daily Light (Lux)	-1156.81	588.56	-2337.95	24.34	0.68
Percent Motile	Velocity	-613.18	671.66	-1960.97	734.61	0.26
Percent Motile	Submergence Ratio	307.16	615.95	-925.31	1539.63	0.24
Percent Motile	Average Temperature (Submergence)	439.84	708.73	-980.21	1859.90	0.23
Percent Motile	Average Depth (m)	-95.23	622.41	-1340.71	1150.25	0.21
Percent Motile	(Intercept)	5378.15	361.91	4651.71	6104.58	NA
Simpsons Index	Depositional Rate (cm/day)	-0.11	0.05	-0.21	-0.02	0.65

response	variable	Estimate	Std.Error	lower.CI	upper.CI	rvi
Simpsons Index	Average Daily Light (Lux)	-0.06	0.03	-0.12	0.00	0.58
Simpsons Index	Average Temperature (Submergence)	-0.06	0.04	-0.14	0.02	0.49
Simpsons Index	Average Depth (m)	0.04	0.03	-0.02	0.10	0.38
Simpsons Index	Submergence Ratio	0.02	0.03	-0.04	0.08	0.23
Simpsons Index	Velocity	-0.01	0.04	-0.08	0.06	0.20
Simpsons Index	(Intercept)	0.77	0.04	0.70	0.85	NA
Species Richness	Velocity	-1.06	0.83	-2.71	0.60	0.40
Species Richness	Average Temperature (Submergence)	-1.25	0.98	-3.22	0.72	0.38
Species Richness	Submergence Ratio	0.62	0.61	-0.61	1.84	0.30
Species Richness	Average Depth (m)	0.57	0.62	-0.68	1.82	0.28
Species Richness	Average Daily Light (Lux)	-0.57	0.74	-2.06	0.91	0.25
Species Richness	Depositional Rate (cm/day)	0.43	1.34	-2.25	3.11	0.22
Species Richness	(Intercept)	10.63	2.24	6.14	15.11	NA
Total Abundance	Velocity	-0.62	0.21	-1.03	-0.21	0.90
Total Abundance	Average Temperature (Submergence)	-0.45	0.28	-1.01	0.11	0.54
Total Abundance	Submergence Ratio	-0.23	0.16	-0.56	0.10	0.46
Total Abundance	Average Depth (m)	-0.22	0.18	-0.59	0.14	0.39
Total Abundance	Depositional Rate (cm/day)	0.31	0.28	-0.25	0.87	0.33
Total Abundance	Average Daily Light (Lux)	-0.15	0.26	-0.66	0.36	0.26
Total Abundance	(Intercept)	12.44	0.34	11.76	13.12	NA
Total Biovolume	Velocity	-1.08	0.26	-1.60	-0.57	1.00
Total Biovolume	Depositional Rate (cm/day)	0.52	0.38	-0.24	1.29	0.43
Total Biovolume	Average Depth (m)	-0.19	0.21	-0.62	0.24	0.28
Total Biovolume	Average Temperature (Submergence)	-0.24	0.33	-0.89	0.42	0.27
Total Biovolume	Average Daily Light (Lux)	-0.13	0.25	-0.64	0.38	0.22
Total Biovolume	Submergence Ratio	0.00	0.20	-0.39	0.40	0.18
Total Biovolume	(Intercept)	0.87	0.45	-0.04	1.77	NA

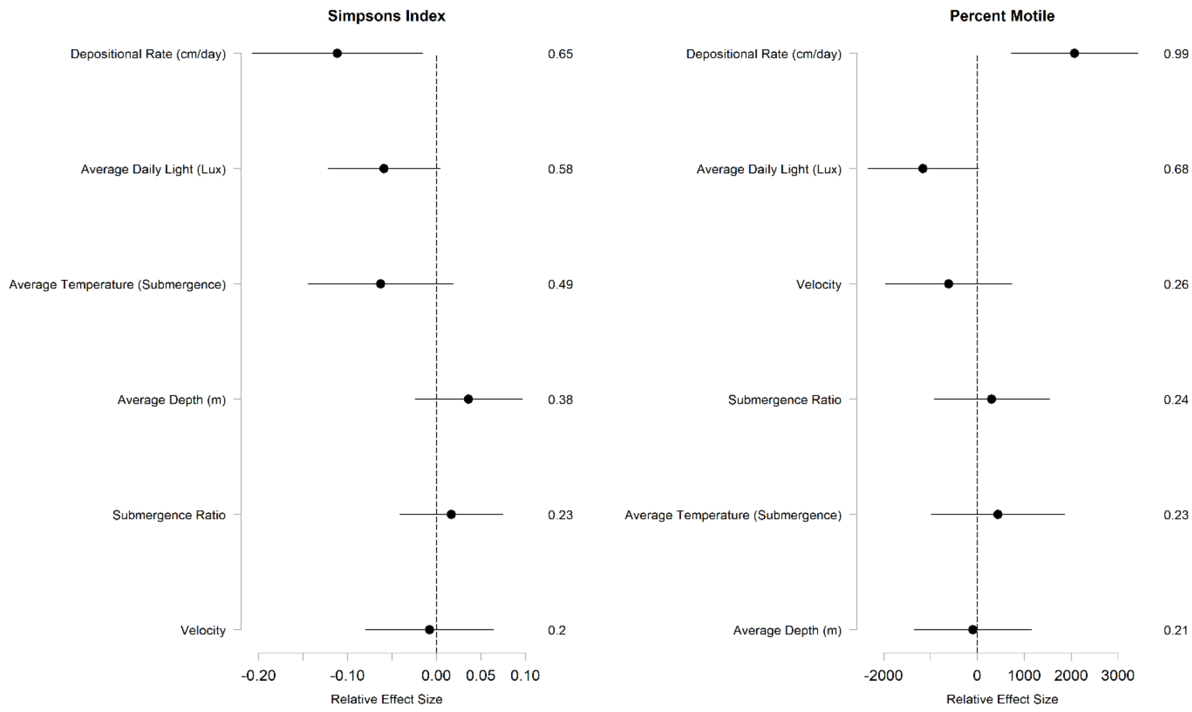

Figure A85 **The coefficients and their 95% CLs of standardized explanatory variables of periphyton production in Peace River considering all permanently submerged transects. Periphyton responses included Simpson's Index and Percent Motile. Explanatory variables included mean temperature, submergence time, water velocity, average daily light intensity, sediment deposition rates, and average depth. Coefficients were standardized to allow comparisons of the direction and size of effects, noting that variables with CLs that do not cross zero have an effect on the response variable. Key explanatory variables are those that have a relative variable importance (RVI) of greater than 0.6-0.7 and the RVI is shown on the right-hand side of each figure.**

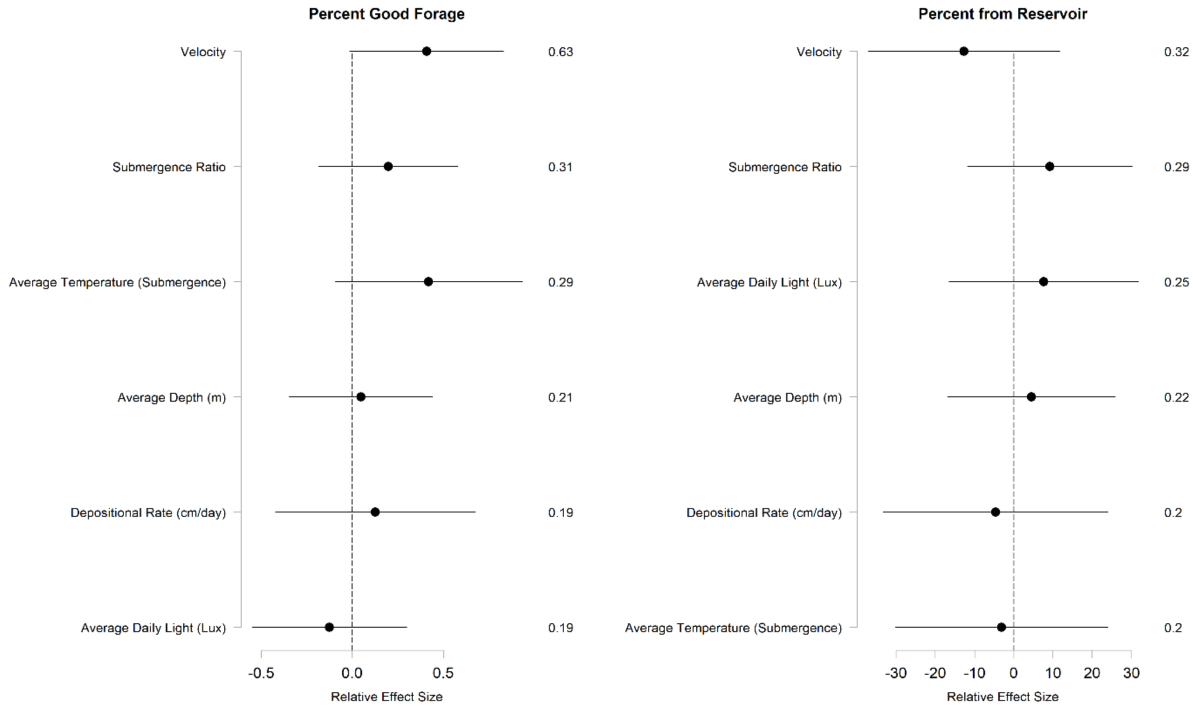

Figure A86 **The coefficients and their 95% CLs of standardized explanatory variables of periphyton production in Peace River considering all permanently submerged transects. Periphyton responses included Percent Good Forage and Percent from Reservoir. Explanatory variables included mean temperature, submergence time, water velocity, average daily light intensity, sediment deposition rates, and average depth. Coefficients were standardized to allow comparisons of the direction and size of effects, noting that variables with CLs that do not cross zero have an effect on the response variable. Key explanatory variables are those that have a relative variable importance (RVI) of greater than 0.6-0.7 and the RVI is shown on the right-hand side of each figure.**

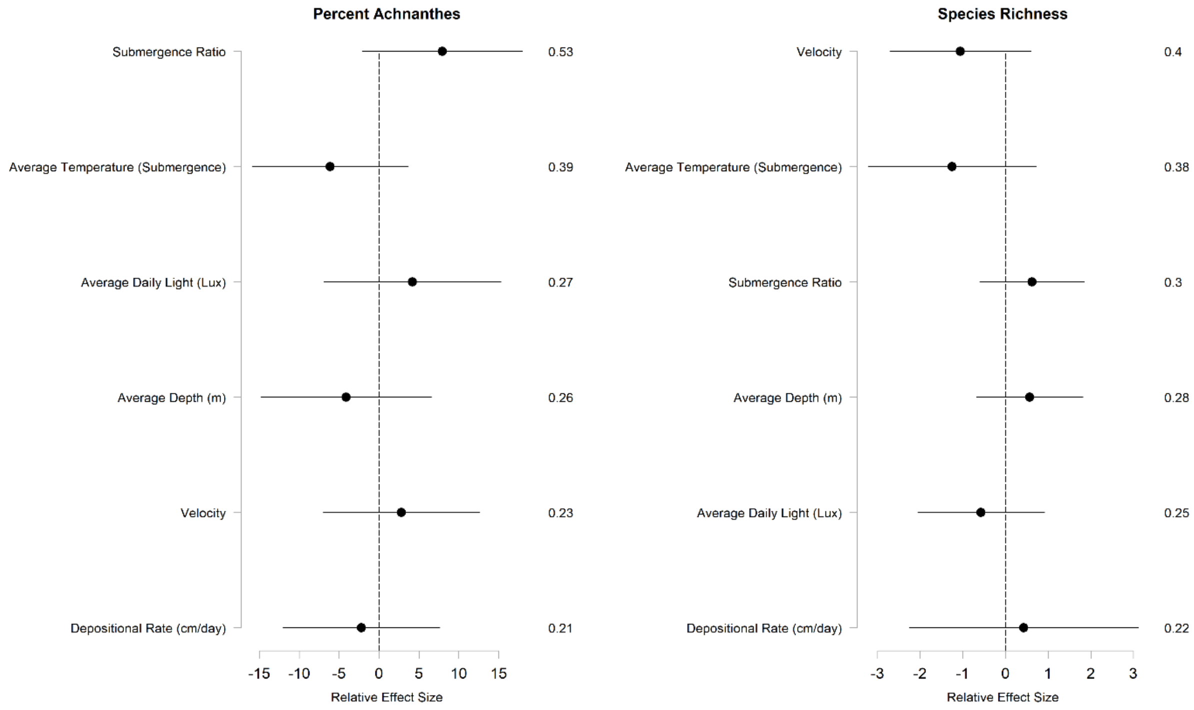

Figure A87 **The coefficients and their 95% CLs of standardized explanatory variables of periphyton production in Peace River considering all permanently submerged transects. Periphyton responses included Percent Achnanthes and Species Richness. Explanatory variables included mean temperature, submergence time, water velocity, average daily light intensity, sediment deposition rates, and average depth. Coefficients were standardized to allow comparisons of the direction and size of effects, noting that variables with CLs that do not cross zero have an effect on the response variable. Key explanatory variables are those that have a relative variable importance (RVI) of greater than 0.6-0.7 and the RVI is shown on the right-hand side of each figure.**

Appendix O Invertebrate Production Model Results

Table A25 Summary of the number of plausible models identified using model averaging (those with a ΔAIC <3) and the range of pseudo-R^2 values for selected models for samplers across all transects

# of plausible models	minr2	maxr2	Invertebrate Production Metric
16	0.07	0.16	Good Food
10	0.36	0.45	Log Total Abundance
6	0.5	0.53	Log Total Biomass
12	02	0.10	Percent EPT
11	0.09	0.15	Simpson's Index

Table A26 Model average summaries of benthic invertebrate models for all transects. The explanatory variables have standardized coefficients with 95% CLs.

response	variable	Estimate	Std.Error	lower.CI	upper.CI	rvi
Good Food	Velocity	-15.60	8.68	-32.91	1.71	0.65
Good Food	Total Submergence Time (Hours)	13.52	8.07	-2.57	29.62	0.41
Good Food	Average Temperature (Submergence)	10.50	9.23	-7.90	28.90	0.38
Good Food	Depositional Rate (cm/day)	7.16	10.82	-14.40	28.71	0.22
Good Food	Average Depth (m)	-1.26	8.62	-18.43	15.92	0.20
Good Food	(Intercept)	63.77	7.66	48.46	79.08	NA
Log Total Abundance	Average Temperature (Submergence)	-0.92	0.18	-1.28	-0.56	1.00
Log Total Abundance	Velocity	0.42	0.18	0.07	0.77	0.86
Log Total Abundance	Depositional Rate (cm/day)	0.25	0.19	-0.12	0.63	0.46
Log Total Abundance	Total Submergence Time (Hours)	0.05	0.16	-0.28	0.37	0.20
Log Total Abundance	Average Depth (m)	-0.03	0.18	-0.40	0.34	0.20
Log Total Abundance	(Intercept)	2.58	0.09	2.40	2.75	NA
Log Total Biomass	Average Temperature (Submergence)	-0.64	0.17	-0.98	-0.31	1.00
Log Total Biomass	Velocity	0.85	0.19	0.46	1.23	1.00
Log Total Biomass	Depositional Rate (cm/day)	0.29	0.18	-0.07	0.65	0.55
Log Total Biomass	Average Depth (m)	0.18	0.18	-0.18	0.54	0.30
Log Total Biomass	Total Submergence Time (Hours)	-0.02	0.19	-0.41	0.36	0.19
Log Total Biomass	(Intercept)	2.15	0.30	1.54	2.75	NA
Percent EPT	Average Temperature (Submergence)	15.50	9.05	-2.57	33.56	0.60
Percent EPT	Total Submergence Time (Hours)	8.85	8.10	-7.32	25.03	0.35
Percent EPT	Velocity	-8.02	9.56	-27.07	11.03	0.30
Percent EPT	Average Depth (m)	6.76	9.24	-11.66	25.17	0.24
Percent EPT	Depositional Rate (cm/day)	1.37	9.62	-17.83	20.57	0.18
Percent EPT	(Intercept)	51.97	4.83	42.31	61.63	NA
Simpson's Index	Average Depth (m)	0.05	0.03	-0.01	0.11	0.47
Simpson's Index	Total Submergence Time (Hours)	0.04	0.03	-0.02	0.10	0.38
Simpson's Index	Depositional Rate (cm/day)	0.06	0.04	-0.03	0.14	0.38
Simpson's Index	Average Temperature (Submergence)	0.05	0.04	-0.03	0.13	0.32
Simpson's Index	Velocity	0.03	0.04	-0.05	0.11	0.25
Simpson's Index	(Intercept)	0.78	0.03	0.72	0.83	NA

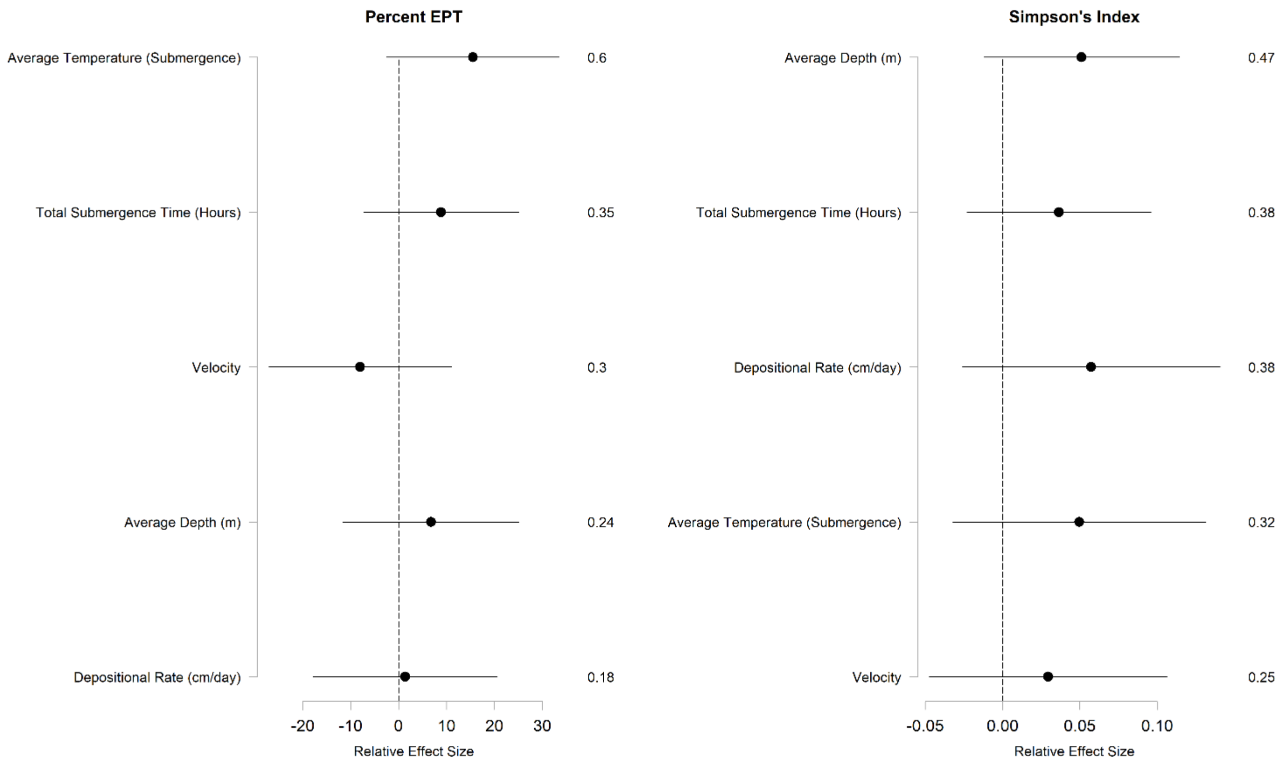

Figure A88 **The coefficients and their 95% CLs of standardized explanatory variables of invertebrate production in Peace River considering the full varial zone (transect 1 to 4). Invertebrate responses included Percent EPT and Simpson's Index. Explanatory variables included mean temperature, submergence time, water velocity, sediment deposition rates, and average depth. Coefficients were standardized to allow comparisons of the direction and size of effects, noting that variables with CLs that do not cross zero have an effect on the response variable. Key explanatory variables are those that have a relative variable importance (RVI) of greater than 0.6-0.7 and the RVI is shown on the right-hand side of each figure.**

Table A27 Summary of the number of plausible models identified using model averaging (those with a ΔAIC <3) and the range of pseudo-R^2 values for selected models for samplers across all permanently submerged transects

# of plausible models	minr2	maxr2	Invertebrate Production Metric
10	0.10	0.21	Good Food
10	0.36	0.45	Log Total Abundance
5	0.47	0.53	Log Total Biomass
12	0.00	0.15	Percent EPT
11	0.09	0.15	Simpson's Index

Table A28 Model average summaries of benthic invertebrate models for all samplers across all permanently submerged transects. The explanatory variables have standardized coefficients with 95% CLs.

response	variable	Estimate	Std.Error	lower.CI	upper.CI	rvi
Good Food	Velocity	-19.87	8.86	-37.66	-2.08	0.76
Good Food	Submergence Ratio	10.59	7.84	-5.15	26.32	0.42
Good Food	Average Temperature (Submergence)	8.06	8.87	-9.76	25.88	0.29
Good Food	Depositional Rate (cm/day)	10.66	10.66	-10.77	32.10	0.22
Good Food	Average Depth (m)	1.98	8.66	-15.39	19.34	0.19
Good Food	(Intercept)	63.13	9.58	43.88	82.39	NA
Log Total Abundance	Average Temperature (Submergence)	-0.86	0.20	-1.26	-0.46	1.00
Log Total Abundance	Velocity	0.35	0.20	-0.06	0.76	0.60
Log Total Abundance	Depositional Rate (cm/day)	0.33	0.20	-0.07	0.73	0.53
Log Total Abundance	Submergence Ratio	-0.20	0.18	-0.57	0.17	0.26
Log Total Abundance	Average Depth (m)	0.08	0.19	-0.31	0.46	0.21
Log Total Abundance	(Intercept)	2.66	0.10	2.45	2.87	NA
Log Total Biomass	Velocity	0.70	0.23	0.24	1.16	0.91
Log Total Biomass	Average Temperature (Submergence)	-0.57	0.21	-0.99	-0.16	0.88
Log Total Biomass	Depositional Rate (cm/day)	0.35	0.22	-0.10	0.80	0.52
Log Total Biomass	Average Depth (m)	0.36	0.22	-0.08	0.80	0.50
Log Total Biomass	Submergence Ratio	-0.02	0.20	-0.43	0.39	0.19
Log Total Biomass	(Intercept)	2.21	0.36	1.48	2.93	NA
Percent EPT	Velocity	-16.37	9.35	-35.13	2.40	0.59
Percent EPT	Submergence Ratio	15.84	9.09	-2.40	34.08	0.55
Percent EPT	Average Temperature (Submergence)	12.67	8.59	-4.60	29.93	0.47
Percent EPT	Average Depth (m)	6.44	9.67	-12.96	25.84	0.21
Percent EPT	Depositional Rate (cm/day)	-3.08	9.52	-22.20	16.03	0.18
Percent EPT	(Intercept)	50.15	4.26	41.59	58.70	NA
Simpson's Index	Submergence Ratio	0.05	0.03	-0.02	0.11	0.48
Simpson's Index	Depositional Rate (cm/day)	0.05	0.05	-0.04	0.14	0.29
Simpson's Index	Average Depth (m)	0.04	0.04	-0.04	0.11	0.28
Simpson's Index	Average Temperature (Submergence)	0.03	0.04	-0.06	0.11	0.22
Simpson's Index	Velocity	-0.01	0.04	-0.09	0.08	0.21
Simpson's Index	(Intercept)	0.77	0.03	0.72	0.83	NA

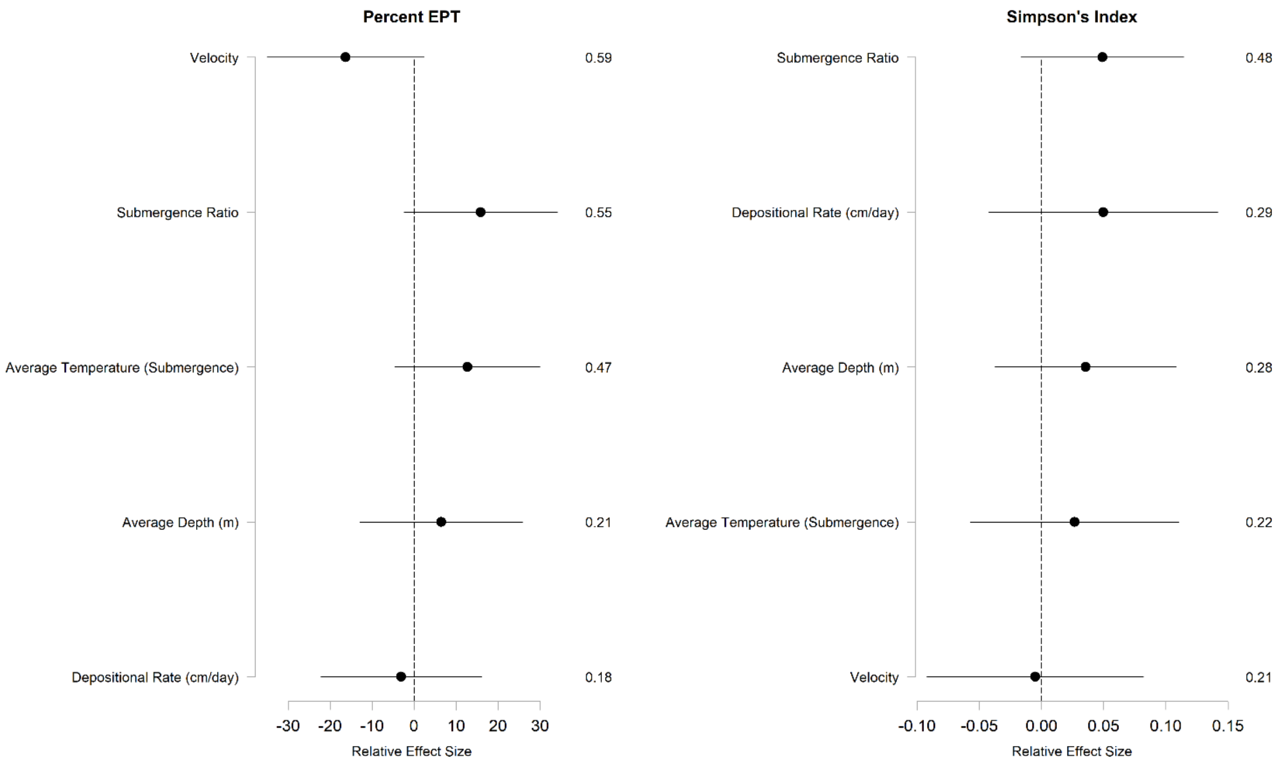

Figure A89 **The coefficients and their 95% confidence limits of standardized explanatory variables of invertebrate production in Peace River considering the submerged (transect 1-2 to 4). Invertebrate responses included Percent EPT and Simpson's Index. Explanatory variables included mean temperature, submergence time, water velocity, sediment deposition rates, and average depth. Coefficients were standardized to allow comparisons of the direction and size of effects, noting that variables with CLs that do not cross zero have an effect on the response variable. Key explanatory variables are those that have a relative variable importance (RVI) of greater than 0.6-0.7 and the RVI is shown on the right-hand side of each figure.**

Table A29 Summary of the number of plausible models identified using model averaging (those with a ∆AIC <3) and the range of pseudo-R^2 values for selected models for Ekman or Basket samplers using 2017 data

# of plausible models	minr2	maxr2	Invertebrate Production Metric
2	0.26	0.27	Good Food
7	0.36	0.45	Log Total Abundance
6	0.45	0.47	Log Total Biomass
7	0.01	0.09	Percent EPT
7	0.21	0.29	Simpson's Index

Table A30 Model average summaries of benthic invertebrate models for Ekman or Basket samplers using 2017 data. The explanatory variables have standardized coefficients with 95% CLs.

response	variable	Estimate	Std.Error	lower.CI	upper.CI	rvi
Good Food	Velocity	27.09	10.73	5.38	48.81	0.87
Good Food	Depositional Rate (cm/day)	-27.21	10.39	-48.27	-6.16	0.78
Good Food	Total Submergence Time (Hours)	6.18	9.27	-12.67	25.02	0.19
Good Food	Average Depth (m)	1.77	9.54	-17.66	21.20	0.16
Good Food	Average Temperature (Submergence)	2.40	14.14	-26.19	30.99	0.16
Good Food	(Intercept)	56.61	5.42	45.58	67.63	NA
Log Total Abundance	Total Submergence Time (Hours)	0.35	0.18	-0.02	0.73	0.63
Log Total Abundance	Average Depth (m)	0.28	0.23	-0.18	0.74	0.38
Log Total Abundance	Velocity	-0.28	0.23	-0.74	0.18	0.36
Log Total Abundance	Average Temperature (Submergence)	0.30	0.49	-0.68	1.27	0.19
Log Total Abundance	Depositional Rate (cm/day)	-0.01	0.35	-0.71	0.70	0.16
Log Total Abundance	(Intercept)	1.91	0.28	1.35	2.48	NA
Log Total Biomass	Velocity	-0.29	0.23	-0.75	0.17	0.37
Log Total Biomass	Total Submergence Time (Hours)	0.14	0.20	-0.25	0.54	0.24
Log Total Biomass	Average Depth (m)	0.12	0.23	-0.34	0.59	0.21
Log Total Biomass	Average Temperature (Submergence)	0.27	0.49	-0.72	1.25	0.19
Log Total Biomass	Depositional Rate (cm/day)	-0.11	0.39	-0.90	0.67	0.18
Log Total Biomass	(Intercept)	0.82	0.36	0.09	1.54	NA
Percent EPT	Depositional Rate (cm/day)	2.88	2.00	-1.17	6.93	0.37
Percent EPT	Velocity	-2.33	2.11	-6.61	1.94	0.28
Percent EPT	Average Depth (m)	2.30	2.03	-1.82	6.43	0.25
Percent EPT	Total Submergence Time (Hours)	1.26	1.84	-2.48	5.00	0.18
Percent EPT	Average Temperature (Submergence)	0.97	2.89	-4.87	6.80	0.18
Percent EPT	(Intercept)	2.12	1.18	-0.28	4.52	NA
Simpson's Index	Average Depth (m)	-0.10	0.03	-0.17	-0.03	0.96
Simpson's Index	Depositional Rate (cm/day)	0.06	0.03	-0.01	0.12	0.48
Simpson's Index	Velocity	-0.03	0.04	-0.11	0.04	0.25
Simpson's Index	Total Submergence Time (Hours)	0.04	0.04	-0.04	0.12	0.22
Simpson's Index	Average Temperature (Submergence)	0.00	0.05	-0.10	0.10	0.18
Simpson's Index	(Intercept)	0.73	0.04	0.65	0.81	NA

Appendix P Model Results Comparing Ekman and Basket Methods

Table A31 Summary of an ANCOVA of Invertebrate abundance and biomass using a Ekman and Invertebrate Sampling Basket Method on the Peace River, where depth of the sample was treated as a covariate.

variable	term	estimate	std.error	statistic	p.value
tot.abun	(Intercept)	3.280411508	0.169	19.403	<0.001
tot.abun	mean_depth_over_deploy	0.227144921	0.066	3.439	0.001
tot.abun	factor(method)ponar	-0.121680385	0.177	-0.686	0.495
tot.abun	model	0.148543169	0.124	6.106	0.004
tot.biom	(Intercept)	2.715635566	0.162	16.734	<0.001
tot.biom	mean_depth_over_deploy	0.265592486	0.063	4.190	<0.001
tot.biom	factor(method)ponar	-0.729022758	0.170	-4.283	<0.001
tot.biom	model	0.334587994	0.316	17.599	<0.001