Peace River Project Water Use Plan

PEACE RIVER PRODUCTIVITY

Implementation Year 2

Reference: GMSMON5

Peace River Water Use Plan Monitoring Program: Peace River Productivity Monitoring

Survey Period: 2014

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PEACE RIVER PRODUCTIVITY MONITORING YEAR 2 (2014)

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EXECUTIVE SUMMARY

This report summarizes Year 2 of a 10 year study on fish habitat productivity in trial side channels of the Peace River. The study aims to address management questions that examine changes in the benthic community as a result of proposed side channel habitat improvements that are intended to enhance fisheries productivity within the side channel habitats on the Peace River. Year 1 (2013) focussed on collection of baseline and pre-enhancement data, and therefore, the results were tailored to summarizing the physical habitat conditions of side channel areas. Year 2 focussed on comparisons of the pre-and post-construction of a side channel enhancement channel intended to increase flows through the 102.5R trial side channel site near the Pine River confluence.

The following are the study management questions:

1. What is the composition of the invertebrate and periphyton community in the side channels of the Peace River?
2. Does increased water flow to side channels as a result of side channel enhancement or change in the minimum base flow regime alter the biomass/composition of the periphyton and invertebrate community?
3. After side channel enhancement or implementation of an alternative minimum base flow regime, does the resulting periphyton and invertebrate community increase the food availability (i.e., increased abundance of invertebrate prey) to fish populations?

The following are the management hypotheses and associated status following Year 2 of the study.

GMSMON5 - Status of Objectives Management Questions and Hypotheses After Year 1	
Management Hypotheses	Year 1 (2013) Preliminary Status
H_1: There is a difference in the accrual rate of periphyton sampled from the trial side channel habitats of the Peace River between pre and post enhancement states.	H_1: 2014 data was collected after habitat enhancement construction in the spring. The data suggests that turbidity, deposited sediment and location in the Test or Control side channel were all important determinants of periphyton productivity and accrual. Although, construction may have had an adverse effect, it is believed that 2014 data from the Test side channel was not indicative of a stable, post-treatment condition and future years of data are required to elucidate the effects of pre and post enhancement conditions on periphyton accrual.
H_2: There is a difference in biomass and diversity of invertebrates between pre and post enhancement states of trial side channels habitats in the Peace River.	H_2: In the months following construction, sediment deposition in the Test side channel was up to 8 times higher than in the Control side channel. The community observed at 102.5R Test had a greater prevalence of tolerant species such as *Oligochaeta.* Due to the high rates of deposition, the productivity and diversity were generally less. However, because we cannot differentiate between any lingering construction-related effects and those expected to continue post-treatment, more data is required to answer this question. The data collected to date suggest that turbidity, sediment deposition, and location are all important determinants of benthic productivity.
H_3: There is a difference in biomass and diversity of periphyton between pre and post enhancement states of trial side channels habitats in the Peace River.	H_3: Similar to H_1 and H_2, it is too early in the study process to answer this management question. Turbidity and sedimentation appear to play an important role in restricting the diversity and biomass of periphyton communities. Algal and periphyton production on substrates within side channels is low compared to other main channel areas we have sampled or can find comparisons for. Photosynthetic bacteria may also play an important role in primary production within the side-channel substrates. Donation of diatom species from upstream locations was an important source of photosynthetic material that deposited with sediment in the side channels and was independent of enhancement efforts.

In the Peace River side channels, flows and flow regulation affect the physical habitat conditions present. Temperatures in the Peace side channels were similar to adjacent mainstem sites. Turbidity ranged from 10 to >40 NTU, and sediment deposition over the 50 day summer deployment period ranged from 5 to >100 mm depending upon location.

Artificial substrate sampler deployment occurred in late July following low annual flows, at depths of approximately 0.5 to 2 m in permanently submerged areas at a deep (~1.5 m depth) and shallow transect (~0.5 m). The most productive areas of the side channels occurred at river elevations that created depths between 0 (elevation of minimum flow over the past 60 days) and 1.5 m, with production tapering by 3 meter depths.

Periphyton productivity was assessed using six metrics: Abundance, Biovolume, Chlorophyll-a (chl-a), Ash Free Dry Weight (AFDW), Simpson's Index, and Species Richness. Levels of production metrics in the Peace side channels were lower than those typical in mainstems of regulated rivers around BC. Since light scatters and attenuates rapidly in turbid waters, we hypothesize that turbidity or sediment deposition rates are extremely important to periphyton production and this was corroborated by results from habitat modelling. About 40-50% of the total periphyton diatom biovolume was imported from upstream areas, while the *in situ* periphyton growth was dominated by genera that are motile and/or have rapid reproduction rates, allowing them to withstand continuous burial by sediment deposition. Substrate size and sampling location were also important predictors of the periphyton community. It is important to note that we chose to model silt depth as a factor in 2014, at the sacrifice of velocity due to collinearity of variables, but we acknowledge that both of these variables may be important.

Invertebrate productivity was assessed using eight metrics: Abundance, Biomass, Percent Ephemeroptera / Plecoptera / Trichoptera (EPT), Percent Chironomidae, Species Richness, EPT Richness, Simpson's Index, and Hilsenhoff Biotic Index (HBI). Turbidity or light attenuation, and sediment deposition rates had strong influences on invertebrate productivity, with higher invertebrate abundance and biomass in less turbid sampling locations. Oligochaetes were the most predominant taxon observed in the side channels. This collector-gatherer foraging group was successful because it tends to reside in depositional sediments where detritus and other foods are readily available. Modelling of the HBI indicates that sediment deposition rates result in a higher predominance of more pollution tolerant species, or groups such as Oligochaetes, noting that the HBI only distinguishes between pollution and non-pollution tolerant species. From these results, the amount of high forage value food available to fishes in Peace River side channel areas is directly influenced by sediment deposition rates and water turbidity.

2014 was only Year 2 of this study and the first year following enhancement construction in 102.5R Test side channel, noting that this report contains the first reporting of 2013 invertebrate data from the 32L sites. Future sampling years will provide more data to better understand the specific effects of physical habitat enhancement and the associated changes to benthic communities of the Peace River side-channel study sites.

Small adjustments to the 2014 study methodology were made to contend with sediment deposition, and to ensure that this project will answer the management questions within the study period.

Keywords:
Peace River, Side Channel, Benthic Invertebrates, Periphyton, Ecological Productivity

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ACRONYMS AND ABBREVIATIONS

AICc	Akaike information criterion corrected for small sample sizes
AFDW	ash free dry weight
ANOSIM	analysis of similarity
BC Hydro/BCH	British Columbia Hydro and Power Authority
CFU	colony forming units (bacteria culture)
chl-a	chlorophyll-a
d.f.	degrees of freedom
DW	dry weight
EPT	Ephemeroptera (mayflies), Plecoptera (stoneflies) & Trichoptera (caddis flies)
F	F-Statistic
FFG	Functional Foraging Group
GMSMON	Peace River Side Channels Program
GMSMON2	Peace River Ecological Fish Indexing
GMSMON5	Peace River Ecological Productivity Monitoring (this study)
GMSMON7	Peace River Side Channel Monitoring
HBI	Hilsenhoff Biotic Index
HTPC	heterotrophic plate count (non-photosynthetic bacteria)
LCR	Lower Columbia River
MCR	Middle Columbia River
m	metre
min	minimum
max	maximum
NMDS	non metric multi-dimensional scaling
NTU	nephelometric turbidity units
PAR	photosynthetically Available Radiation
PCA	principal component analysis
PCD	Peace Canyon Dam
RVI	relative variable importance
SD	standard deviation
VIF	variance inflation factor
WUP	Peace River Water Use Plan Consultative Committee

DEFINITIONS

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

Term	Definition
Accrual rate	A function of cell settlement, actual growth and losses (grazing, sloughing)
Autotrophic	Capable of photosynthesis
Autotrophic Index AI	Autotrophic Index is the proportion of the organic matrix which is viable algae. It is usually calculated as (AFDW / chl-a) The inverse is known as autotrophic potential or AP
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
Bioavailable	Available for use or uptake by plants or animals
Catastrophic flow	Flow events that have population level consequences of >50% mortality
Chlorophyll-a	The most common plant pigment that absorbs light energy for growth
Cyanobacteria	Algae-like bacteria having cyanochrome as the main photosynthetic pigment
Diatoms	A major group of common algae that have silica-based shells called frustules
Euphotic depth	The depth to which light is sufficient to support photosynthesis
Eutrophic	Nutrient-rich, biologically productive water body
Flow	The instantaneous volume of water flowing at any given time (e.g., 1200 m^3/s)
Frustule	The silica-rich cell wall of a diatom
Functional Feeding group	(FFG) Benthic invertebrates can be classified by mechanism by which they forage, referred to as functional feeding or foraging groups
Invertebrate Production	Benthic invertebrate biomass, abundance, and measures of diversity
Light attenuation	Reduction of sunlight strength during transmission through water
Microflora	The sum of algae, bacteria, fungi, Actinomycetes, etc., in water or biofilms
Myxotrophic	Organisms that can be photosynthetic or can absorb organic materials directly from the environment as needed
Nano plankton	Minute algae that are less than 5 microns in their largest dimension
Operations / operating regime	The day to day changes in flow associated with on- demand power generation
Pico plankton	Minute algae that are less than 2 microns in their largest dimension
Peak biomass	The highest density, biovolume or chl-a attained in a set time on a substrate
Periphyton	Microflora that are attached to aquatic plants or solid substrates
Periphyton production	Periphyton productivity measures include chl-a, biovolume, and abundance.
Phytoplankton	Algae that float, drift or swim in the water columns of reservoirs, lakes and large rivers
Riparian	The interface between land and a stream or lake
Secchi depth	A measure of light attenuation in water involving viewing a black & white disk
Varial zone	The maximum and minimum water elevations over a specific period of time.
Zooplankton	Minute animals that graze algae, bacteria, and detritus in water columns

1.0 INTRODUCTION

Regulation of rivers can have direct effects on fisheries productivity of aquatic habitats. The magnitude of this effect depends upon many factors such as flow regulation and the types of habitat present (Schleppe *et al,* 2013, Gregory *et al.* 1991, Allan and Flecker 1993, Blinn *et al.* 1995). The absence of historic peak flows due to impoundment by the hydro-electric dams on the Peace River has led to numerous morphological changes, such as reduced flushing rates at the mouth of side channels (Church *et al.* 1997). These morphological changes are anticipated to take 1000 years before being fully realized, with most of the observable change occurring during the first 100 years (Church, 1995). Narrowing of the river channel resulting from reduced scour and increased sediment accumulation rates, coupled with subsequent colonization by streamside vegetation, was a notable change in channel morphology anticipated in the Peace River. These anticipated changes in river morphology have the potential to affect fish habitat, including fisheries productivity.

The Peace River Water Use Plan Consultative Committee (WUP), recommended a physical works trial be initiated to address negative impacts of flow regulation by the Peace Canyon Dam (PCD) to downstream fish populations. The physical works were intended to restore the surface water connection to isolated side channel habitat in lieu of increasing dam release via minimum flows. The Peace WUP side channel management plan involves excavation of side channel substrate and inverts to ensure adequate water supply, residence time for thermal buffering, and fish access during lower flow and/or deep refugia that maintains fish during periods of isolation (BCH, 2008). Studies on other river systems provide a general framework for understanding how biophysical habitat parameters in these excavated side channels may affect benthic productivity and how benthic communities respond to changes in regulated flow regimes. One component of the Peace River Side Channels Plan (BCH, 2008) is benthic productivity and community composition monitoring. Benthic productivity monitoring is key to measuring changes in fisheries-related productivity and to assessing the effectiveness of proposed side channel enhancements. In addition, monitoring of benthic communities in side channels will provide information to inform the Peace River Ramping Plan.

The results from the Peace River Productivity Monitoring will be integrated with other Peace WUP monitoring programs, including GMSMON2 Fish Population Indexing Surveys and GMSMON7, Side Channel Fisheries. The findings from these monitoring programs will be collectively used to evaluate if proposed side channel improvements provide benefits for fish, and if considerations of other minimum flow regimes should be considered. These data will serve to quantify long-term trends in the productivity of periphyton and benthic invertebrates, and will provide valuable information pertaining to the ecological health of side channel habitats downstream of the PCD.

This report summarizes Year 2 (2014) of the benthic monitoring program. The construction of the trial at site 102.5R, near Peace Island Park, was completed on April 22nd, 2014. The hypothesized result was greater surface water connection between the Year 1 study sites and the Peace River mainstem. Thus, the 2014 sampling season is the first year of sampling following enhancement construction on the first side channel. Also during 2014, regulatory approvals for construction of a new hydro power facility on the Peace resulted in elimination of sampling at site 32L. Sampling effort was re-focused on characterizing how physical habitat parameters affect periphyton and invertebrate production because our intent is to understand how side channel enhancement may affect the physical processes that directly affect benthic productivity. These changes could help better guide future side channel enhancement, site selection, and design, and better meet intended functional objectives.

1.1 Objectives, Questions, and Hypotheses

The two main objectives of the Peace River Monitoring program (GMSMON5) are as follows:

1. To provide long-term data on the productivity of benthic communities in side channel habitats, and

2. To assess how the recommended side channel enhancement program affects the availability of food for fishes in the Peace River side channels.

A conceptual model of habitat attributes affecting productivity within the Peace River side channels is presented in Figure 1-1. The conceptual model highlights potential interactions among the complex factors that may be affected by side channel habitat improvements or flow regulation. Although the relative importance and role of each parameter has yet to be fully clarified, this model identifies the many variables that can influence benthic productivity and ultimately food for fish, noting that not every possible factor or interaction has been included for simplicity. Further, this model highlights areas for which data is being collected to address the management questions. At the forefront of the model are BC Hydro and Power Authority (BC Hydro) operations that determine quantity and duration of water release.

To comprehensively address the three main objectives, three management questions with related hypotheses were developed. Table 1.1 lists each of the management questions/hypotheses, and relevant components of our study that addresses them. Although several of the hypotheses/questions refer specifically to the habitat improvements within side channel areas, Ecoscape understands as per GMSMON5 Terms of Reference (BC Hydro, 2008), that evaluation of Peace River Ramping Plan is also requested.

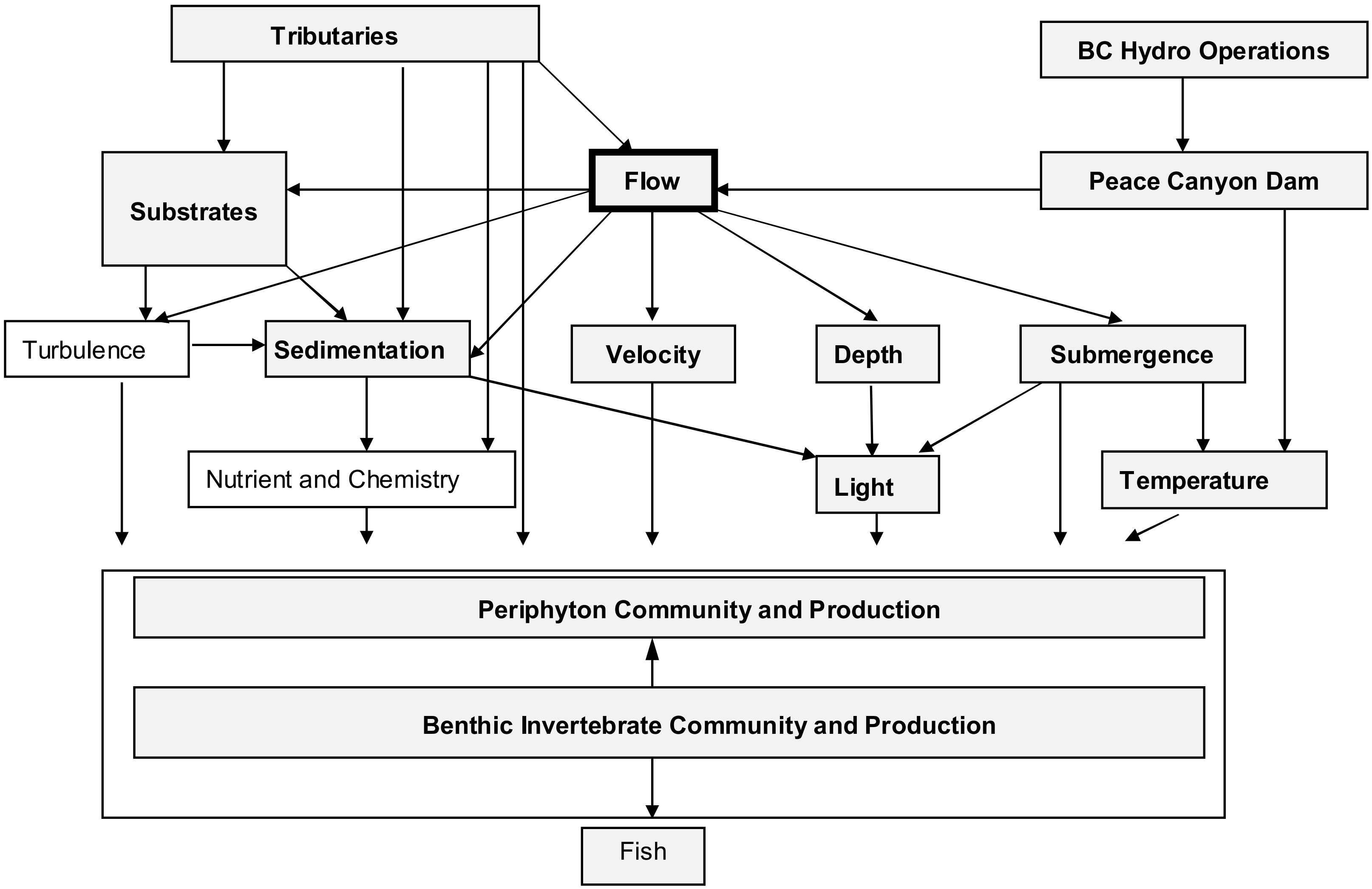


Figure 1-1: Conceptual interactions model of habitat variables and benthic production as they relate to food for fish in the Peace River. Variables highlighted with bold text in grey boxes represent parameters being assessed in this study.

Table 1-1: Management hypotheses and pertinent study components to address them

Management Hypotheses:	Study Components to Address Management Questions/Hypotheses
H_1. There is a difference in the accrual rate of periphyton sampled from the trial side channel habitats of the Peace River between pre and post enhancement states;	Artificial sampler arrays were deployed across two Control and two Test locations (treatment) in the Peace River. Data collection includes: • Periphyton abundance • Diversity – taxonomy indices for periphyton include species richness, Simpson's Index, and community structure • Production/Biomass – chl-a, AFDW/DW, biovolume Accrual rates are considered after a 48 day deployment period. Currently, the control and test sites are depositional in nature, and both deposited sediment and the periphyton productivity on artificial samplers were compared. Statistical models containing a variety of parameters describing habitat characteristics are used to determine effects on the different measures of production.
H_2. There is a difference in biomass and diversity of invertebrates between pre and post enhancement states of trial side channels habitats in the Peace River;	Artificial sampler arrays were deployed across two Control and two Test locations (treatment) in the Peace River. Data collection includes: • Invertebrate Abundance • Invertebrate Diversity – taxonomy indices for invertebrates included Species Richness, EPT Richness, Percent Chironomidae, Simpson's Index and Hilsenhoff Index • Invertebrate Biomass Benthic invertebrate diversity and biomass were assessed using artificial substrates for 48 days. A variety of different measures of productivity were considered at two Test and two Control locations. Statistical models containing a variety of parameters describing habitat characteristics are used to determine effects on the different measures of benthic invertebrate production.
H_3. There is a difference in biomass and diversity of periphyton between pre and post enhancement states of trial side channels habitats in the Peace River.	Artificial sampler arrays were deployed across two Control and two Test locations (treatment) in the Peace River, during Pre (2013) and Post (2014) years. Data collection includes: • Periphyton Abundance • Diversity – taxonomy indices for periphyton include Species Richness, Simpson's Index, and community structure • Production/Biomass – chl-a, AFDW/DW, biovolume Statistical models containing a variety of parameters describing physical habitat characteristics and the effects of pre and post treatment at control and test sampling locations are used to determine effects on the different measures of production.

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

2.0 METHODS

2.1 Study Area

The study area is located in the Peace Region in northeast British Columbia on the Peace River downstream of the W.A.C. Bennett and Peace Canyon Dam (Figure 2-1). The study area was previously divided into two study locations but the 32L side channels were not sampled this year at the request of BCH. The 102.5R study location is further divided into control and monitoring sites (Table 2-1). The second study location includes two side channels in the vicinity of the boat launch at Peace Island Park referred to as 102.5R Test and 102.5R Control. 102.5R Monitoring is immediately upstream of the boat launch at Peace Island Park on the right bank and 102.5R Control is approximately 8 km downstream of the boat launch on the left bank of the Peace River. There are several large tributaries to the Peace River that likely influence overall productivity. The 102.5R monitoring location is immediately downstream of the Pine River confluence, a significant source of turbidity with an estimated sediment production that is 2.2 million tonnes and approximately 1.6 times greater than the Peace River post regulation (Knight Piesold, 2012). The values “32” and “102.5” correspond to the relative distance of the sites downstream of the Peace Canyon Dam and the terms “L” and “R” refer to the location of these sites on either the “Left” or “Right” bank respectively. For reporting and study design clarity, the monitoring and control sites were labelled with the same distance and bank qualifiers when looking downstream even though the sites are slightly further upstream/downstream from each other. Within each Control or Test site, ten samplers were deployed at random locations that would allow enough water to ensure the samplers would remain submerged. The sampling design includes one additional sampler in each side channel when compared to the 2013 program. Each side channel had ten samplers: five in “deep” water – targeting areas of between 1.5 and 2.0 m depth and five in shallow water – targeting areas of between 0.5 and 1.0 m depth at low flows.

Figure 2-1 shows the study area and study locations along the Peace River.

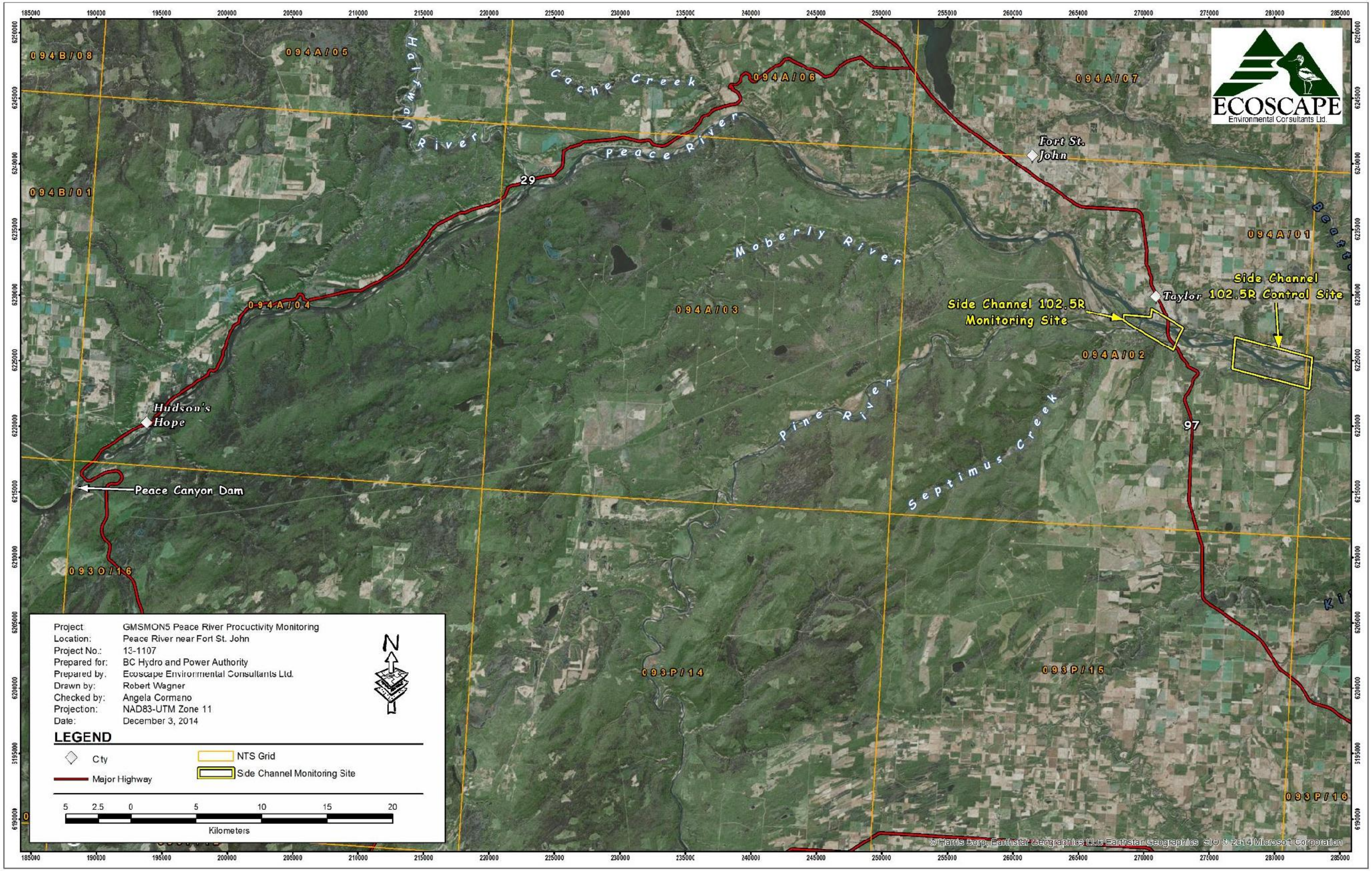


Figure 2-1: Map of the study area and sampling locations.

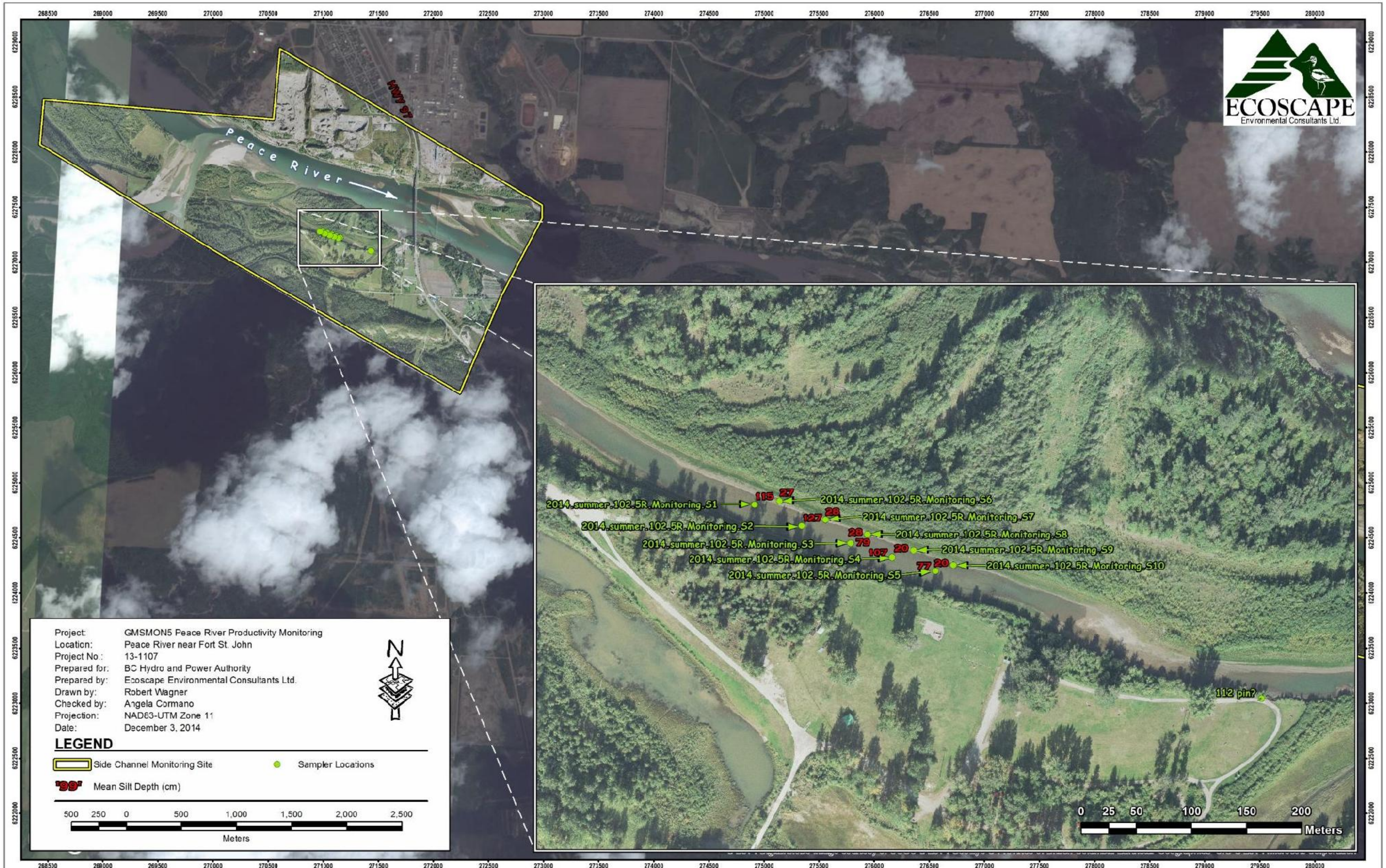


Figure 2-2: Map of the 102.5R Test (Monitoring) study area

Figure 2-3: Map of the 102.5R Control study area

2.2 Periphyton and Invertebrate Community Sampling Using Artificial Samplers

2.2.1 Artificial Sampler Design and Deployment

Samplers and rigging were assembled and deployed on July 30, 2014 at the 102.5R side channel sites. Deployment was initially planned for earlier in July but had to be delayed because of a wildfire near Hudson's Hope that prevented access to gear stored in the Hydro yard near the W.A.C. Bennett Dam. One day was spent preparing gear prior to deployment by boat.

Figure 2-4 illustrates the standard artificial sampler design which was modified from other projects completed in the Lower Columbia and Middle Columbia River for BC Hydro. This design differed from the design used in 2013 because sediment samplers and an extra float line were added to allow for quanitification of sediment accumulation in the side channels.

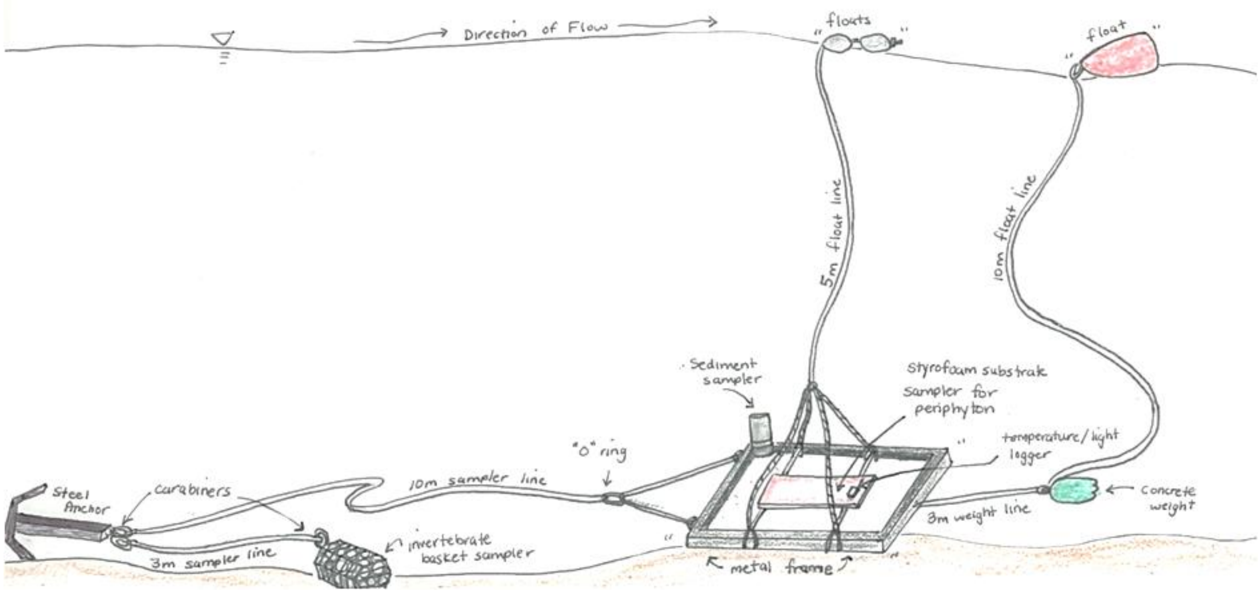


Figure 2-4: Schematic drawing of a standard artificial substrate sampler including the new sediment sampling apparatus

This sampling apparatus included a separate sampling line for the benthic invertebrate sampler to allow the invertebrate basket to remain on the bottom of the river during periphyton sampling. The periphyton samplers were held on the bottom with a concrete weight attached with a 3-5 m cord on the rear of the sampler. A float used for retrieval was attached with rope to the back of the plate via the concrete weight. A sediment trap sampler consisting of a plastic tube with a sample jar inside was attached to the metal frame. A float line and floats were then attached to the plate to allow it to be retrieved vertically to minimize sediment loss from the plate or from the sediment jar. At the time of deployment, the sampler locations were marked with a Trimble GeoXT GPS unit. Sample locations were surveyed at retrieval using an RTK survey system.

Sampling in 2013 included a time series sampling event to collect periphyton samples approximately half way through the deployment period. This time series sampling event was abandoned in 2014 because it disturbed sediment accumulations over the deployment period and could affect production estimates. Although time series sampling was not completed this year, the sampling apparatus remained unchanged during this year's field study, for consistency in sampling design and to avoid additional effort required to reorganize the sampling apparatus design and setup.

All of the deployed samplers were retrieved with no loss or damage during this year's field effort (Table 2-1).

In addition to the temperature and light loggers deployed in the side channels, loggers were installed on shore at the 102.5R Control and 102.5R Monitoring sites to correlate submerged data with conditions at the surface.

Table 2-1: Artificial Sampler Deployment and Retrieval in 2014

Site	Treatment	Periphyton Samplers		Invertebrate Samplers		Temp/Light Loggers	
		#Deployed	#Retrieved	#Deployed	#Retrieved	#Deployed	#Retrieved
102.5R	Control	10	10	10	10	10	10
102.5R	Test (Monitoring)	10	10	10	10	10	10

2.2.2 Artificial Sampler Retrieval

Artificial samplers remained in the river for a total of 48-49 days, within the previously defined incubation period of 40-50 days for attainment of peak biomass (Perrin et al. 2004). It is important to note that specific growth curves for the Peace River have not been developed, and it is possible that the growth curve may differ from the assumed period required to achieve peak biomass. Sampling in 2014 was delayed for approximately 2 to 3 weeks due to forest fires and safe access concerns. These small time shifts are not anticipated to have an observable effect on productivity and data analysis has assumed this is the case. However, the potential effects of the assumptions of achieving peak biomass have not been investigated and could influence results.

The sampling conditions within the Peace River side channels necessitated a revision of the sampling methodology. Field results during 2013 time series sampling showed that many of the samplers were covered in a fine sediment film that we anticipated would have an effect on periphyton abundance and chlorophyll-a. The retrieval protocol was altered during 2013 at the time of sampling to include both fines and styrofoam samples and this method was carried over into 2014. At retrieval, three styrofoam punches were randomly collected from each periphyton plate sampler in fines and three samples were collected in styrofoam. The condition of the plate upon retrieval dictated the sampling method. If the entire plate was covered with fine sediment, three samples were collected in sediment and the plate was lightly rinsed in order to collect styrofoam samples free of fines for comparison purposes. Where the plate was retrieved with no visible sediment, no fines sample was collected. The sediment collected in the sediment sample bottles was used to quantify the accumulation of sediment over time. By retrieving the plates using the second set of floats, less sediment was lost from the plates and associated samples during retrieval in 2014.

The following metrics were assessed based on the samples collected: 1) chlorophyll-a to give an estimate of only live autotrophic biomass; 2) Ash-Free Dry Weight AFDW (volatile solids) / total dry weight to give an estimate of the carbon component (Stockner and Armstrong, 1971); and 3) taxa abundance and biovolume to give an accurate estimate of live and dead standing crop (Wetzel and Likens, 1991). Two taxa punches were collected per sampler. In specific circumstances where the amount of fines was limited, only samples for periphyton taxonomy were collected. The AFDW sample was collected from the styrofoam only. At the time of collection, punches were placed in pre-labeled containers and stored on ice until further processing. Chlorophyll-a samples were placed in a dark collection bag and frozen.

Benthic invertebrate baskets were retrieved similar to previous years following guidelines developed by Perrin (2004). A 250 µm mesh net was brought along at retrieval to collect any invertebrates that could have been lost as baskets were lifted from the water, however, it became a safety/navigability concern because the net has a long pole and is very difficult to handle within the smaller side channel areas. Given the difficult circumstances, every effort was made to transfer the basket immediately into the bin as it broke the water's surface and given the low overall number of benthics in the samples, losses are expected to be minimal. Ecoscape has observed minimal, if any, benthic invertebrates in the net following sampling on the Columbia River and this small methodological change is not anticipated to have an effect. Sampling of natural substrates has been completed to help correlate natural stream substrate to our artificial sampling methodology. For these reasons, we believe that amending the proposed methodology had minimal effects on the data. A smaller net could be manufactured for use in future field efforts on the Peace.

Upon completion of sampler retrievals from each site, individual rocks from each basket were scrubbed with a soft brush to release clinging invertebrates. Washed rocks were then rinsed in the sample water before being placed back in the basket and stored. The contents from each bucket were then captured on a 297 µm sieve, rinsed into pre-labeled containers and preserved in alcohol for analysis.

2.2.3 Time Series Samplers

Time series samples were not collected during 2014. However, an effort to sample on a weekly basis should be considered to understand and develop a Peace River specific accrual curve for periphyton and more accurately determine the time to peak biomass.

2.2.4 Natural Periphyton Samples

Periphyton samples were collected from the boat in water depths ranging from 1.5 to 1.7 m (side channel 102.5R Test) and from 0.8 to 1.1 m (side channel 102.5R Control) using a peat auger (area of each core is 11.8 cm^2). Briefly, sand or silt substrate samples were collected by inserting the auger into random locations along the margins of the channel that were assumed to be permanently inundated. A one cm thick sample was collected from each auger. This method was selected because water levels were too high to allow for sampling from shore in permanently inundated sites and was adapted from standardized methods. Three 11.8 cm^3 samples were agitated in a plastic sample bottle with 500 mL of 0.45 micron filtered river water and a 250 mL sample was promptly decanted into a pre-labeled sample jar. This was repeated three times to get three replicate samples from each sample location. Three sample locations were randomly selected for the monitoring and the control side channels for a total of nine samples.

2.2.5 Natural Invertebrate Samples

A total of 3 benthic invertebrate samples were collected from each of the side channels (i.e. three samples from 102.5R Control and 3 samples from 102.5R Test) using an Eckman dredge. The position of each of the dredges was randomly selected. Samples were then sieved in a wash bucket with 297 micron mesh and transferred to a labeled sample bottle. Samples were preserved with ethanol.

2.2.6 Post Processing of Periphyton Samples and Enumeration

All periphyton sampling and processing follow those methods used in BC Hydro Columbia Projects

(Schleppe *et al.* 2012, 2013; Larratt *et al.* 2013). To our knowledge, this is the first periphyton study of the silt-laden habitats in side channels of the Peace River, and adjustments to standard methods used on other BC Hydro projects were necessary. In our review of other productivity works on the Peace River, sediment deposition did not appear to be as prevalent, probably due to increased velocity within the mainstem areas (Golder, 2012), or simply due to high inter annual variation.

Of the styrofoam punches obtained from each artificial substrate:

- One 6.6 cm^2 punch was stored frozen in black bags and shipped to Caro Labs Kelowna BC, for the processing of low-detection limit fluorometric chl-a analysis.
- The larger 56.7 cm^2 punch was chilled and transferred to Caro Labs in Kelowna, BC for analysis of dry weight and ash free dry weight (volatile solids).
- One 6.6 cm^2 punches were used for taxonomic identification and enumeration by H. Larratt.
- The final 6.6 cm^2 punch was preserved using Lugol's solution and stored for additional taxonomic identification and biovolume measurements if necessary.
- Species cell density and total biovolume were recorded from each sample.

Detailed protocols on periphyton laboratory processing are available from Larratt Aquatic. Analogous methods were used for the silt samples.

Removal of the periphyton from the Styrofoam punch followed the Perrin and Chapman (2010) method which involved using a fine spray from a dental cleaning instrument within an enclosed chamber to avoid loss of cells. For samples collected from deposited sediment, the same rinsing method was used. Samples were then blended to help break up filamentous and colonial taxa and to homogenize cell distribution as per Blinn (2000).

Silt samples were opaque and a 1:10 dilution with distilled water was required for microscope work.

Periphyton samples were allowed to settle in counting chambers over 24 hours. Cells were counted along mid-section transects examined at 500X-900X magnification under an inverted microscope. Intact cells containing cytoplasm were counted as live, and cells without cytoplasm were counted as dead to arrive at the live : dead ratios. Counts continued until taxa relative abundance stabilized or 300 cells were counted, whichever was greater. Cell biovolumes were calculated from measurements to the nearest 0.1 micron. All parts of the microflora were evaluated, noting prevalence of detritus, vascular debris, nano- and pico-periphyton, bacteria, fungi, yeasts etc., and their micrograzers (protozoa) to accurately estimate productivity. Microscope photographs of typical assemblages were taken from each sample and archived for BC Hydro.

The prevalence of silt in these samples meant that entire diatom frustules were seldom visible, precluding their identification beyond the genus level in many cases.

2.2.7 Post Processing of Invertebrate Samples and Enumeration

Preserved benthic invertebrate samples were transported to Cordillera Consulting in Summerland BC. Upon arrival, the sand and gravel in the sample was separated by elutriation using a small bucket and a 400 µm sieve. The removed sand and gravel was examined for molluscs and trichopterans under a dissecting scope and any organisms remaining were picked and added to the organic portion of the sample. Further sample examination was conducted as follows:

- The organic portion of the sample was examined for large leaves, twigs or large clumps of algae and any invertebrates found were returned to the whole sample.
- The remaining whole organic portion of the sample was sieved through 1 mm and 250 µm sieves (macro and micro fractions).
- The micro fraction was examined to determine whether there was a need for sub-sampling with a large plankton splitter.
- The macro portion was sorted in its entirety unless there appeared to be more than 200 organisms. If more than 200 benthic invertebrates were found, sub-sampling was used. The sample was floated on a level screened tray and the tray divided into 48 squares. The squares were randomly chosen and sorted in their entirety until 200 invertebrates were found. Forty five (45%) percent of samples were subsampled in 2013 and 25% of samples were subsampled in 2014.

Samples were then sorted and identified to the genus-species level where possible. The following summarizes the sorting procedure:

- Using a gridded Petri dish, fine forceps, and a low power stereo microscope the sorting technician removed the invertebrates and they were sorted into family/orders at the same time.
- The sorting technician kept a running tally of total numbers as they sorted the invertebrates into family/order specific vials. The total number of *Porifera, Nemata, Platyhelminthes*, *Ostracoda, Copepoda, and Cladocera* were not determined for the subsample enumeration. Further, terrestrial drop-ins such as aphids were also not enumerated.
- Invertebrates were stored in 80% ethanol in separate vials (according to family/order) and an interior label using heavy rag paper was used to track site names, date of sampling, site code numbers, and the portion sub-sampled.
- The sorted portion of the debris was preserved and labeled separately from the unsorted portion and was tested for sorting efficiency. The unsorted portion was labeled and preserved in a separate jar.

Benthic invertebrate identification and biomass calculations followed standard procedures. After samples were sorted, all macro invertebrates were identified to species and all micro portions were identified following The Standard Taxonomic Effort lists compiled by the Xerces Society for Invertebrate Conservation for the Pacific Northwest. A reference sample was kept for each unique taxon found and stored in a reference collection for the project. A sampling efficiency of 95% was used for benthic invertebrate identification and was determined through independent sampling. Two in ten samples were randomly processed by a second sorter for quality control. An efficiency of 95% was not attained, the previous 10 samples were re-sorted. A minimum of 15 samples were resorted for this project.

Sampling efficiency was calculated as follows:

$$\frac{\#OrganismsMissed}{TotalOrganismsFound} * 100 = \%OM$$

Numerous keys were referenced in the identification of benthic invertebrate taxa and a partial list of references is provided in Schleppe *at al*. (2012). Species abundance and biomass were determined for each sample. Biomass estimates were completed using standard regression from Banke (1999) for invertebrates and Smock (1980) for *Oligochaetes*. If samples were large, subsamples were processed following similar methods. Further details on invertebrate laboratory processing protocols are available from Cordillera Consulting (Appendix 4).

Further quality control was achieved by sending 10% of the samples to another taxonomist for verification and using a similarity test both in terms of total numbers and in terms of percent agreement of taxa name and level. For samples with less than a 90% agreement in total numbers, all of the vials were recounted. In cases of disagreements between the taxonomists over taxon name or level, an agreement was either achieved or the sample was sent to a third taxonomist.

Note that invertebrate data from 2013 at the 32L site is presented for the first time in this report due to availability at the time or report production during 2013.

2.2.8 Physical Habitat Data

Physical habitat data was jointly collected with the GMSMON7 and this report should be referred to also for specific information on the methods used to collect some of the physical habitat data (Mainstream, 2014 in prep). Table 2-2 provides a summary of how collected physical data was used in physical habitat modelling.

2.2.9 Field Turbidity and Water Transparency Measurements

In situ turbidity measurements were collected near the surface of the water column using a Hach 2100 P (±1% scale) turbidity meter by Mainstream Aquatics as part of GMSMON7 and reporting for this project contains information on calibration and collection methods. Water transparency was measured by lowering a Secchi disc to the depth where it was no longer visible, raising it to the point where the disc could be sighted again, and averaging these two depths. All measurements were taken mid-day, on the shaded side of the boat.

2.3 Analytical Methods and Statistical Procedures

A variety of statistical methods were used to address H1, H2, and H3 by determining whether there are differences among categorical groupings of data (upstream/downstream, Control versus Test, Pre versus Post Treatment, etc.) and by determining the relative influences of physical habitat variables on periphyton and benthic invertebrate productivity and community structure across sampling sites.

2.3.1 Development and Interpolation of Explanatory Variable Data

Temperature and light data were collected continuously at 0.5 hour intervals during deployment from the data loggers. All other data was collected as point samples at varying frequencies over deployment. All of these data were subsequently reduced to one data point to reflect conditions that could be associated with productivity over the duration of deployment. In order to maintain consistency among studies, spatial habitat data collected by Mainstream Aquatics as part of GMSMON7, including substrate variables (scores, D90, compaction), water clarity, and water turbidity were used in the present study (Table 2-2). A full discussion of collection methods, sample sizes, and other pertinent information can be found in GMSMON7 report (2015 in prep). Because Mainstream's habitat transects and sampling locations differed from those of benthic and periphyton sampling sites, it was necessary to spatially interpolate this data for deployment locations. To construct a dataset of these explanatory variables corresponding to response variables from samplers, spatial rasters comprised of 0.5 m^2 intervals were constructed in ArcGIS for each reach-treatment combination. Each interval was populated with data derived through kriging with a Gaussian semivariogram from 2 – 4 measured data points (from surveyed transects or sites) (Watson and Philip 1985; ESRI 2013; Appendix 1), noting that the attributes were used rather than the Z values from the kriging algorithm as shown in the Appendix. Data for each individual sampler was then extracted from the spatial interval in the raster in which the sampler was located. Interpolated data values derived from rasters were then confirmed and corrected through detailed visual assessment of air photos and field notes.

The set of explanatory variables (Table 2-2) was reduced using methods described by Zuur *et al.* (2010). We examined multicollinearity among habitat variables using a variance inflation factor (VIF) (Appendix 2). VIF quantifies multicollinearity through ordinary least squares regression analysis that measures the level to which the variance of an estimated regression coefficient is increased due to collinearity among explanatory variables. Highly collinear variables (VIF > 5) were dropped from subsequent analyses. In case of two highly correlated variables, the variable with the most biological relevance and the greatest potential for future spatial model development was kept. In 2014, velocity was removed as a parameter from models due to collinearity with silt depth (correlation coefficient of 0.90). Silt depth was selected over velocity due to the high silt deposition rates observed, but we acknowledge that velocity may still be an important variable and will continue to be considered during future modelling of productivity data.

2.3.2 Periphyton and Invertebrate Community

Non-parametric multidimensional scaling (NMDS) using Bray-Curtis dissimilarity matrices of non-transformed dispersion-weighted abundance estimates was used to explore variation in benthic community composition between reaches (up or down-stream), treatments (Control or Test), year of sampling (2013 or 2014), and sampling medium (Artificial or Natural Substrates) (Clarke *et al.* (2006)). To interpret data, Ward cluster diagrams of the Bray Curtis matrix were constructed (Ward 1963, Kaufman and Rousseeuw 1990). Analysis of similarities (ANOSIM) is a non-parametric, permutation-based approach which provides an appropriate alternative to traditional analysis of variance (ANOVA) for testing for significant differences among biological communities (Clarke and Green 1998). Here ANOSIM was used to determine if groups were significantly different in composition. NMDS was conducted for both periphyton and benthic invertebrate communities at the taxonomic level of genus to avoid confounding effects of rare species, and because species level identification was not always possible.

All non-parametric community analyses were conducted using the packages Cluster (Maechler 2013), ade4 (Chessel *et al.* 2013), and vegan (Oksanen *et al.* 2013) in R.

2.3.3 Benthic and Periphyton Production

Exploratory analysis of production responses to predictors was completed for raw or log-transformed data using scatterplots for all response – predictor combinations (boxplots in the case of categorical predictors). This graphical representation of data was used to assess the quality and general patterns in relationships and gauge the applicability of potential explanatory variables prior to their inclusion in the main statistical analyses (see Appendix 2 for correlations between predictors and Appendix 3 for scatterplots of response variables and all included explanatory variables).

Six response variables for periphyton and eight response variables for benthic invertebrates were modeled. Periphyton response variables included: 1) abundance, 2) biovolume, 3) Species Richness, 4) Simpson's Index, 5) chlorophyll-a, and 6) Ash free Dry Weight. Invertebrate production and diversity response variables included: 1) abundance, 2) biomass, 3) Species Richness, 4) percent EPT, 5) percent Chironomids, and 6) Hilsenhoff Biotic Index. Periphyton abundance, biovolume, chl-a, and AFDW, and benthic invertebrate abundance, biomass, and % EPT data were log transformed (x+0.1) to adhere to the assumptions of least-squares multiple regression (e.g., normal distribution and heteroscedacity of residuals). Only data from the 102.5R R site was used in modelling to avoid any confounding influences of an unequal sampling design.

The Hilsenhoff Biotic Index is typically used as a measure of oxygen concentration in organic loading of rivers, relating water quality conditions to the benthic biota where higher index values are indicative of low dissolved oxygen conditions. The index incorporates the sensitivity and abundance of different taxonomic groups to low oxygen conditions. To some extent, low oxygen conditions originating from poor water quality are similar to extremes associated with dewatering or other associated stresses. In this case, the HBI index is useful because it may detect community shifts from taxa such as Chironmidae or Oligochaeta to Ephemeroptera / Plecoptera / Trichoptera as flows increase within side channel areas. The Hilsenhoff Biotic Index is calculated as follows:

$$HBI = \sum \frac{x_i t_i}{n}$$

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

We used multiple linear regression and model selection via Akaike information criterion corrected for small sample sizes (AICc) to evaluate the relative effects of a suite of explanatory variables describing physical and environmental characteristics of channels, and treatment (Control or Test) or Flow Period (Pre and Post) (Table 2-2) on periphyton and benthic invertebrate production response variables. More specifically, we used an all model combinations approach (n = 512 and n= 512 for benthic invertebrate and periphyton models respectively) where we constructed candidate models describing production response variables with all combinations of explanatory variables, and competed them using AICc, in which the lower the ΔAICc value and higher the AICc weight (w_i), the greater the support for a given candidate model (Burnham and Anderson 2002; Anderson 2008). We then used multi-model averaging to determine the relative direction, magnitude, and variability in the effects of individual explanatory variables through calculating averaged parameter estimates and 95 % CI from top candidate models (those with Δ AICc < 3). We also determined support for individual explanatory variables through their relative variable importance (RVI), which is the sum of AICc weights from all models containing the variable of interest (Burnham and Anderson 2002; Grueber *et al.* 2011). These RVI values are on a scale of increasing importance from 0 to 1. An RVI of 1 for a predictor means that there is a 100% probability that this predictor will occur in the AIC_C best model. In addition to these measures of support for models and individual explanatory variables, we use R^2 (pseudo-R^2 for linear mixed-effects models, derived from regressions of the observed data versus fitted values; e.g., Piñeiro *et al.* 2008) values for high-ranking models, which gives an indication of the proportion of the variance in response variables explained by a given model.

We conducted the above analyses after standardizing continuous explanatory variables by subtracting global means from each value (centering) and dividing by two times the standard deviation (SD) (scaling) to compare among all parameters of varying scales, including both continuous and categorical variables (Gelman 2008). All model selection and averaging analyses were conducted using the MuMIn package in R (Barton 2013). While periphyton response variable data from fine sediment and Styrofoam samples were kept separate for descriptive analyses and NMDS, they were summed and divided by the total volume of the sediment sample to get total combined values per cm^3 for each sampler prior to analyses through linear regression. Finally, in some cases, standard transformation techniques could not meet the assumptions of linear modelling techniques identified by inspection of residuals and the effects of individual data point leverage. In these cases, the model average coefficients of the violating and non-violating model with high leverage data points removed are presented.

All data management was conducted in Excel and R (R Development Core Team 2013). All rastering was conducted using the IDW tool in ArcGIS (ESRI, 2013), and all statistical analyses were conducted in R. Attempts have been made to reference the most pertinent packages and scripts used in development of our analysis. Credit for all unreferenced R scripts and analyses shall be given to the original authors.

Table 2-2: Variables considered (normal text) and used (bolded text) in describing periphyton and benthic invertebrate responses in relation to side channel habitats and physical conditions during deployment.

Variable	Definition
Average Maximum Daily Light Intensity (lux)	The average maximum daily light intensity observed over the duration of deployment was correlated with the average daily intensity. This variable was not considered in modelling this year. This variable is collected continuously on 0.5 hr increments over deployment.
Average Daily Light Intensity (lux)	**Average daily light intensity observed over the duration of deployment. This variable is collected continuously on 0.5 hr increments over deployment.**
Silt Depth	**The mean silt depth[1] of accumulated sediment depth on the samplers over the duration of deployment. This data is collected at the end of the deployment period.**
Turbidity	**In situ turbidity measurement using a Hach 2100 meter interpolated using GIS. Section 2.3.1 contains methods for how data was interpolated using GIS. This data was point data that was extrapolated between sites. Readers should refer to GMSMON7 for details on data collection.**
Average Maximum Daily Water Temperature (˚C)	The average maximum daily water temperature observed over the duration of deployment. This variable was not considered in modelling this year. This variable is collected continuously on 0.5 hr increments over deployment.
Average Daily Water Temperature (˚C)	**Average daily water temperature observed over the duration of deployment. This variable is collected continuously on 0.5 hr increments over deployment.**
Substrates	**Substrates scores were calculated by multiplying the estimated percent of river substrate for a given transect made up of five substrate types by their corresponding maximum classification diameter (boulder = 256; cobble = 160; gravel = 33; sand = 1.03; fines = 0.06 in mm) and adding these values together. This data was point data that was extrapolated between sites. Readers should refer to GMSMON7 for details on data collection.**
D90 Substrate Size	**D90 substrate sizes were collected by Mainstream in 2013 and 2014, please refer to their methods for collection techniques. Section 2.3.1 contains methods for how data was interpolated using GIS. As D90 increases, so does substrate size. This data was point data that was extrapolated between sites. Readers should refer to GMSMON7 for details on data collection.**
Reach	Reach is defined as upstream sites (32L) and downstream sites (102.5R) and was included as a random effect in linear mixed-effects models describing periphyton productivity.
Flow Period (Pre or Post)	**Flow period defines the period before and after construction of the side channel improvements in 2014.**
Velocity (m/s)	Velocities were collected at deployment and retrieval. The two data points were averaged to determine an approximate average velocity representative of site conditions.
Control – Test	**Treatment is defined as Control sites where no dredging will occur, and Test sites where future dredging will be conducted. This variable was included to determine whether there are pre-existing differences among Control and Test sites in the present sampling event prior to restoration efforts, and to determine the influence of restoration activities in future sampling events.**

[1] Mean silt depth was collected by measuring the depth of silt deposited on the Styrofoam substrate in 2013 and in the sediment collection jar in 2014. Although we anticipate some differences between techniques, we do not anticipate these will affect modelling or interpretation of data as the observed sediment depths on the Styrofoam substrates during 2013 were similar to those in 2014.

2.3.4 Assumptions for Use of Artificial Substrates

As with all Peace River side channel samples, depositing sediment coated the artificial substrates and impacted results. Our attempts to correct for this are discussed elsewhere. We made the assumption that the data is still representative by comparing it to natural substrates. Further, lab analyses and taxonomic analyses on the artificial substrate samples may have been hindered by the deposited sediment. Again, we make the assumption that the analyses were not unduly impacted.

The effects of foraging invertebrates on periphyton growth were assumed to be randomly distributed over the artificial substrate within and between all sites. It is acknowledged that invertebrates may spend more time foraging on the edges of the substrata affecting productivity along the edges of artificial samplers. However, foraging intensity on samples is still considered small when compared to each sample as a whole, reducing potential effects of data skewing associated with invertebrate grazing. Further, it is probable that invertebrate distributions around plates were clumped, reducing the potential of invertebrate graze on periphyton samplers across multiple replicates.

Our analyses also assume that artificial substrates do not bias results toward a given algal taxa nor do they bias towards those taxa actively immigrating at the time and location of the sampler submergence. Although we have made this assumption, field data indicated that silt deposition in Peace River side channel systems exerted considerable shading on the substrates. For the period from deployment until >5 mm of silt had accumulated, the artificial substrate may not have provided analogous growth opportunities as the natural substrates around it. Finally, closed cell styrofoam similar to what is used in the LCR (Larratt et al, 2013) was selected because our bench studies have shown that it better met this assumption than the open-celled styrofoam used in the MCR (Schleppe *et al.* 2013).

Benthic rock baskets provided a unique habitat that was not analogous to the surrounding compacted silt substrate and may have attracted a unique invertebrate community. However, this sampling method was chosen because it allowed comparison to other BCH projects completed in the Peace River, and an analogous sampling method to other ongoing BCH studies on the Columbia. Further, use of the rock baskets allowed us to sample deeper areas (1.5 to 2 m depth) ensuring that we sampled permanently submerged habitat. Use of alternative methods, such as a HESS sampler would have made sampling these deeper areas more difficult.

3.0 RESULTS

3.1 Patterns in Flow, Light, Sediment Deposition, and Temperature in the Peace River

Water temperature data have been collected on the Peace River since 2009 (Diversified, 2013) and the review in Schleppe et al. 2013 indicated that mainstem temperatures of the Peace River were similar to side channel locations. As a result, only temperature data from the side channels are presented for 2014. Water temperatures in the upper and lower side channel (32L) over the summer sampling period were very similar to those of the main channel of the Peace River in 2013.

Side channel temperatures during the 2014 summer deployment were typically between 10 and 18 ºC and declined from the start of deployment in July until retrieval in September (Figure 3-1). The observed temperatures were similar to 2013 at the start of deployment and decreased over the deployment period to a lower average in 2014. Lower water temperatures in the 102.5R side channel may be influenced by water entering the river from upstream tributaries (Figure 3-2) at the test location, but may also be the result of sampling several weeks later during the 2014 summer period.

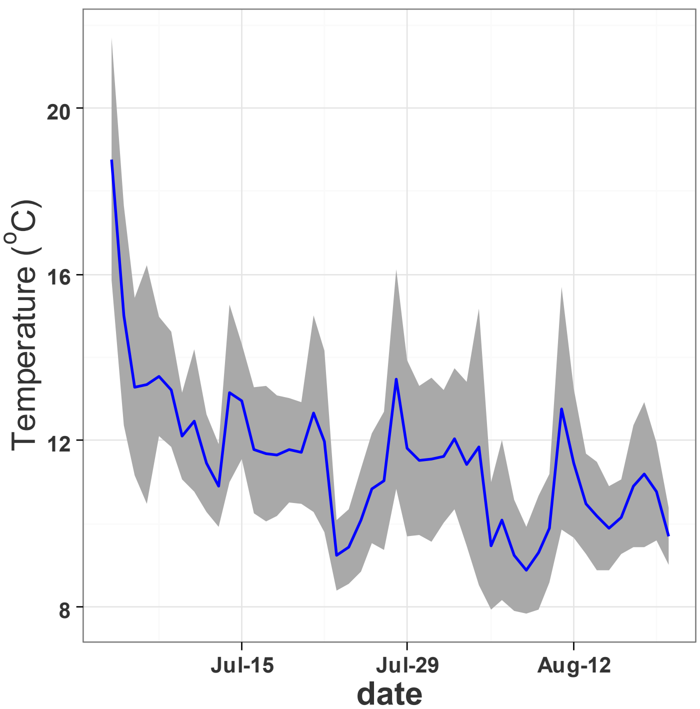


Figure 3-1: Average daily water temperature in the side channels of the Peace River during 2013/2014 (blue lines) with SD (grey). Data is pooled between Control and Test locations.

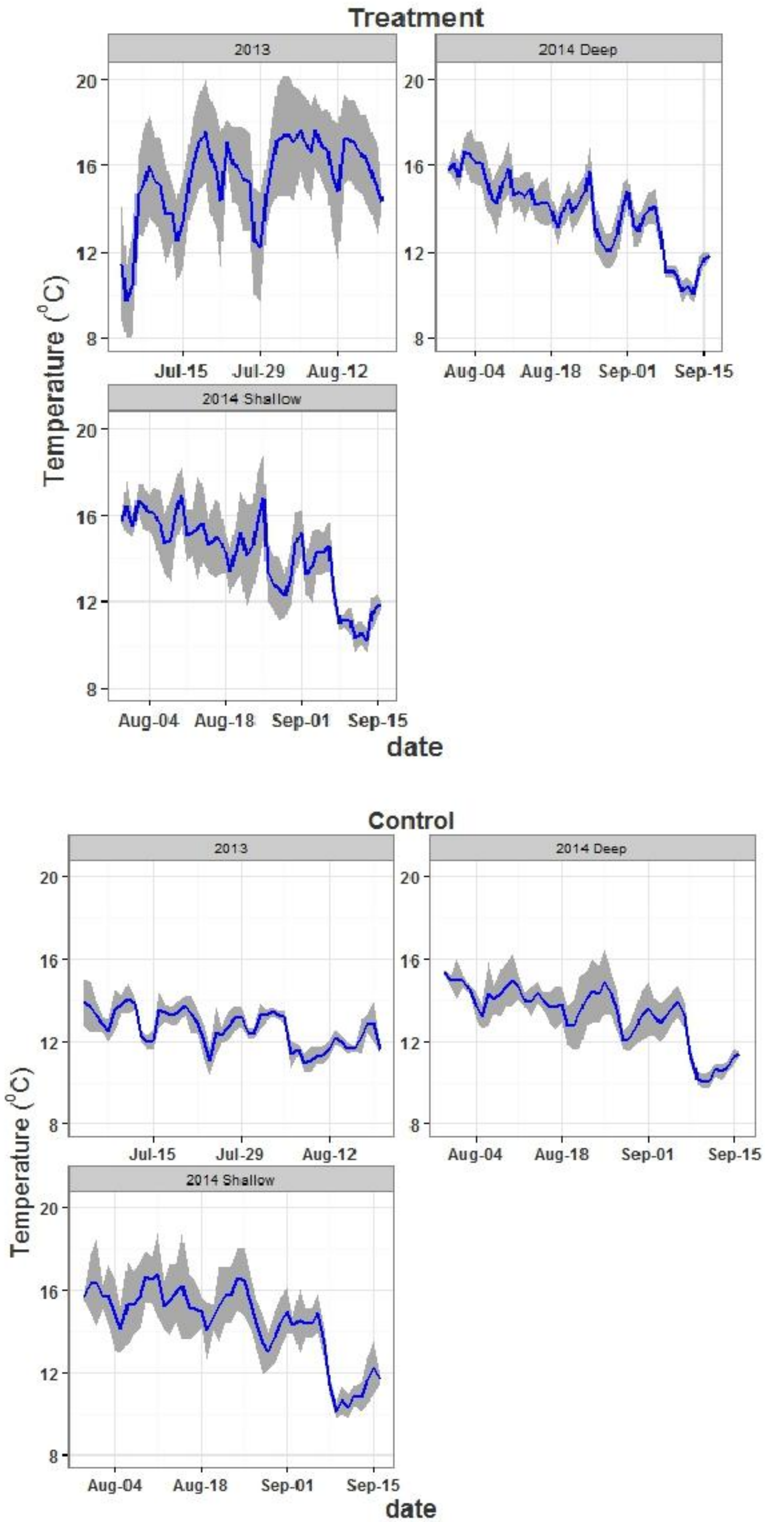


Figure 3-2: Average daily water temperature in 102.5R side channels of the Peace River during 2013 and 2014 with SD (grey) from deep and shallow sites. .

Peace River mainstem flow data from Peace Canyon dam between 2008 and 2014 was analyzed to understand flow variability during deployment and patterns in flow ramping over the study period. Water elevations, assessed via mainstem flows, are important because flows determine the depth, velocity, area of wetted substrates and other important parameters within side channel areas that directly affect benthic productivity, noting that we have not included tributary flows in this analysis for downstream sites.

Flows in the Peace River are different than a natural hydrograph. During the spring freshet period, flows are lower, whereas during the fall and winter periods, baseline flows are typically higher than a natural hydrograph (Figure 3-3). High freshet flows occurred during 2012. Since the sampling locations are below key tributaries, a similar flow comparison was completed using flow data from the Water Services Canada (WSC) gauge 07FD002 which occurs downstream of the Pine River confluence. Graphing of this data showed similar trends to the mainstem data, although the peaks were not as dramatic. These data, combined with results from GMSMON7 suggest that water elevations are directly linked to flows in the Peace River. Investigation into the relationships between depth and flow will continue using data from the Peace River side channels program. Flows in 2014 were higher than average at the commencement of the sampling period, but were lower than average until its conclusion.

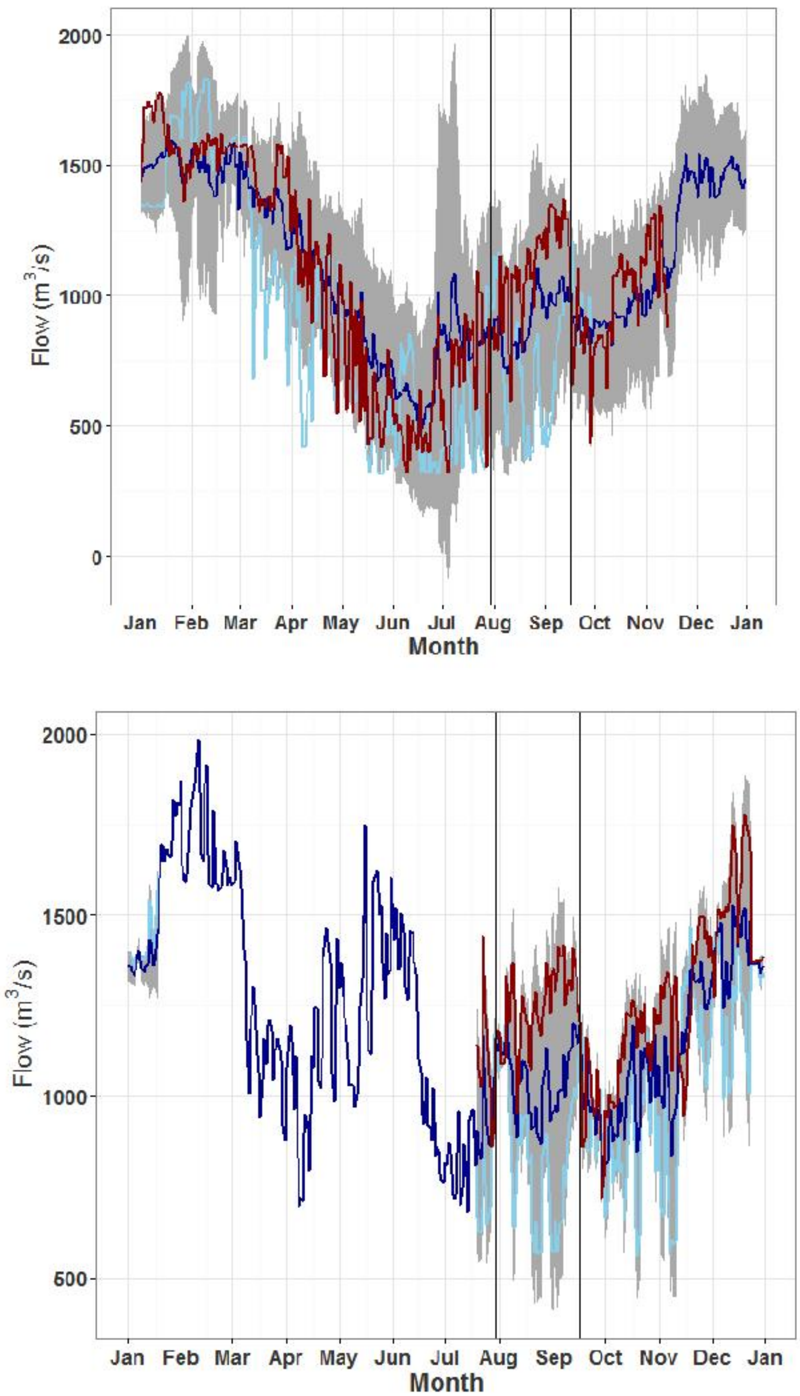


Figure 3-3: The pattern of annual flow in the Peace River. The top figure presents data between 2008 and 2014 based on Peace Canyon Dam releases. 2014 data (daily mean) are shown in light blue, 2013 flows shown in dark red, and the average between 2008 and 2014 (daily mean ± SD) is shown in dark blue with SD shaded in grey. The bottom figure shows the same data from July 2013 to January 2015 from WSC gauge 07FD002.

Turbidity in the Peace River system is high relative to other large rivers in BC. It is always high enough to impact periphyton photosynthesis. In a turbid summer such as 2013, it exceeded 40 NTU in side channels, while in 2014, turbidity was much lower, generally < 10 NTU, with small differences between sample locations.

Periphyton photosynthesis was estimated with light loggers deployed with the artificial samplers. They measured wavelengths between 400 and 700 nm, which is the photosynthetically available radiation or PAR utilized by phytoplankton. A summary of the daily light intensity data for downstream (2013) and upstream light loggers (2013 and 2014) showed peaks and valleys in the light data (Figure 3-4). In 2014, light intensities were substantially greater than they were in 2013 at the sampling locations in the river, likely due to lower turbidity levels. Also, in 2014, downstream samplers were deployed at variable depths, with 5 samplers deployed around 0.5 to 1 m depth and 5 samplers deployed at 1.5 to 2 m depth which also partially explains the difference in observed light intensities. Strong peaks and valleys in the 2014 shallow logger data appear to correlate with both natural variation in light intensity (i.e., cloud cover) and flows, where deeper water cover decreased light intensity on the substrates, while a return to lower flows and shallower water cover increased light intensities (Figure 3-4). Data from loggers indicated that light intensities steadily declined over time and this trend was observed in both shallow and deep loggers and in 2013 and 2014. Light intensities were greatest at the shallow locations but the observed levels of light intensity decrease were less noticeable. Based upon the available data, it is estimated that the PAR zone in side channel areas includes areas with less than 3 m of water cover and is directly influenced by turbidity. Finally, the data demonstrate increasing light attenuation over the course of deployment from a combination of sedimentation on the light loggers and decreasing light intensities due to the onset of fall.

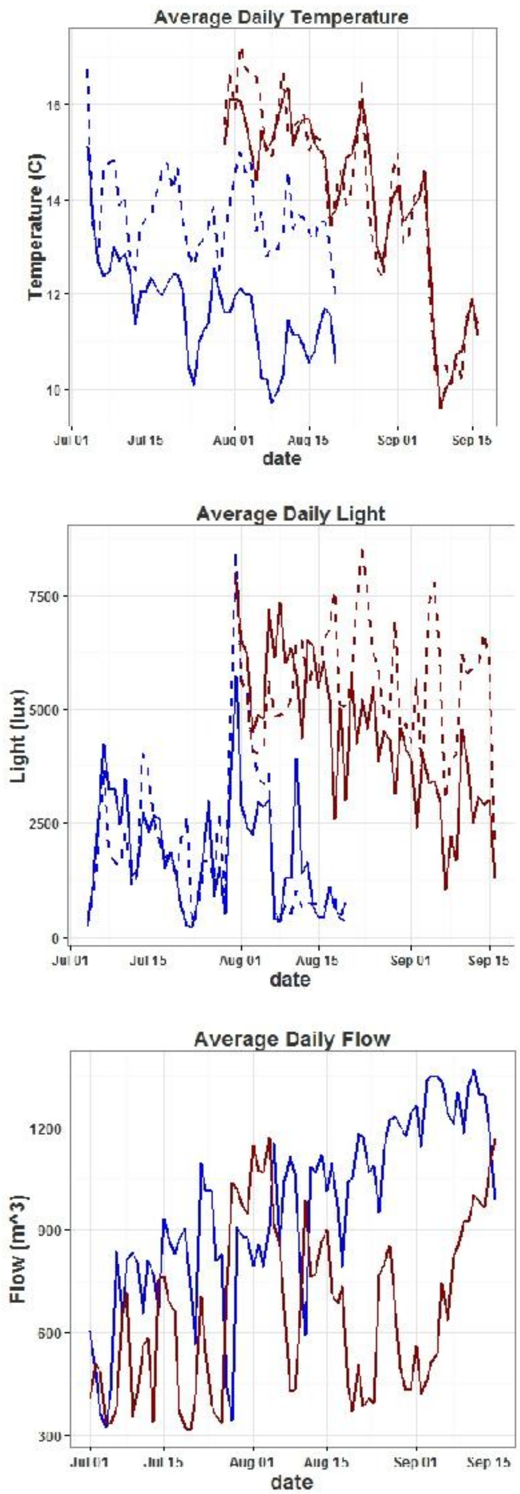


Figure 3-4: Flow (m^3/s), light intensity (lux), and temperature in 2013 and 2014 at Control (solid) and Test (dashed) locations in Peace River side channels in 2013 (blue) and 2014 (red).

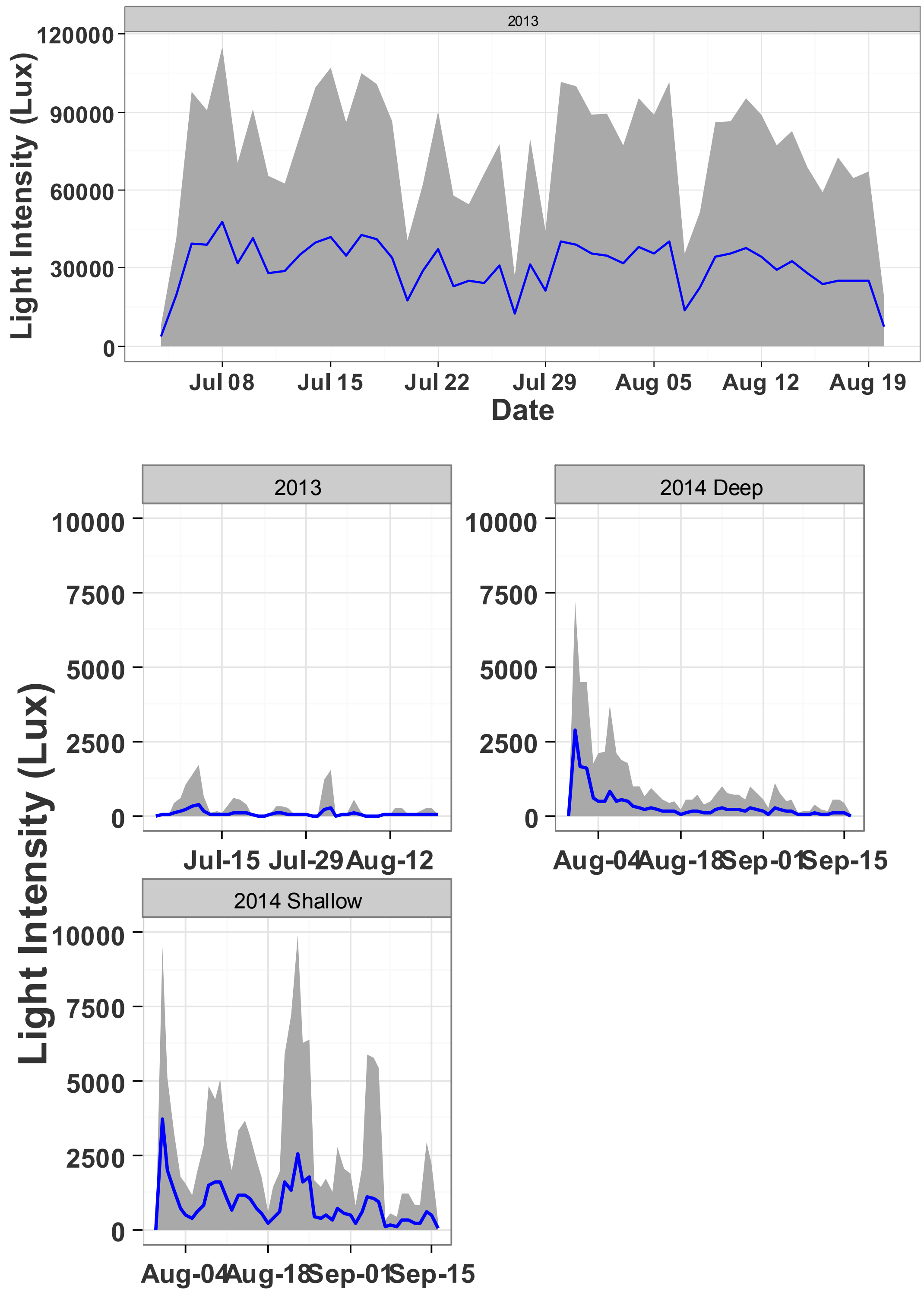


Figure 3-5: Light Logger data for Upstream (32L – top panel for 2013 data) and Downstream (102.5R R – bottom panel for 2013 and 2014) light intensity data (Lux (1 lumen per m^2)) in side channels of the Peace River. In 2014, samplers at 102.5R were deployed in shallow (~0.5-1.5 m) and deep (~1.5-2.5 m) locations. The light loggers measured wavelengths between 400 and 700 nm, termed PAR (Photosynthetically Available Radiation)

Turbidity in the Peace system is primarily caused by suspended silt. Sediment deposition rates in the side channels are high, ranging from 0.02 to 0.16 mm/day in the Control side channel. The site location Figure 2-1 presents the accumulated silt depths observed in 2014. Although not formally analyzed, a spatial pattern of higher deposition at deeper sites was observed. Secchi depths obtained from GMSMON7 show a measure of water transparency and were low, ranging from medians of 0.25 m in 2013 and 0.8 m in 2014 at the 102.5R side channels.

Sediment deposition in 2014 at the Test site was orders of magnitude larger than that observed in 2013 or 2014 at the Control site (Figure 3-6). In 2013, sediment depths were measured after the plate was removed from the river, whereas in 2014 sediment depths were measured with a sediment sampling apparatus that minimized lost sediments during retrieval. In 2015, sampling using both methods is recommended, because sediment loss during plate retrieval has been observed and this technique would allow an approximation of sediment lost to correct 2013 data. In 2013, the mean silt accumulation depth over the deployment period was 2.29 ± 2.34 mm and 1.19 ± 1.9 mm at 102.5R Control and Test side channels respectively, whereas in 2014 it was 8.1 ± 1.97 mm and 62.8 ± 43 mm at Control and Test sites respectively. Since productivity was corrected for silt depth, it is hypothesized that the differences (typically less than 5 mm) between the two methodologies will influence data interpretation by artificially reducing corrected productivity in 2014 versus 2013.

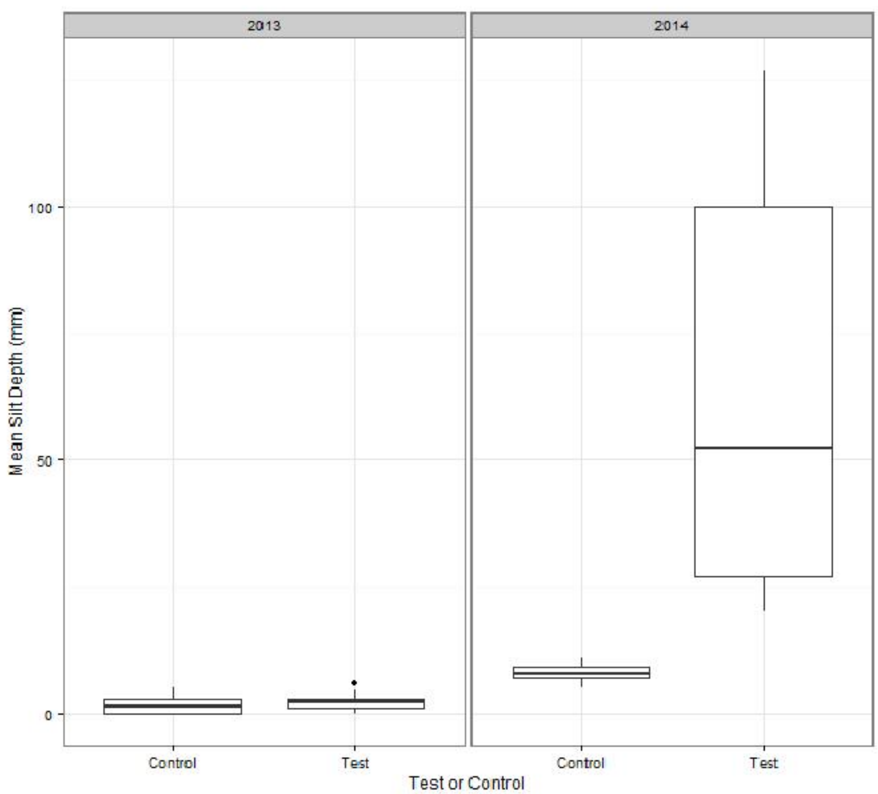


Figure 3-6: Sediment deposition rates at the 102.5R sampling location in the Peace River in 2013 and 2014. Note that methods of collection varied between years, with 2013 slightly underestimating actual sediment deposition rates. Sediment deposition in 2014 was orders of magnitude larger than either control locations or previous years.

3.2 Periphyton

3.2.1 Periphyton Productivity and Community Structure

Median periphyton productivity metrics on samplers were low in Peace River side channels relative to levels observed in the main stems of the Peace and of other rivers

Table 3-1: Summary of range of Peace periphyton metrics from 2013 and 2014, with comparison to

(Table 3-1).

Samples from substrates deployed in Peace side channels showed numeric dominance of cyanobacteria because of their small cell size, while diatoms made a greater contribution when biovolumes were considered, a result consistent with most riverine systems (Table 3-2). Green filamentous algae were less frequent but important to biovolume estimates. The very small nano and pico flagellates were important components of periphyton communities found in the Peace River side channel samples in 2013 and 2014. These flagellates were more abundant in 2013 with high turbidity and comprised a lower percentage of the periphyton community in 2014 when Peace turbidity was lower in side channels and other algae types became more abundant. Large inter-annual shifts between 2013 and 2014 were observed in the abundance of these algae groups that reflect differing growing conditions between years, possibly the result of differences in light regimes.

Despite the inter-annual shifts in periphyton community structure, prevalent periphyton taxa were similar in 2013 and 2014. In 2014 they included:

- Diatoms imported from upstream reservoirs (e.g., *Asterionella formosa, Fragilaria crotonensis, Synedra spp., Cyclotella spp.*)
- Diatoms imported from upstream flow areas (e.g., *Achnanthidium minutissima, Diatoma tenue, Hannaea arcus*)
- Diatoms that likely grew *in situ* because they are highly mobile and able to migrate upward as sediment settles (e.g., *Navicula spp., Nitzschia spp., Frustulia sp.)*
- Cyanobacteria species that grew in situ because they are able to tolerate low light conditions (e.g., *Synechocystis sp., Planktolyngbya limnetica*)
- Myxotrophic flagellated algae that grew in situ because they can migrate in the water column to obtain light, or do without by consuming bacteria or other small organics for energy (e.g., *Ochromonas spp., Chromulina sp., Euglena sp.*)
- Green filamentous algae from upstream or shoreline areas were present in the Control samples but not in the samples from Test locations (e.g., *Cladophora sp., Mougeotia sp., Spirogyra sp.)*

oligotrophic, typical, and productive large rivers

Metric	Oligotrophic or stressed	Typical large rivers	Eutrophic or productive	Upper Peace Mainstem 2010 - 2011	Side-channel 102.5R and 32L Summer 2013	Side-channel 102.5R Summer 2014
Number of taxa live & dead	<20 – 40	25 - 60	Variable	19 - 39	2 – 23 (10-15)	10 – 21 (10-17)
Chlorophyll-a µg/cm^2	<2	2 – 5 (7)	>7 – 10 (30+)	1.7 – 2.9	0.24 – 5.53	0.18 - 9.6
Algae density cells/cm^2	<0.2 x10^6	1 - 4 x10^6	>10 x10^6		0.12 – 4.0 x10^6 (0.3 – 0.6)	0.49 – 7.2 x10^6 (0.6 – 1.3)
Algae biovolume cm^3/m^2	<0.5	0.5 – 5	20 - 80		0.04 – 8.4 (0.18 – 0.6)	0.02 – 25 (0.6 – 1.0)
Diatom density frustules/cm^2	<0.15 x10^6	1 - 2 x10^6	>20 x10^6		0.001 – 0.68 x10^6	0.05 – 4.3 x10^6
Biomass – AFDW mg/cm^2	<0.5	0.5 - 2	>3		0.18 – 37.01	0.05 – 0.67
Total biomass – dry wt mg/cm^2	<1	1 – 5	>10		1.97 – 799.44	0.333 – 21.46
Organic matter (% of dry wt)		4 – 7%			2.2 – 15.4%	2.4 – 15.1%
Accrual chl-a µg/cm^2/d	<0.1	0.1 – 0.6	>0.6		0.005 – 0.115	0.004 – 0.200

(Median shown in brackets) Biovolume conversion: Microns^3/ cm^2 = cm^3/m^2 x 10^{-8}

Comparison data obtained from Flinders and Hart 2009; Biggs1996; Peterson and Porter 2000; Freese et al. 2006; Durr and Thomason 2009; Romani 2009; Biggs and Close 2006. Dodds et al, 1998, Golder. 2012.

In both years of study and in all Peace side channel samples, the abundance and biovolume of dead algae cells was high relative to other rivers. For example, side channel dead diatom counts were 60% of the live count in 2014, while 10 – 20% is typical for riverine periphyton (Larratt et al. 2013).

Table 3-2: Relative abundance and biovolume of periphyton taxonomic groups from Control and Test locations at the 102.5R side channel study area in 2013 and 2014.

Algae Group	2013 Control Relative Abundance (%)	2013 Control Relative Biovolume (%)	Algae Group
Flagellate	48.6	54.6	Flagellate
Blue Green	48.0	37.1	Diatom
Diatom	3.3	8.3	Blue Green
Green	0	0	Green
Algae Group	**2014 Control Relative Abundance (%)**	**2014 Control Relative Biovolume (%)**	**Algae Group**
Blue Green	62.1	69.6	Diatom
Diatom	32.9	26.1	Blue Green
Flagellate	3.4	2.5	Flagellate
Green	1.6	1.8	Green
Algae Group	**2013 Test Relative Abundance (%)**	**2013 Test Relative Biovolume (%)**	**Algae Group**
Blue Green	53.4	69.6	Diatom
Flagellate	40.0	26.1	Green
Diatom	6.5	2.4	Blue Green
Green	0.17	1.8	Flagellate
Algae Group	**2014 Test Relative Abundance (%)**	**2014 Test Relative Biovolume (%)**	**Algae Group**
Blue Green	62.2	98.2	Diatom
Diatom	37.0	1.5	Blue Green
Flagellate	0.8	0.3	Flagellate
Green	0.05	0.01	Green

3.2.2 Periphyton Habitat Preference and Indicator Taxa

Many of the diatom species found in the 2013 and 2014 102.5R side channel samples were phytoplankton types that originated in upstream reservoirs or upstream areas with strong flowing conditions. These diatom taxa remain in suspension until water velocity slows causing their deposition along with fine silt. Imported taxa accounted for 44-51% of periphyton abundance in 2014 side channel sediment samples. Algae deposited from drift are therefore an important source of photosynthetic material to the side channels, particularly at deep sites, where settlement of sediments was observed to be higher and light penetration is typically lower. This drift contribution was also evident in AFDW (can also include terrestrial detritus) and in chlorophyll-a (will also include photosynthetic bacteria and can include leaf detritus) (Figure 3-6, 3-7).

All Peace side channel periphyton taxa were classified by habitat preference into:

1. drift - taxa that only grow in standing water of lakes or reservoirs
2. immigrant – taxa from reservoirs + taxa torn off cobble substrates
3. resident – taxa known to grow in sand, silt, mud substrates or on aquatic plants

The drift and immigrant categories represent algae produced elsewhere that can be imported to the side channels, and they are compared to resident taxa that grew in the fine substrates of side channels in Table 3-3. When abundance of habitat indicator taxa are considered, the 32L side channels that are approximately 70 km closer to upstream reservoirs contained 68% immigrant taxa versus 38% immigrant taxa at 102.5R side channels. When periphyton biovolume is considered, the large size of reservoir diatoms means that drift taxa biovolume was 11x greater at the 32L side channels than at the 102.5R side channels. 79% of the total periphyton biovolume at 32L was from immigrant taxa when compared to 51% observed at the 102.5R side channels during 2013. Finally, there was 3x more biovolume from resident taxa at 32L compared to 102.5R side channels in 2013. This is corroborated by periphyton community data in which overall biovolume, chl-a and AFDW productivity was greater at 32L than at 102.5R (Figures 3.6 - 3-8). Also, like the whole periphyton data set, indicator taxa abundance and biovolume at the 32 L side channels and at the 102.5R Control and Test side channels gave comparable results in both 2013 and 2014. This comparison of 32L and 102.5R side channels confirms the importance of imported algae to their productivity.

Table 3-3: Relative abundance (cells/cm^2) and biovolume (um^3/cm^2) for indicator immigrant and resident algal taxa in the 32L side channels, 102.5R R side channels and the drift from reservoir sources, 2013 – 2014.

Abundance

32L			102.5R			Reservoir Drift		
2013	Control	Test	2013	Control	Test	2013	Control	Test
Immigrant	45667	65451	Immigrant	46810	81661	102.5	90236	194656
Resident	14996	18356	Resident	20272	59832	32L	100389	138291
			2014			2014		
not sampled in 2014			Immigrant	81025	93878	102.5	194864	199224
			Resident	8872	18472	32L	n/s	n/s

Biovolume

32L			102.5R			Reservoir Drift		
2013	Control	Test	2013	Control	Test	2013	Control	Test
Immigrant	21600288	14277165	Immigrant	1330431	3273609	102.5	1842176	2077543
Resident	3200099	4344764	Resident	925698	1424129	32L	29568436	13510700
			2014			2014		
not sampled in 2014			Immigrant	16318554	22293617	102.5	13436159	23398607
			Resident	5067493	5074523	32L	n/s	n/s

When habitat indicator taxa are compared for inter-annual variation at 102.5R side channels, biovolume of immigrant taxa increased dramatically from 2013 to 2014 (12x Control; 6.8x Test) versus half that increase in resident taxa (5.5x Control; 3.6x Test) (Table 3-3). Biovolume proportions for resident taxa were closely matched each year, while immigrant taxa contributions to side channel algal standing crops were more variable. For example, immigrant taxa associated with cobble substrates, presumably from the Pine River, were more abundant and contributed more biovolume at the Test side channel than at the Control side channel in both years. Overall, the greater productivity of habitat indicator taxa at the 102.5R Test side channel over the Control diminished in 2014, suggesting construction impact.

3.2.2 Periphyton Productivity at Control and Test Sites

There are several features of the 102.5R side channels (Test and Control) that should be considered in detail before comparing results from these sites. First, silt deposition in the 102.5R side channels was high, ranging from 0.5 to 12 cm during the 48 day 2014 sampler deployment period (Control range = 5 - 11 mm; Test range = 20 – 115 mm). This sediment deposition results in increased substrate shading and periphyton burial. Second, the Test site is close to the Pine River inflow which has very high sediment loads and turbidity when compared to flows in the Peace originating from the reservoir. Third, construction of an enhancement channel to improve flow through the Test site occurred in 2014, and was completed several weeks before sampling commenced. The construction works likely exposed new substrates and for a period of time following construction, fine substrates were mobilized typical of any instream construction project. The combined influence of sediment laden waters from Pine River flows and possibly increased sediment release from construction could influence water quality in the Test side channel. Finally, it is important to note that the Pine River's influence is stronger on the right bank of the Peace mainstem, meaning that this tributary would exert a smaller influence on the left bank at the Control site.

Most inter-annual differences among the major algae groupings were common to both the Control and test sites. For example, between 2013 and 2014, proportions of diatom and blue-green (cyanobacteria) groups increased while flagellates decreased (Table 3-2). Only green algae showed differing inter-annual shifts between the two side channels. During 2013 and during 2014 field collections, obvious bands of filamentous green algae were observed in shallow areas of the Control side channel but these bands were not as apparent in the Test side channel in 2014 that is under greater influence from turbid Pine River flows (and presumably a greater frequency of recreation boating due to boat launch proximity). Of the three filamentous green taxa identified from Control samples, *Cladophora* was the most common genera, as it often is in flowing fresh water. It would appear that 2014 conditions in the Test side channel were not as conducive to filamentous green algae growth as those in the Control side channel.

Total species richness and diatom diversity were greater at the Test site over the Control by about 16% in both years (Table 3-4). Both sites showed twice the number of taxa in 2014 compared to 2013 (Figure 3-7). Although periphyton diversity increased from 2013 to 2014, the dominant diatom taxa were consistent, with the cosmopolitan diatom *Achnanthidium minutissima as* the most prevalent diatom in both years.

Table 3-4: Species richness at 102.5R Control and Test side channels

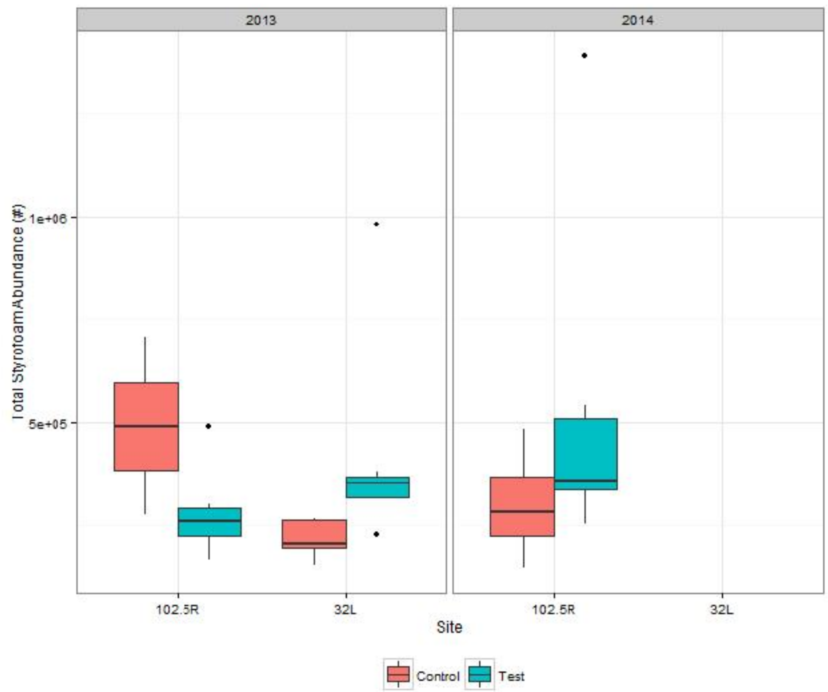
	2013		2014	
	diatoms	total	diatoms	total
Control 112L	12	24	35	48
Test 102.5R	18	29	39	57

Periphyton growth metrics calculated from the combined styrofoam artificial substrate and the sediment that accumulated on it appeared to be less in 2014 than those in 2013 at both sites (Appendix 5). Since there is a positive relationship between sediment depth and periphyton production metrics, a correction for sediment depth is required to directly compare samples. This was accomplished by dividing periphyton production metrics by the depth of deposited sediment to arrive at production estimates on an aerial basis (per cm^2). This correction is not without associated error. The sampling methods used to measure silt depths were improved for 2014 by using sediment traps, whereas the 2013 method only measured sediment depth after the sampler plate had been retrieved. The 2013 correction factor may have over-estimated actual values of production while the 2014 estimates are probably more accurate but would underestimate production when compared to 2013 due to sediment losses associated with sampling. This issue was investigated by assuming silt deposition was identical between 2013 and 2014 at Control locations, and then adjusting the silt depth mean using an approximate correction factor of 4 (Figure 3-6, where 2014 silt depths were approximately 4 times larger than 2013). When this was done, the data suggested that production in 2013 was similar to 2014 across all metrics (data not shown). In 2015, we propose that silt depth be measured both on the plate during retrieval like 2013 and in the sediment samplers like 2014, which will allow us to directly compare loss rates, determine a relative percent loss from the sediment samplers, and then accurately correct the data for sediment depth, all of which will allow a more direct comparison across years. The data presented in Appendix 5 is corrected for silt depth, but the 2013 data likely overestimates the actual production relative to the 2014 data.

Figures 3.7 – 3.9 illustrate periphyton production from the styrofoam artificial sampling substrate only and is presented to confirm our theory of similar production between 2013 and 2014 because these samples are not as prone to biases associated with sampling of deposited sediment. The styrofoam substrate provides a record of deposited and *in situ* periphyton growth during the early weeks of the deployment prior to heavy sediment cover. At the Control 102.5R side channel, productivity metrics showed lower abundance, comparable AFDW, but increased biovolume and chl-a in 2014 over the more turbid 2013 results. At the Test side channel, abundance and biovolume increased in 2014 compared to 2013, while chl-a and AFDW were both lower. The biggest discrepancy between the two side channels occurred in periphyton abundance. The discrepancy between chl-a and periphyton abundance at both sites may relate to chl-a contributed by photosynthetic bacteria.

Overall median productivity and diversity was lower in the Test side channel than it was in the Control side channel for most metrics in 2014. The exception was abundance and this may be the result of small diatoms preferentially imported to the test site by Pine River inflows.

Collectively, these results suggest a construction-related effect may have occurred on the 102.5R Test side channel in 2014. However based on 2014 data alone, we cannot differentiate between effects of sampling close to completion of construction, and potential changes in long-term periphyton productivity.



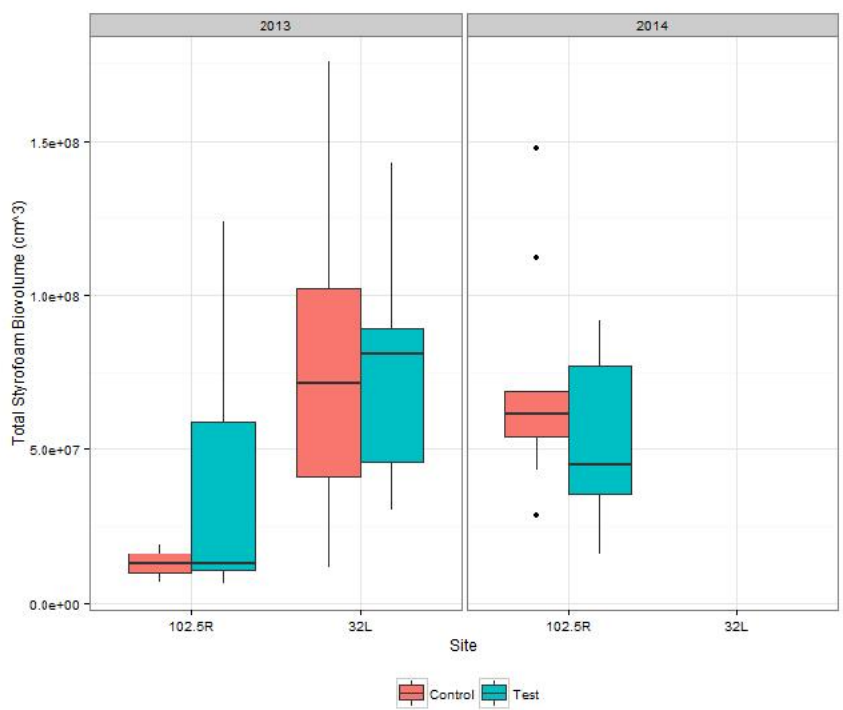


Figure 3-7: Total abundance (cells/cm^2) and total biovolume (cm^3/cm^2) on artificial styrofoam substrates in the Peace River at the 32L and 102.5R sampling sites in 2013 and 2014.

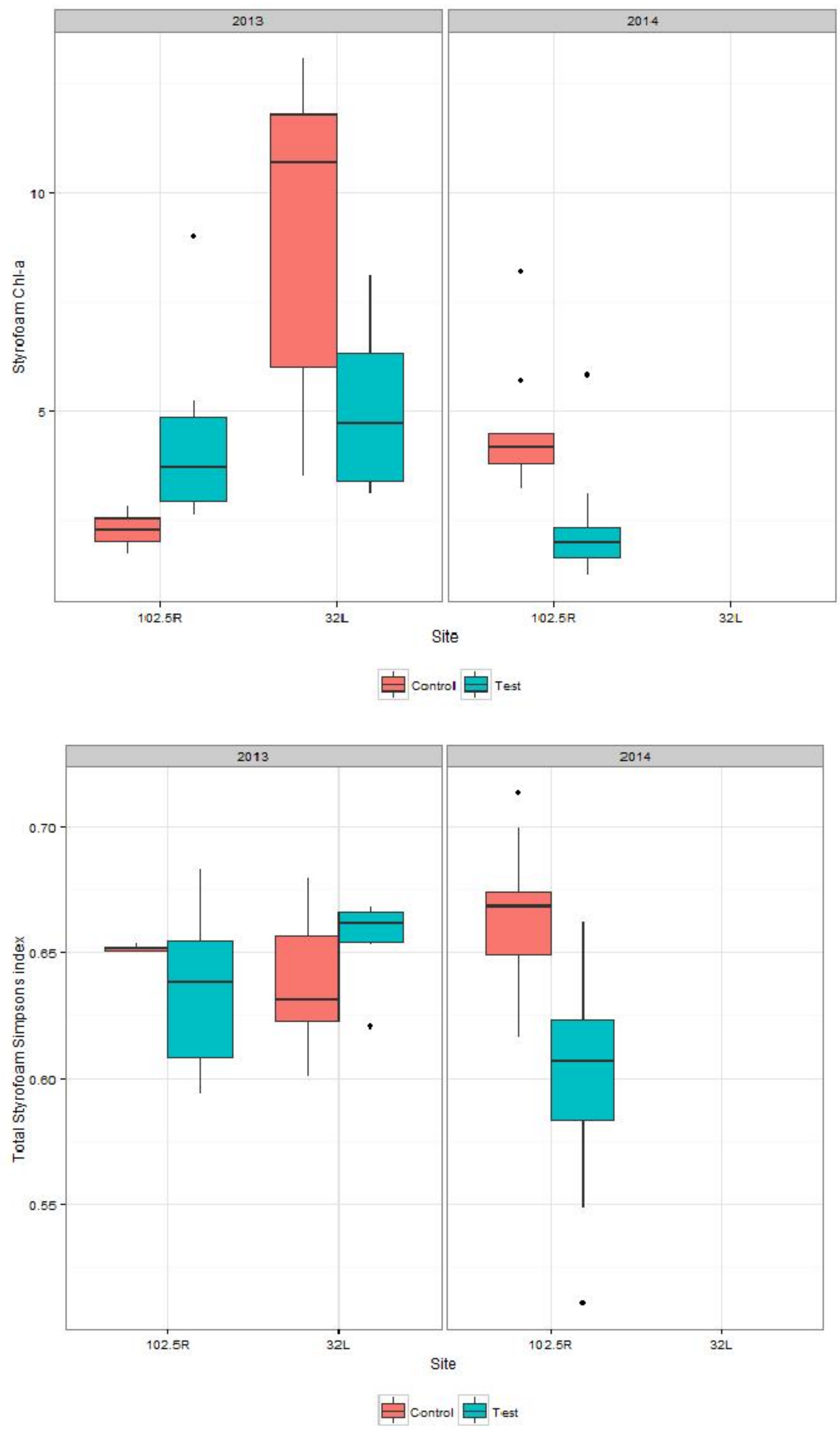


Figure 3-8: Chl-a and Simpson's Index on artificial styrofoam substrates in the Peace River at the 32L and 102.5R sampling sites in 2013 and 2014.

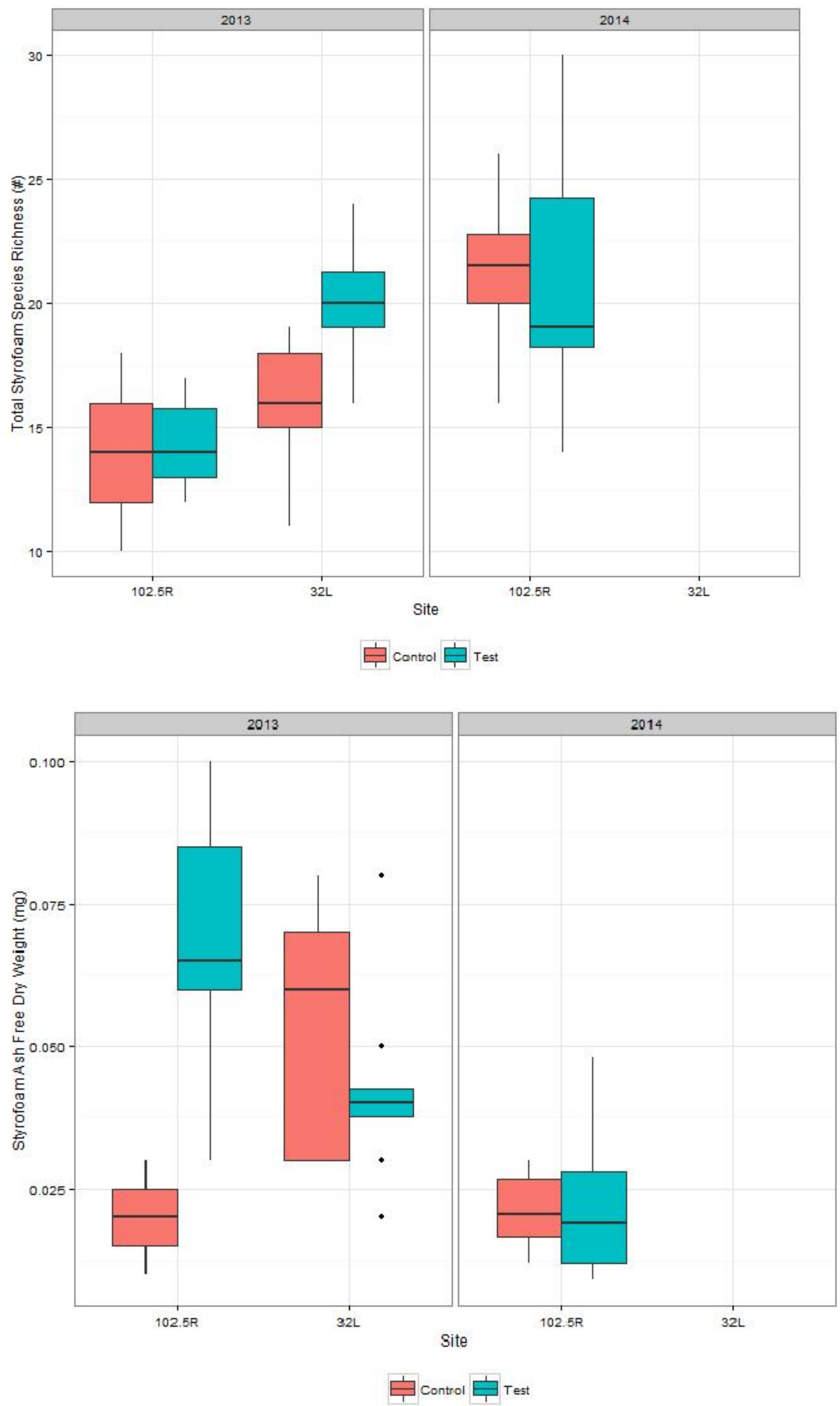


Figure 3-9: Species Richness and Ash Free Dry Weight on artificial styrofoam substrates in the Peace River at the 32L and 102.5R sampling sites in 2013 and 2014.

3.2.3 Periphyton Productivity on Natural Substrates, Sediment Fines and Artificial Substrates

There was little difference between the algae found in fines deposited on the artificial substrates and the natural substrate fines at the Test site during 2014. However, samples from the Control side channel showed more green algae in the sediments deposited on the samplers than in the natural sediments (Appendix 5, Table A5-1). Flagellates tended to be more abundant in samples that had more filamentous green algae. On the natural substrates, imported taxa accounted for 51% of periphyton abundance, while on artificial substrate fines and styrofoam samples they accounted for 44% and 21% of abundance in 2014.

Across all sample sites in both the Test and Control side channels, the photosynthetic component of both artificial substrate types were similar, but with important differences that occurred in both the 2013 and the 2014 data. Deposited fine sediment samples included more cyanobacteria, photosynthetic bacteria and flagellates but fewer diatoms and lower overall diversity than the corresponding styrofoam samples (Appendix 5, Table A5-2, Figure 3-8). The periphyton community metric box plots show slightly greater species richness and Simpson's Index for the styrofoam samples over the deposited silt samples in both 2013 and 2014 (Figure 3-10). Abundance, biovolume and chl-a were all higher in the fines/silt samples than in the corresponding styrofoam samples, indicating that both artificial substrates need to be considered when assessing side channel periphyton productivity.

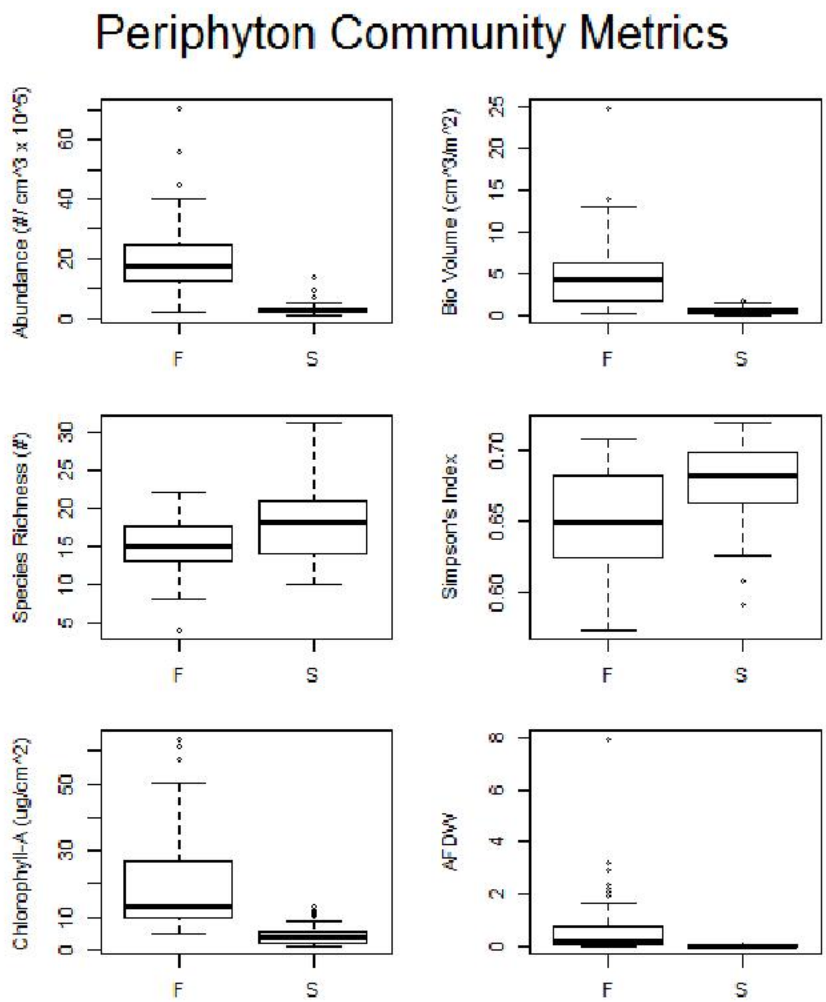


Figure 3-10: Box plots of periphyton community metrics comparing deposited fine sediments (F) and styrofoam (S) samples in summer 2013 and 2014

3.2.4 Periphyton Productivity in Deep and Shallow Sites

In recognition of the importance of rapid silt deposition and limited light available to substrates in the Peace side channels, artificial substrate samplers were deployed in deep and shallow sites during 2014. All metrics of algae productivity were only 2 – 5% greater at the shallow sites (0.5 – 1m depth) where available light intensities were typically greater than at the deep sites (1.5 – 2m depth). Diversity was also slightly greater at the shallow sites. Chl-a was also greatest in the shallow sites over the deep sites, probably because the shallow sites received more light (Appendix 3). AFDW was the only metric that was significantly different between the deep and shallow sites in 2014.

3.2.5 Statistical Periphyton Community Analyses

Statistical community analyses of the full periphyton data set from 2013 and 2014 were completed at the genus level, which allows detection of large-scale trends between river sites. Periphyton communities were grouped by year (ANOSIM, R: 0.28, $p = 0.001$), the combination of year and substrate type (artificial or natural) (ANOSIM, R: 0.40, $p = 0.001$), depth (shallow or deep) (ANOSIM, R: 0.32, $p = 0.001$), but not by site (ANOSIM, R: -0.08, $p = 0.996$) (Figure 3-11). The effects of year, substrate type by year, combined with the effects of depth suggest that periphyton communities in the Peace River side channels are complex. The NMDS stress value was 0.21, meaning only a moderate level of confidence can be given to the two dimensional plot representing the relationships observed (Clarke 1993). These results corroborate the preceding descriptive characterization of periphyton results.

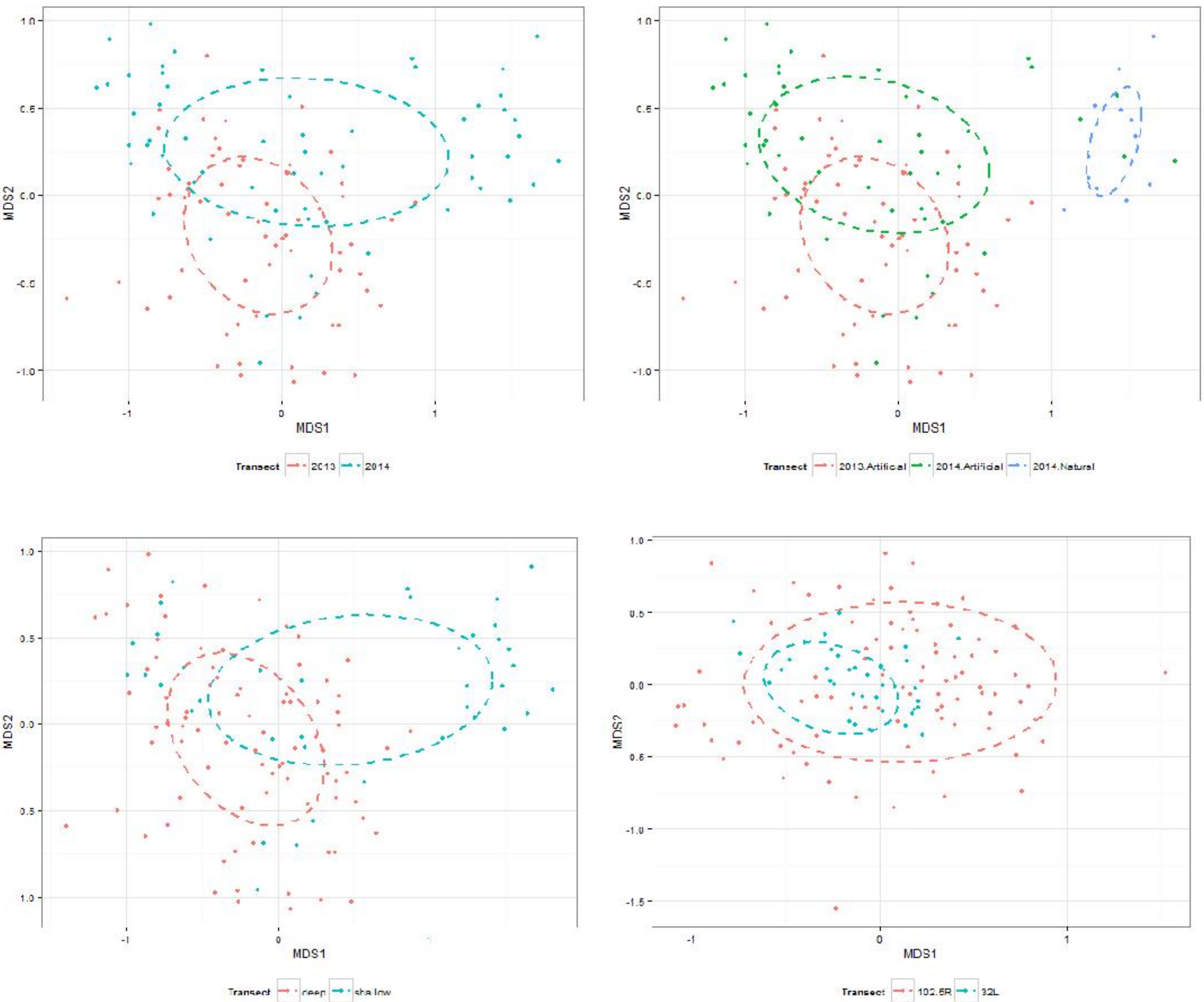


Figure 3-11: NMDS of periphyton genus level abundance grouped by Year (2013 or 2014), Year by Sampling Substrate Type (Artificial or Natural), Depth (shallow or deep), and Reach (102.5R and 32L) in Peace River side channels sampled during the summer.

3.2.6 Periphyton Production Models

Both sediment deposited on the styrofoam and the artificial styrofoam substrate itself contributed to the total production observed at any given site. Therefore, they were combined to consider the total production in linear mixed-effects models of periphyton productivity. To avoid confounding results, only those sites where samples of both deposited fines and an artificial styrofoam sample were collected were used in the analysis. This avoided confounding effects of sediment removal at sites where all sediment was removed during retrieval.

For each different measure of production, numerous top models were considered (those with an Δ AICc < 3). The total number of top models varied between the different production metrics and ranged from 3 (abundance model) to 18 (chl-a). These models typically explained roughly 30% (Simpson's Index) to 91% (abundance) of the variation (via pseudo R^2), suggesting that the explanatory variables assessed were reasonable predictors of periphyton productivity. Similar to other studies, models of species diversity explained less variation than those for production (Larratt et al., 2013).

The most meaning in relationships observed can be taken from response / predictor combinations that have a relative variable importance (RVI) of 0.8 or greater. Turbidity was negatively associated with abundance, and with species richness, where these response/predictor combinations had high relative variable importance (greater than 0.8), a large correlation coefficient, and confidence limits that did not span zero (Figure 3-10). Turbidity may also be negatively associated with Simpson's Index and biovolume, as trends were observed but confidence was lower due to the lower observed RVI around 0.4 and confidence intervals spanning zero. Turbidity was positively associated with AFDW, indicating that organic content increased with increasing sediment in the water and presumably increased sediment deposition.

Side channel construction may also have had an effect because abundance was greater in 2013 (pre-construction) than in 2014 (post-construction) at 102.5R sites. Another interesting trend indicated that biovolume was greater at the 102.5R Control than at the Test location. Chl-a and biovolume were positively associated with substrate size, meaning that production may be greater in areas with a larger substrate size. Finally, small changes in sampler depth (0.5-1m versus 1.5-2m) did not appear to have a significant effect on periphyton production.

Similar to last year, the models developed to describe periphyton production suggest that depth of sediment deposition and turbidity were important determinants of periphyton community development and overall production. The importance of both treatment (Control and Test) and flow periods (Pre / Post enhancement) suggests that there may be effects of construction, but since the timing of sampling was so close to the actual construction event, we cannot differentiate between construction related effects and long term changes in productivity associated with habitat enhancement.

The wide variability in the direction and magnitude of averaged parameter values, which in most cases vary between negative and positive, show that no one explanatory variable could describe periphyton responses well and indicate low to moderate accuracy in observed patterns from this analysis (Figure 3.12). Future model development will aim to refine these models in conjunction with improving explanatory variable sets, to allow a better understanding of these relationships.

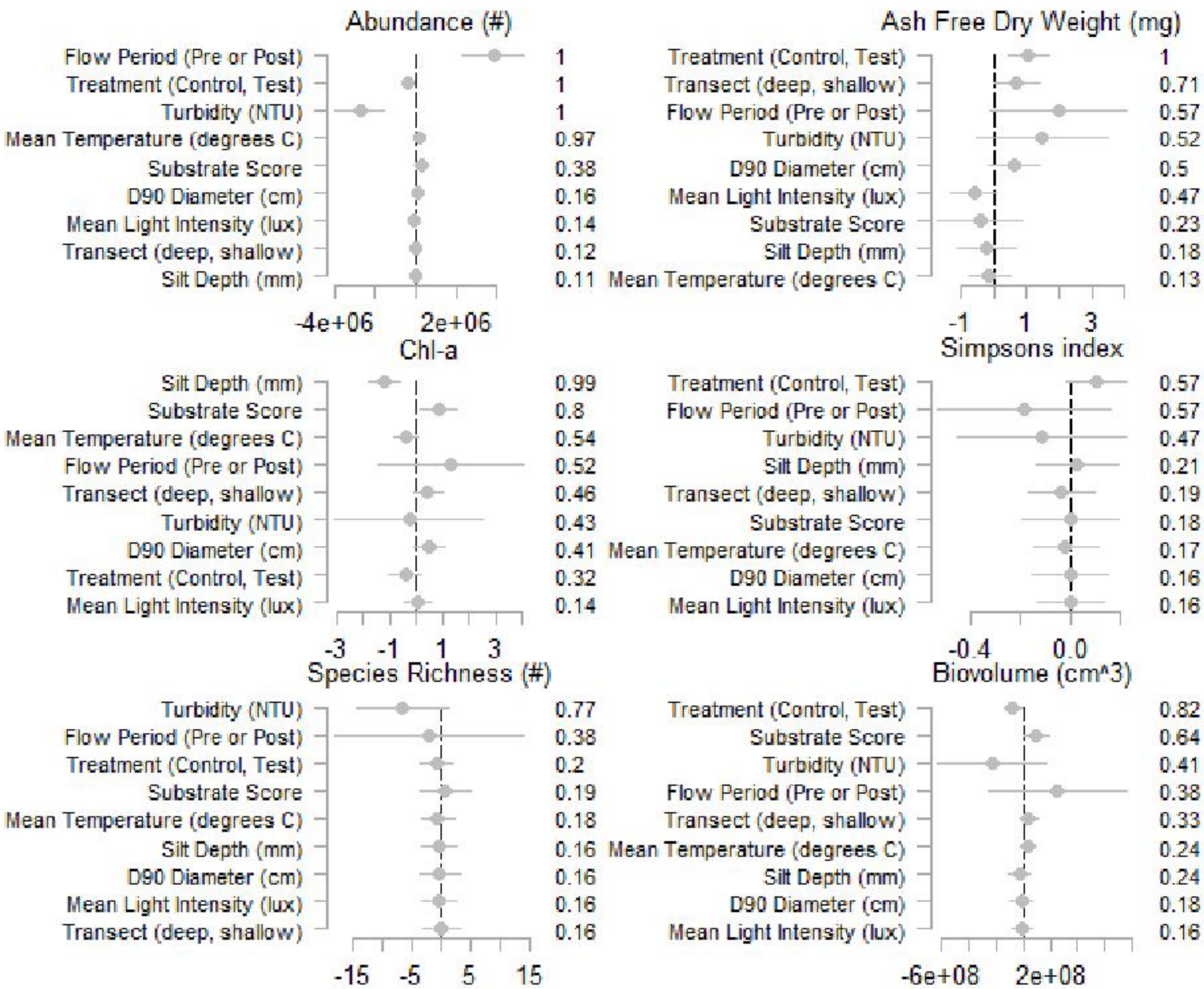


Figure 3-12: Mean coefficients and their 95% confidence limits of standardized explanatory variables of periphyton production in the Peace River during the summer of 2013. Periphyton responses included abundance, biovolume, Simpson's Index, chlorophyll-a, and AFDW. Coefficients are standardized to allow direct comparisons of the direction and size of effects, noting that variables with confidence limits that encompass zero can have either a positive or negative effect depending upon which model is considered. Key explanatory variables are sorted by their relative variable importance (RVI), values on the right hand side y-axis of each panel.

In summary, depth of deposited silt was a key driver controlling periphyton production in Peace side channel 102.5R. Volatile solids, chl-a and abundance were all positively correlated to silt depth while diversity showed no relationship.

3.3 Benthic Invertebrates

3.3.1 Invertebrate Abundance, Biomass and Diversity

Measures of production and diversity at 32L were consistent with those observed at 102.5R in 2013. In 2014, total abundance was greater at 102.5R than in 2013, while species richness was slightly lower. Other measures of diversity, including Simpson's Index, Percent EPT and Percent Chironomidae were similar at 102.5R between 2013 and 2014. Natural substrates had comparable diversity and production metrics compared to artificial substrates collected at 102.5R. The only noteworthy difference was the Hilsenhoff Biotic Index, where natural substrates had a higher score than artificial substrates, likely because embeddedness of samples was greater than artificial rock baskets placed on top of the river bottom (Figure 3-13 to 3-15). A higher Hilsenhoff Biotic Index observed in 2014 at 102.5R indicates a greater predominance of more tolerant taxa such as *Oligochaeta.* Interestingly, the HBI score at the 102.5R Test location was most similar to that of the natural substrates. In support of the HBI values, it is important to note that the relative abundance and biomass of Ephemeroptera taxa was notably lower in 2014 when compared to 2013 at both Control and Test locations.

Oligochaeta and Chironomidae were the most predominant taxa observed (Table 3-5). However, similar to 2013, EPT had proportionally more relative biomass than abundance. These trends were similar at 32L in 2013 and from natural substrates collected in 2014. Of the EPT taxa that are good fish food, Plectoperans were the most common taxa observed at Control and Test locations. Taxa from Ephemertopera had a noticeably lower relative abundance and biomass at both Control and Test locations when comparing 2014 to 2013.

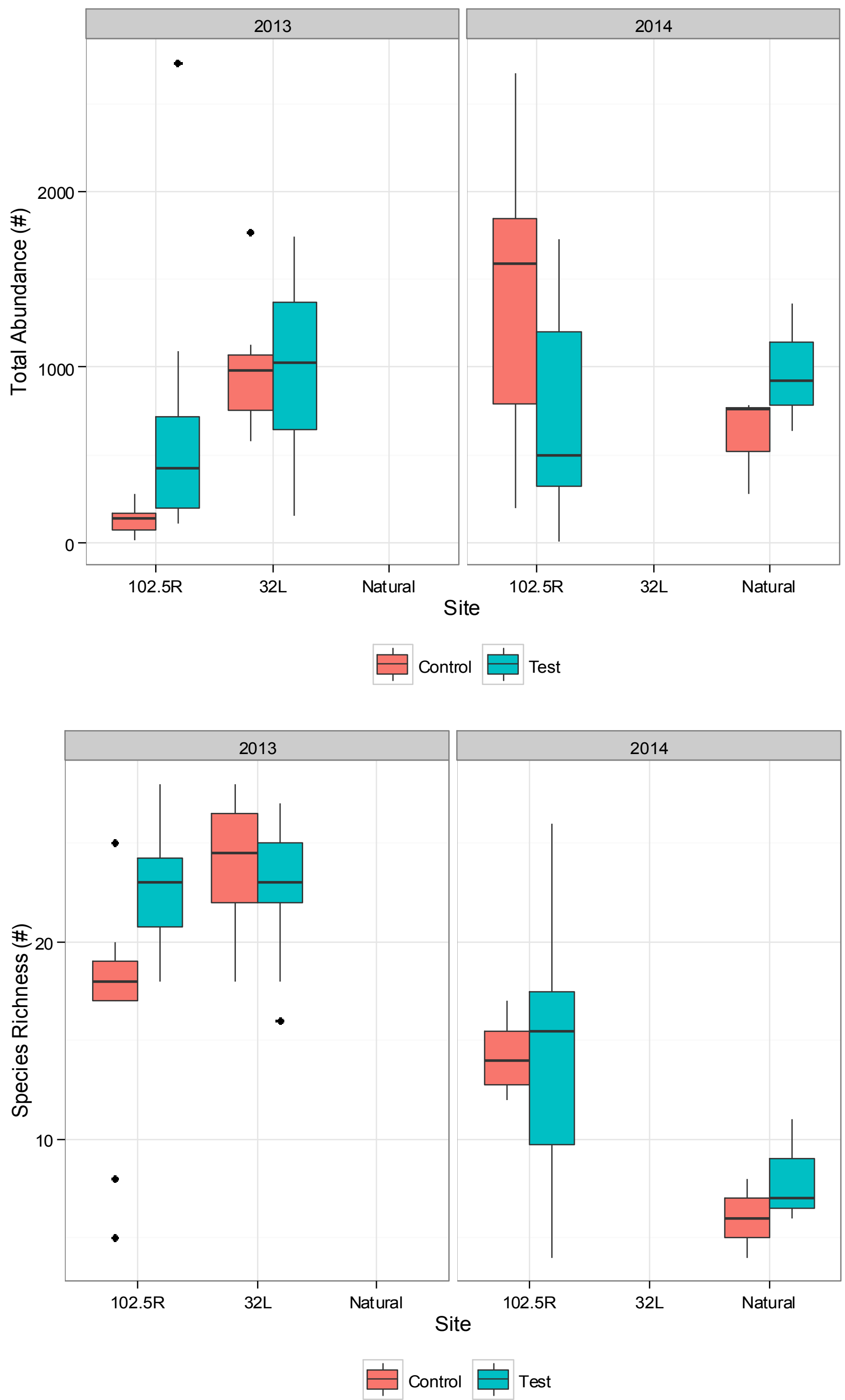


Figure 3-13: Boxplots of benthic invertebrate community composition and productivity metrics compared between Control and Test locations from downstream side channel sites on the Peace River (102.5R).

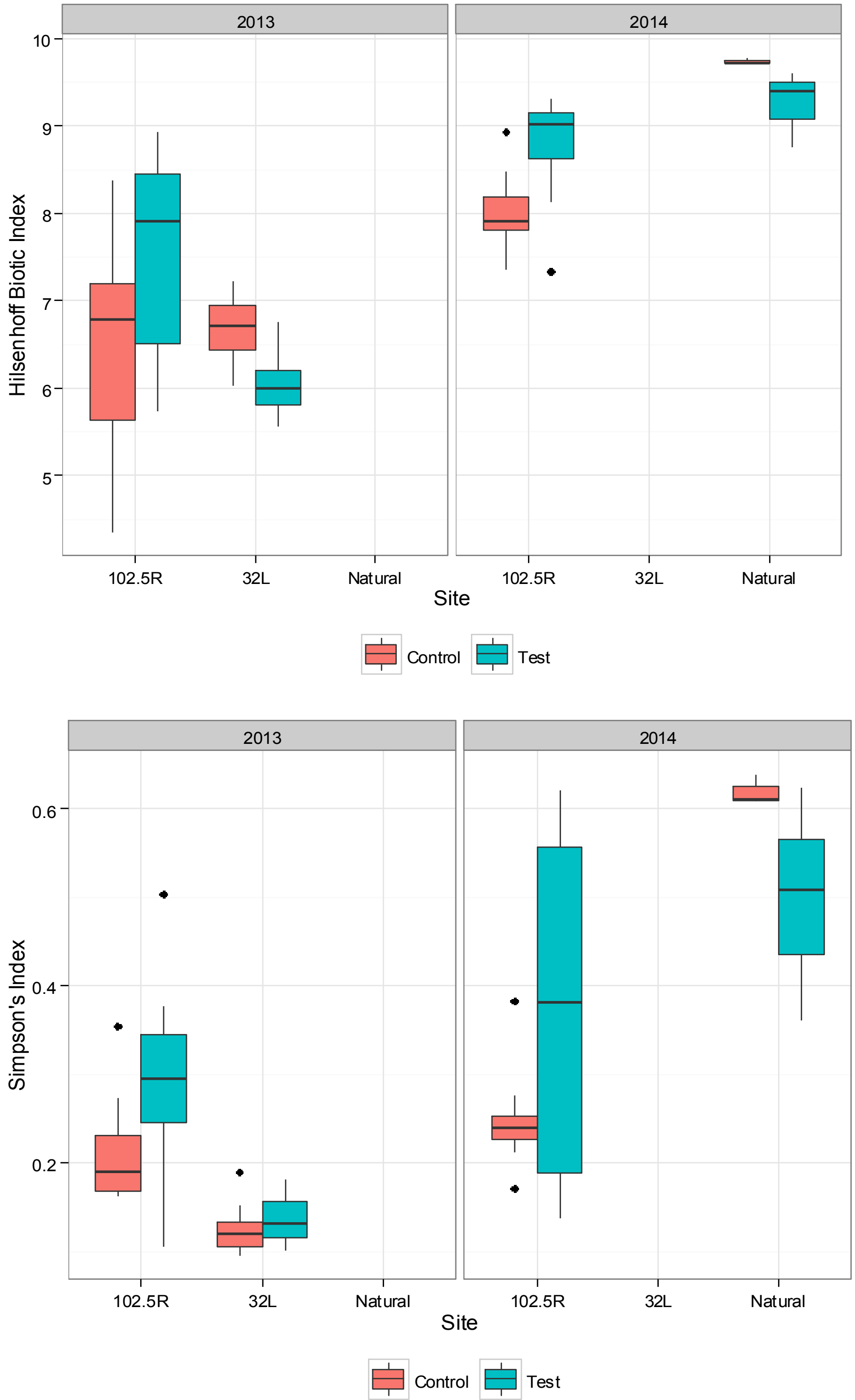


Figure 3-14: Boxplots of benthic invertebrate community composition and productivity metrics compared between Control and Test locations from downstream side channel sites on the Peace River (102.5R).

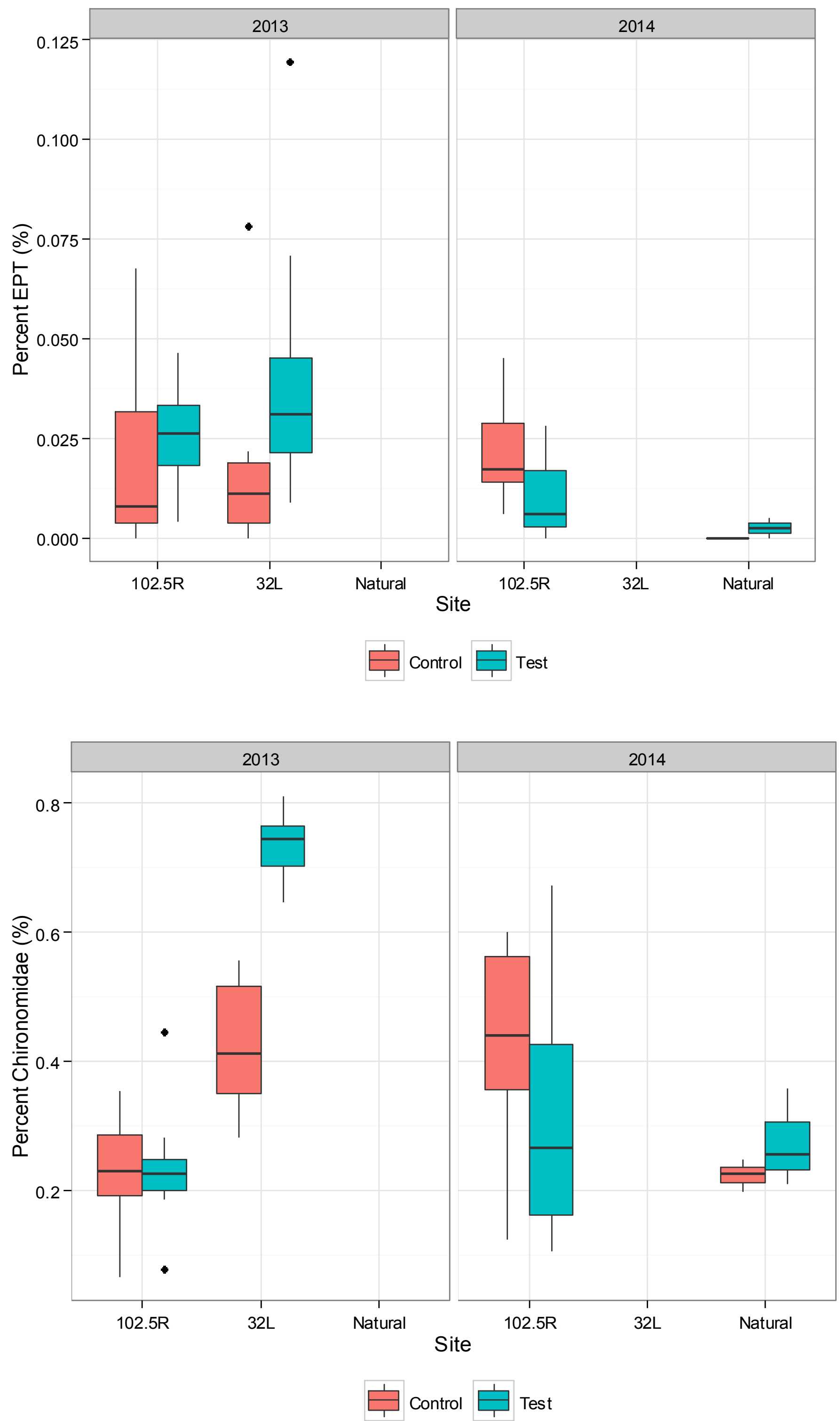


Figure 3-15: Boxplots of benthic invertebrate community composition and productivity metrics compared between Control and Test locations from downstream side channel sites on the Peace River (102.5R).

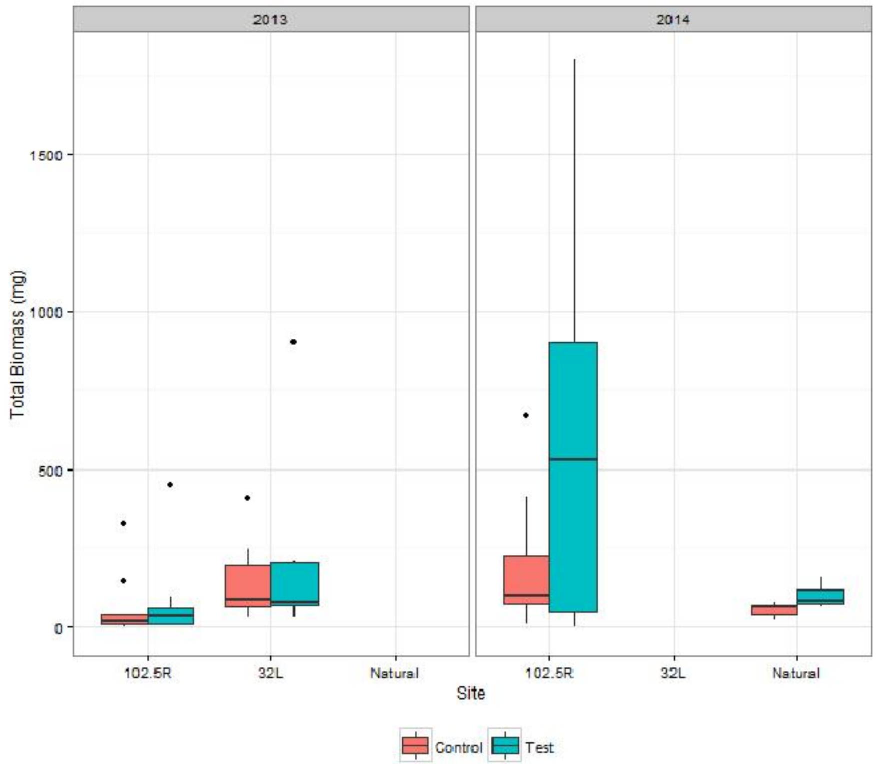


Figure 3-16: Boxplots of benthic invertebrate community composition and productivity metrics compared between Control and Test locations from downstream side channel sites on the Peace River (102.5R).

Table 3-5: Relative abundance and biomass of invertebrate taxonomical groups from Test and Control locations at 32L and 102.5R Peace River sampling locations in 2013 and 2014. Natural substrate samples, collected from side channels using an Eckman dredge are also presented for reference to natural conditions.

32L – 2013

Species Group	Relative Abundance (%)	Species Group	Relative Biomass (%)
Test			
Chironomidae	73.33%	Trichoptera	34.37%
Oligochaeta	13.69%	Chironomidae	34.01%
Other	4.18%	Gastropoda	11.69%
Trichoptera	4.11%	Oligochaeta	7.54%
Gastropoda	1.85%	Other	7.20%
Arachnida	1.61%	Coleoptera	4.90%
Coleoptera	0.52%	Bivalvia	0.17%
Diptera	0.51%	Diptera	0.10%
Ephemeroptera	0.10%	Ephemeroptera	0.02%
Bivalvia	0.10%	Arachnida	0.00%
Crustacea	0.00%	Crustacea	0.00%
Megaloptera	0.00%	Megaloptera	0.00%
Plecoptera	0.00%	Plecoptera	0.00%
Control			
Chironomidae	42.06%	Chironomidae	46.12%
Oligochaeta	36.95%	Oligochaeta	16.29%
Other	15.47%	Gastropoda	14.13%
Arachnida	2.01%	Trichoptera	10.35%
Gastropoda	1.44%	Other	8.97%
Plecoptera	0.81%	Diptera	3.31%
Trichoptera	0.69%	Ephemeroptera	0.72%
Ephemeroptera	0.29%	Plecoptera	0.10%
Diptera	0.27%	Arachnida	0.00%
Bivalvia	0.00%	Bivalvia	0.00%
Coleoptera	0.00%	Coleoptera	0.00%
Crustacea	0.00%	Crustacea	0.00%
Megaloptera	0.00%	Megaloptera	0.00%

102.5R – 2013

Species Group	Relative Abundance (%)	Species Group	Relative Biomass (%)
Test			
Oligochaeta	64.12%	Oligochaeta	30.21%
Chironomidae	23.52%	Chironomidae	18.31%
Other	3.26%	Ephemeroptera	17.67%
Diptera	2.70%	Trichoptera	12.08%
Crustacea	1.54%	Diptera	9.17%
Ephemeroptera	1.50%	Crustacea	6.11%
Arachnida	0.94%	Gastropoda	2.62%
Trichoptera	0.84%	Plecoptera	1.90%
Gastropoda	0.81%	Coleoptera	1.87%
Coleoptera	0.42%	Bivalvia	0.04%
Plecoptera	0.31%	Other	0.02%
Bivalvia	0.04%	Arachnida	0.00%
Megaloptera	0.00%	Megaloptera	0.00%
Control			
Oligochaeta	55.84%	Oligochaeta	34.82%
Chironomidae	22.96%	Ephemeroptera	23.62%
Other	10.07%	Plecoptera	21.25%
Arachnida	5.26%	Chironomidae	15.16%
Diptera	3.39%	Trichoptera	3.94%
Ephemeroptera	0.74%	Diptera	0.85%
Plecoptera	0.67%	Other	0.20%
Trichoptera	0.62%	Crustacea	0.09%
Gastropoda	0.18%	Megaloptera	0.06%
Crustacea	0.17%	Gastropoda	0.01%
Megaloptera	0.08%	Arachnida	0.00%
Bivalvia	0.00%	Bivalvia	0.00%
Coleoptera	0.00%	Coleoptera	0.00%

102.5R – 2014

Species Group	Relative Abundance (%)	Species Group	Relative Biomass (%)
Test			
Oligochaeta	56.37%	Diptera	33.02%
Chironomidae	34.31%	Plecoptera	21.53%
Diptera	3.77%	Bivalvia	19.27%
Other	3.73%	Chironomidae	10.29%
Gastropoda	0.73%	Coleoptera	9.07%
Trichoptera	0.55%	Trichoptera	4.10%
Ephemeroptera	0.34%	Oligochaeta	1.62%
Plecoptera	0.13%	Gastropoda	0.83%
Coleoptera	0.08%	Other	0.27%
Arachnida	0.00%	Arachnida	0.00%
Bivalvia	0.00%	Crustacea	0.00%
Crustacea	0.00%	Ephemeroptera	0.00%
Megaloptera	0.00%	Megaloptera	0.00%
Control			
Oligochaeta	52.40%	Diptera	32.77%
Chironomidae	39.30%	Plecoptera	28.49%
Other	4.62%	Trichoptera	22.43%
Trichoptera	1.70%	Oligochaeta	10.74%
Diptera	1.24%	Gastropoda	3.55%
Arachnida	0.25%	Ephemeroptera	0.95%
Gastropoda	0.18%	Chironomidae	0.74%
Ephemeroptera	0.15%	Other	0.27%
Coleoptera	0.13%	Bivalvia	0.06%
Plecoptera	0.04%	Arachnida	0.00%
Bivalvia	0.00%	Coleoptera	0.00%
Crustacea	0.00%	Crustacea	0.00%
Megaloptera	0.00%	Megaloptera	0.00%

102.5R – 2014 Natural Substrates

Species Group	Relative Abundance (%)	Species Group	Relative Biomass (%)
Test			
Oligochaeta	76.38%	Plecoptera	61.34%
Chironomidae	22.39%	Bivalvia	37.06%
Diptera	1.02%	Chironomidae	0.69%
Gastropoda	0.11%	Diptera	0.55%
Bivalvia	0.10%	Other	0.27%
Arachnida	0.00%	Oligochaeta	0.10%
Coleoptera	0.00%	Arachnida	0.00%
Crustacea	0.00%	Coleoptera	0.00%
Ephemeroptera	0.00%	Crustacea	0.00%
Megaloptera	0.00%	Ephemeroptera	0.00%
Other	0.00%	Gastropoda	0.00%
Plecoptera	0.00%	Megaloptera	0.00%
Trichoptera	0.00%	Trichoptera	0.00%
Control			
Oligochaeta	66.28%	Plecoptera	60.26%
Chironomidae	27.37%	Oligochaeta	30.23%
Diptera	4.38%	Diptera	8.38%
Other	1.72%	Gastropoda	0.62%
Plecoptera	0.17%	Other	0.32%
Trichoptera	0.09%	Trichoptera	0.18%
Arachnida	0.00%	Arachnida	0.00%
Bivalvia	0.00%	Bivalvia	0.00%
Coleoptera	0.00%	Chironomidae	0.00%
Crustacea	0.00%	Coleoptera	0.00%
Ephemeroptera	0.00%	Crustacea	0.00%
Gastropoda	0.00%	Ephemeroptera	0.00%
Megaloptera	0.00%	Megaloptera	0.00%

3.3.2 Invertebrate Community Groupings

Invertebrate communities were grouped by depth of sampling (deep or shallow), (ANOSIM, R: 0.37, p = 0.001), year (2013 or 2014) (ANOSIM, R: 0.28, p = 0.001), year by substrate type (artificial or natural) (ANOSIM, R: 0.25, p = 0.001), and year by reach (102.5R or 32L) by substrate type (ANOSIM, R: 0.36, p = 0.001) (Figure 3-17). The NMDS stress value was 0.22, suggesting a reasonable level of confidence can be given to the two dimensional plot accurately representing the relationships observed. The data suggest that invertebrate communities are highly influenced by inter annual variation, the depth of the side channel, and the sites within the river (i.e., upstream or downstream sites). Also, the data suggest that using rock baskets as substrate may exert an influence on the invertebrate community that develops in them.

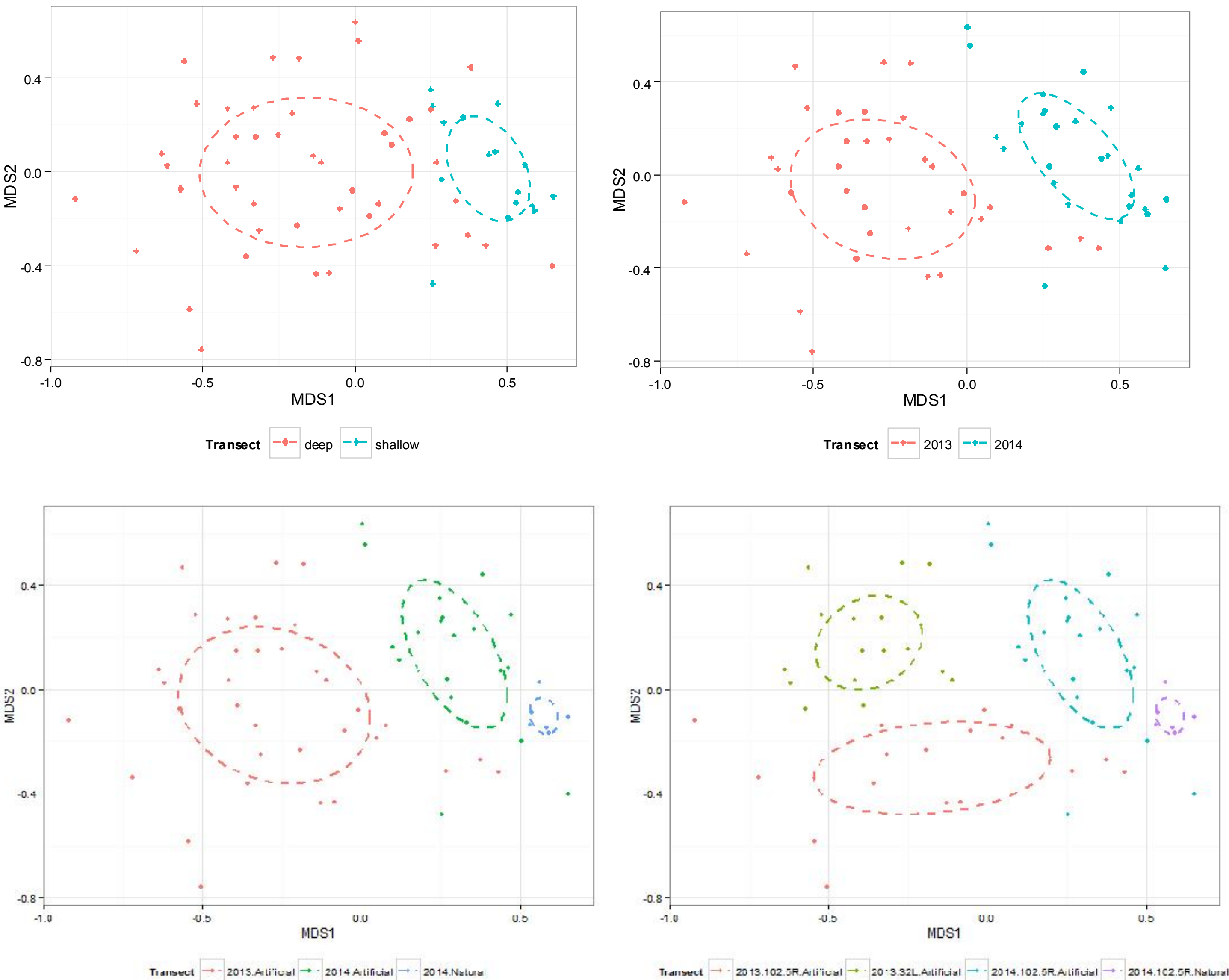


Figure 3-17: NMDS of Benthic Invertebrate Abundance at family level for data grouped by Depth (Deep or Shallow), Year (2013 or 2014), Year by Substrate Type (Artificial or Natural), and Year by Reach (102.5R or 32L) by substrate type from the Peace River side channels in the summer of 2013 and 2014.

3.3.3 Invertebrate Production Models

For each different metric of productivity, there were numerous plausible (top performing) models considered (those with an AICc < 3), the number of which varied among metrics (a range of 7 (Percent Chironomidae) to 42 (Percent EPT) models) (Figure 3-18). Benthic models typically explained less variation in response variables (R^2 = 0.00-0.60) than periphyton models, suggesting that more years of data and more predictors are likely required to fully describe key factors affecting invertebrate production in side channels of the Peace River. Of particular note was the model for Percent EPT, which had an R^2 that did not exceed 0.17 and was as low as 0, meaning our predictors described very little variability in the percentage of EPT taxa observed.

Some important relationships were evident in the modelling. A key trend observed was an overall decrease in invertebrate production with an increase in sedimentation measured either through turbidity (e.g., decreasing total abundance with turbidity) or settled sediments (e.g., an increase in Percent Chironomidae and decrease in Percent EPT with mean silt depth). Channel substrate size also appeared to be important, but observed trends were not consistent with expectations because both EPT richness and total biomass appeared to decrease with increasing substrate size noting that no model predictors in either of these responses had an RVI of greater than 0.8 which reduces confidence in modelled effects. Other key trends were the distinct differences in the HBI index between Test and Control locations, another factor likely linked to the observed sedimentation occurring at Test locations.

The models developed to describe invertebrate production suggest that substrates and sediment, turbidity, and location may influence invertebrate community structure and overall productivity. However, in many models, the specific effects may be inconsistent between responses, suggesting the coarse nature of most explanatory variables and a limited sample size reduce ability to identify specific causal relationships. The sedimentation observed at the test site appears to support the critical role sediments play on the Peace River however. More data is required to develop more accurate benthic habitat response models to assess how, and to what extent physical parameters influence invertebrate production in side channels.

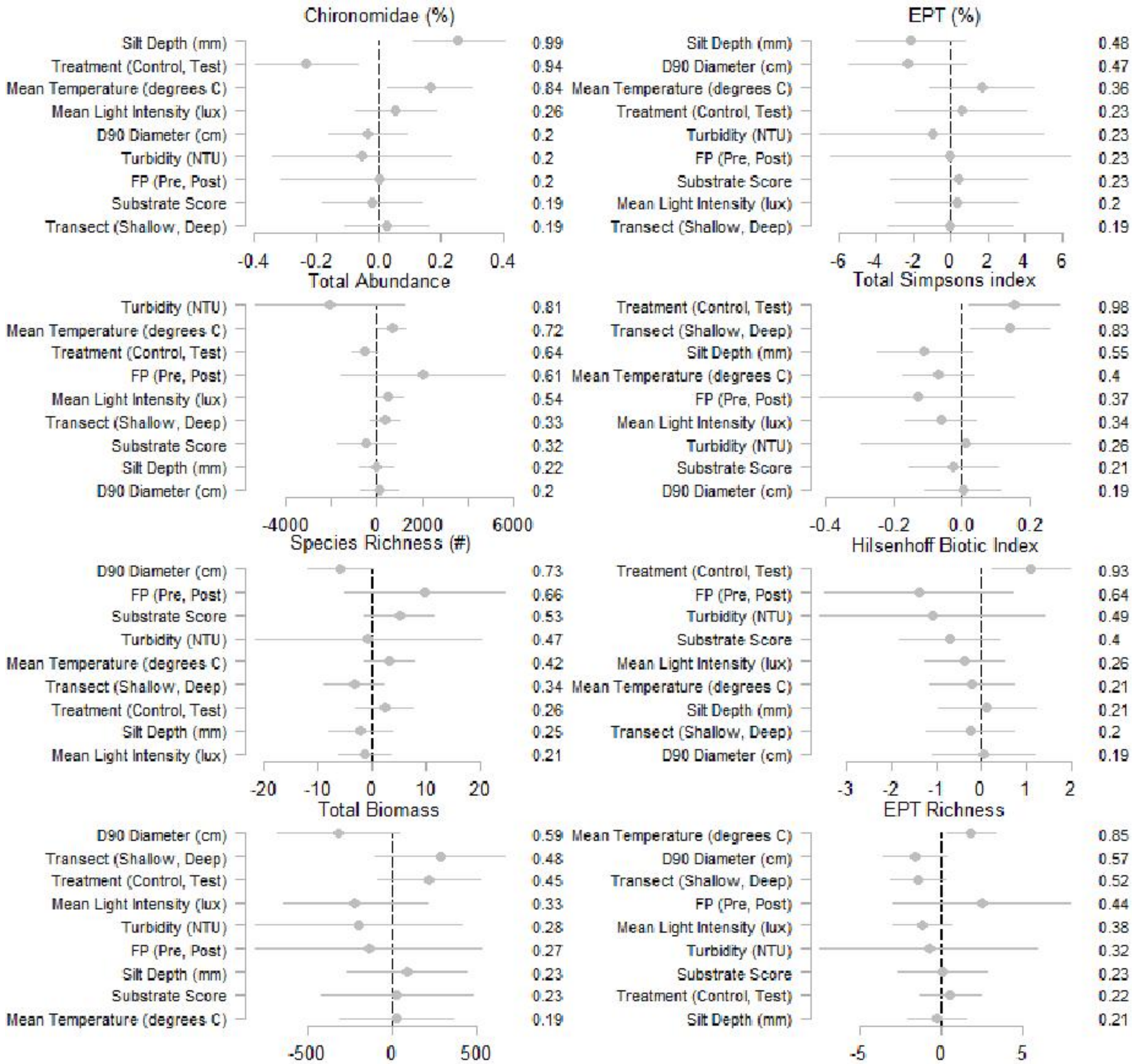


Figure 3-18: Mean coefficients and their 95% confidence limits of standardized explanatory variables of benthic production in the Peace River side channels. Invertebrate responses included abundance, biomass, species richness, EPT Richness, % EPT, % Chironomidae, Simpson's Index, and Hilsenhoff Biotic Index. Coefficients are standardized to allow direct comparisons of the direction and size of effects, noting that variables with confidence limits that encompass zero can have either a positive or negative effect depending upon which model is considered. Key explanatory variables are sorted by their relative variable importance (RVI), values on the right hand y-axis of each panel.

4.0 DISCUSSION

Decreased peak flows resulting from impoundment by hydro-electric dams on the Peace River have reduced flushing rates at the mouths of side channels, causing increased sediment accumulation, terrestrial vegetation encroachment and a reduction in available fish habitat (Church *et al.* 1997; NHC 2013). To mitigate this, and as a desirable alternative to increasing dam release minimum flows, the BC Hydro Peace River Water Use Plan Consultative Committee (WUP) have proposed to excavate the mouths of Peace River side channels to restore fish habitat and side channel connectivity to the mainstem channel, particularly during low flows. To assess the success of proposed channel alterations on the productivity of lower trophic levels, three management questions have been proposed:

1. What is the composition of the invertebrate and periphyton communities in the side channels of the Peace River?

2. Does increased water flow to side channels as a result of side channel enhancement or change in the minimum base flow regime alter the biomass/composition of the periphyton and invertebrate community?

3. After side channel enhancement or implementation of an alternative minimum base flow regime, does the resulting periphyton and invertebrate community increase the food availability (i.e., increased abundance of invertebrate prey) to fish populations?

The long-term goal of this study is to address all three management questions. The 2014 work program upon which this report is based aimed to collect data at the 102.5R Control and Test side channels, several months after construction of Test side channel enhancements designed to improve flow conditions. 2014 post-construction results were compared to the first year of baseline conditions collected in 2013. Similar to last year, our approach has been to assess multiple metrics of periphyton and benthic production and identify larger-scale trends in responses pre and post side channel enhancement. Adjustments to 2014 methods were made to accommodate for the high sediment deposition that occurs in Peace side channels during the summer deployment periods.

4.1 Physical Habitat Conditions

Benthic production is usually greatest during the summer, when both growth rates and total production are higher than spring or fall periods (Larratt *et al.* 2013). Temperature is a key factor directly linked to benthic production, and our data to date show that Peace side channels were similar to mainstem areas in this regard. 2013 temperature data suggest that temperatures in the 102.5R side channels were different between Control and Test, whereas in 2014, temperatures were more similar. Since the Test location is in close proximity to the Pine River, the influence of temperature is likely dependent upon the amount of water derived from the Pine River versus that of the mainstem Peace River, all of which may depend upon flows and operational changes in river elevation associated with regulation. Since flows affect the water elevations, and water elevation is likely affecting water entering the Test side channel, it is difficult to draw firm conclusions from temperature data as we cannot fully discern the source of variation.

Patterns in observed light intensity were different in 2014 than in 2013. During 2014, increased light intensity was observed on both shallow and deep samplers, noting that only deep samplers were collected in 2013. The observed decrease in light intensity over the sampling period was caused by a combination of reduced light intensities as fines settled onto light logger sensors, and the onset of fall. The increased light intensities observed is likely due to lesser turbidity in 2014 than in 2013, which allowed greater light penetration to side channel substrates.

Turbidity levels and therefore light attenuation were also much lower in 2014 compared to 2013. Thus, the zone of sufficient light penetration to underlying substrates to support photosynthesis was greater in 2014, likely resulting in a larger area of productive habitat compared to 2013. However, even with reduced turbidity and increasing light penetration, sediment deposition was still high, most notably on the samplers at the 102.5R Test site. Sediment deposition was an important driver of production, and presumably more so at the Test site than at the Control site, most likely due to the higher observed rates of deposition. The 102.5R side channel location experienced deposition rates that were between 2 to 10 times greater than the Control location. The sources of this increased deposition include construction related effects, an increase in water within the side channel originating from the more turbid Pine River, or other factors not assessed. What is clear is that far more sedimentation was observed at the Control location than at the Test site and this observed difference coincided with recent channel enhancement construction.

One important feature to note was the positive relationship between velocity and sediment depth at sampling sites, which is counter-intuitive. Typically, sediment deposition should decrease with increasing velocities because small particles are carried away before they settle. This correlation is the result of the high deposition rates observed at the Test locations, and the subsequent small increases in velocity that were also observed (i.e., the velocities were approximately 0.1 m/s at Control and 0.3 m/s at Test sites). Apparently, the small increase in observed velocities were insufficient to reduce the rates of sediment deposition at the Test location, resulting in the positive yet counter-intuitive relationship. This forms part of the reason for eliminating velocity from our modelling and maintaining silt depth as a predictor of more interest.

The hydrograph for the Peace River is different from a natural system (NHC, 2013), where high peak freshet flows are not observed and low flows occur in the middle of June. Flows in summer 2013 and 2014 were within the normal operating range, and deployments were conducted following low flows. Flows were most similar during the first half of deployment, and then they dropped and were typically lower during the second half of deployment in 2013 and 2014 data. The trends at the WSC 07FD002 gauge were similar to flow releases from the reservoir, but were less apparent due to the effects of tributary inflows. Of particular importance for productivity is the effects of the hydrograph on water depths, especially during periods of high turbidity because water depth and light penetration are directly related.

Hydro operations create a ramping pattern on a daily basis, similar to other regulated rivers. The hourly variation in the hydrograph largely determines when, for how long, at what depth, and at what velocity substrate submergence occurred at any given side channel. Samplers in this study were placed in permanently submerged areas to reduce the confounding effects of ramping and variable submergence. However, consideration of these patterns in flow are important, because physical factors such as depth, velocity, and light were all directly related to flows and subsequently affected benthic productivity. The 2014 data show a strong, positive linear relationship between side channel elevation and river flows or stage (GMSMON7). In future years of study, we will consider investigating this relationship further. We will attempt to develop a depth variable for incorporation into our models when a river 2D channel model such as HEC RAS becomes available for side channel areas.

Peace side-channel samplers were deployed between 0.5 to 2 meters depth where they would remain submerged in 2014. A very productive zone at this depth range has been observed on other rivers (Larratt *et a*l. 2013; Schleppe *et al*. 2013). At these depths, our data indicate that turbidity is a key factor restricting benthic productivity. Therefore, in the Peace River side channels, the areas of greatest productivity are likely to occur in shallow areas that remain permanently submerged, because they have the highest light intensities. However, these more productive areas may be exposed occasionally as part of the normal operating flow regime. This small, highly productive band extended from the shoreline to 1.5 m depth and its productivity was disproportionate to the small area of river it occurred in, meaning it is very important to the overall productivity in Peace side channels.

4.2 Periphyton Production Summary

Suspended sediment affected the 2013 and 2014 periphyton production in the studied Peace River side channels. Periphyton productivity at the shallow 0 – 1.5 m sample locations was slightly greater where PAR and shading/light scatter by turbidity was lower, and deposition of fines was lower. Periphyton community structure changes attributable to shading from the high and sustained sediments loads have been widely documented (Henley et al. 2010, Hotzel and Croome 1994). Other Peace River system research determined that the large and fluctuating suspended sediment load reduced light penetration, resulting in greatly reduced periphyton and submerged macrophyte populations compared to less turbid rivers (Truelson and Warrington 1994).

Table 3-1 presents the summer 2013 Peace side-channel periphyton data with typical data from large rivers. Median metrics of the algal component of the periphyton would place the Peace River side channel habitat in the stressed category. Metrics that include all photosynthetic periphyton were closer to the typical range, reinforcing the importance of photosynthetic bacteria to this habitat. Imported detritus was also important to overall side channel productivity, and it was associated with deposited fines.

Prevalent periphyton taxa included those imported from upstream sites and those that grew *in situ* In regulated rivers, the contribution made by reservoir algae drifting into the river is important (Larratt *et al*. 2013). Their progressive deposition in slow-flowing water explains why significantly more reservoir taxa drifted to the 32L side channels than the 102.5R side channels. Similarly, areas with swifter flows can import lotic species that get torn off substrates. The influence of cobble substrate algae was more evident at the Test 102.5R side channel that receives more flow from the Pine River than at the Control side channel on the opposite bank. *In situ* or resident types were motile, reproduce rapidly and/or had low light requirements, allowing them to withstand high sediment deposition occurring in Peace side channels. Overall, the most productive areas were in the 0 – 1.5 m shallows, and production tapered to 3 m depth.

When habitat indicator taxa are compared for inter-annual variation at 102.5R side channels, biovolume proportions for resident taxa were closely matched each year, while immigrant taxa contributions (40 – 50% of total periphyton productivity) to side channel algal standing crops were more variable between years, perhaps driven by fluctuating turbidity. The greater productivity of habitat indicator taxa at the 102.5R Test side channel over the Control diminished in 2014, suggesting construction impact on the Test site. The algae group that demonstrated the greatest inter-annual difference between the 102.5R side channels was the filamentous green taxa. These high light-requiring algae were apparently excluded from the Test site in 2014 by turbidity and sediment deposition following enhancement construction and increased influence of turbid Pine River flows.

If the median of 40-50% immigrant algae taxa are subtracted from the already low productivity estimates demonstrated in the 2013 and 2014 data respectively, then it becomes clear that local algae productivity in these side channel environments is low relative to mainstem levels in the Peace and to other larger BC rivers (Table 3.1).

The overarching trend of decreasing productivity with increasing turbidity and silt deposition is considered to be independent of channel construction because it has been observed in data from 2013 and 2014 at Control and Test side channels. The extent of construction-related effects on these trends is difficult to determine. Further, the time required for habitat stabilization after large scale riverine changes can be from several months to several years. This means more data from future years are required to understand the periphyton production response to the enhancement construction at the Test 102.5R side channel. Further, it also means that understanding a wider range of habitat conditions within side channels is needed to fully assess whether the anticipated benefits can be realized at the Test side channel or at any other site.

In summary, suspended sediment was the dominant factor affecting periphyton community structure and productivity in the Peace River side channel habitats. Observed sediment deposition impacts at the Test side channel in 2014 may be the result of construction rather than a long-term habitat change.

4.3 Invertebrate Production Summary

Similar to 2013, Peace River side channels were dominated by *Oligochaete* taxa in 2014, while dominate taxa in mainstem areas were Trichoptera and Gastropoda (Golder 2012). In contrast with other rivers of BC such as the Columbia, Thompson, or Fraser, *Chironomidae* and/or EPT taxa were more predominant in mainstem samples from these rivers than side channel samples from the Peace River (Table 4-1). These differences between the mainstem samples from less turbid systems and the more turbid Peace side channels may be the result of the high sediment deposition rates because they create conditions most suitable for taxa such as *Oligochaete. Oligochaetes* and Gastropods are collector-gather foragers associated with finer sediments and lower oxygen environments (Rodriguez and Reynoldson 2011). Although numerically less abundant, Plecopterans, a good food for fish, had high relative biomass and were more abundant in natural substrates when compared to artificial substrates, suggesting that this group may be an important forage item in side channel areas. We have not specifically investigated any sampling associated bias that the artificial rock baskets may introduce when compared to the natural substrate collection methods using a dredge. However, we do presume that some differences exist, if for no other reason than the differences in substrate (fine natural substrate consisting of sands and silts versus 2.5 to 5 cm rock). However, despite this, the current sampling methodology is considered very useful because it provides a consistent, repeatable, and comparable sampling method to other ongoing BC Hydro initiatives such as the CLBMON projects 15b and 44 that isn't biased by natural substrate variation.

Benthic invertebrate communities were different between Test and Control locations at 102.5R, between natural and artificial substrates, and between years or flow period. In 2014, the increased Hilsenhoff Biotic Index at 102.5R Test sites means more tolerant species, such as *Oligochaete*, were more abundant than at the control sites that had a much lower rate of sediment deposition. The general trends in invertebrate community structure indicate that sediment deposition was an important determinant of the benthic community. Sites with high sediment deposition rates had increasing prevalence of highly tolerant communities and they had lower fish food value. Our habitat modelling data also suggests that factors such as turbidity and sediment deposition are important determinants of the invertebrate community productivity and diversity. Future years of this study will continue to investigate the effects of side channels enhancements, and the specific effects of sedimentation and physical habitat variables on Peace side-channel benthic productivity.

Overall benthic abundance in the Peace side channels was most similar to the Fraser River or Mid-Columbia River. In 2014, with construction of habitat enhancement at the Test side channel, the data suggest that communities were not as productive as those at Control locations. We hypothesize that this observed difference stems from the high sediment deposition rates between the sites, with the most notable effects being a reduced % chironomidae, a reduced total abundance, an increased HBI (meaning fewer tolerant taxa), and an increased Simpson's Index. The high rates of observed sediment deposition at the test location may be the result of construction, or may be a post-treatment effect that will occur year after year. Our analysis cannot differentiate between these two scenarios, and future years of data and analyses will help confirm the extent of long-term changes in the benthic community as a result of side channel enhancement.

Table 4-1: Comparison of the Peace River system to other BC River systems.

River	Average Annual Discharge (m^3/s)	Mean # of Invertebrates (±SE)	Total # of Taxa	Diversity (Simpson's Index)	Most Abundant Taxa (percent abundance)
MCR (Revelstoke)	955	278(±380)	27	0.48	*Hydra sp*. (43) *Orthocladiinae* (15) *Orthocladius* complex (9.4) *Enchytraeidae* (2)
LCR (Castlegar)	1,997	3575(±2093)	40	0.65	*Hydropsychidae* (25) *Parachironomus* (9) *Tvetenia discoloripes* gr. (7.2) *Synorthocladius* (5.1)
Fraser River (Agassiz)	3,620	829 (±301)	55	0.84	*Orthocladiinae* (62.7) *Baetis spp*. (7.2) *Ephemerella spp*. (5.4)
Thompson River (Spences Bridge)	781	2108 (±1040.8)	48	0.44	*Orthocladiinae* (62.7) *Baetis spp*. (7.2) *Ephemerella spp*. (5.4)
Peace River		407.8(±158.7)	145	0.95	*Oligochaeta* (59) *Chironomidae* (21) Other (7)
Peace River 2014		1039.42 (±161.31)	58	0.706	*Tubificidae* (33.18%) *Tanytarsus* (16.69%) *Lumbriculidae* (15.03%)
Peace River 2014 Natural		789.5 (±144.93)	18	0.472	*Tubificidae* (71.09%) *Stictochironomus* (11.69%) *Procladius* (8.59%)
Cheakamus River	–	1252 (±1149)	6	–	*Ephemeroptera* *Plecoptera* *Diptera* w/o *chironomids*

Data sources include Schleppe *et al*. 2013, Reece & Richardson 2000, Triton Environmental Consultants Ltd. 2008 and this report.

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APPENDICES:

Appendix 1: Rastering and IDW methods

The following description of ArcGIS rastering methods comes directly from the help file available for the IDW tool suite in ArcGIS 10.2 (ESRI 2013).

How IDW works

Inverse distance weighted (IDW) interpolation determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance. The surface being interpolated should be that of a locationally dependent variable.

IDW neighborhood for selected points

This method assumes that the variable being mapped decreases in influence with distance from its sampled location. For example, when interpolating a surface of consumer purchasing power for a retail site analysis, the purchasing power of a more distant location will have less influence because people are more likely to shop closer to home.

Controlling the influence with the Power parameter

IDW relies mainly on the inverse of the distance raised to a mathematical power. The Power parameter lets you control the significance of known points on the interpolated values based on their distance from the output point. It is a positive, real number, and its default value is 2.

By defining a higher power value, more emphasis can be put on the nearest points. Thus, nearby data will have the most influence, and the surface will have more detail (be less smooth). As the power increases, the interpolated values begin to approach the value of the nearest sample point. Specifying a lower value for power will give more influence to surrounding points that are farther away, resulting in a smoother surface.

Since the IDW formula is not linked to any real physical process, there is no way to determine that a particular power value is too large. As a general guideline, a power of 30 would be considered extremely large and thus of questionable use. Also keep in mind that if the distances or the power value are large, the results may be incorrect.

An optimal value for the power can be considered to be where the minimum mean absolute error is at its lowest. The ArcGIS Geostatistical Analyst extension provides a way to investigate this.

Limiting the points used for interpolation

The characteristics of the interpolated surface can also be controlled by limiting the input points used in the calculation of each output cell value. Limiting the number of input points considered can improve processing speeds. Also consider that input points far away from the cell location where the prediction is being made may have poor or no spatial correlation, so there may be reason to eliminate them from the calculation.

You can specify the number of points to use directly, or specify a fixed radius within which points will be included in the interpolation.

Variable search radius

With a variable search radius, the number of points used in calculating the value of the interpolated cell is specified, which makes the radius distance vary for each interpolated cell, depending on how far it has to search around each interpolated cell to reach the specified number of input points. Thus, some neighborhoods will be small and others will be large, depending on the density of the measured points near the interpolated cell. You can also specify a maximum distance (in map units) that the search radius cannot exceed. If the radius for a particular neighborhood reaches the maximum distance before obtaining the specified number of points, the prediction for that location will be performed on the number of measured points within the maximum distance. Generally, you will use smaller neighborhoods or a minimum number of points when the phenomenon has a great amount of variation.

Fixed search radius

A fixed search radius requires a neighborhood distance and a minimum number of points. The distance dictates the radius of the circle of the neighborhood (in map units). The distance of the radius is constant, so for each interpolated cell, the radius of the circle used to find input points is the same. The minimum number of points indicates the minimum number of measured points to use within the neighborhood. All the measured points that fall within the radius will be used in the calculation of each interpolated cell. When there are fewer measured points in the neighborhood than the specified minimum, the search radius will increase until it can encompass the minimum number of points. The specified fixed search radius will be used for each interpolated cell (cell center) in the study area; thus, if your measured points are not spread out equally (which they rarely are), there are likely to be different numbers of measured points used in the different neighborhoods for the various predictions.

Using barriers

A barrier is a polyline dataset used as a breakline that limits the search for input sample points. A polyline can represent a cliff, ridge, or some other interruption in a landscape. Only those input sample points on the same side of the barrier as the current processing cell will be considered.

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Usage

Interpolates a raster surface from points using an inverse distance weighted (IDW) technique.

The output value for a cell using inverse distance weighting (IDW) is limited to the range of the values used to interpolate. Because IDW is a weighted distance average, the average cannot be greater than the highest or less than the lowest input. Therefore, it cannot create ridges or valleys if these extremes have not already been sampled (Watson and Philip 1985).

The best results from IDW are obtained when sampling is sufficiently dense with regard to the local variation you are attempting to simulate. If the sampling of input points is sparse or uneven, the results may not sufficiently represent the desired surface (Watson and Philip 1985).

The influence of an input point on an interpolated value is isotropic. Since the influence of an input point on an interpolated value is distance related, IDW is not "ridge preserving" (Philip and Watson 1982).

Some input datasets may have several points with the same x,y coordinates. If the values of the points at the common location are the same, they are considered duplicates and have no effect on the output. If the values are different, they are considered coincident points.

The various interpolation tools may handle this data condition differently. For example, in some cases, the first coincident point encountered is used for the calculation; in other cases, the last point encountered is used. This may cause some locations in the output raster to have different values than what you might expect. The solution is to prepare your data by removing these coincident points. The “Collect Events” tool in the Spatial Statistics toolbox is useful for identifying any coincident points in your data.

The barriers option is used to specify the location of linear features known to interrupt the surface continuity. These features do not have z-values. Cliffs, faults, and embankments are typical examples of barriers. Barriers limit the selected set of the input sample points used to interpolate output z-values to those samples on the same side of the barrier as the current processing cell. Separation by a barrier is determined by line-of-sight analysis between each pair of points. This means that topological separation is not required for two points to be excluded from each other's region of influence. Input sample points that lie exactly on the barrier line will be included in the selected sample set for both sides of the barrier.

Barrier features are input as polyline features. IDW only uses the x,y coordinates for the linear feature; therefore, it is not necessary to provide z-values for the left and right sides of the barrier. Any z-values provided will be ignored.

Using barriers will significantly extend the processing time.

This tool has a limit of approximately 45 million input points. If your input feature class contains more than 45 million points, the tool may fail to create a result. You can avoid this limit by interpolating your study area in several pieces, making sure there is some overlap in the edges, then mosaicking the results to create a single large raster dataset. Alternatively, you can use a terrain dataset to store and visualize points and surfaces comprised of billions of measurement points.

If you have the Geostatistical Analyst extension, you may be able to process larger datasets.

The input feature data must contain at least one valid field.

Appendix 2: Tables showing correlations among explanatory variables

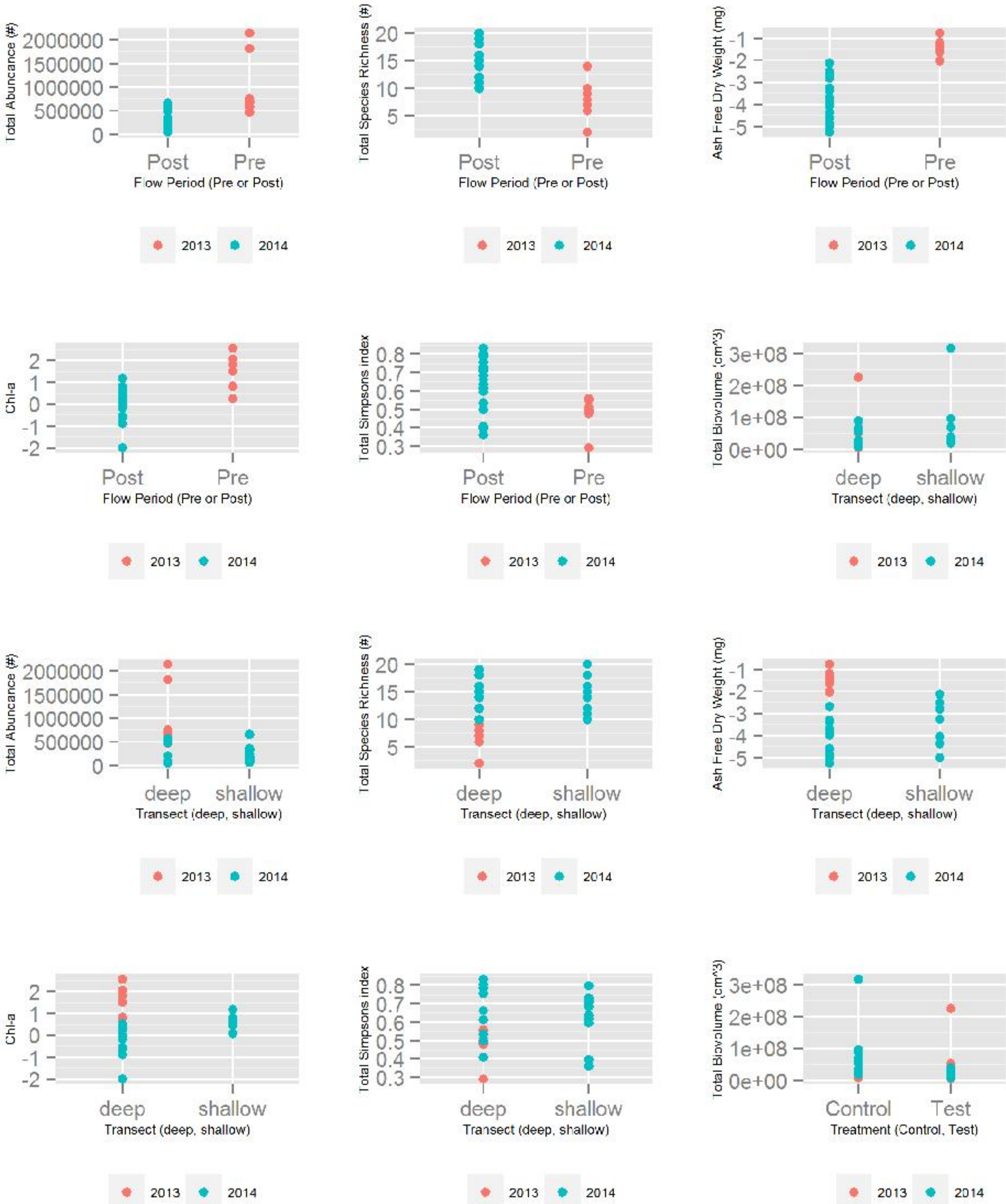
Table A-2-1: Correlation coefficients and variance inflation factors (VIF) of explanatory variables included in linear regressions for periphyton community and productivity metrics.

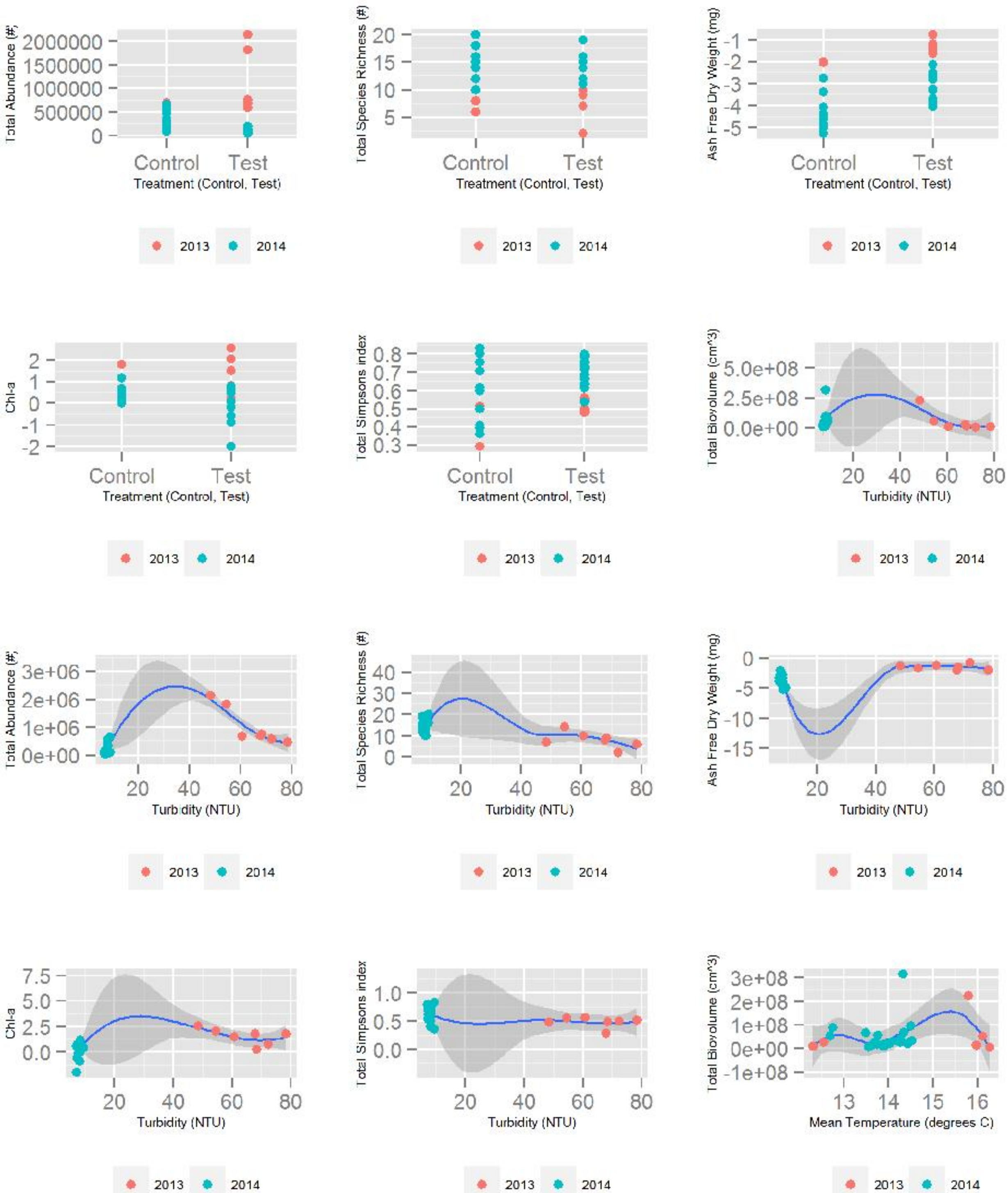
	substrate_score	D90_cm	silt_depth_mean	turbidity_NTU	lux.mean	temp.mean
substrate_score	1.00	0.64	0.05	0.33	-0.24	0.44
D90_cm	0.64	1.00	-0.06	0.58	-0.52	0.19
silt_depth_mean	0.05	-0.06	1.00	-0.38	-0.17	-0.15
turbidity_NTU	0.33	0.58	-0.38	1.00	-0.44	0.18
lux.mean	-0.24	-0.52	-0.17	-0.44	1.00	0.16
temp.mean	0.44	0.19	-0.15	0.18	0.16	1.00

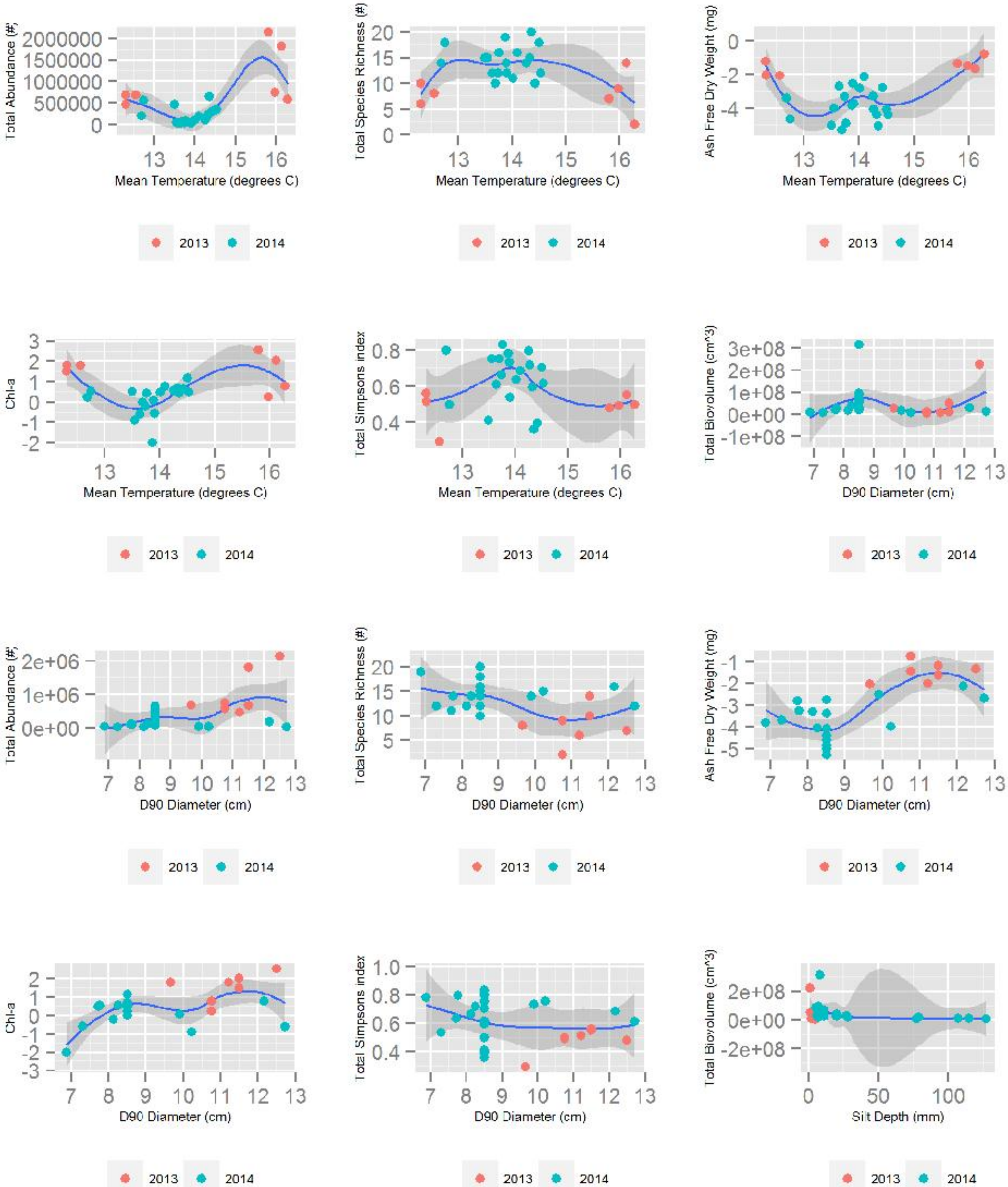
Table A-2-2: Correlation coefficients and variance inflation factors (VIF) of explanatory variables included in linear regressions for benthic invertebrate community and productivity metrics.

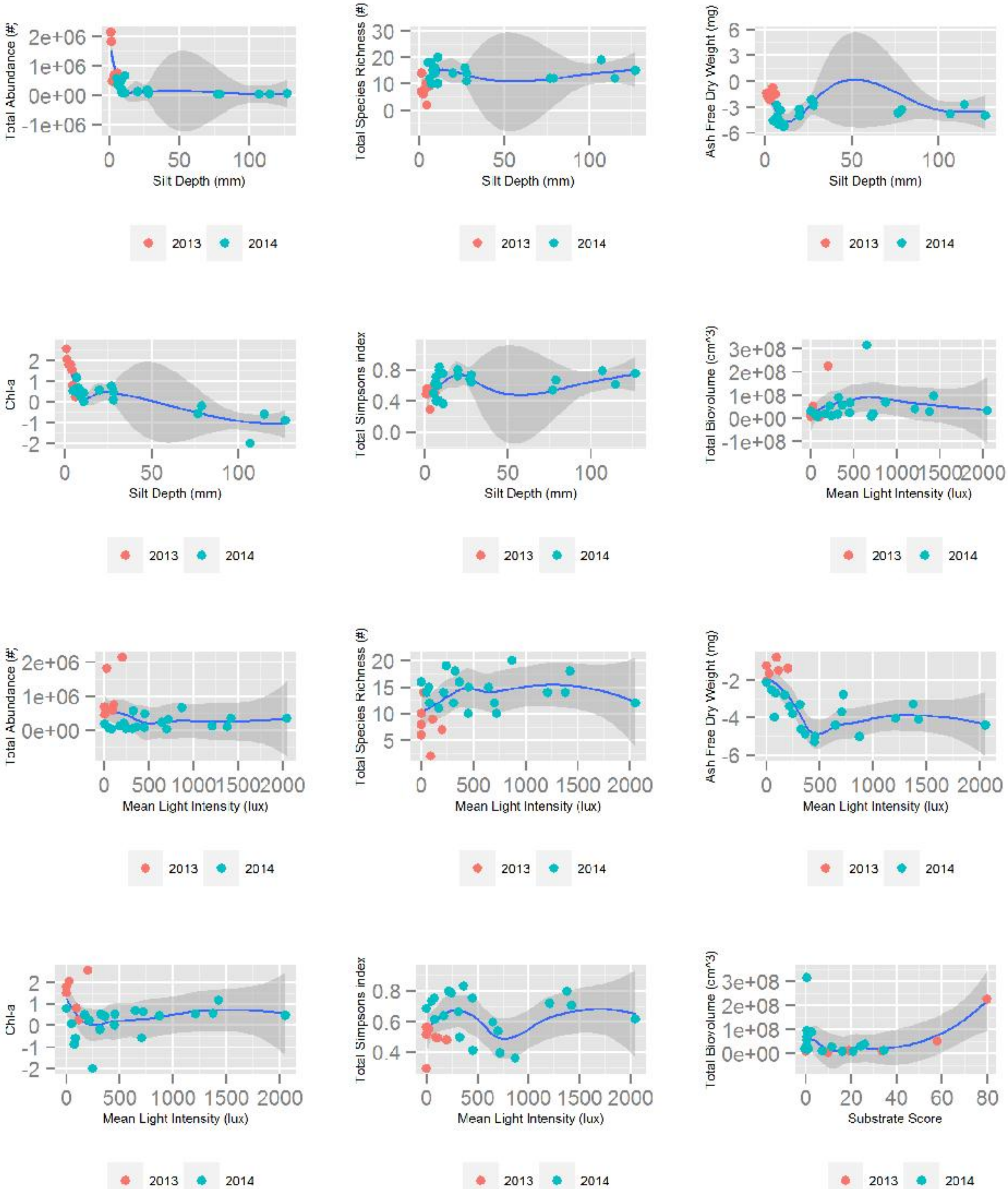
	substrate_score	D90_cm	silt_depth_mean	turbidity_NTU	lux.mean	temp.mean
substrate_score	1.00	0.64	0.05	0.33	-0.24	0.44
D90_cm	0.64	1.00	-0.06	0.58	-0.52	0.19
silt_depth_mean	0.05	-0.06	1.00	-0.38	-0.17	-0.15
turbidity_NTU	0.33	0.58	-0.38	1.00	-0.44	0.18
lux.mean	-0.24	-0.52	-0.17	-0.44	1.00	0.16
temp.mean	0.44	0.19	-0.15	0.18	0.16	1.00

Appendix 3: Biplots showing relationships between individual response variables and each explanatory variable.




Total Abundance (#)
Treatment (Control, Test)
Control
Test
Total Species Richness (#)
Ash Free Dry Weight (mg)
2013
2014
Chl-a
Total Simpsons index
Total Biovolume (cm^3)
Turbidity (NTU)
Mean Temperature (degrees C)


Total Abundance (#)
Mean Temperature (degrees C)
Total Species Richness (#)
Ash Free Dry Weight (mg)
Chl-a
Total Simpsons index
Total Biovolume (cm^3)
D90 Diameter (cm)
Silt Depth (mm)
2013
2014


Total Abundance (#)
Silt Depth (mm)
Total Species Richness (#)
Silt Depth (mm)
Ash Free Dry Weight (mg)
Silt Depth (mm)
2013
2014
Chl-a
Silt Depth (mm)
Total Simpsons index
Silt Depth (mm)
Total Biovolume (cm^3)
Mean Light Intensity (lux)
2013
2014
Total Abundance (#)
Mean Light Intensity (lux)
Total Species Richness (#)
Mean Light Intensity (lux)
Ash Free Dry Weight (mg)
Mean Light Intensity (lux)
2013
2014
Chl-a
Mean Light Intensity (lux)
Total Simpsons index
Mean Light Intensity (lux)
Total Biovolume (cm^3)
Substrate Score
2013
2014

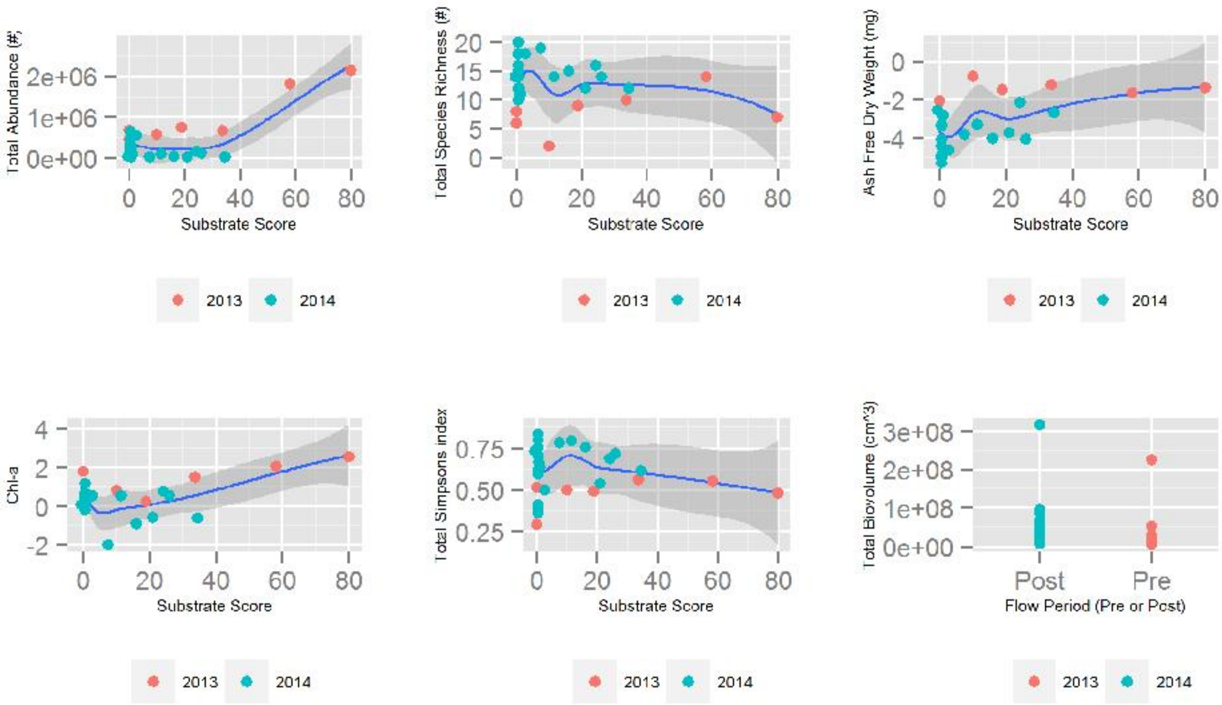
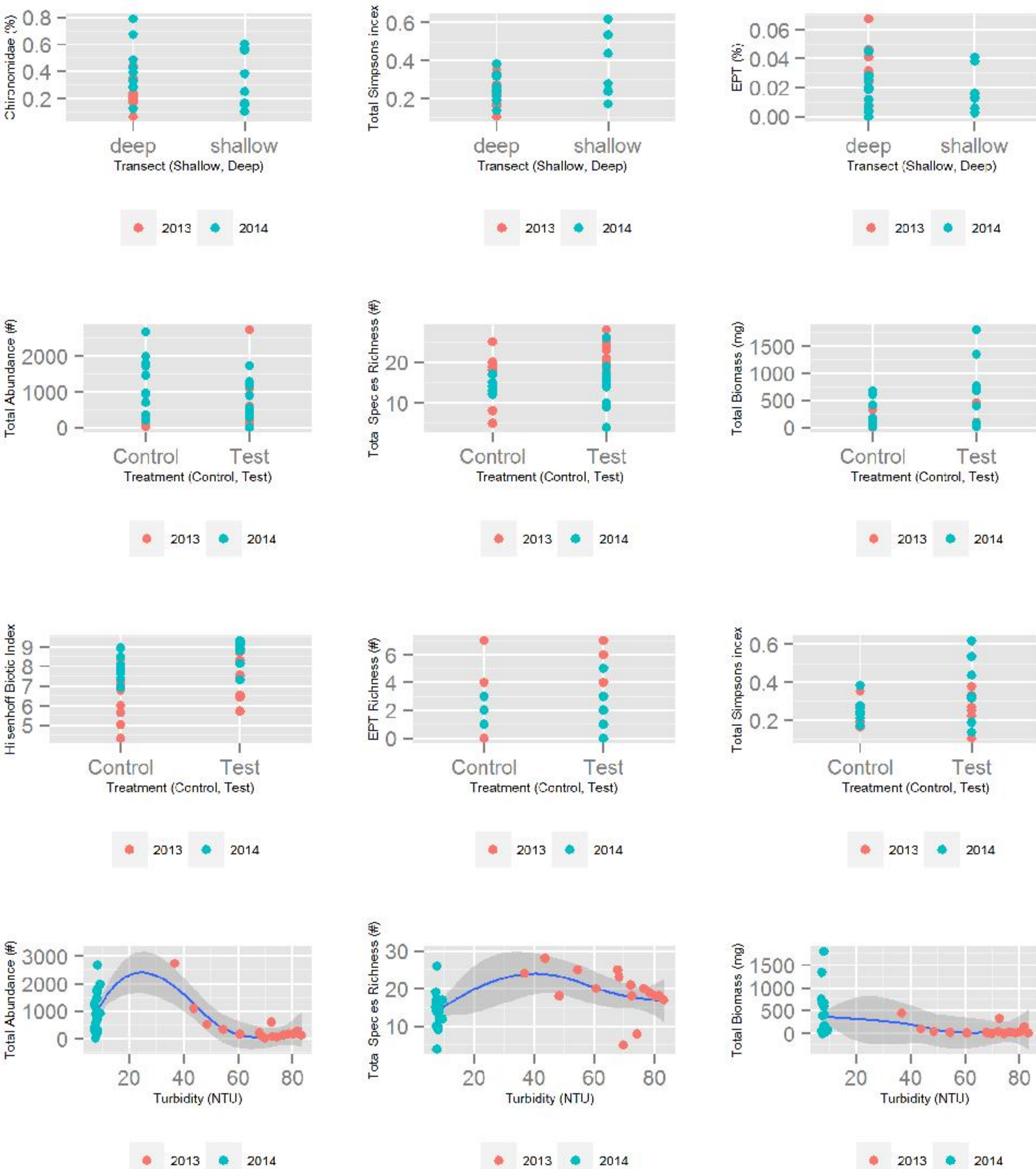
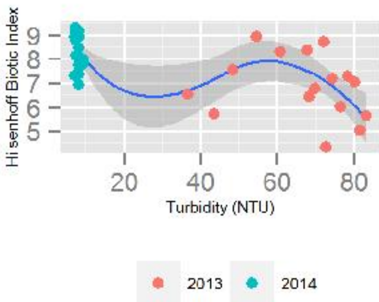
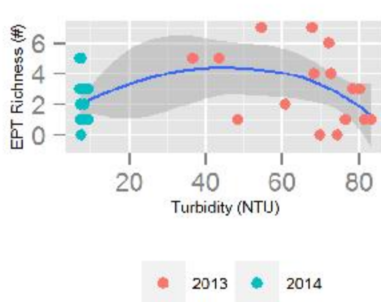


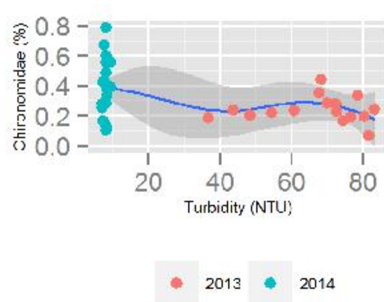
Figure A-3-1: Biplots of periphyton response variables (Abundance, biovolume, Species richness, Chl-a, and AFDW) and explanatory variables including substrate score, D90 (D90_cm), water turbidity (turb_NTU), average daily water temperature, average daily light intensity, Test of Control, and Flow Period (Pre or Post) in linear mixed effects models. Fitted lines were generated using a locally weighted polynomial regression method (LOWESS).

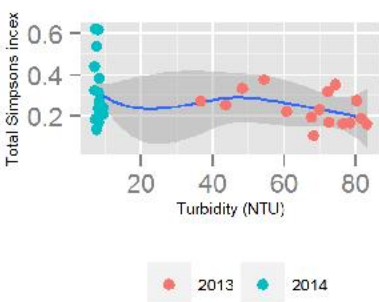

Tota Spec es Richness (#)
Post Pre
FP (Pre, Post)
2013 2014
Total Biomass (mg)
Post Pre
FP (Pre, Post)
2013 2014
Hi senhoff Biotic Index
Post Pre
FP (Pre, Post)
2013 2014
EPT Richness (#)
Post Pre
FP (Pre, Post)
2013 2014
Chironomidae (%)
Post Pre
FP (Pre, Post)
2013 2014
Total Simpsons incex
Post Pre
FP (Pre, Post)
2013 2014
EPT (%)
Post Pre
FP (Pre, Post)
2013 2014
Total Abundance (#)
deep shallow
Transect (Shallow, Deep)
2013 2014
Tota Spec es Richness (#)
deep shallow
Transect (Shallow, Deep)
2013 2014
Total Biomass (mg)
deep shallow
Transect (Shallow, Deep)
2013 2014
Hi senhoff Biotic Index
deep shallow
Transect (Shallow, Deep)
2013 2014
EPT Richness (#)
deep shallow
Transect (Shallow, Deep)
2013 2014

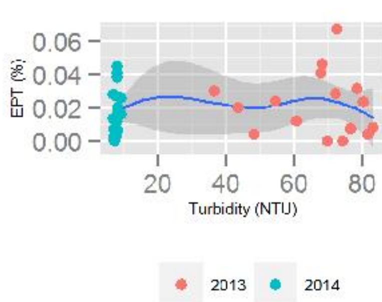

Chironomidae (%)
0.8
0.6
0.4
0.2
deep
shallow
Transect (Shallow, Deep)
2013
2014
Total Simpsons index
0.6
0.4
0.2
deep
shallow
Transect (Shallow, Deep)
2013
2014
EPT (%)
0.06
0.04
0.02
0.00
deep
shallow
Transect (Shallow, Deep)
2013
2014
Total Abundance (#)
2000
1000
0
Control
Test
Treatment (Control, Test)
2013
2014
Total Species Richness (#)
20
10
Control
Test
Treatment (Control, Test)
2013
2014
Total Biomass (mg)
1500
1000
500
0
Control
Test
Treatment (Control, Test)
2013
2014
Hilsenhoff Biotic Index
9
8
7
6
5
Control
Test
Treatment (Control, Test)
2013
2014
EPT Richness (#)
6
4
2
0
Control
Test
Treatment (Control, Test)
2013
2014
Total Simpsons index
0.6
0.4
0.2
Control
Test
Treatment (Control, Test)
2013
2014
Total Abundance (#)
3000
2000
1000
0
20
40
60
80
Turbidity (NTU)
2013
2014
Total Species Richness (#)
30
20
10
20
40
60
80
Turbidity (NTU)
2013
2014
Total Biomass (mg)
1500
1000
500
0
20
40
60
80
Turbidity (NTU)
2013
2014

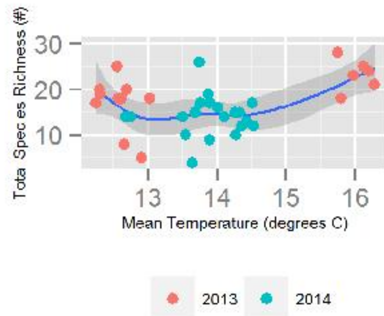

Hilsenhoff Biotic Index
9
8
7
6
5
20 40 60 80
Turbidity (NTU)
2013 2014

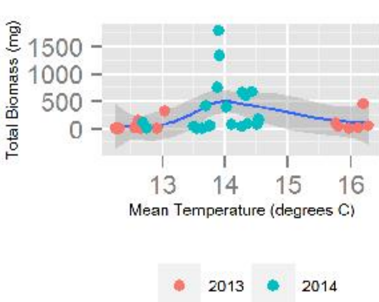

EPT Richness (#)
6
4
2
0
20 40 60 80
Turbidity (NTU)
2013 2014

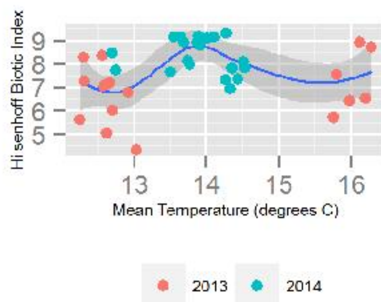

Chironomidae (%)
0.8
0.6
0.4
0.2
0.0
20 40 60 80
Turbidity (NTU)
2013 2014

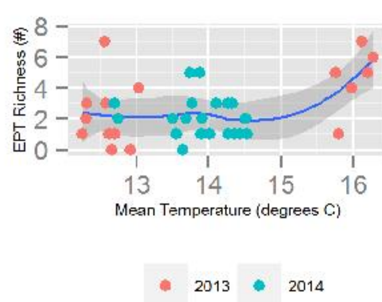

Total Simpsons index
0.6
0.4
0.2
20 40 60 80
Turbidity (NTU)
2013 2014

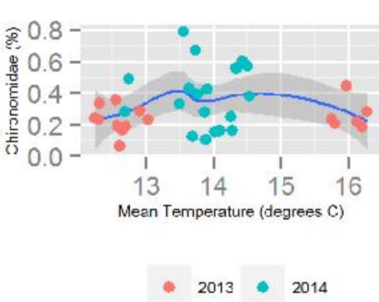

EPT (%)
0.06
0.04
0.02
0.00
20 40 60 80
Turbidity (NTU)
2013 2014

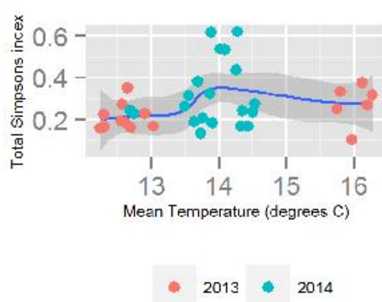

Total Species Richness (#)
30
20
10
13 14 15 16
Mean Temperature (degrees C)
2013 2014

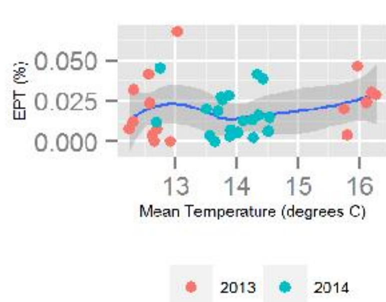

Total Biomass (mg)
1500
1000
500
0
13 14 15 16
Mean Temperature (degrees C)
2013 2014

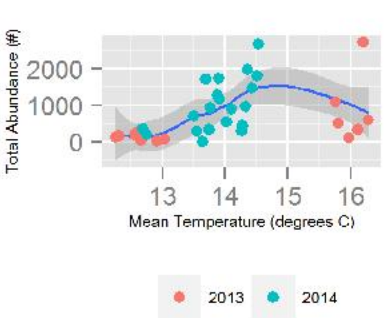

Hilsenhoff Biotic Index
9
8
7
6
5
13 14 15 16
Mean Temperature (degrees C)
2013 2014

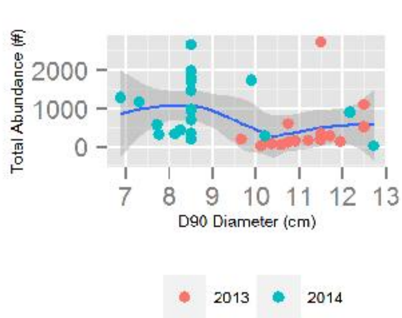

EPT Richness (#)
8
6
4
2
0
13 14 15 16
Mean Temperature (degrees C)
2013 2014

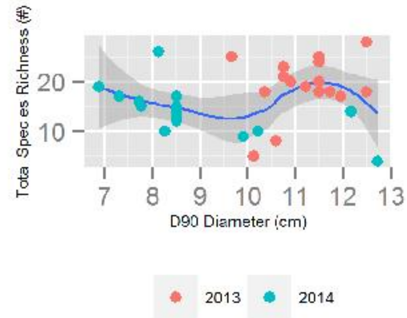

Chironomidae (%)
0.8
0.6
0.4
0.2
0.0
13 14 15 16
Mean Temperature (degrees C)
2013 2014

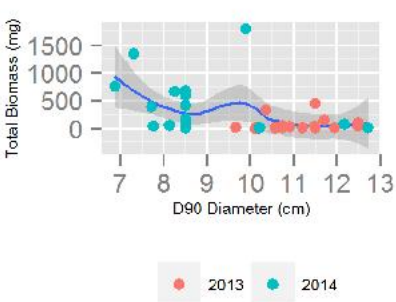

Total Simpsons index
0.6
0.4
0.2
13 14 15 16
Mean Temperature (degrees C)
2013 2014

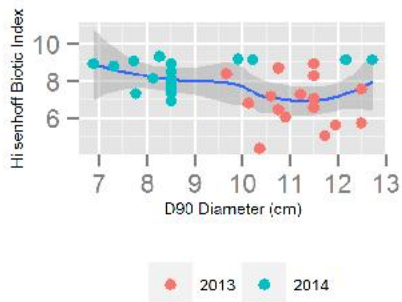

EPT (%)
0.050
0.025
0.000
13 14 15 16
Mean Temperature (degrees C)
2013 2014

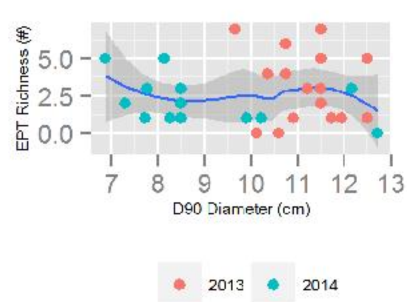

Total Abundance (#)
Mean Temperature (degrees C)
2013
2014

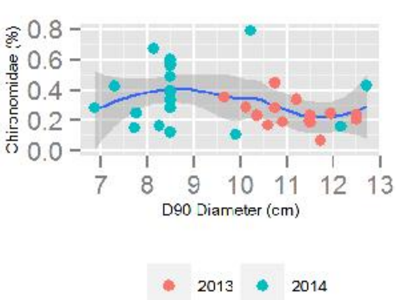

Total Abundance (#)
D90 Diameter (cm)
2013
2014

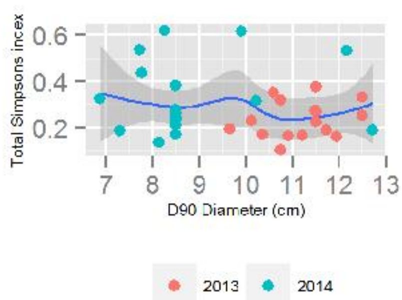

Tota Spec es Richness (#)
D90 Diameter (cm)
2013
2014

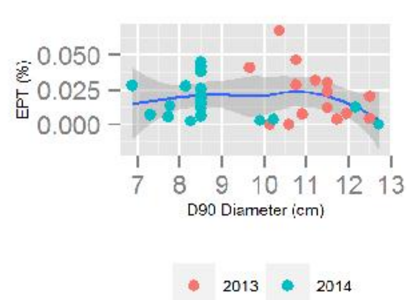

Total Biomass (mg)
D90 Diameter (cm)
2013
2014

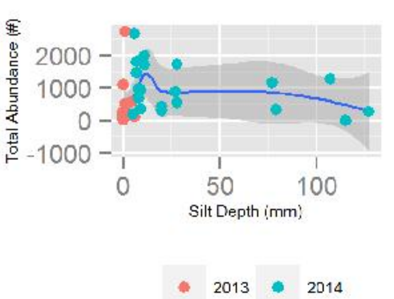

Hi senhoff Biotic Index
D90 Diameter (cm)
2013
2014

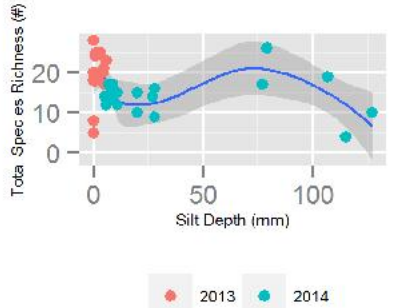

EPT Richness (#)
D90 Diameter (cm)
2013
2014

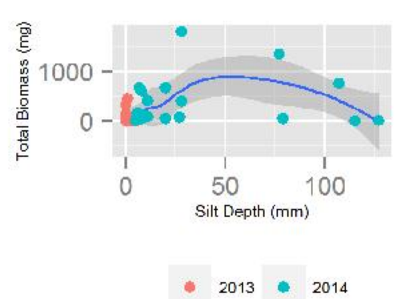

Chironomidae (%)
D90 Diameter (cm)
2013
2014


Total Simpsons incex
D90 Diameter (cm)
2013
2014

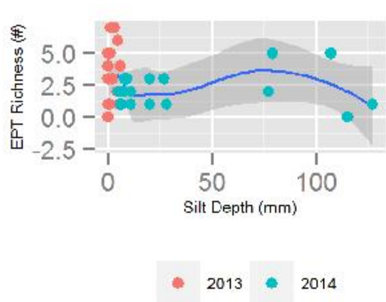

EPT (%)
D90 Diameter (cm)
2013
2014


Total Abundance (#)
Silt Depth (mm)
2013
2014

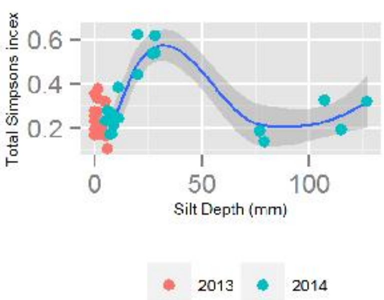

Tota Spec es Richness (#)
Silt Depth (mm)
2013
2014

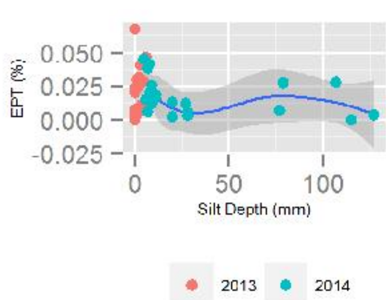

Total Biomass (mg)
Silt Depth (mm)
2013
2014

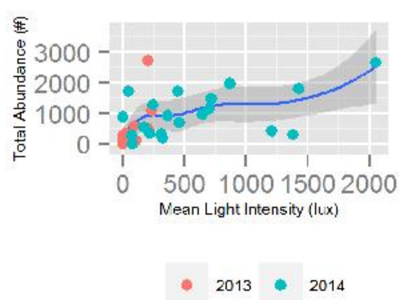

Hi senhoff Biotic Index
Silt Depth (mm)
2013
2014

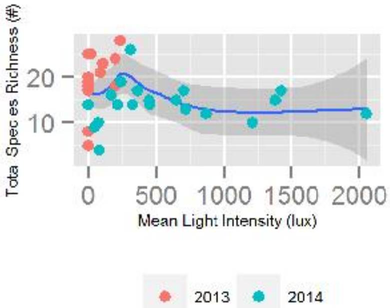

EPT Richness (#)
Silt Depth (mm)
2013
2014

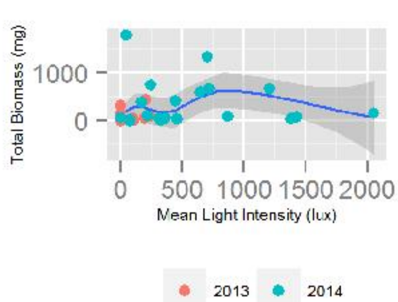

Chironomidae (%)
Silt Depth (mm)
2013
2014

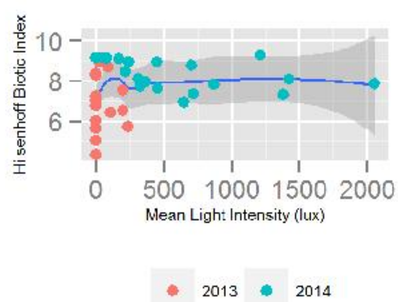

Total Simpsons index
Silt Depth (mm)
2013
2014

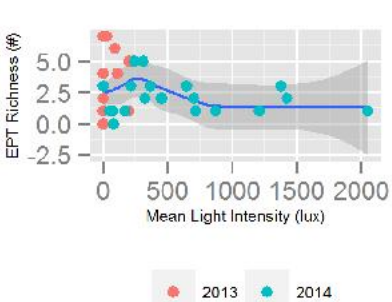

EPT (%)
Silt Depth (mm)
2013
2014

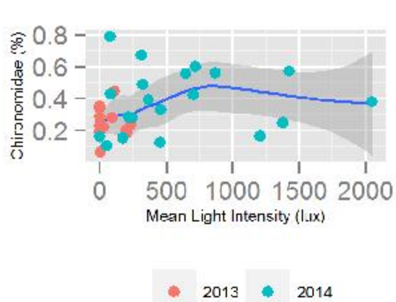

Total Abundance (#)
Mean Light Intensity (lux)
2013
2014

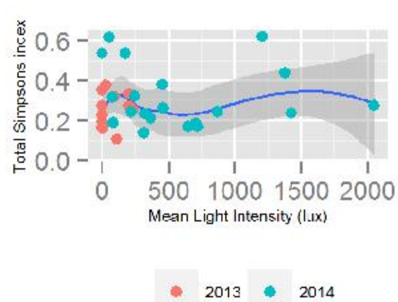

Total Species Richness (#)
Mean Light Intensity (lux)
2013
2014


Total Biomass (mg)
Mean Light Intensity (lux)
2013
2014


Hi senhoff Biotic Index
Mean Light Intensity (lux)
2013
2014


EPT Richness (#)
Mean Light Intensity (lux)
2013
2014


Chironomidae (%)
Mean Light Intensity (lux)
2013
2014


Total Simpsons index
Mean Light Intensity (lux)
2013
2014

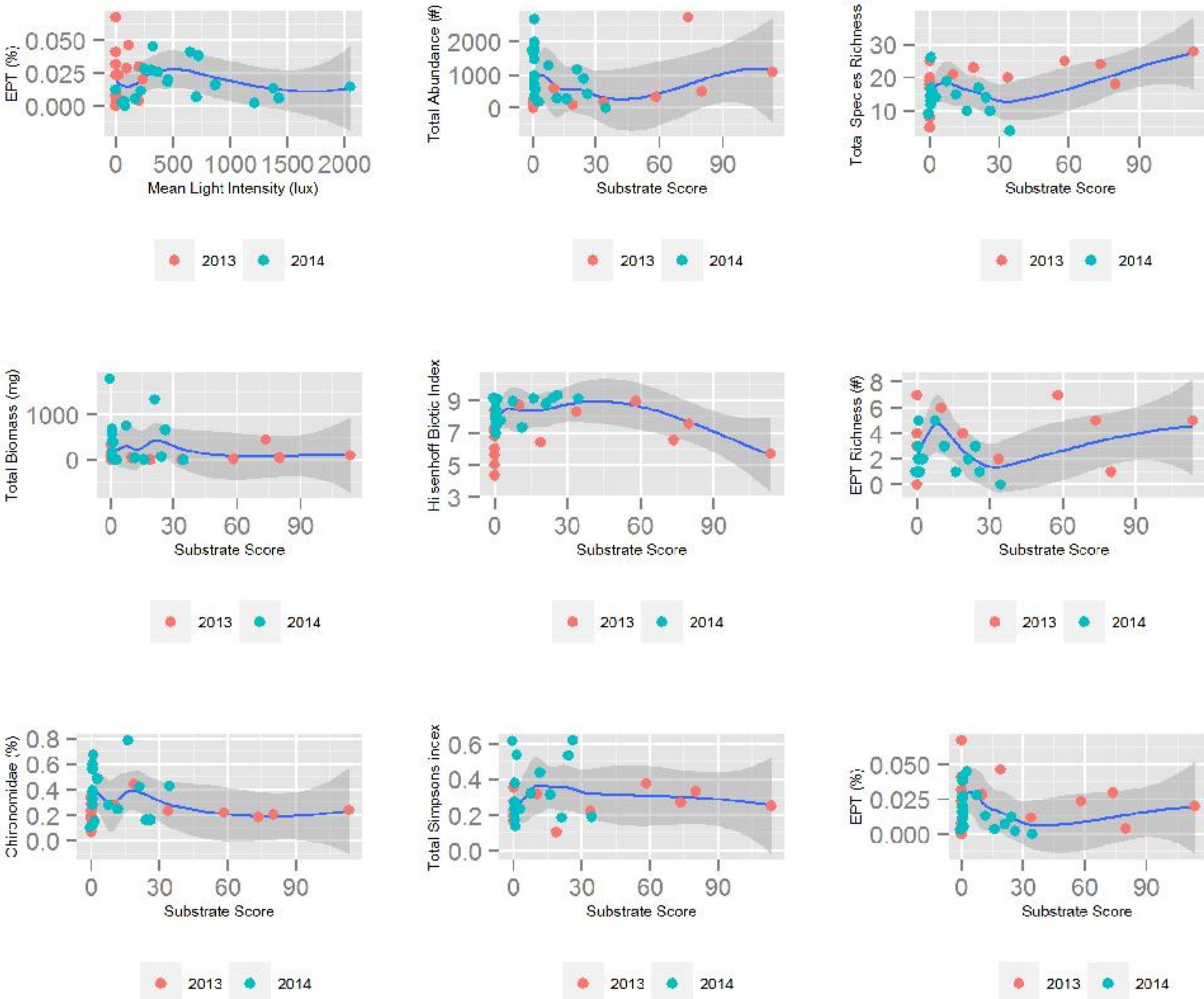


Figure A-3-2: Biplots of benthic invertebrate response variables (Total Abundance, Total Biomass, EPT Percent, Chironomidae Percent, EPT Richness, Simpson's Diversity Index and Hilsenhoff Biotic Index) and explanatory variables including D90 (D90_cm), mean silt depth, pre and post enhancement, control and treatment, substrate score, mean maximum daily water temperature (temp.dmax), and mean daily light intensity (Lux), and shallow or deep included in multiple linear regressions.

Appendix 4: Alternative Benthic Modelling

The following presents the benthic invertebrate response modelling for all parameters with three data points of high leverage removed. The responses to the predictors are largely the same as those presented in the discussion, with the exception of Percent EPT (%), where the predictors set varied dramatically. Typically, within each response, different predictors only shifted one or two positions in .priority, but generally had a similar RVI value. Although these models adhere better to general linear model assumptions, we have chosen to present the alternative model scenario because at these sites, there were no EPT taxa found, meaning they are true zeros. Since EPT taxa are deemed an important diet item for fish, sites that are true zero's should likely be considered. Despite violation of model assumptions, the discussion presented is consistent with interpretation using either modelling scenario.

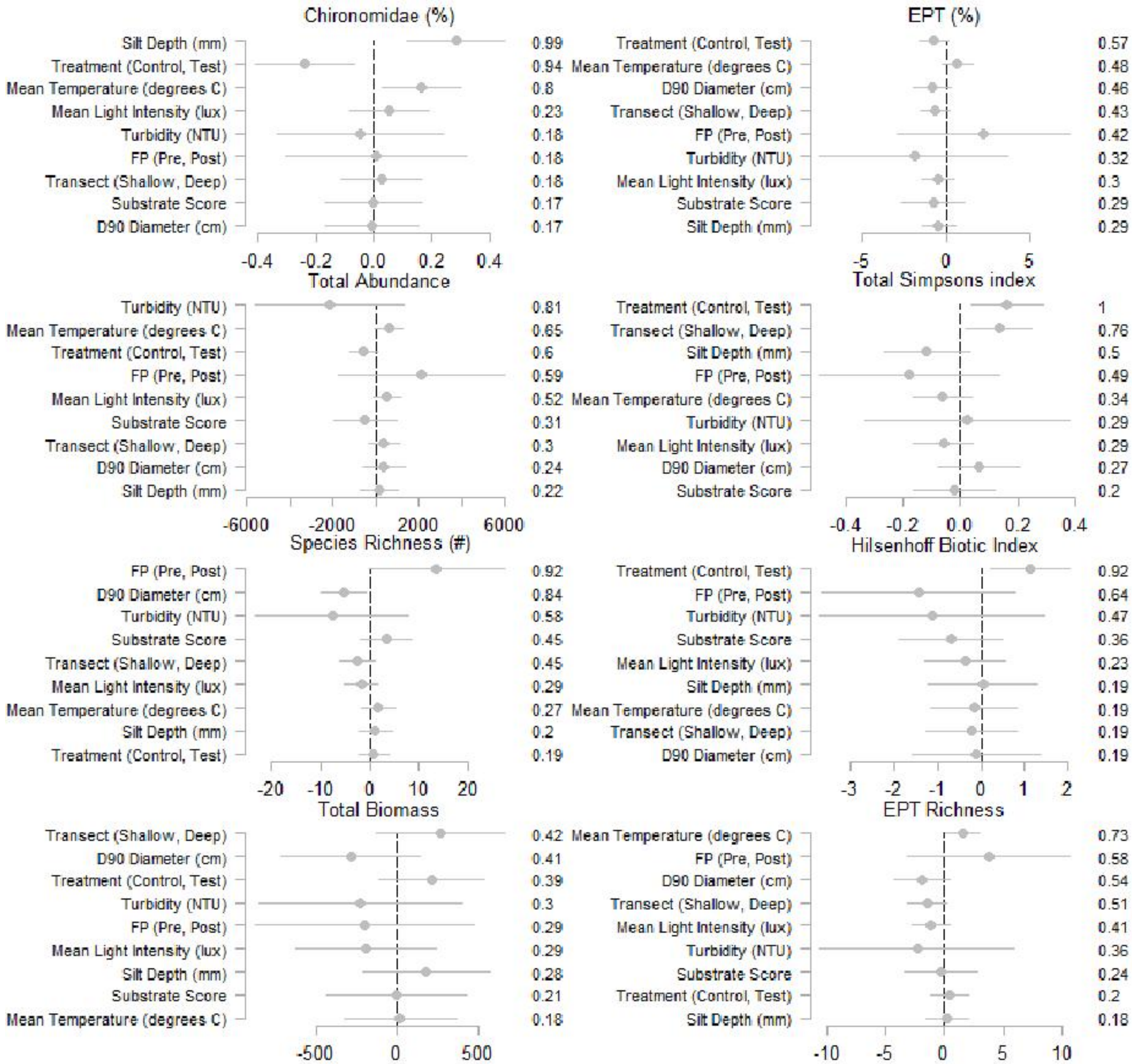
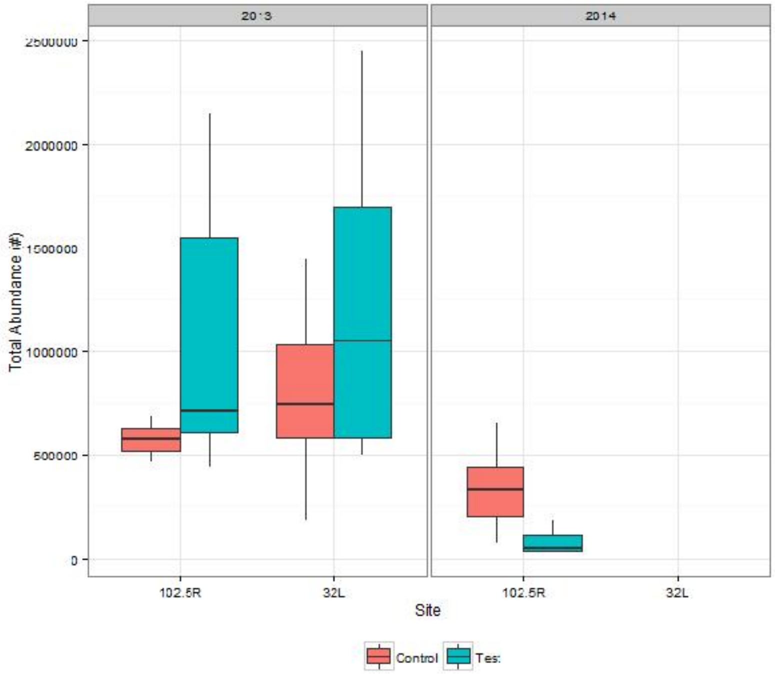


Figure A-4-1: Mean coefficients and their 95% confidence limits of standardized explanatory variables of benthic production in the Peace River side channels. Invertebrate responses included abundance, biomass, species richness, EPT Richness, % EPT, % Chironomidae, Simpson's Index, and Hilsenhoff Biotic Index. Coefficients are standardized to allow direct comparisons of the direction and size of effects, noting that variables with confidence limits that encompass zero can have either a positive or negative effect depending upon which model is considered. Key explanatory variables are sorted by their relative variable importance (RVI), values on the right hand y-axis of each panel.

Appendix 5: Styrofoam and Fines Periphyton Boxplots

The following presents a summary of the periphyton production data for the Styrofoam and fines substrates with the later corrected for depth of deposited sediment. This data is was treated differently in 2013 and 2014 due to an improved methodology to retain sediment on the samplers in 2014.

The effect of treatment was observable in a few metrics, with reduced abundance, biovolume, and possibly chl-a on samplers in the 102.5R Test side channel compared to the Control side channel (Figure 3-6). The unusually high deposition rates observed at the Test site in 2014 following enhancement construction may skew our correction factor because the depth of sediment on Test sample locations was substantially greater than that of Control locations.



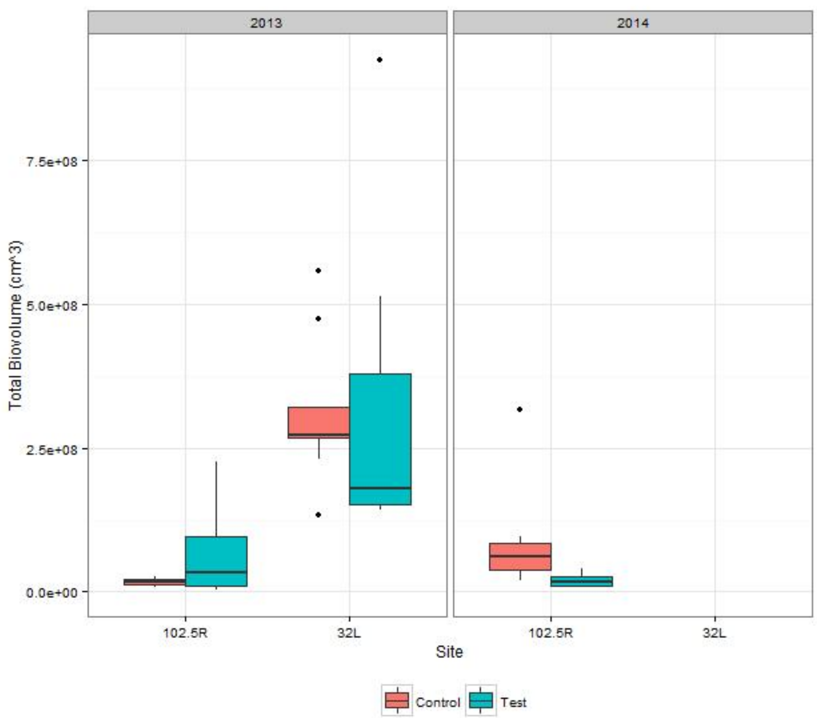
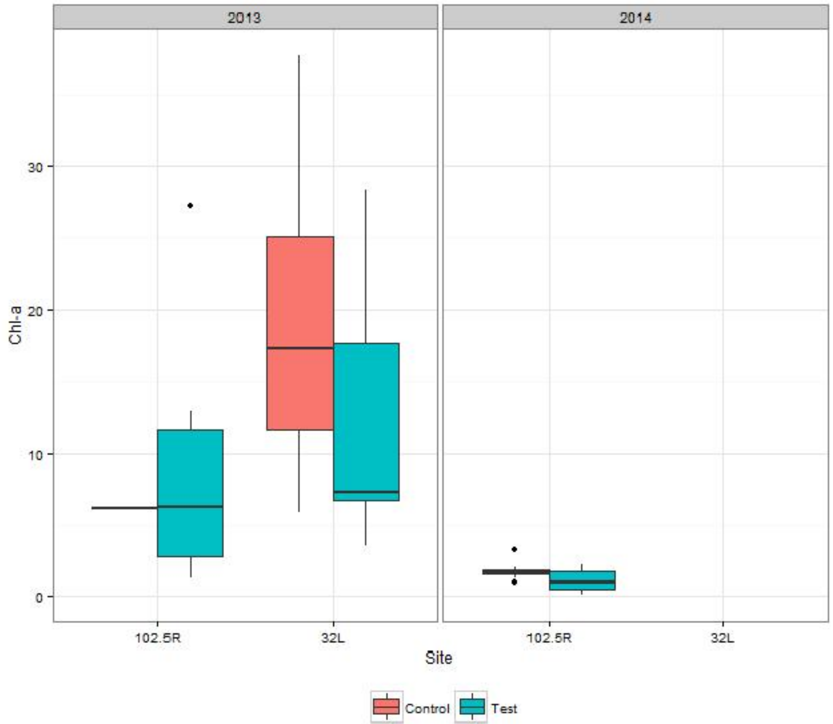


Figure A5-1: Box plots of Total Biovolume (cm^3/cm^2) and Total Abundance (# $cells/cm^2$) at control and test locations at the 102.5R and 32L sampling sites, broken down by sampling year (2013 Left / 2014 Right). The data is the combined total of samples from deposited sediments and from artificial styrofoam, adjusted for depth of deposited sediment



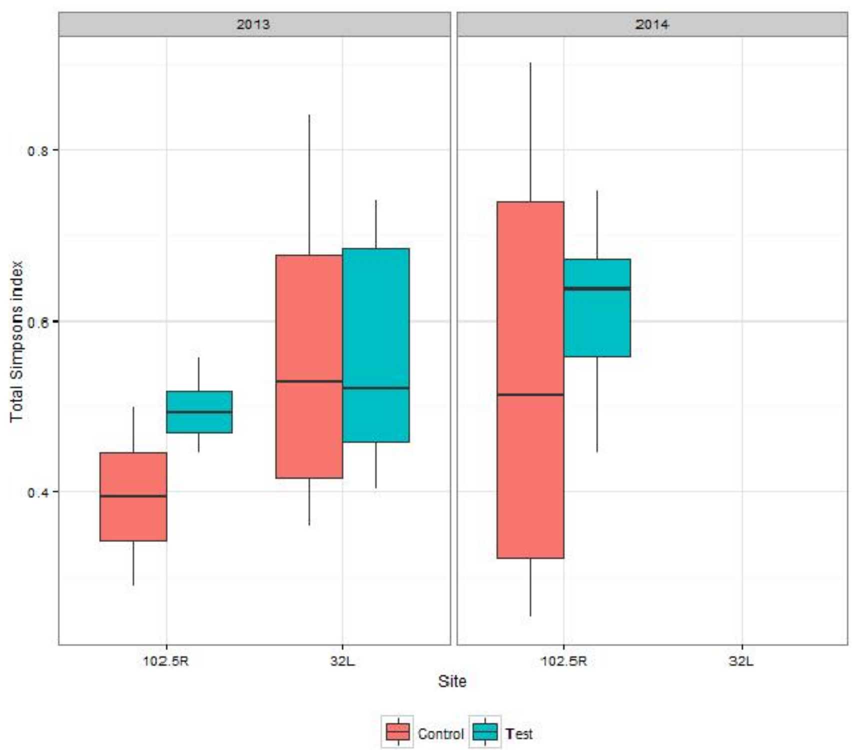
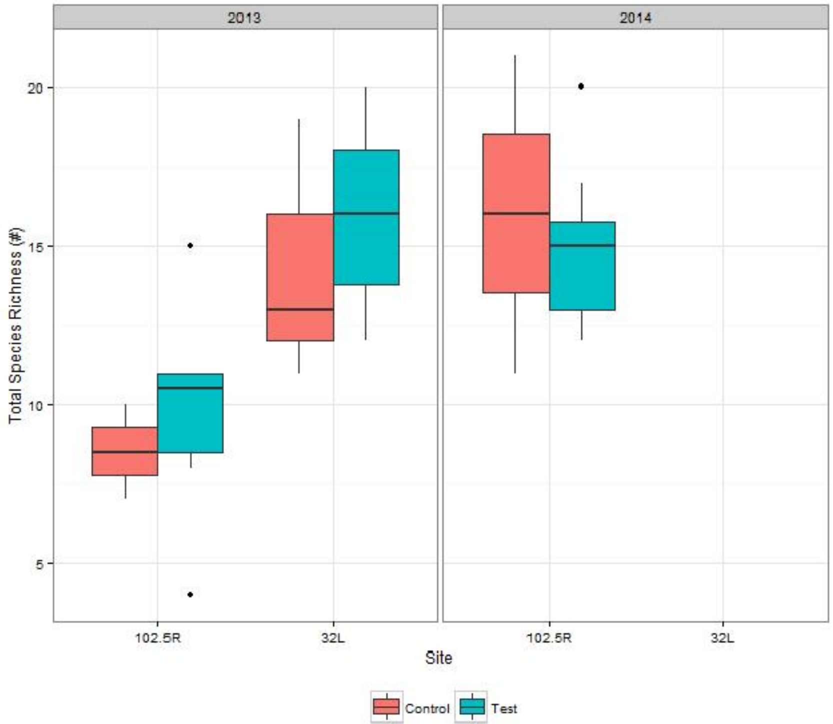


Figure A-5-2: Box plots of chl-a (ug/cm^2) and Simpson's Index at control and test locations at the 102.5R and 32L sampling sites, broken down by sampling year (2013 Left / 2014 Right). The data is the combined total of samples from sediments and from artificial styrofoam, adjusted for depth of deposited sediment.



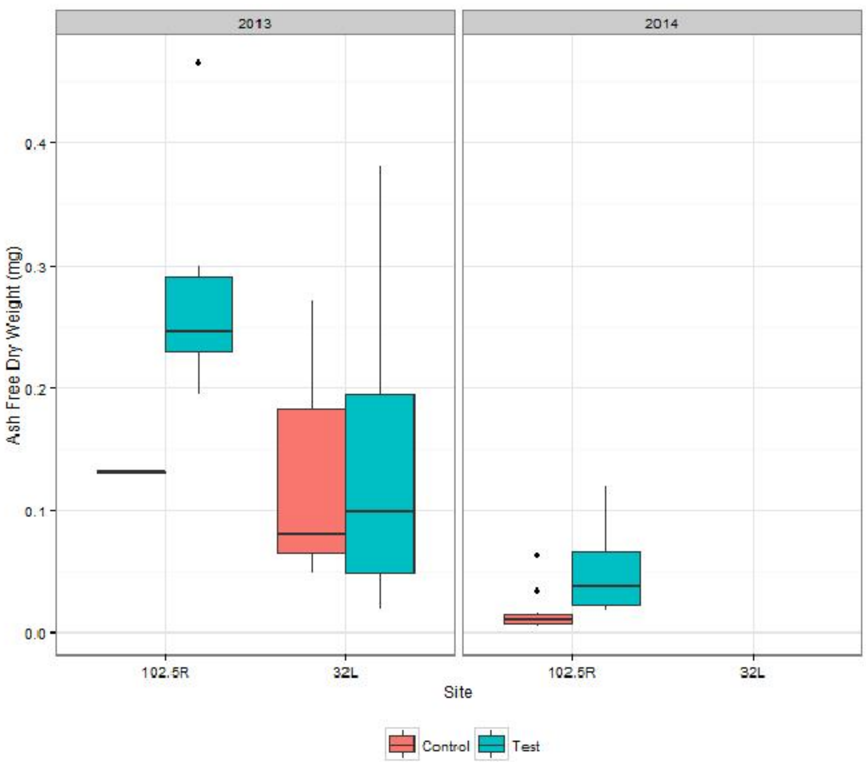


Figure A-5-3: Box plots of Species Richness (# taxa) and Ash Free Dry Weight (mg) at control and test locations at the 102.5R and 32L sampling sites, broken down by sampling year (2013 Left / 2014 Right). The data is the combined total of samples from sediments and from artificial styrofoam, adjusted for depth of deposited sediment.

Table A5-1: Relative abundance and biovolume of periphyton taxonomical groups from artificial Styrofoam substrates, deposited sediments and natural substrates at the 102.5R Control and Test sites in 2014.

Algae Group	Control - Styrofoam		Algae Group
	Abundance (%)	Biovolume (%)	
Blue Green	69.83%	57.19%	Diatom
Diatom	20.09%	36.02%	Green
Flagellate	7.81%	5.21%	Flagellate
Green	2.28%	1.58%	Blue Green
Algae Group	**Test - Styrofoam**		**Algae Group**
	Abundance (%)	Biovolume (%)	
Blue Green	51.82%	91.54%	Diatom
Diatom	44.41%	6.15%	Blue Green
Flagellate	3.51%	2.24%	Flagellate
Green	0.26%	0.07%	Green
Algae Group	**Control - Sediment**		**Algae Group**
	Abundance (%)	Biovolume (%)	
Blue Green	56.56%	75.75%	Diatom
Diatom	38.65%	20.45%	Green
Flagellate	3.22%	2.74%	Blue Green
Green	1.56%	1.06%	Flagellate
Algae Group	**Test - Sediment**		**Algae Group**
	Abundance (%)	Biovolume (%)	
Blue Green	62.83%	98.47%	Diatom
Diatom	36.74%	1.35%	Blue Green
Flagellate	0.42%	0.17%	Flagellate
Green	0.00%	0.00%	Green
Algae Group	**Control - Natural**		**Algae Group**
	Abundance (%)	Biovolume (%)	
Blue Green	61.65%	96.50%	Diatom
Diatom	37.88%	3.42%	Blue Green
Flagellate	0.47%	0.08%	Flagellate
Green	0.00%	0.00%	Green
Algae Group	**Test - Natural**		**Algae Group**
	Abundance (%)	Biovolume (%)	
Blue Green	70.92%	90.79%	Diatom
Diatom	27.97%	5.48%	Green
Flagellate	0.97%	3.43%	Blue green
Green	0.14%	0.29%	Flagellate

Appendix 6: Summary of Habitat Variables Considered in Modelling

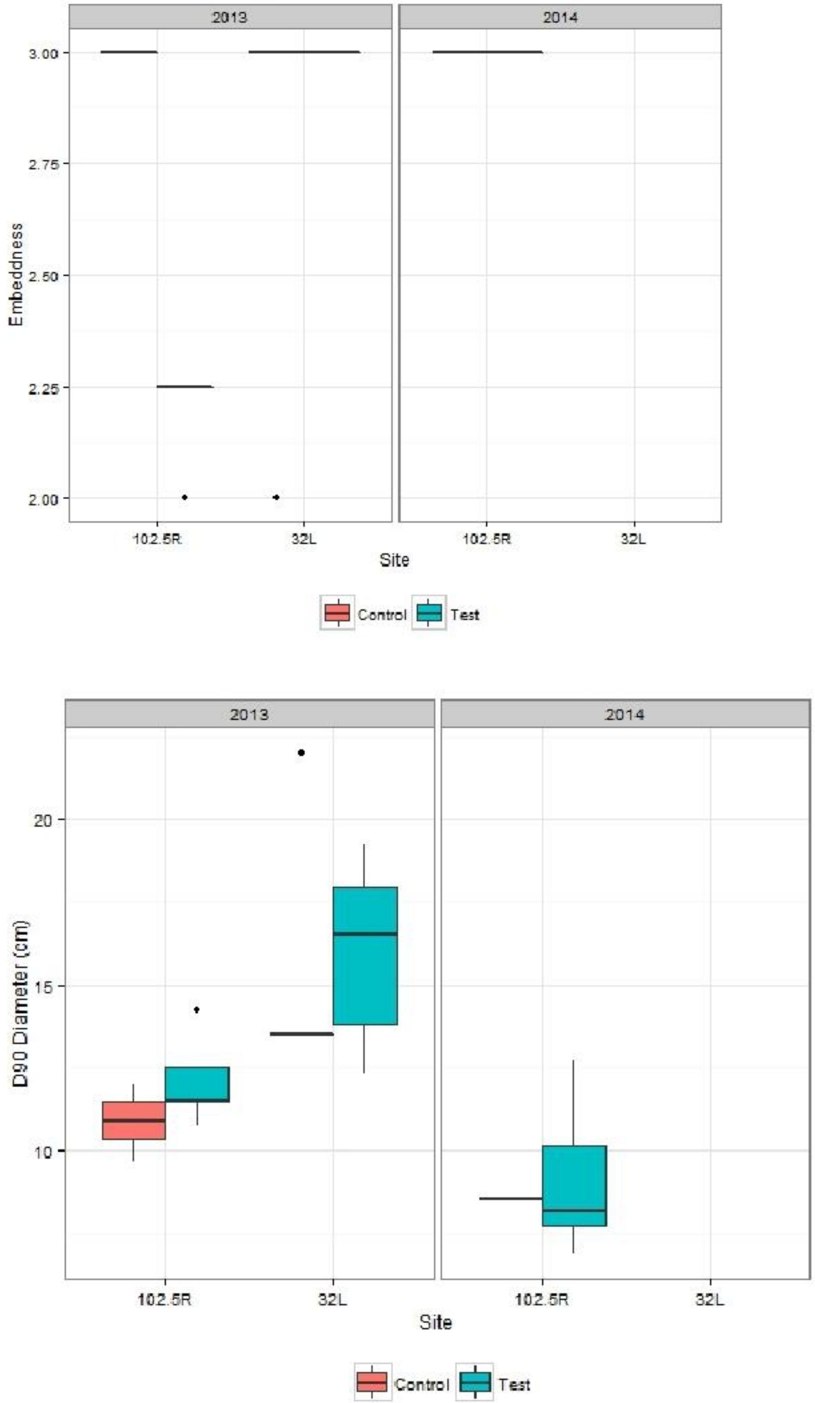


Figure A-6-1: Embeddedness and D90 Diameter of substrate size in the Peace River at the 32L and 102.5R sampling sites in 2013 and 2014.

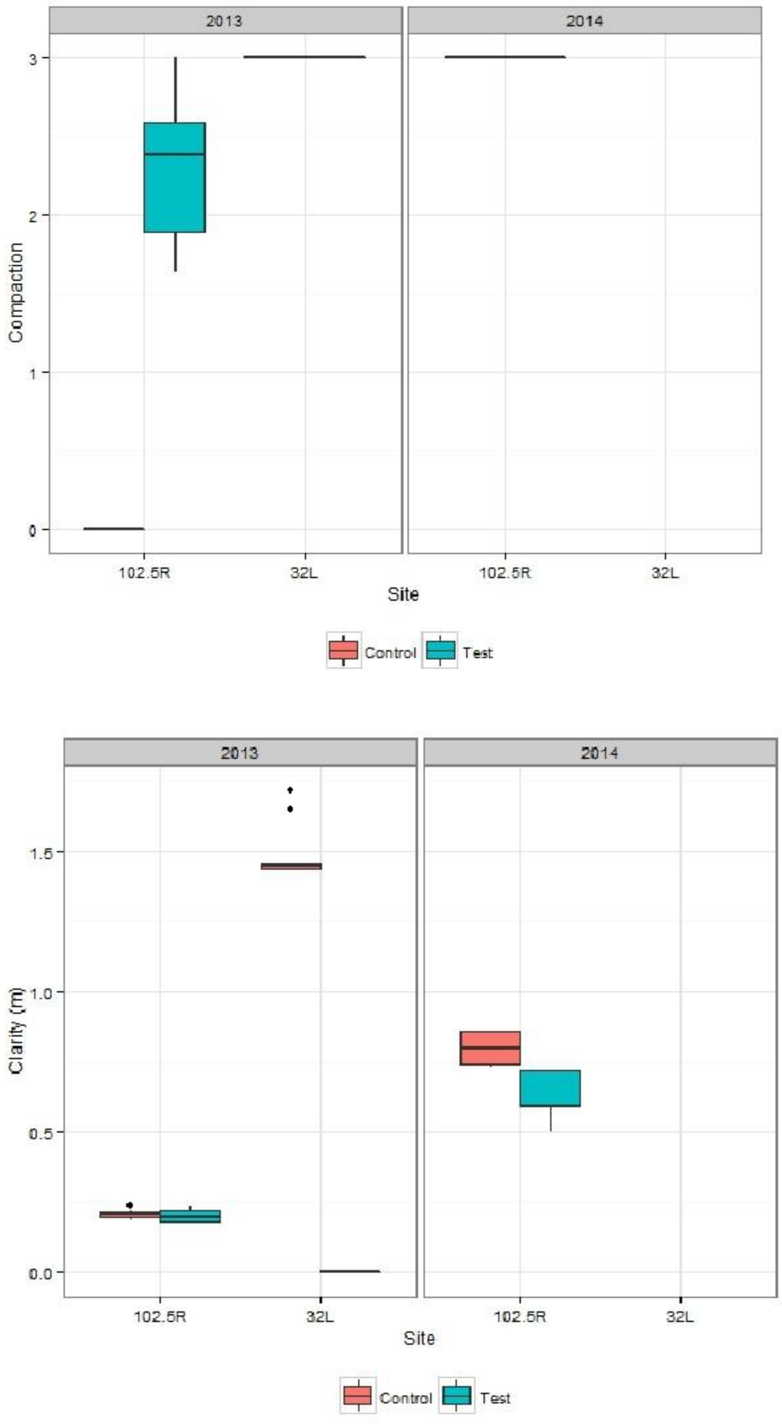


Figure A-6-2: Clarity and Substrate compaction at the 32L and 102.5R sampling sites in 2013 and 2014.

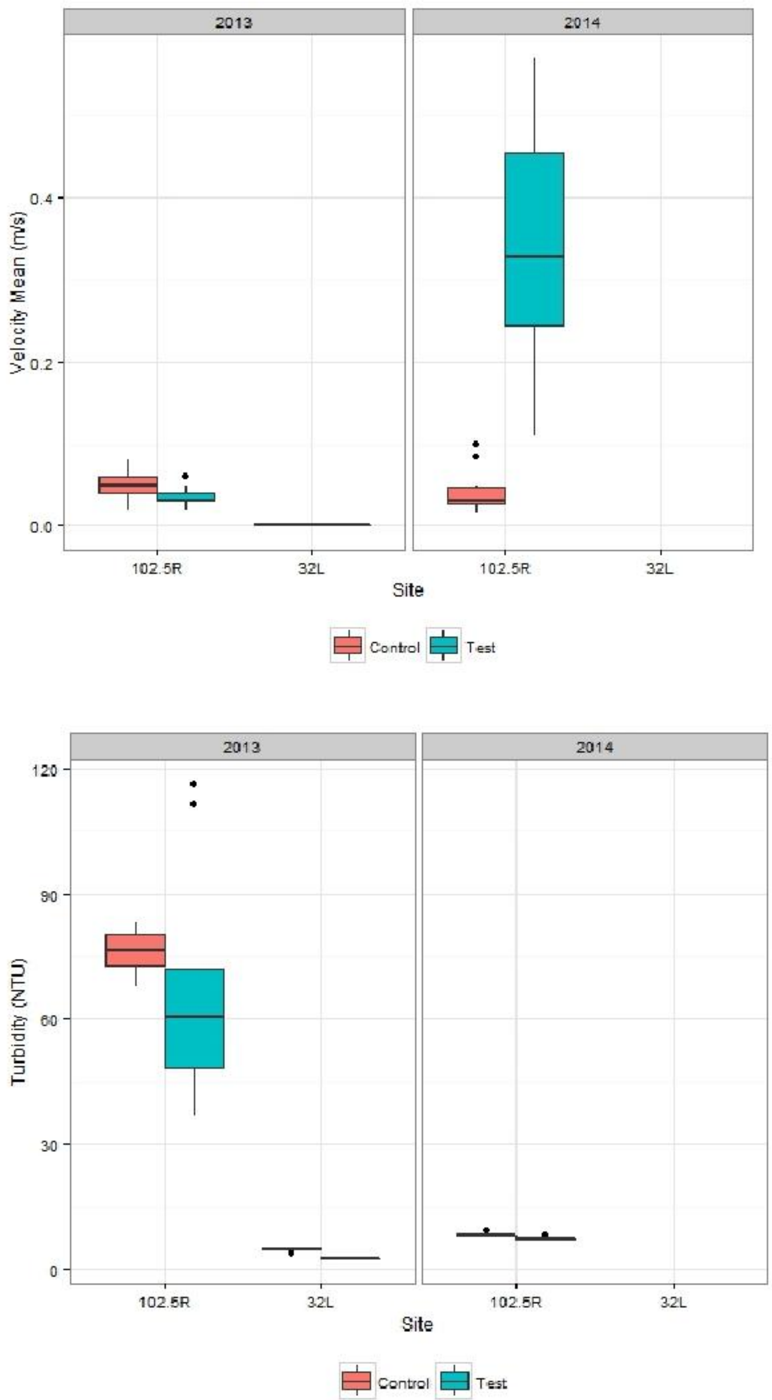
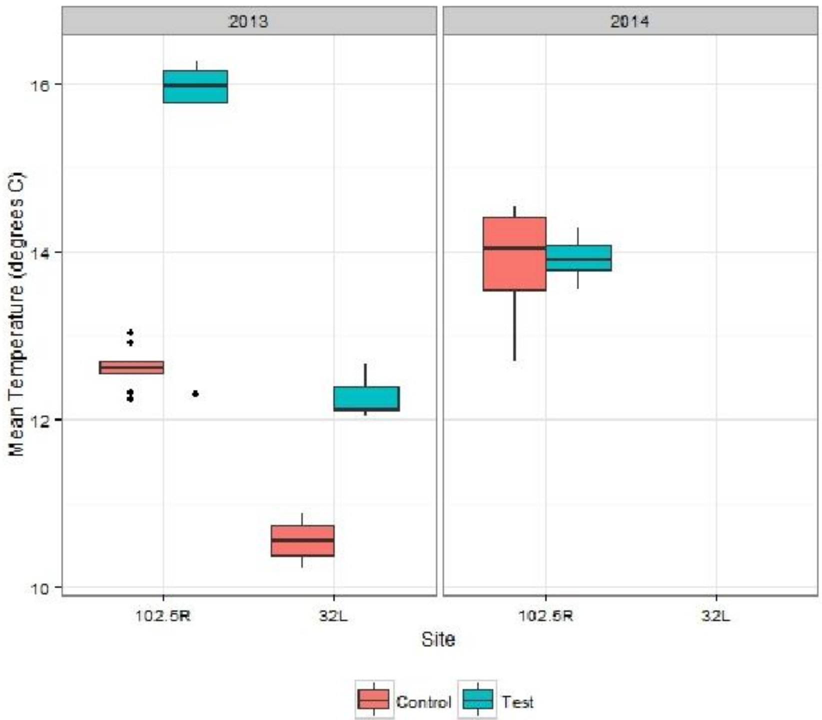


Figure A-6-3: Turbidity and Velocity in the Peace River at the 32L and 102.5R sampling sites in 2013 and 2014.



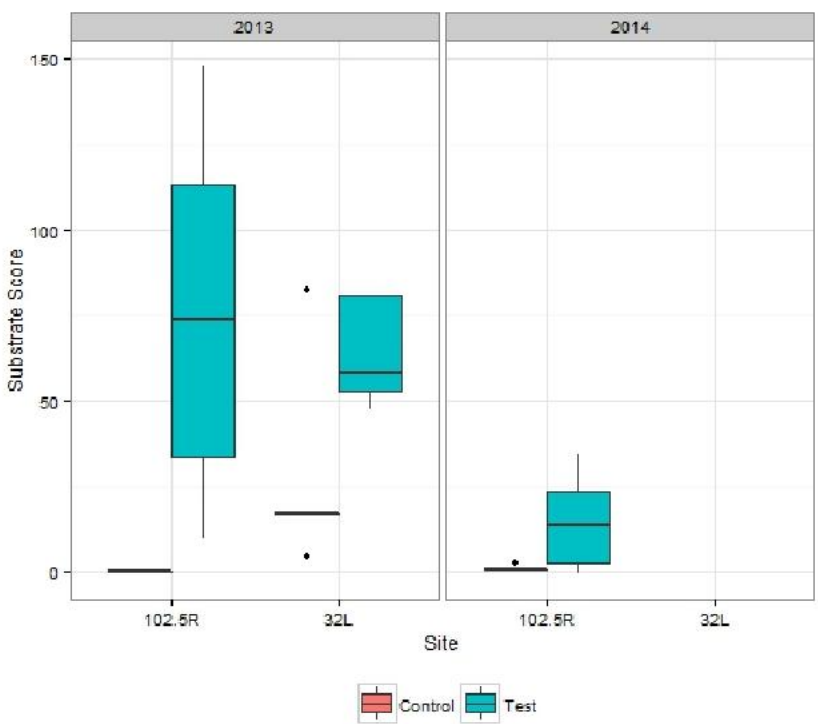


Figure A-6-4: Substrate Score and Mean temperature in the Peace River at the 32L and 102.5R sampling sites in 2013 and 2014.

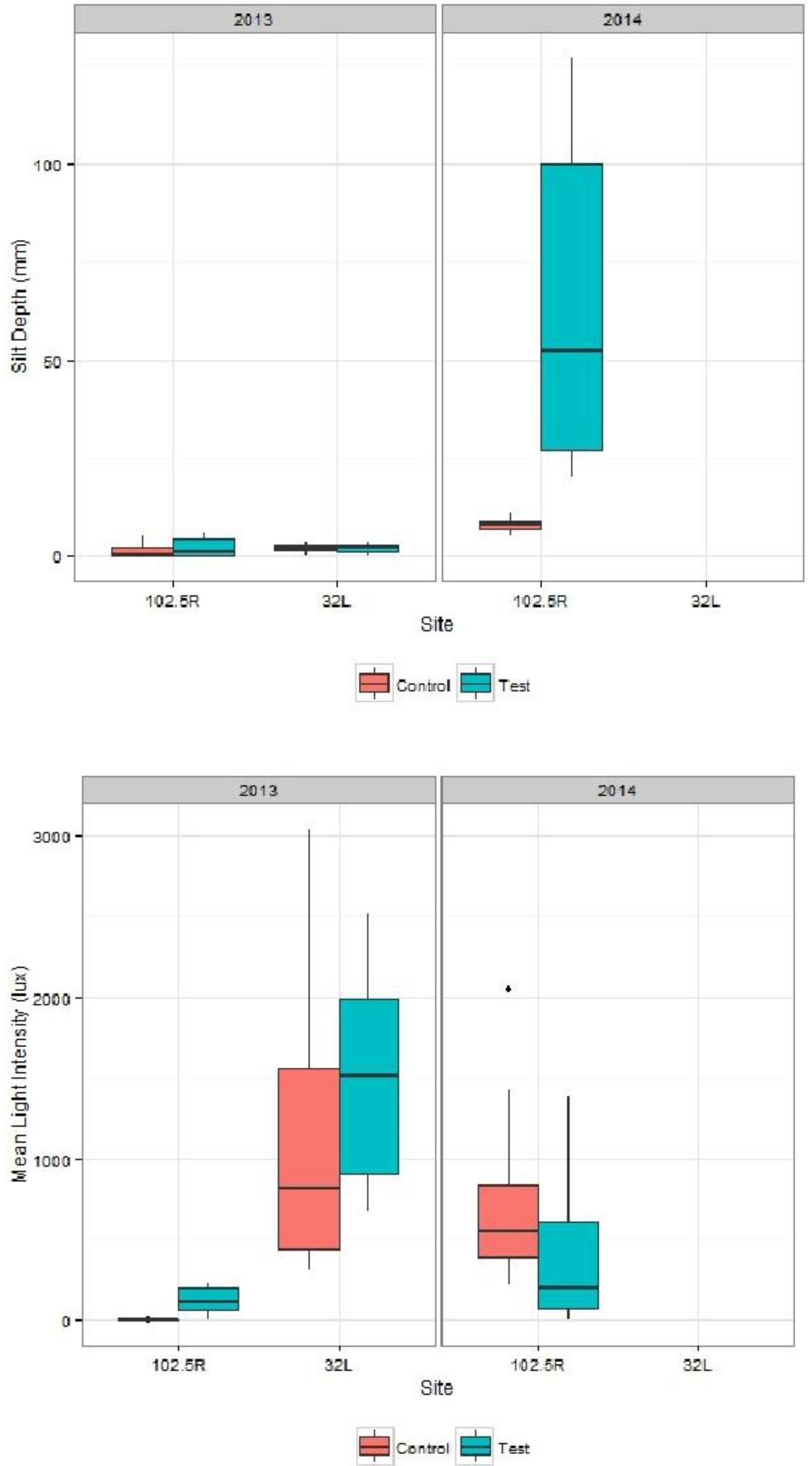


Figure A-6-2: Mean Light Intensity and Silt Depth in the Peace River at the 32L and 102.5R sampling sites in 2013 and 2014.