Peace River Project Water Use Plan

Peace River Productivity

Implementation Year 1

Reference: GMSMON-5

Peace River Water Use Plan Monitoring Program:

Peace River Productivity Monitoring

Study Period: 2013

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PEACE RIVER PRODUCTIVITY MONITORING YEAR 1 (2013)

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EXECUTIVE SUMMARY

This report summarizes Year 1 of a multi-year study on benthic production in 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 intended to enhance fisheries productivity within side channel habitats on the Peace River. Year 1 focussed on collection of baseline and pre-construction data, and therefore, the results are tailored to summarizing the physical habitat conditions of side channel areas. The following are the 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 1 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: 2013 was intended to collect baseline data prior to habitat augmentation. As a result, it is too early to answer this management question. Baseline data suggests that turbidity, sediments and location are all important determinants of periphyton productivity in side channel locations. The data collected suggest that the photic zone within side channels is typically less than 2 m, meaning that accrual likely occurs in different bands within the river that vary with depth and therefore light penetration.
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: 2013 was intended to collected baseline data, prior to habitat augmentation. Thus, it is too early to provide an answer regarding this management question. The data collected in 2013 at the downstream location suggests that turbidity, sediments, 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, 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. A considerable proportion of the algal community originated from upstream reservoirs (e.g., Dinosaur) and was deposited on side channel substrates, while algal and periphyton production on substrates within side channels is comparatively low. Photosynthetic bacteria may also play an important role in primary production within the side-channel substrates.

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. Artificial substrate sampler deployment occurred immediately following low annual flows in mid-June, at depths of approximately 1.5 to 2 m. Samplers were deployed at locations that would be permanently submerged and within a typical productive zone (1.5 – 2 m) to avoid confounding effects of varial zone submergence or water depth. These water depths, coupled with high turbidity, were sufficient to substantially attenuate light at sampling locations, suggesting that the most productive areas of the side channels occurs at river elevations that create depths between 0 (elevation of minimum flow over the past 60 days) and 1.5 m.

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 at 1.5 to 2 m depth were substantially lower than those typical in mainstems of regulated rivers, likely due to the high light attenuation observed. Since light scatters and attenuates quickly in turbid waters, we speculate that turbidity or sediment deposition rates are extremely important and this was corroborated by results from preliminary habitat modelling. Substrate size and sampling location were also important predictors of the periphyton community.

Invertebrate productivity was assessed using eight metrics: Abundance, Biomass, Ephemeroptera / Plecoptera / Trichoptera (EPT) Richness, Percent EPT, EPT Richness, Percent Chironomidae, Simpson's Index, and Hilsenhoff Biotic Index (HBI). Turbidity or light attenuation 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 river. This collector-gatherer foraging group was more predominant because it tends to reside in river sediments where detritus and other foods are readily available. Modelling of the HBI indicates that as water clarity decreases, there is a higher predominance of more pollution tolerant species, or groups such as Oligochaetes, acknowledging that the HBI does not distinguish between turbidity tolerant and pollution / turbidity tolerant species. Food available for fishes in Peace River side channel areas is therefore likely influenced by water turbidity in these channels. Since light attenuates very quickly in turbid water, changes in water depth resulting from flow regulation are also extremely important.

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.

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
GMSMON	Peace River Side Channels Program
GMSMON5	Peace River Ecological Productivity Monitoring (this study)
GMSMON2	Peace River Ecological Fish Indexing
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
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 (AFDM / 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 or event	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	Algae that have hard, silica-based "shells" frustules
Euphotic	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)
Functional Feeding group	(FFG) Benthic invertebrates can be classified by mechanism by which they forage, referred to as functional feeding or foraging groups
Invertebrate Production	Benthic invertebrate biomass, abundances, and measures of diversity
Light attenuation	Reduction of sunlight strength during transmission through water
Microflora	The sum of algae, bacteria, fungi, Actinomycetes, etc., in water or biofilms
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

Regulated rivers can have direct effects on fisheries productivity of aquatic habitats. The magnitude of this effect depends upon many factors such as flow regulation (e.g., Schleppe *et al,* 2013) and the types of habitat present (Gregory *et al.* 1991, Allan and Flecker 1994, Blinn *et al.* 1995). On the Peace River, the absence of historic peak flows due to impoundment by the hydro-electric dams has led to numerous morphological changes, such as reduced flushing rates at the mouth of side channels for instance (Church *et al.* 1997). These morphological changes are anticipated to take 10^3 years before being fully realized, with most of the observable change occurring during the first 100 years (Church, 1995). A 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 to occur in the Peace River. The anticipated changes in river morphology also have the potential to affect fish habitat, including fisheries productivity.

The Peace River Water Use Plan Consultative Committee (WUP), of the BC Hydro Power Authority (BCH), is seeking to mitigate negative impacts of flow regulation by the Peace Canyon Dam (PCD) to downstream fish populations. In lieu of increasing dam release minimum flows, the Peace WUP plan is to excavate side channel access areas in order to improve fish habitat at low flows. Studies on other river systems provide a general framework for understanding how various 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 as part of the Peace River Ramping Plan. 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 Peace Canyon Dam.

This report summarizes Year 1 (2013) of the benthic monitoring program. A focus has been placed on characterizing how physical habitat parameters affect periphyton and invertebrate diversity and production because this year was intended to collect baseline information on control sites and experimental test sites that will be dredged. For invertebrates, only downstream areas were assessed because the short time between field collection and reporting deadlines meant that not all data had been processed at the time of report preparation. For periphyton, both upstream and downstream locations were assessed.

1.1 Objectives, Questions, and Hypotheses

The two main objectives of the Peace River Monitoring program 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 improvement program affects the availability of food for fishes in the Peace River.

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. 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 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 the Request for Proposals, that the evaluation of Peace River Ramping Plan is also to occur.

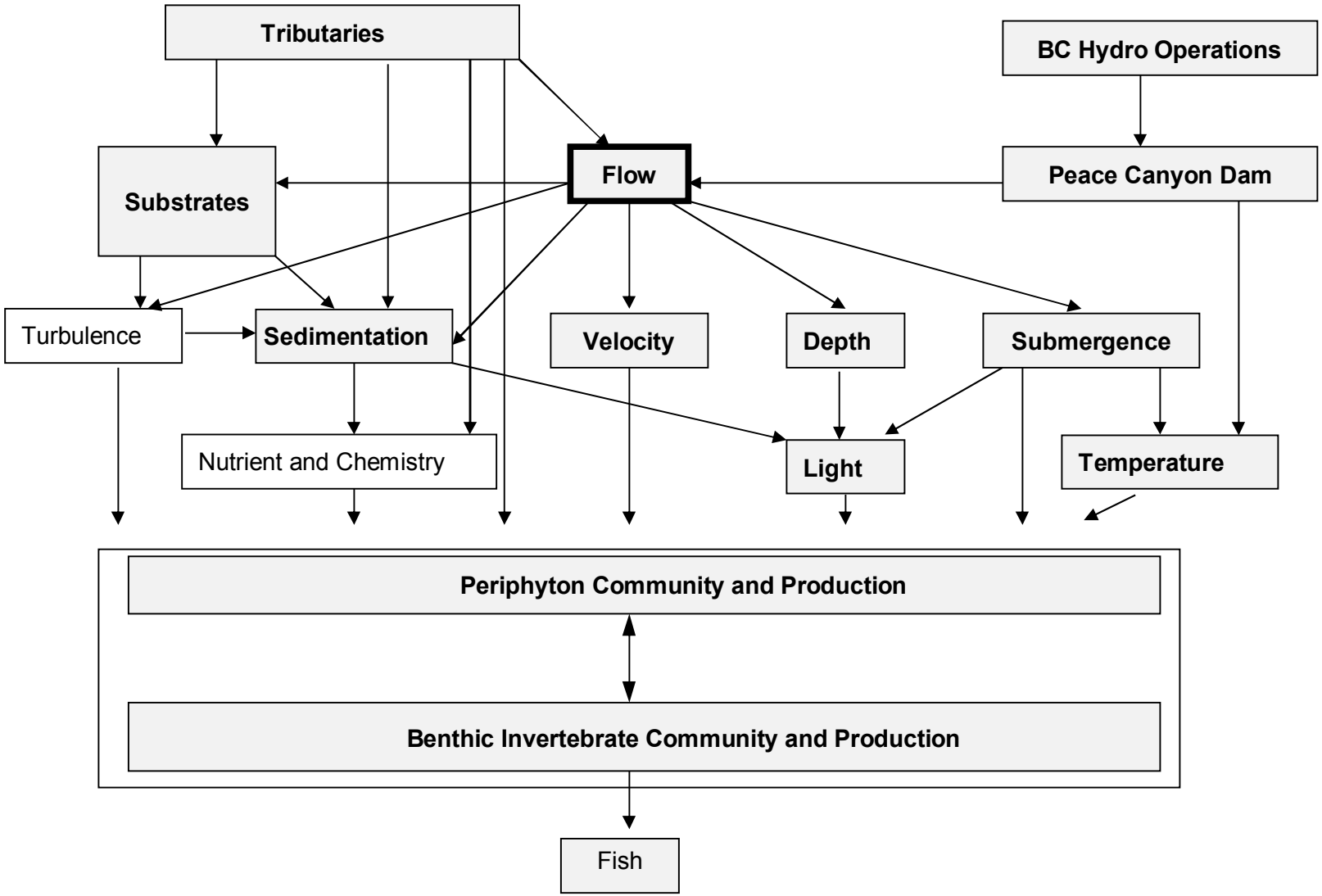

Figure 1-1: Conceptual interactions model of habitat variables and benthic production as they relate to food for fish in the Peace River. Variables highlighted with bold text in grey boxes represent parameters being assessed in this study.

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, noting that in 2013 only the downstream data (50% of the total dataset) is presented. 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.	This program element has not yet been addressed because only baseline data prior to construction of the first demonstration channels is available.

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 Dams (Figure 2-1). The study area is divided into two study locations which are further divided into Control and Test sites (Table 2-1 & Figures 2-1 to 2-5) selected by BCH (NHC, 2010).

The first study location includes two side channels downstream of Hudson's Hope and upstream of the Halfway River: 32L Test and 32L Control. 32L Control and 32L Test are approximately 1 km and 11 km upstream of the mouth of the Halfway River, respectively. Both sites are located on the river left or the left side of the river when looking downstream.

The second study location includes two side channels in the vicinity of the boat launch at Peace Island Park: 102.5R Test and 102.5R Control. 102.5R Test 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. The downstream sites occur below the Pine, Moberly, and Halfway River tributaries. These tributaries are the largest sources of turbid water within the Peace system within the study area of concern in this work.

The values "32" and "102.5" correspond to the approximate 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 clarity, the test and control sites were labelled with the same distance and bank qualifiers even though they are slightly further upstream/downstream from each other. Within each Control or Test site, nine samplers were deployed at random locations at depths between 1.5 to 2 m.

Another key difference among these two study areas is their orientation to unregulated tributaries flowing into the Peace River. 32L is upstream of the confluences of the Halfway, Moberly, and Pine Rivers. Consequently, the effects of these tributaries on these side channels are likely to be minimal. In contrast, 102.5R is below the confluence of these rivers, and their flows are likely to greatly mitigate measureable effects of Peace Canyon Dam flow regulation on side channel stage level in this downstream location. These tributaries can also be major sources of suspended solids which could results in additional differences in turbidity among 32L and 102.5R.

Figure 2-1 shows the study area and study locations along the Peace River. There are several large tributaries to the Peace River that likely influence overall productivity within it. Halfway River is immediately downstream of the 32L sites and Pine River is immediately upstream of the 102.5R sites.

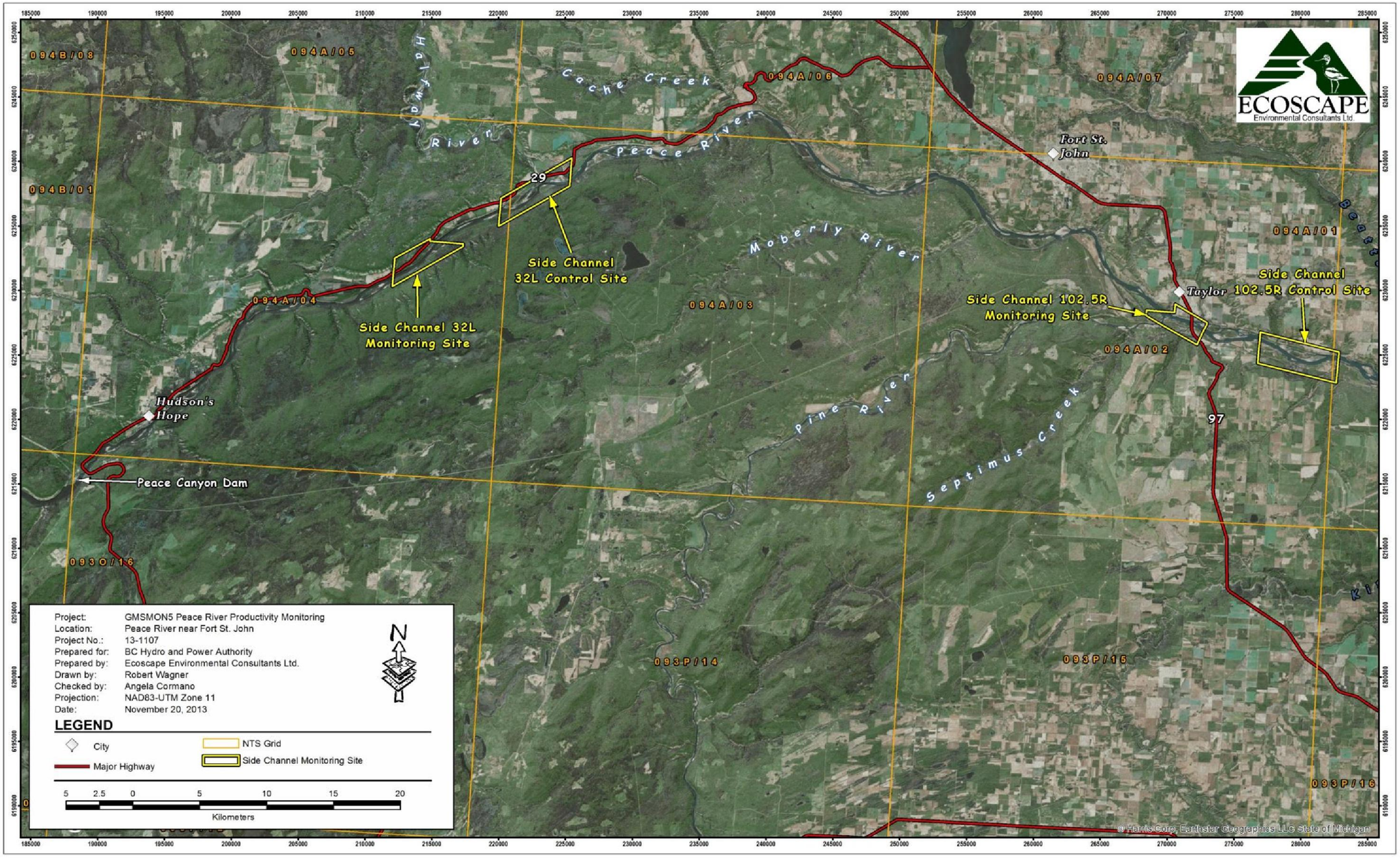

Figure 2-1: Map of the study area and sampling locations.

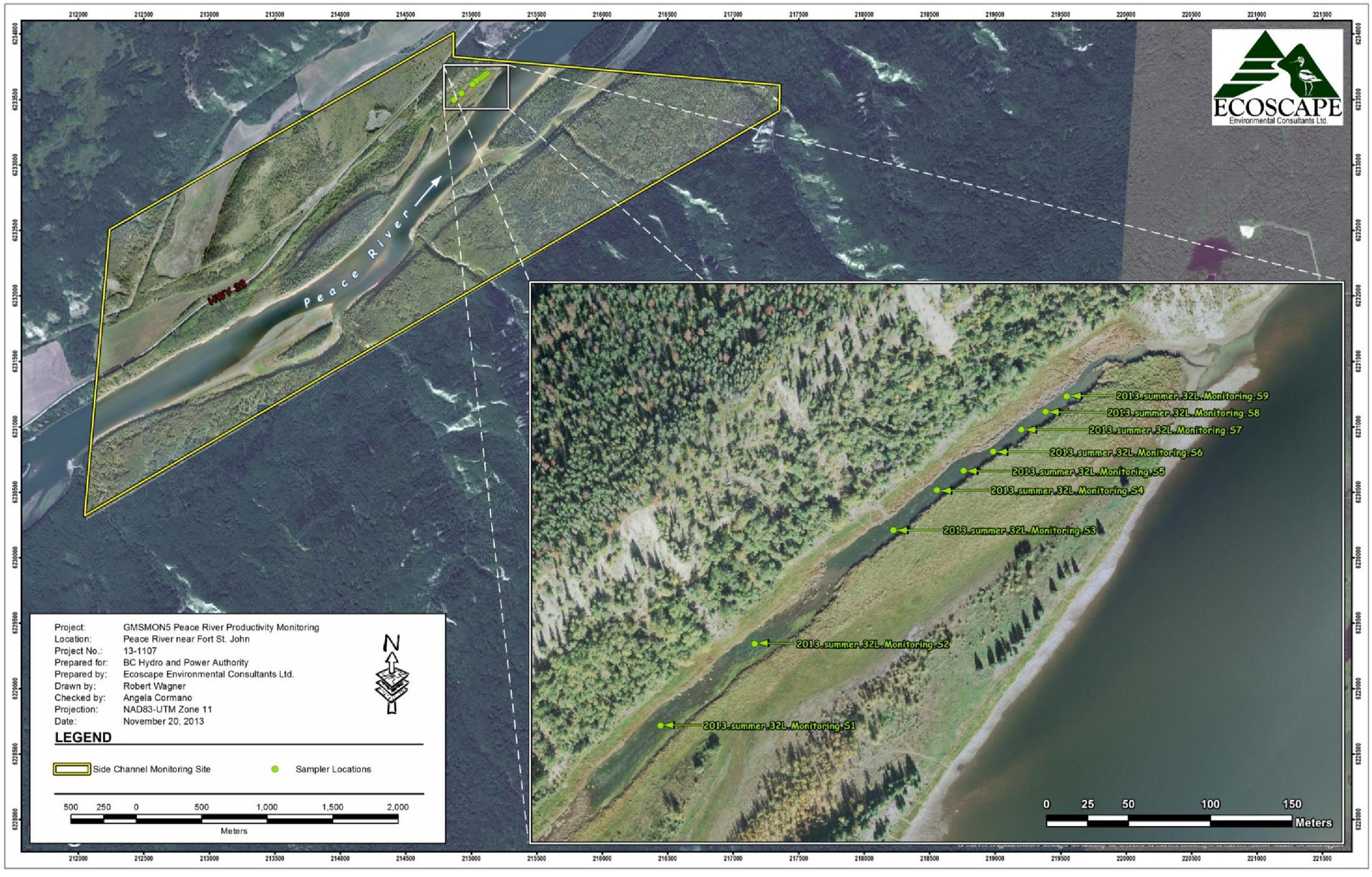

Figure 2-2: Map of the 32L Test study area

Figure 2-3: Map of the 32L Control study area

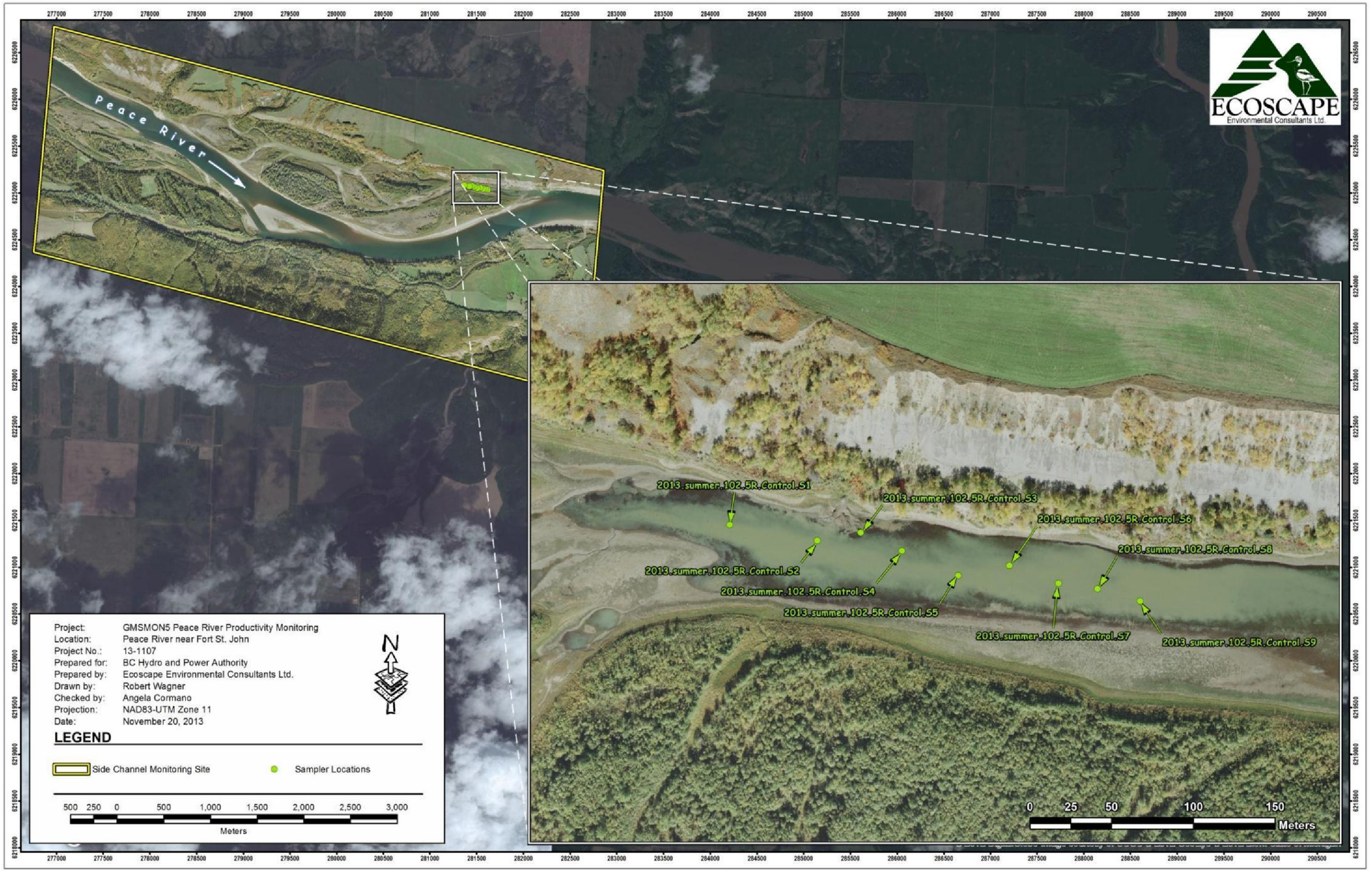

Figure 2-4: Map of the 102.5 Control study area

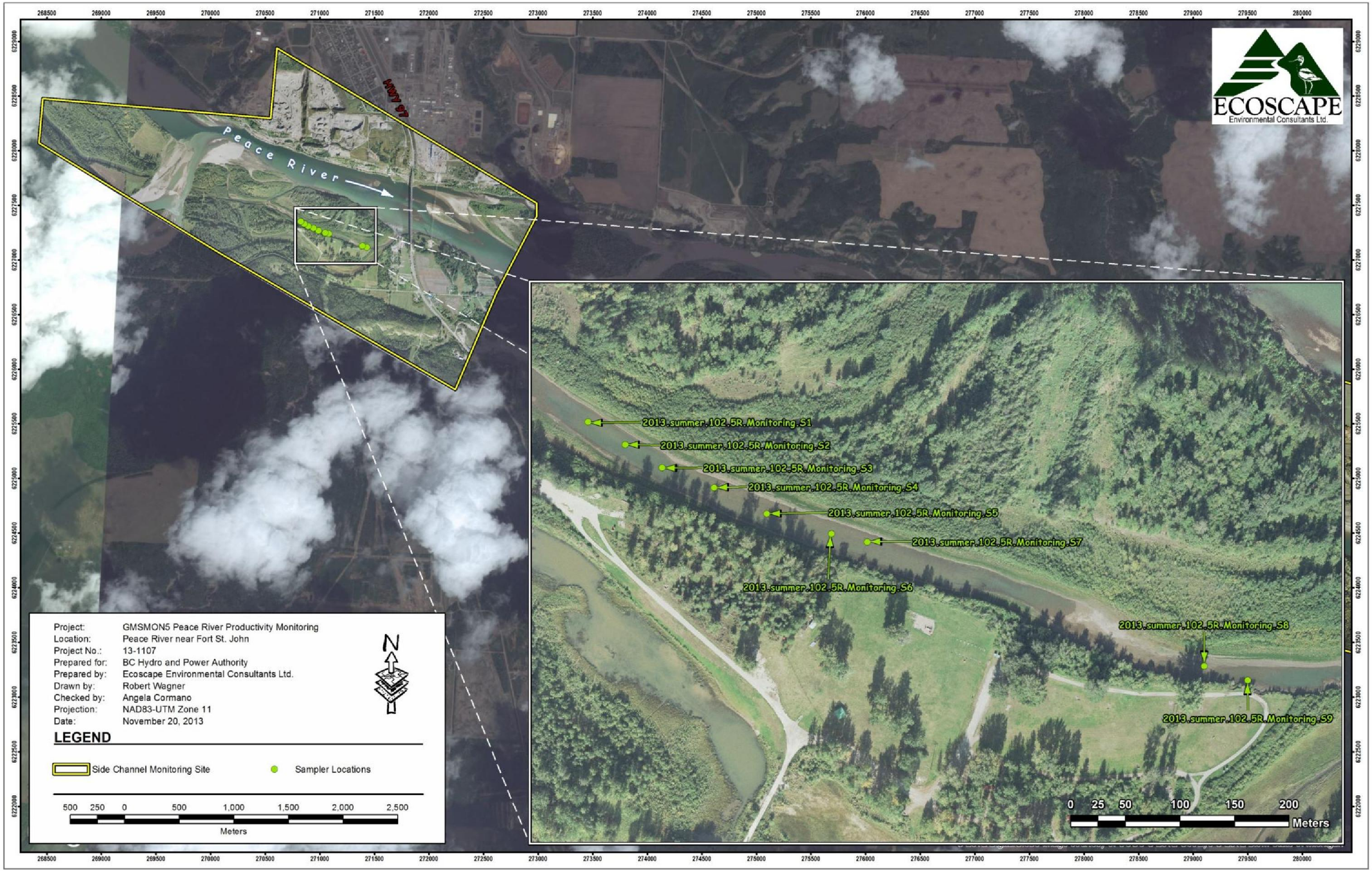

Figure 2-5: Map of the 102.5 Test study area

2.2 Periphyton and Invertebrate Community Sampling Using Artificial Samplers

2.2.1 Artificial Sampler Design and Deployment

The benthic sampler design was based on Perrin (2004) and involved a mounted closed-cell Styrofoam sheet as a periphyton artificial substrate and a wire basket filled with 2.5 to 5 cm rock as a benthic invertebrate artificial substrate.

Samplers and rigging were assembled and deployed on July 3, 2013 at the 102.5R side channel sites and on July 4, 2013 at the 32L side channel sites. All samplers in the 102.5R side channels, and six of nine samplers in the 32L Control site were deployed by boat. The remaining three 32L Control site samplers and all nine samplers in 32L test sites were deployed by wading because of low flows. Figure 2-6 illustrates the standard artificial sampler design which was modified from other projects completed in the Lower Columbia and Middle Columbia River (Schleppe *et al.* 2012, 2013).

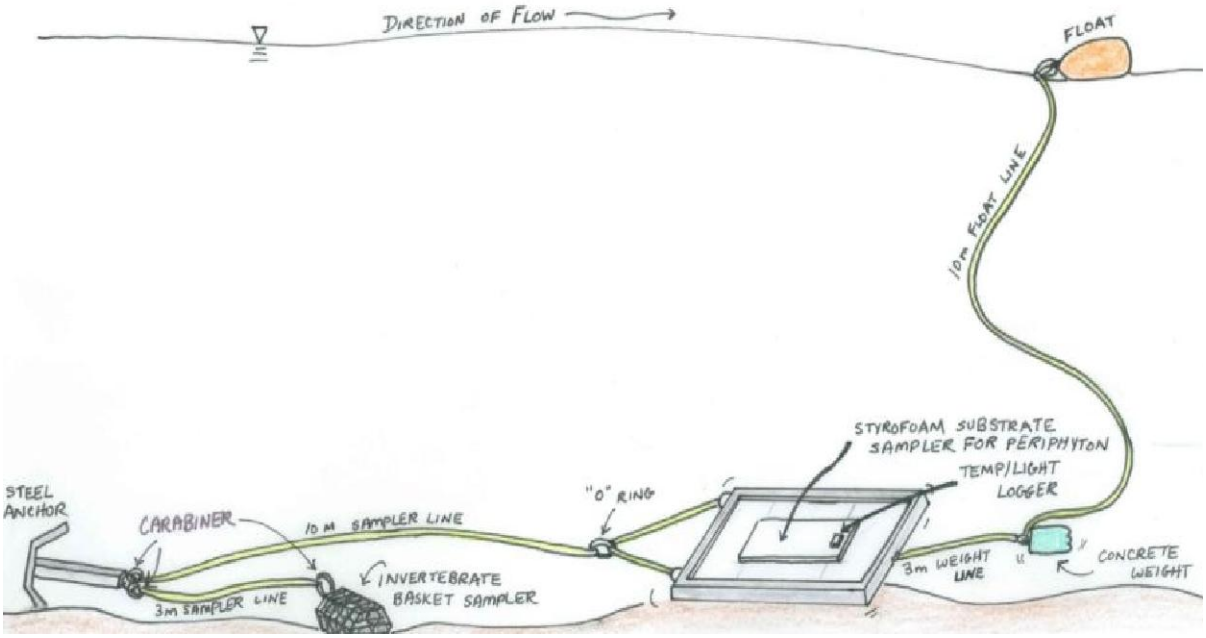

Figure 2-6: Schematic drawing of a standard artificial substrate sampler

This sampling apparatus included a separate sampling line for the benthic invertebrate sampler to allow the sampler to remain undisturbed on the bottom of the river during periphyton time series sampling. Periphyton accrual time series samplers were held on the bottom with a concrete weight attached to a 3 to 5 m cord to the back of the sampler. A float used for retrieval was attached with rope to the back of the plate via the concrete weight. 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.

Samplers were deployed at depths of 1.5 to 2 m within permanently submerged areas. This depth range was chosen because it is typically a highly productive zone (Larratt et al, 2013) and because it was anticipated that samplers at these depths would remain permanently submerged. Deploying samplers in areas that remain permanently submerged reduces confounding effects of variable submergence. This is similar to

GMSMON2, where only permanently submerged areas that fish had access to were assessed (Mainstream, in prep).

Table 2-1: Artificial sampler deployment and retrieval in 2013

Site	Treatment	Periphyton Samplers		Invertebrate Samplers		Temp/Light Loggers	
		#Deployed	#Retrieved	#Deployed	#Retrieved	#Deployed	#Retrieved
32L	Control	9	9	9	8	9	9
32L	Test	9	9	9	9	9	9
102.5R	Control	9	9	9	9	9	9
102.5R	Test	9	8	9	8	9	7

Table 2-1 provides a summary of the samplers deployed and retrieved. One of the baskets at the 32L Control site was lost and the field team suspected the sampling apparatus was likely tampered with and that the invertebrate basket was "unclipped". At the 102.5R Test site one entire sampling apparatus including the periphyton sampling plate, invertebrate rock basket, light/temperature logger, and anchors were lost likely due to tampering, as the float was discovered "unclipped". One of the plates that was retrieved from 102.5R was missing a temperature/light logger. Sampler number 3 (S3) in 32L Control side channel was found at the mouth of the channel at retrieval instead of where it was deployed. Given the low flows and water velocities in these side channels these losses and movements of samplers were likely due to tampering rather than damage from high flows.

In addition to the 36 Onset Hobo temperature and light loggers (Accuracy ± 0.53°C from 0° to 50°C) deployed on the sampler apparatus, three additional loggers were installed on shore adjacent to the 32L Control, 102.5R Control and 102.5R Test sites to correlate submerged data with conditions at the river surface. Loggers were set to take temperature and light measurements every 0.5 hours over the duration of deployment.

2.2.2 Artificial Sampler Retrieval

Artificial samplers remained in the river for a total of 48 days, within the previously defined incubation period of 40-50 days for attainment of peak biomass (Perrin et al. 2004).

Periphyton samples were collected for the following metrics: 1) Chlorophyll-a, as an estimate of live autotrophic biomass; 2) Ash-Free Dry Weight (volatile solids) / total dry weight, as an estimate of the carbon component (Stockner and Armstrong, 1971); and 3) taxa abundance, composition, and biovolume, which provide an accurate estimate of live and dead standing crop (Wetzel and Likens, 1991).

The sampling conditions within the Peace side channels that were present at the time series sampling event necessitated a revision to the sampling methodology proposed by Ecoscape and used on other large river studies on the Columbia River. During time series, it was observed that many of the samplers were covered in a fine sediment film, which was anticipated to have an effect on periphyton abundance and chlorophyll-a (chl-a). The retrieval sampling protocol was subsequently altered to include both sediment (fines) and Styrofoam samples. Upon retrieval, three 6.6 cm^2 punches (one for Chlorophyll-a, one for taxa analyses, and one for quality assurance/backup), and a fourth

56.6 cm^2 punch (for AFDW) were randomly collected from each periphyton plate, for both Styrofoam and fines. The condition of the plate upon retrieval dictated the sampling method. If the entire plate was covered with fine sediment, the three 6.6 cm^2 and one 56.6 cm^2 fines punches were collected, after which the plate was lightly rinsed in order to collect Styrofoam samples free of fines. Where the amount of fines on a sampler were too limited, only the three smaller fines punches were collected and not the larger punch for AFDW. Finally, where the plate was retrieved free of visible sediment, no fines samples were collected. Where fines samples were collected, three measurements of average fines depth (in millimeters) were taken to quantify the amount of fines deposited on the plate at the sample location. At the time of collection, punches were placed in pre-labeled containers and stored on ice until further processing (see below). While plates were lifted through the water column carefully to avoid considerable loss of deposited fine sediments, such losses invariably did occur in some cases. While this likely led to some unaccounted for error in fines depth, the effects on productivity or community measurements are likely to be minimal as these were calculated per unit area/volume of collected sediment.

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 as per the methodology used on other large river productivity projects. However, using this net gave rise to serious safety and navigational concerns due to it being large and awkward to use in the limited workspace available on deck with three to four crew members and other cumbersome equipment (plates, survey gear, etc.). Use of a net is more pertinent in higher water velocities, where risks of invertebrate losses are greater (e.g., velocities in excess of 1 m/s). Owing to these circumstances, the net was not used during retrieval, but every effort was made to transfer the basket immediately into the bin as it broke the water's surface. Given the low overall number of benthics in samples, and minimal losses to nets observed in other field surveys employing this method in high water velocities (e.g., Schleppe *et al.* 2012), losses were expected to be minimal. Sampling of natural substrates in future years will help to correlate natural samples to our artificial sampling methodology. Therefore, this amendment to the proposed methodology will have minimal effects on the quality of data. However, Ecoscape will consider sourcing a smaller, more compact net to 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 in order to release clinging invertebrates. Washed rocks were then rinsed in the sample water, before being placed back in the basket and stored for re-use in future years. The contents from each bucket were then captured on a 100 µm sieve, rinsed into pre-labeled containers, and preserved in 95% Ethanol for later analysis.

2.2.3 Time Series Samplers

In addition to samples collected during retrieval, time series samples were also collected within 26-29 days of deployment, in which one set of Styrofoam punches were randomly sampled from each periphyton plate. Because large accumulations of sediment on the samplers before time series sampling was not expected, only one set of punches (combined sediment and Styrofoam) was collected per plate and separate Styrofoam and fines data are not available.

2.2.4 Post Processing of Periphyton Samples and Enumeration

All periphyton sampling and processing follow those used in BC Hydro Columbia Projects (e.g., 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 our standard methods were necessary. In our review of other productivity works on the Peace River, sediment deposition did not appear to be as prevalent, possibly due to increased velocity within the mainstem areas (Golder, 2012).

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 too opaque and a 1 **:** 10 dilution with distilled water was required for microscope work.

Samples were allowed to settle in counting chambers over 24 hours. Cells were counted along mid-section transects examined at 500X-900X magnification under a Carl Zeiss 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.

2.2.5 Post Processing of Invertebrate Samples and Enumeration

Following retrieval, 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 µ 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 organisms were found, sub-sampling was used. The sample was floated on a level screened tray and the tray divided into 48 squares. The squares are randomly chosen and sorted in their entirety until 200 invertebrates were found.

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, 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 is either achieved or the sample was sent to a third taxonomist.

2.2.6 Physical Habitat Data

Physical habitat data was jointly collected with GMSMON2and this report should be referred to also for specific information on the methods used to collect some of the physical habitat data (Mainstream, 2013 in prep). Table 2-2 provides a summary of how collected physical data was used in physical habitat modelling.

2.2.7 Field Turbidity and Water Transparency Measurements

In situ turbidity measurements were taken near the surface of the water column using a Hach 2100 P (±1% scale) turbidity meter by Mainstream Aquatics as part of GMSMON2 and reporting for this project contains information on calibration and collection methods. Water transparency was measured by lowering a standard 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. A view tube was not used because the Peace side-channel Secchi depths were all less than 1 m.

2.2.8 Sediment Settling Experiment

Sediment setline rates were determined to better understand both the rate of settlement and the size of particles settling on the samplers. Sediment samples from the 32L Control sites were used for this analysis. The sediment was washed off of each punch from the 32L Control sample series (S1 - S8) into 20 mL of de-ionized water. Each prepared silt sample was then added to the top of a 1 L Brewer's flask filled with 1 litre of room-temperature (~21 °C) de-ionized water. A Stempler pipette was used to sample the surface water in each Brewer's flask into 10 mL cuvettes at set time intervals for a duration of 125 hours. The time intervals sampled had increased frequency during the initial 25 hours and then a subsequent reduced frequency during the remaining 100 hours. The filled cuvettes were then read immediately on a Hach 2100 P turbidity meter.

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 sites versus future Test sites) and by determining the relative influences of physical habitat variables on periphyton and benthic invertebrate productivity and community structure across sampling sites. Effects of categorical groupings, particularly treatment, are not expected as sampling was conducted prior to any experimental manipulations. Such effects would therefore be due to some unmeasured differences among these sites, which would need to be accounted for in order to attribute shifts in responses to future channel excavations.

2.3.1 Development and Interpolation of Explanatory Variable Data

In order to maintain consistency among studies, spatial habitat data collected by Mainstream Aquatics, including substrate variables (scores, D90, compaction), water clarity, and water turbidity were used in the present study. 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 inverse distance weighted (IDW) interpolation from 2 – 4 measured data points (from surveyed transects or sites) using ordinary kriging with a Gaussian semivariogram (Watson and Philip 1985; ESRI 2013; Appendix 1). 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.

We reduced our set of explanatory variables (Table 2-2) using methods described by Zuur *et al.* (2010). We examined multicollinearity among habitat variables using 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 either combined with similar variables through principal component analysis (PCA) or dropped from subsequent analyses (Swain *et al.* 2013).

Light and water turbidity variables were all highly auto-correlated and collinear with other explanatory variables so light penetration into the water column was characterized using the first principal component of these four variables (Table 2-2) for benthic invertebrate analyses. This axis explained over 99% of the variation in these variables, and was driven by mean maximum daily lux, overall mean lux (which loaded positively on this axis with eigenvalues of 0.99 and 0.16 respectively), and was less influenced by water clarity and turbidity (with eigenvalues of only 1.57^{-5} and 4.38^{-3} respectively). Because we were specifically interested in the effect of water turbidity on periphyton productivity responses, and because this variable was not overly collinear with other explanatory variables when both 32L and 102.5R data were used, we include this variable separately in periphyton models, and used the first principal component of mean maximum daily lux, overall mean lux, and water clarity to characterize mean maximum daily lux, mean overall lux, and water clarity, all of which loaded positively on this axis with eigenvalues of 0.99, 0.16 and 2.0^{-5} respectively.

2.3.2 Benthic and Periphyton Community

Non-parametric multidimensional scaling (NMDS) using Bray-Curtis dissimilarity matrices was used to explore variation in benthic community composition between reaches (up or down-stream) and treatments (Control or Test). Community data were log (x+1) transformed prior to calculating Bray-Curtis dissimilarity values in order to down weight contributions by dominant taxa. 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. While log transformations were used to down-weight dominant taxa in these analyses, Ecoscape will assess the effects of spatial clustering of taxa and consider using dispersion-weighted abundance estimates in future analyses as per methods described by Clarke *et al.* (2006). 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 and log-transformed data using scatterplots for all response – predictor combinations (boxplots in the case of categorical predictors) in order to assess the quality and general patterns in relationships in order to gauge the applicability of potential explanatory variables prior to their inclusion in the main statistical analyses (see 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) EPT richness, 5) percent EPT, 6) percent Chironomids, 7) Simpson's Index, and 8) 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).

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) (Table 2-2) on periphyton and benthic invertebrate production response variables (linear mixed-effects models with reach as a random effect were used for periphyton to account for the potential non-independence of data in upstream versus downstream sites). More specifically, we used an all model combinations approach (n = 160 and 128 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.

In order to compare among all parameters (variables) of varying scales, including both continuous and categorical variables, we conducted the above analyses after standardizing continuous explanatory variables by subtracting global means from each value (centering) and dividing by two times the SD (scaling) (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.

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.

Table 2-2: Variables used 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.
Average Daily Light Intensity (lux)	Average daily light intensity observed over the duration of deployment.
Clarity (secchi depth)	Measure of water clarity which is the depth at which a secchi disk is no longer visible through the water column.
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.
Light PC1	First principle component of the above four variables (used in benthic invertebrate models).
Light PC2	First principle component of water clarity, average maximum daily light intensity, and average daily light intensity (used in periphyton models).
Average Maximum Daily Water Temperature (˚C)	The average maximum daily water temperature observed over the duration of deployment.
Average Daily Water Temperature (˚C)	Average daily water temperature observed over the duration of 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) and adding these values together.
Substrate Compaction	Low (1), Moderate (2), or High (3) (was used in benthic invertebrate, but not periphyton models).
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.
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.

2.3.4 Assumptions for Use of Artificial Substrates

Community losses along the edges of the artificial substrate were assumed to be negligible. The effects of edges on the artificial substrate, such as the edge between tape adhesive and artificial Styrofoam sampling substrate, were considered in the same manner. Our visual observations of periphyton growth on the samplers support this assumption but we do not have empirical data to otherwise confirm it.

The effects of foraging invertebrates 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 used 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 water zones (1.5 to 2 m depth) that ensured areas sampled had been permanently submerged. Use of alternative methods, such as a HESS sampler would have made sampling these deeper water habitats more difficult.

3.0 RESULTS

3.1 Patterns in Flow and Temperature in the Peace River

Water temperature data has been collected on the Peace River since 2009 (Diversified, 2013). This data was reviewed to understand the temperature regime in mainstem areas of the Peace River and to compare these areas to Peace River side channel locations.

Water temperatures in the upper side channel (32L) over the summer sampling period were very similar to those of the main channel of the Peace River during the same time period in the past three years, while those of the lower side channel were considerably colder, suggesting that holding time in the channels was not long enough to increase water temperature during the summer sampling period and that lower side channel water temperatures may be influenced by lower temperature water entering the river from upstream tributaries (Figure 3-1). Side channel temperatures during the summer deployment were typically between 10 and 18 ºC.

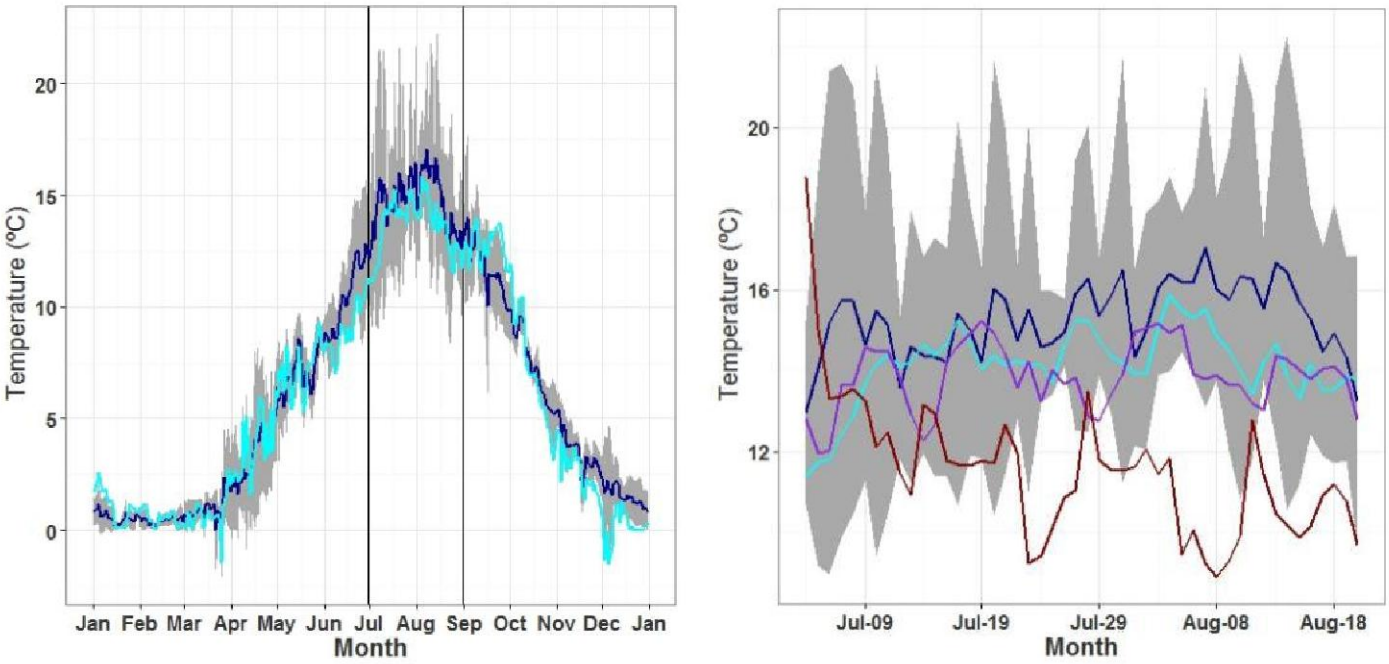

Figure 3-1: Average daily water temperature in the mainstem Peace River for 2010-2012 (dark blue) with SD (grey), and 2012 (light blue) throughout the calendar year with the 2013 sampling period delineated by the black vertical lines (left panel) and shown in detail (right panel) with average 2013 daily water temperatures in upstream (32L) and downstream (102.5R) side channels (red and purple lines, respectively).

Peace River mainstem flow data between 2008 and 2013 (BC Hydro data) from Peace Canyon dam was analyzed to understand water elevations during deployment, immediately prior to deployment, and over the annual period because flows are directly related to water elevations. Water elevations, assessed via mainstem flows are important to understand 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. In assessments from the Columbia River (see Schleppe *et al.* 2013, Larratt *et al*. 2013), the data suggest that the submergence regime of the preceding 60 to 90 days and annually should be considered because of the direct effects it can have on benthic production. Mainstem elevation data has been utilized in this first year report because it was available at the time of document preparation; however, in future years,

elevation and stage data from the side channel sites from GMSMON2 and 3 will be used to better understand water elevations rather than mainstem flows.

Flows in the Peace River are substantially 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 3-2). During the 2012, higher than normal freshet flows occurred. Future years will see continued investigation into the relationships between depth and flow using data from the Peace River side channels program.

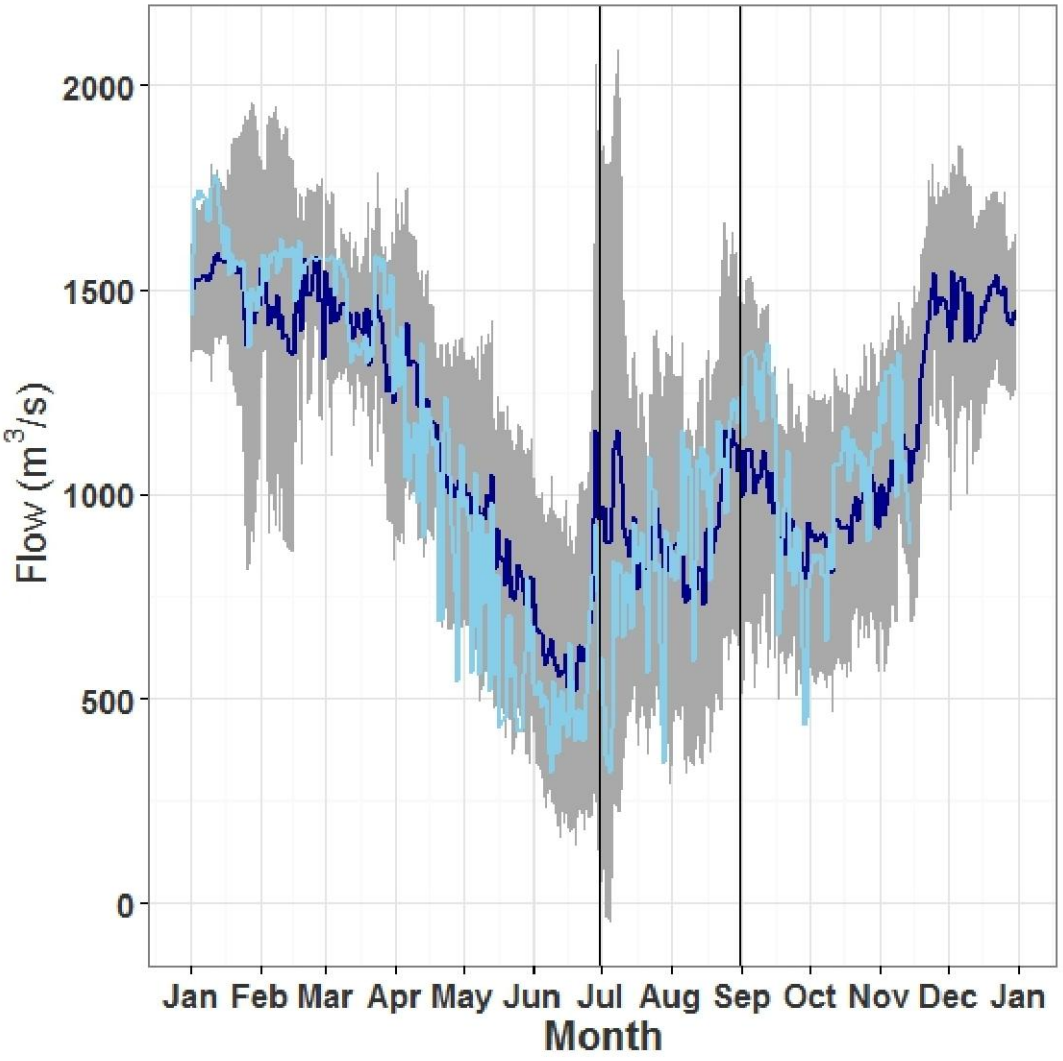

Figure 3-2: The pattern of annual flow in the Peace River between 2008 and 2013 based on Peace Canyon Dam releases. 2013 data (daily mean) is shown in light blue and the average between 2008 and 2013 (daily mean ± SD) is shown in dark blue with SD shaded in grey.

Daily flow release patterns from Peace Canyon Dam during the period of deployment were variable. Generally, lower flow tended to occur between 11 p.m. and 7 a.m., while higher

flows tended to occur between 10 a.m. and 9 p.m. (Figure 3-3). The other periods of the day would be described as ramping periods either up to or down from high daily peak flows. No statistical analysis of this data was completed, and hourly flow patterns appear to be highly variable throughout the day (typical 24 hour period) during the study period. Although it is not possible to directly correlate these flows with water elevations within the side channels, the data does suggest that during daytime periods, water elevations are likely deeper within side channels and shallower during evening periods. These effects are likely greatest at the 32L sites, where influences of tributaries with more constant, unregulated flows, are not present. No specific analysis of tributary influence was assessed, and in future years, analysis of water elevations from within the side channels will be used to address water depths directly.

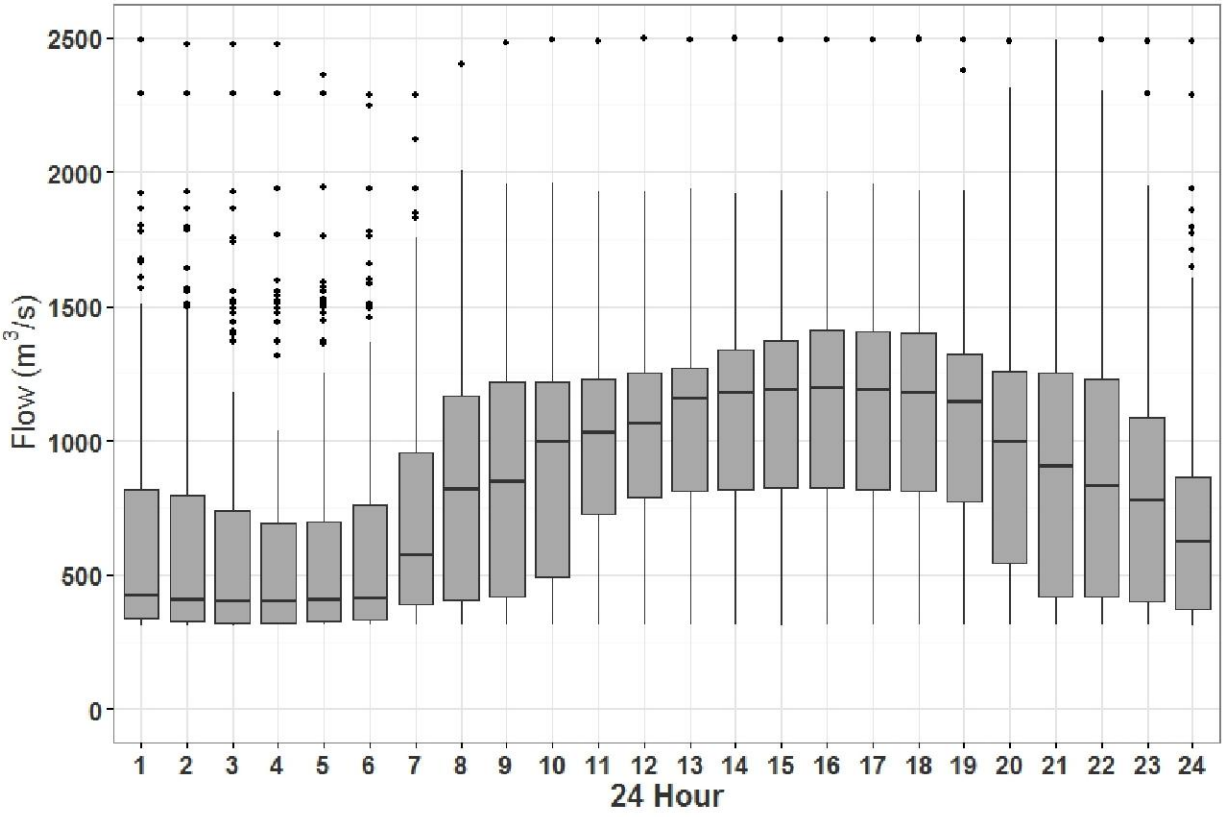

Figure 3-3: The pattern of hourly flow releases from Peace Canyon Dam in July and August, 2009-2013.

3.2 Periphyton

3.2.1 Periphyton Abundance, Biovolume, and Diversity

Overall periphyton productivity on samplers was low in both upstream and downstream side channels relative to levels observed in the mainstems of other rivers (Table 3-1). All samples were numerically dominated by single-celled and filamentous cyanobacteria (blue-green algae), while sample biovolume was dominated by diatoms. Very small flagellates were regularly encountered and green filamentous algae were less frequent in the samples.

Prevalent periphyton species included:

- Diatoms donated from upstream reservoirs (e.g., *Fragilaria crotonensis, F. capucina, Synedra ulna*)
- Diatoms donated from upstream flow areas (e.g., *Tabellaria spp., Achnanthidium minutissima, Diatoma tenue, Didymosphenia geminata*)
- Diatoms that likely grew in situ due to their being highly mobile and able to migrate upward as sediment settles (e.g., *Nitzschia spp., Navicula 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 etc. for energy (e.g., *Ochromonas spp., Chromulina sp., Euglena sp.*)
- Green filamentous algae from upstream or shoreline areas (e.g., *Cladophora sp., Spirogyra sp.)*

3.2.1.1 Periphyton Productivity by Sample Location

Many of the diatom species found in the Peace River samples were phytoplankton types that originated in upstream reservoirs. They remain in suspension until water velocity slows, and then they are deposited along with silt. The 32L samples are closer to Dinosaur Reservoir than the 102.5R samples, accounting for the greater diatom biovolume and diversity of the 32L samples (Table 3-1, Figure 3-4).

Table 3-1: Summary of range of Peace periphyton metrics from 2013, with comparison to oligotrophic, typical, and productive large rivers

Metric	Oligotrophic or stressed	Typical large rivers	Eutrophic or productive	Upper Peace Mainstem 2010 - 2011	Peace Side-channels Summer 2013
Number of taxa (live & dead)	<20 – 40	25 - 60	Variable	19 - 39	2 – 23 (10-15)
Chlorophyll-a µg/cm^2	<2	2 – 5 (7)	>7 – 10 (30+)	1.7 – 2.9	0.24 – 5.53
Algae density cells/cm^2	<0.2 x10^6	1 - 4 x10^6	>10 x10^6		0.12 – 4.0 (3-6) x10^6
Algae biovolume cm^3/m^2	<0.5	0.5 – 5	20 - 80		0.04 – 8.4 (0.18-1.6)
Diatom density frustules/cm^2	<0.15 x10^6	1 - 2 x10^6	>20 x10^6		0.0013 – 0.68 x10^6
Biomass – AFDW mg/cm^2	<0.5	0.5 - 2	>3		0.18 – 37.01
Biomass – dry wt mg/cm^2	<1	1 – 5	>10		1.97 – 799.44
Organic matter (% of dry wt)		4 – 7%			2.2 – 15.37
Bacteria sed. HTPC CFU/cm^2	<4 -10 x10^6	0.4 – 50 ×10^6	>50×10^6 - >10^{10}		N/A
Accrual chl-a µg/cm^2/d	<0.1	0.1 – 0.6	>0.6		0.0051 – 0.1152

(Median shown in brackets)

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.

Table 3-2: Relative abundance and biovolume of periphyton taxonomic groups from river locations upstream (32L) and downstream (102.5R).

Algae Group	102.5 R Sites: Relative Abundance (%)	102.5 R Sites: Relative Biomass (%)	Algae Group
Blue-Green Algae	53%	50.5%	Diatoms
Flagellates	40%	29.3%	Flagellates
Diatoms	7%	11.9%	Blue-Green Algae
Green Algae	0%	8.2%	Green Algae
Algae Group	**32 L Sites: Relative Abundance (%)**	**32 L Sites: Relative Biomass (%)**	**Algae Group**
Blue-Green Algae	51.2%	78.8%	Diatoms
Diatoms	31.6%	15.3%	Green Algae
Flagellates	16.6%	4.5%	Flagellates
Green Algae	0.5%	1.4%	Blue-Green Algae

Flagellate numbers are often higher at depositional sites where they can exploit higher concentrations of bacteria and small particulates available as food sources. The very small nano and pico types were important components of flagellate communities found the Peace River side-channels.

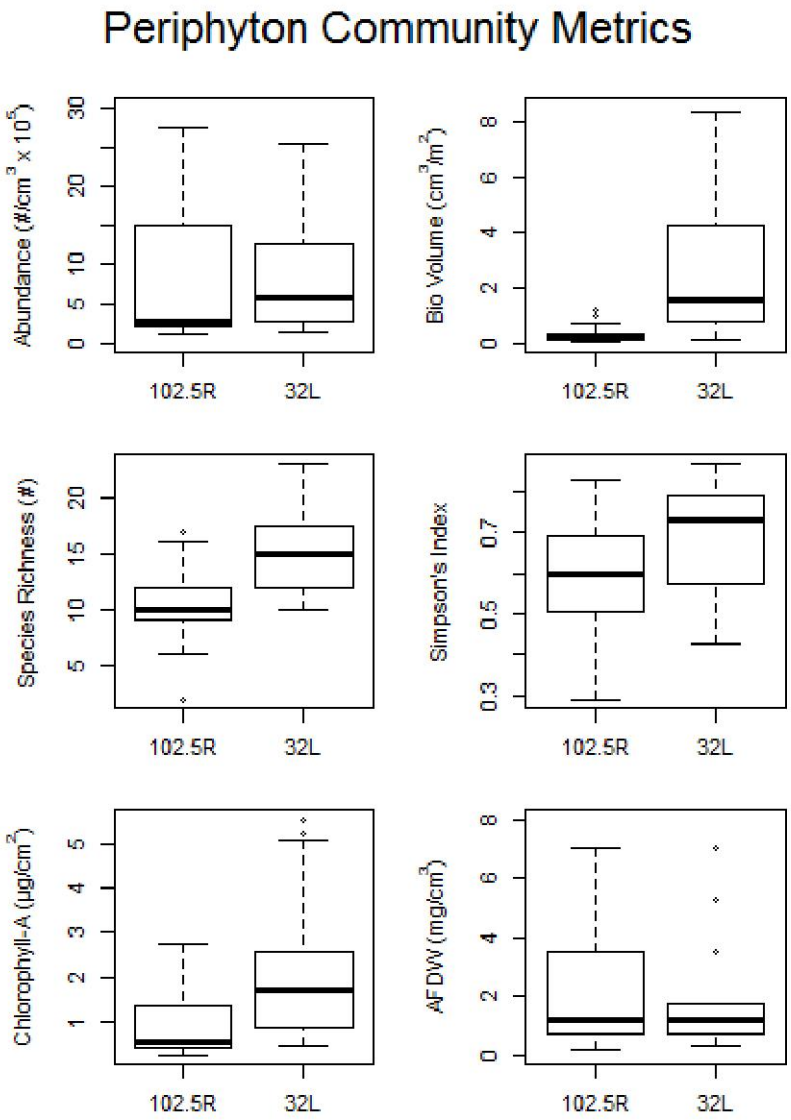

Figure 3-4: Box plots of periphyton community and productivity metrics comparing samples from upstream side channel sites (32L) to those from downstream side channel sites (102.5R).

The community metrics between the two sample areas showed significantly higher biovolume and diversity in the 32L samples then the 102.5R samples. This difference suggests that algae in drift that originated in the reservoir(s) are an important source of photosynthetic material to the downstream river sites. If reservoir derived algae are subtracted from the already low productivity estimates demonstrated in Figure 3-4, then it becomes clear that local algal productivity is very low in these side channels. Only one periphyton productivity metric, chl-a, was greater for the downstream 102.5R sites. This suggests that photosynthetic bacteria are a significant contributor to productivity in this system.

3.2.1.2 Periphyton Productivity in Sediment Fines and on Artificial Substrates

Samples of the silt material were collected whenever possible because deposited silt (fine sediments) was prevalent on the Styrofoam plates. The photosynthetic component of both substrate types were similar, but with important differences. Deposited fine sediment samples included more cyanobacteria and flagellates but fewer diatoms and lower diversity than the corresponding Styrofoam samples (Table 3-3, Figure 3-5). Abundance, biovolume and chl-a were all higher in the silt samples than in Styrofoam samples. Total production at any site was the combined total from the Styrofoam and deposited fine sediment samples.

Table 3-3: Relative abundance and biovolume of periphyton taxonomical groups from deposited sediments and artificial substrates.

Deposited Sediment			
Algae Group	Relative Abundance (%)	Relative Biomass (%)	Algae Group
Blue-Green Algae	58.8%	66.4%	Diatoms
Diatoms	21.1%	18.8%	Green Algae
Flagellates	19.5%	8.1%	Blue-Green Algae
Green Algae	0.6%	6.6%	Flagellates
Artificial Substrate			
Algae Group	Relative Abundance (%)	Relative Biomass (%)	Algae Group
Blue-Green Algae	46.8%	67.3%	Diatoms
Flagellates	31.7%	21.3%	Flagellates
Diatoms	21.3%	7.4%	Green Algae
Green Algae	0.2%	4.0%	Blue-Green Algae

Strands of green algae were far more common in the deposited sediment than on the Styrofoam artificial substrate. These slow-growing algae washed in from upstream or from peripheral substrates that receive adequate light. During field collections, obvious bands of filamentous green algae were observed in side channel areas in shallow water. This taxa group is seldom seen on artificial substrates within a typical 6 week deployment (H.Larratt, personal observation).

The periphyton community metric box plots shown In Figure 3-5 show a slightly greater species richness and Simpson's Index for the Styrofoam samples over the deposited silt samples.

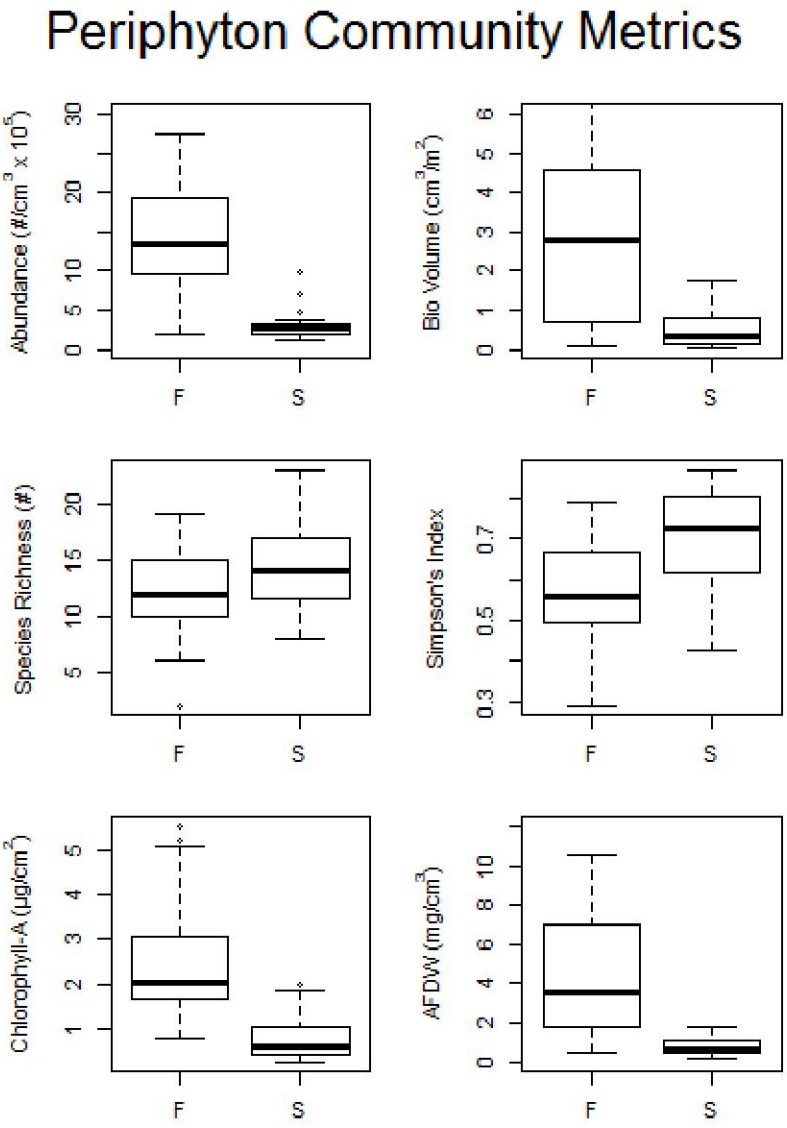

Figure 3-5: Box plots of periphyton community metrics compared between deposited fine sediments (F) and Styrofoam (S) samples

3.2.1.3 Comparison of Periphyton Productivity at Control and Test Sites

When the data are grouped by Control or Test across all locations, the algae groupings are remarkably stable (Table 3-4).

Table 3-4: Relative abundance and biovolume of periphyton taxonomical groups from Test and Control locations.

Algae Group	Test		
	Relative Abundance (%)	Relative Biomass (%)	Algae Group
Blue-Green Algae	57.6%	63.5%	Diatoms
Flagellates	25.2%	18.0%	Green Algae
Diatoms	16.7%	11.3%	Flagellates
Green Algae	0.5%	7.3%	Blue-Green Algae
Algae Group	**Control**		
	Relative Abundance (%)	Relative Biomass (%)	Algae Group
Blue-Green Algae	46.1%	70.6%	Diatoms
Flagellates	27.6%	18.8%	Flagellates
Diatoms	26.0%	6.4%	Green Algae
Green Algae	0.3%	4.2%	Blue-Green Algae

Similarly, Figure 3-6 shows similar community metrics for Control and Test, considering that these represent physically unique side channel sites. The biggest differences occurred in biovolume and chl-a, both of which were higher at the Control sites. The similarity is fortunate since the paired Control and Test sites will be compared after the side channel rehabilitation work to show the effect of the modifications at the Test sites. If the sites were dissimilar, the value of their comparison would be questionable.

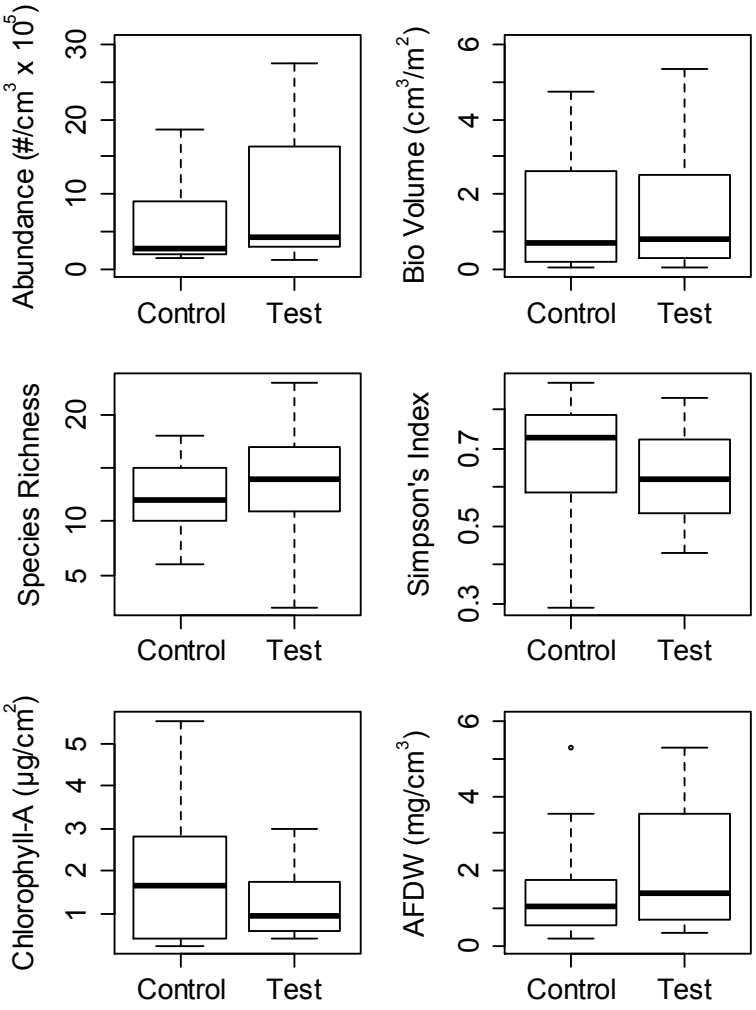

Figure 3-6: Box plots of periphyton community and productivity metrics comparing between control and future test sites in side channel sites on the Peace River

3.2.2 Periphyton Community Composition

Statistical community analyses of the 2013 periphyton data were completed at the genus level, allowing for more large scale trends to be observed between river sites. Periphyton communities were grouped by upstream and downstream river sites (ANOSIM, R: 0.19, p = 0.001) but not by treatment (ANOSIM, R: 0.03, p = 0.08) (Figure 3-7). There was also an effect of site, suggesting that each river location had a unique community of periphyton taxa (ANOSIM, R: 0.17, p = 0.002). There was also a significant difference in periphyton community between samples collected from deposited sediments and the artificial substrates (ANOSIM, R: 0.83, p = 0.001). The NMDS stress value was 0.21, meaning only a moderate level of confidence can be given to the two dimensional plot accurately representing the relationships observed (Clarke 1993). These results corroborate preceding descriptive characterization of periphyton results above.

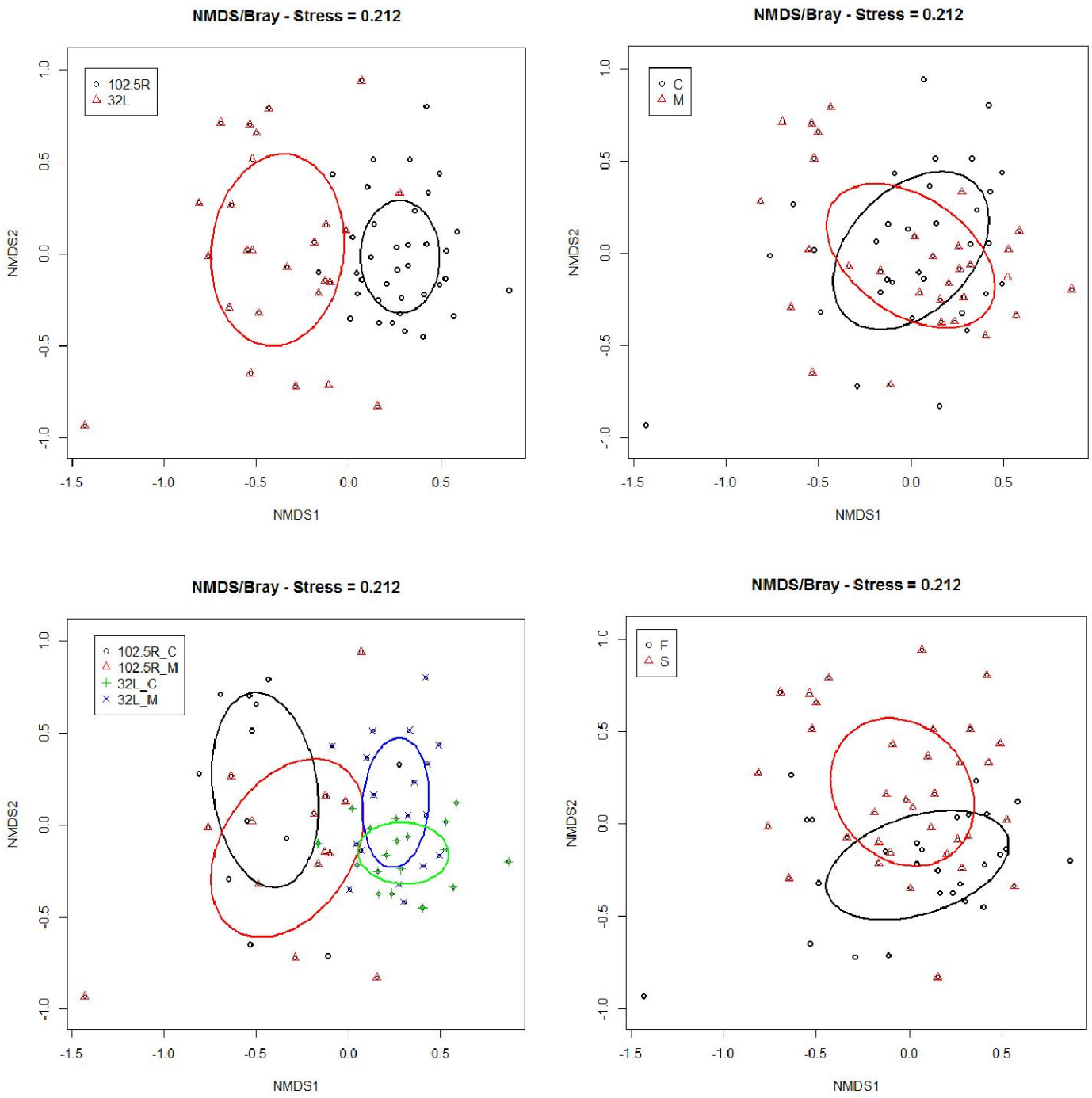

Figure 3-7: NMDS of periphyton genus level abundance grouped by river location (102.5R downstream and 32L upstream), Treatment (Control or Test), site, and by deposited sediment (F) and artificial Styrofoam substrate (S) from Peace River side channels in the summer of 2013

3.2.3 Periphyton Production Models

Both sediment and the artificial Styrofoam substrate 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 any potential effects of sediment removal during retrieval for instance. The boxplots (Figure 3-4 to 3-6) provide insight into potential interactions between deposited sediments and artificial substrates, however, these were not explored in linear models. Rather, the primary intent of these models was to understand how physical parameters may affect periphyton production in the side channels.

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 metrics of production and ranged from 4 (abundance model) to 17 (AFDW). These models typically explained roughly 45 (species richness and Simpson's Index) to 80% (abundance, chl-a) of the variation, suggesting that the explanatory variables assessed are reasonable predictors of periphyton productivity. Similar to other studies, models of species diversity explained less variation than those for production (Larratt et al, 2013). Turbidity was negatively associated with biovolume, species richness, Simpson's Index, and chl-a and typically had a high relative variable importance (greater than 0.8), a large correlation coefficient, and confidence limits that did not span zero (Figure 3-8). Turbidity was positively associated with AFDW and mean silt depth, meaning that organic content increased with increasing sediment deposition. Abundance was also lower and Simpson's Diveristy was higher in Test than Control sites.

The models developed to describe periphyton production suggest that sediment deposition rate and turbidity are important determinants of periphyton community development and overall production. The considerable importance of treatment suggests that there may be some differences between Control and future Test sites not explained by the current suite of explanatory variables. 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 describe periphyton responses well and indicate relatively low accuracy in observed patterns from this analysis (Figure 3.8). Future model development will aim to refine these models in conjunction with improving explanatory variable sets, in order to better understand these relationships.

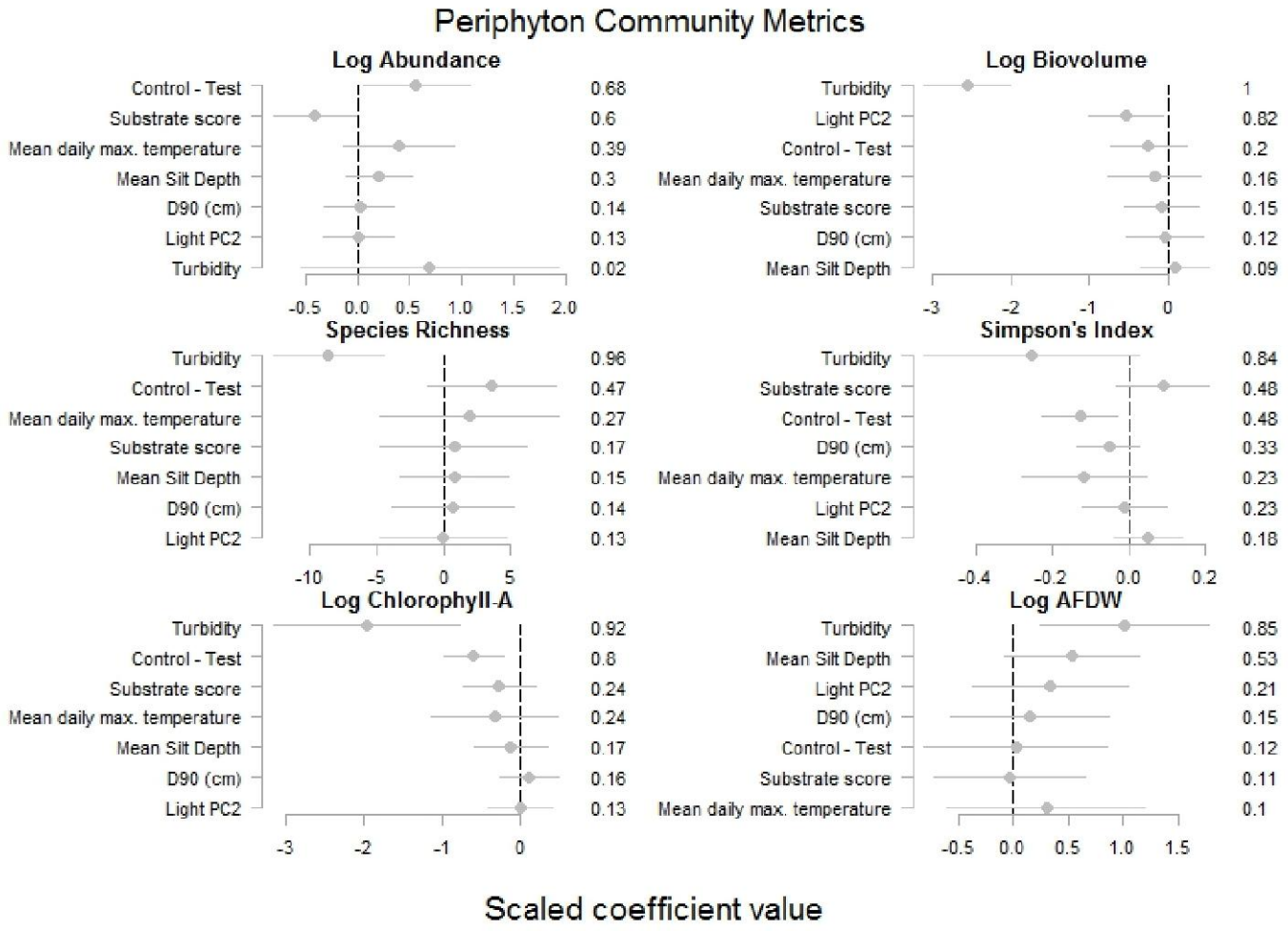

Figure 3-8: Mean coefficients and their 95% confidence limits of standardized explanatory variables of periphyton production in the Peace River during the summer of 2013. Periphyton responses included abundance, biovolume, Simpson's Index, chlorophyll-a, and AFDW. Coefficients are standardized to allow 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.

3.3 Benthic Invertebrates

3.3.1 Invertebrate Abundance, Biomass and Diversity

At the 102.5L sites, invertebrate abundance, biomass, species richness, %EPT, EPT Richness, and % *Chironomidae*, was typically greater, and Simpson's diversity was lower in Test sites than in the Control sites. Hilsenhoff Biotic Index values were somewhat greater in Test sites, although there was great overlap with those in Control sites, with all values above four in both groups of sites indicating moderate to high tolerance of low oxygen conditions. There was little overall difference in other invertebrate metrics between Control and Test sites, although, higher variation was typically observed in future Test sites (Figure 3-9).

Measures of relative abundance found that *Oligochaeta* were the most predominant taxa observed, accounting for 64% and 56% of the relative abundance at Test and Control sites respectively. *Chironomidae* were the next most predominant taxonomic group observed

(Table 3-5). EPT taxa are considered a high value fish food because of their high biomass, meaning that biomass of these taxa must be considered in conjunction with abundance. Relative biomass of EPT taxa was 30% of the total, proportionally more than the relative abundances of these taxa.

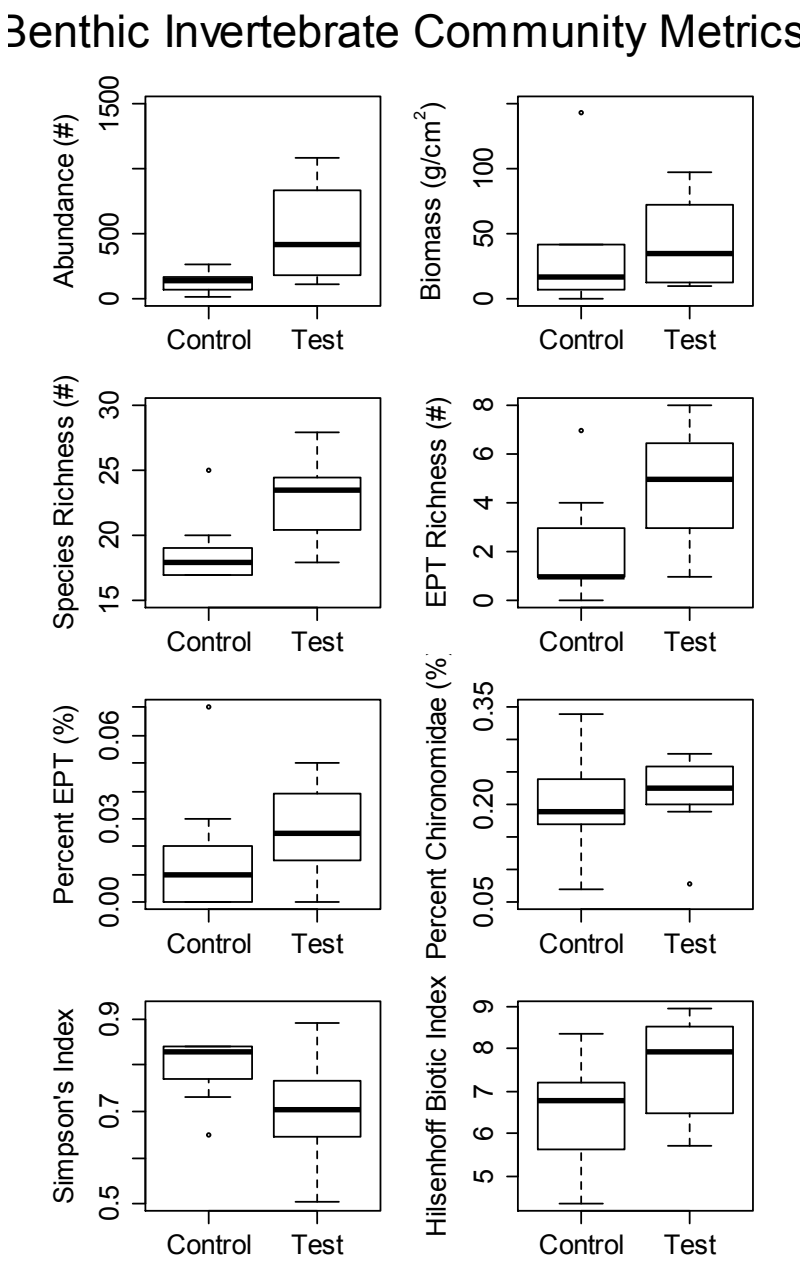

Figure 3-9: Boxplots of benthic invertebrate community composition and productivity metrics compared between Control and future Test locations from downstream side channel sites on the Peace River (102.5R).

Table 3-5: 2013 relative abundance and relative biomass for higher benthic taxonomic groups at Test and Control locations in the downstream (102.5R) Peace River side channels. Relative abundance and biomass are shown in rank order, with species groups on the left and relative percentages on the right, broken down by monitoring (top) and control (bottom) sites.

Test			
Species Group	Relative Abundance (%)	Species Group	Relative Biomass (%)
Oligochaeta	64.1%	Oligochaeta	30.2%
Chironomidae	23.5%	Chironomidae	18.3%
Other	3.3%	Ephemeroptera	17.7%
Diptera	2.7%	Trichoptera	12.1%
Crustacea	1.5%	Diptera	9.2%
Ephemeroptera	1.5%	Crustacea	6.1%
Arachnida	0.9%	Gastropoda	2.6%
Trichoptera	0.8%	Plecoptera	1.9%
Gastropoda	0.8%	Coleoptera	1.9%
Coleoptera	0.4%	Bivalvia	0.0%
Plecoptera	0.3%	Other	0.0%
Bivalvia	0.0%	Arachnida	0.0%
Megaloptera	0.0%	Megaloptera	0.0%
Control			
Species Group	Relative Abundance (%)	Species Group	Relative Biomass (%)
Oligochaeta	55.8%	Oligochaeta	34.8%
Chironomidae	23.0%	Ephemeroptera	23.6%
Other	10.1%	Plecoptera	21.3%
Arachnida	5.3%	Chironomidae	15.2%
Diptera	3.4%	Trichoptera	3.9%
Ephemeroptera	0.7%	Diptera	0.9%
Plecoptera	0.7%	Other	0.2%
Trichoptera	0.6%	Crustacea	0.1%
Gastropoda	0.2%	Megaloptera	0.1%
Crustacea	0.2%	Gastropoda	0.0%
Megaloptera	0.1%	Arachnida	0.0%
Bivalvia	0.0%	Bivalvia	0.0%
Coleoptera	0.0%	Coleoptera	0.0%

3.3.2 Invertebrate Community Groupings

Invertebrate communities were grouped by site or treatment in downstream side channels (ANOSIM, R: 0.63, p = 0.001) (Figure 3-10). The NMDS stress value was 0.15, suggesting high confidence can be given to the two dimensional plot accurately representing the relationships observed. In future years, analysis of the differences between the different sites and treatments will be completed to address the management questions.

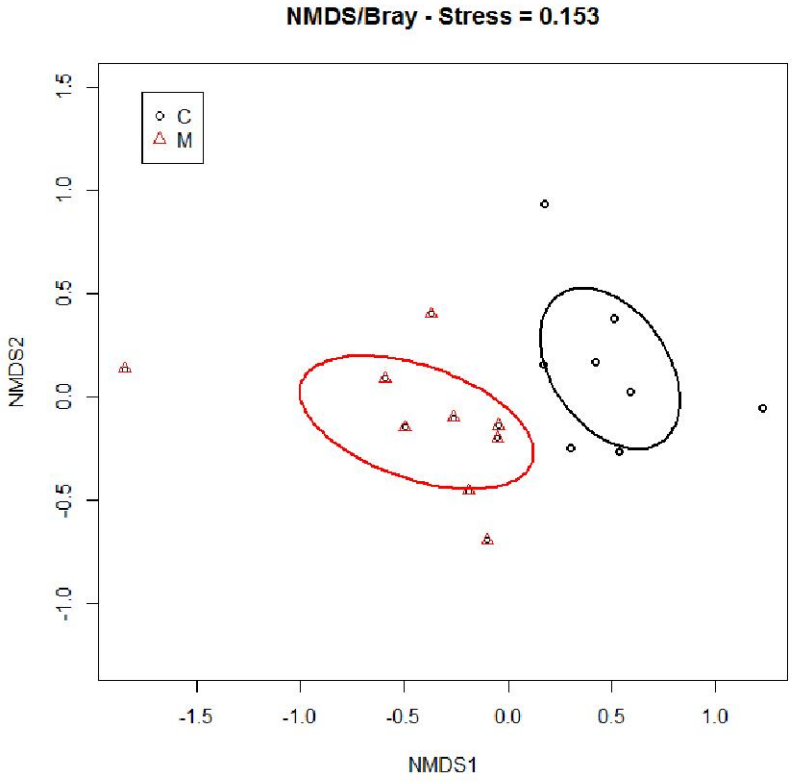

Figure 3-10: NMDS of Benthic Invertebrate Abundance at genus for data grouped by Treatment (Control or Test) from the Peace River downstream (102.5R) side channels in the summer of 2013

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 (8 to 13 models). Benthic models typically explained relatively little of the variation in response variables (R^2 = 0.10-0.30), suggesting that more detailed datasets are likely required to describe drivers of invertebrate production in side channels of the Peace River. However, some relationships were evident. Invertebrate abundance, biomass, and the Hilsenhoff Biotic Index increased with increasing light and decreasing turbidity (related to the light-turbidity PC1; Figure 3-11). Species diversity, EPT richness, and percent *Chironomidae* were greater at Test than Control locations but the confidence limits spanned zero suggesting that these latter trend are not likely to be significant. Other important predictors were typically associated with substrates, such as the D90 or substrate compaction.

The models developed to describe invertebrate production suggest that substrates and sediment, available light, turbidity, and location may influence invertebrate community development and overall production, however, in all cases, their effects are highly inconsistent, likely due to the coarse nature of most explanatory variables and a limited sample size. More data is required to develop more accurate benthic habitat models to assess how, and to what extent physical parameters influence invertebrate production in side channels.

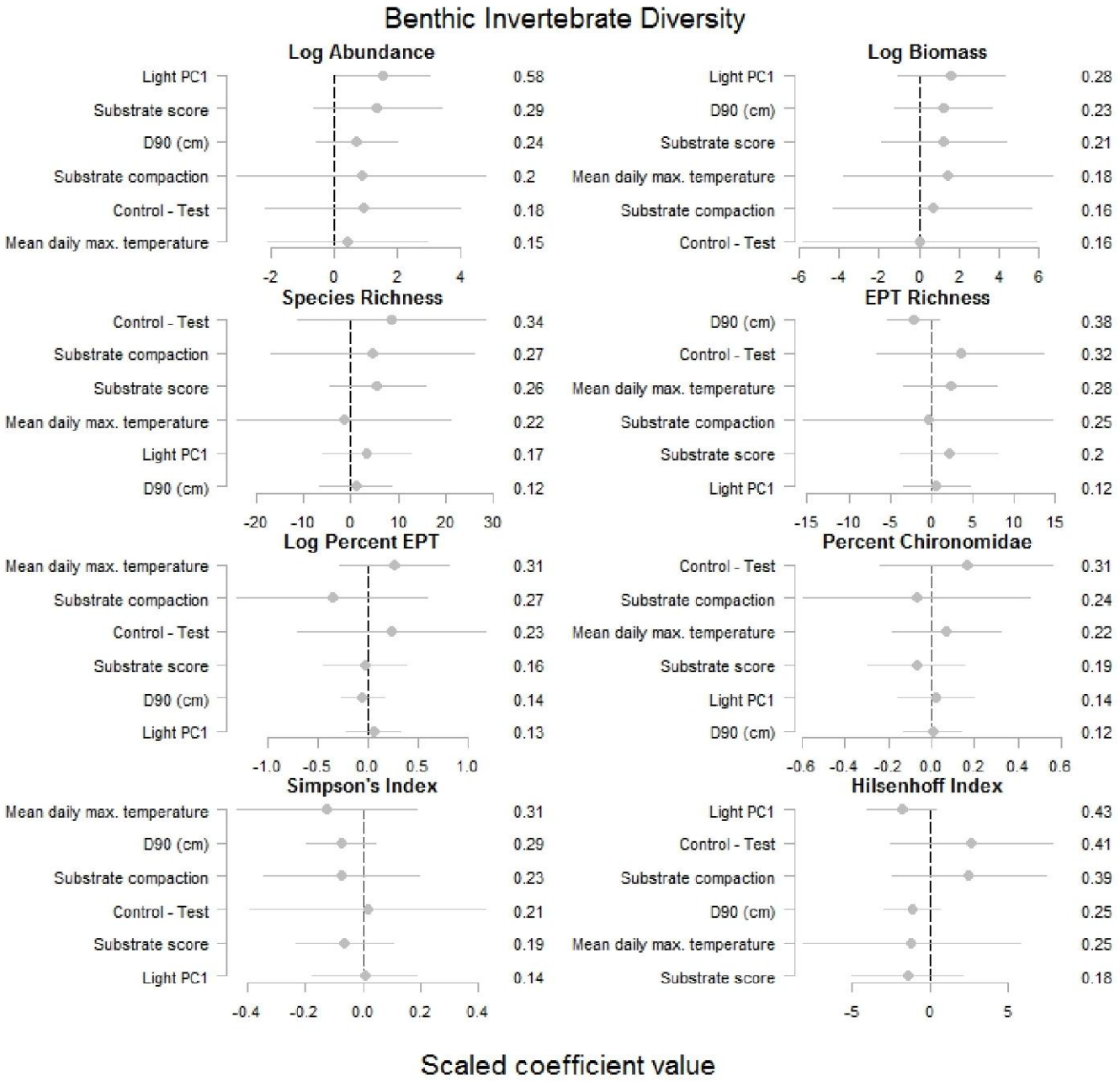

Figure 3-11: Mean coefficients and their 95% confidence limits of standardized explanatory variables of benthic production in the Peace River side channels during the summer of 2013. Invertebrate responses included abundance, biomass, species richness, EPT Richness, % EPT, % Chironomidae, Simpson's Index, and Hilsenhoff Biotic Index. The first principal component of a light / turbidity axis was also considered. 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.

3.4 Suspended Sediment, Light Attenuation and Sediment Fall Test

The suspended sediment load in the Peace River side channel sites affects both water clarity and sedimentation rates because particles intercept and scatter sunlight. As sediment load in river water increases, the depth light penetrates decreases, which can affect photosynthesis. The depth of light penetration can calculated from the equation:

$$Z_{eu} \sim \sqrt{5\, Z_s}$$

Where Z_{eu} = euphotic zone

Z_s = Secchi depth in meters (Tilzer, 1988)

The Secchi depth is reached when the reflectance equals the intensity of light backscattered from the water. For turbid Peace water, this formula predicts a euphotic zone of only 1.6 – 2.2 m (Secchi depths of between 0.1 – 0.2 m), which is substantially less than that for the Columbia River for instance, where light penetration often exceeds 3 m (e.g., Schleppe *et al.* 2013). In practice, photosynthesis of even the most resilient organisms is prevented after light is reduced to < 1% of the light at the water surface. This means that only the periphery of the channel bed will be suitable for active benthic periphyton growth. Since the artificial substrates were placed at between 1.5 - 2 m water depths, they were at the limit of the predicted euphotic zone, which may help explain the low in situ productivity.

Secchi disk measurements do not indicate how attenuation changes with depth or the absorbance of particular wavelengths of light. A total attenuation coefficient K for available light (also called an extinction coefficient ($K = 1.7/Z_s$, or $K = (I_0 - I_D) * D^{-1}$)[1], can be calculated for the available light averaged over the Secchi disk depth or from light logger data. For the Peace side-channel habitats, the summer extinction coefficients were very high relative to that typical of less turbid river mainstems (e.g., Columbia for instance) because the high turbidity scatters and absorbs sunlight.

In contrast to Secchi depth which is not sensitive to light wavelengths, the light loggers primarily measured the visible part of light spectrum with wavelengths between 400 and 700 nm, which is also the photosynthetically available radiation or PAR utilized by phytoplankton for photosynthesis. A summary of the daily light intensity data for downstream and upstream light loggers deployed at 1.5 to 2.0 m depth showed peaks and valleys in the light data (Figure 3-12). Although no specific analyses were conducted, ambient light intensity data from adjacent streamside areas had similar patterns to light intensity observed on the artificial substrate (Figure 3-13). There may be periods where the side channel water clears up and periods where storms cause increased suspended sediment which shaded the substrates. Alternatively, these could be periods of higher and lower flows. Light loggers deployed on the upstream 32L samplers recorded higher light intensities, indicating lower turbidity than the 102.5R downstream locations (Figure 3-12).

[1] The expression for light attenuation with depth using light logger data is: $I_D = I_0\, e^{-(k)\, Z}$ where: I_D = the light intensity at depth D in meters, I_0 = the light intensity at the surface, e = the base of the natural logs, k = the extinction coefficient, in meters, and Z = water depth in meters.

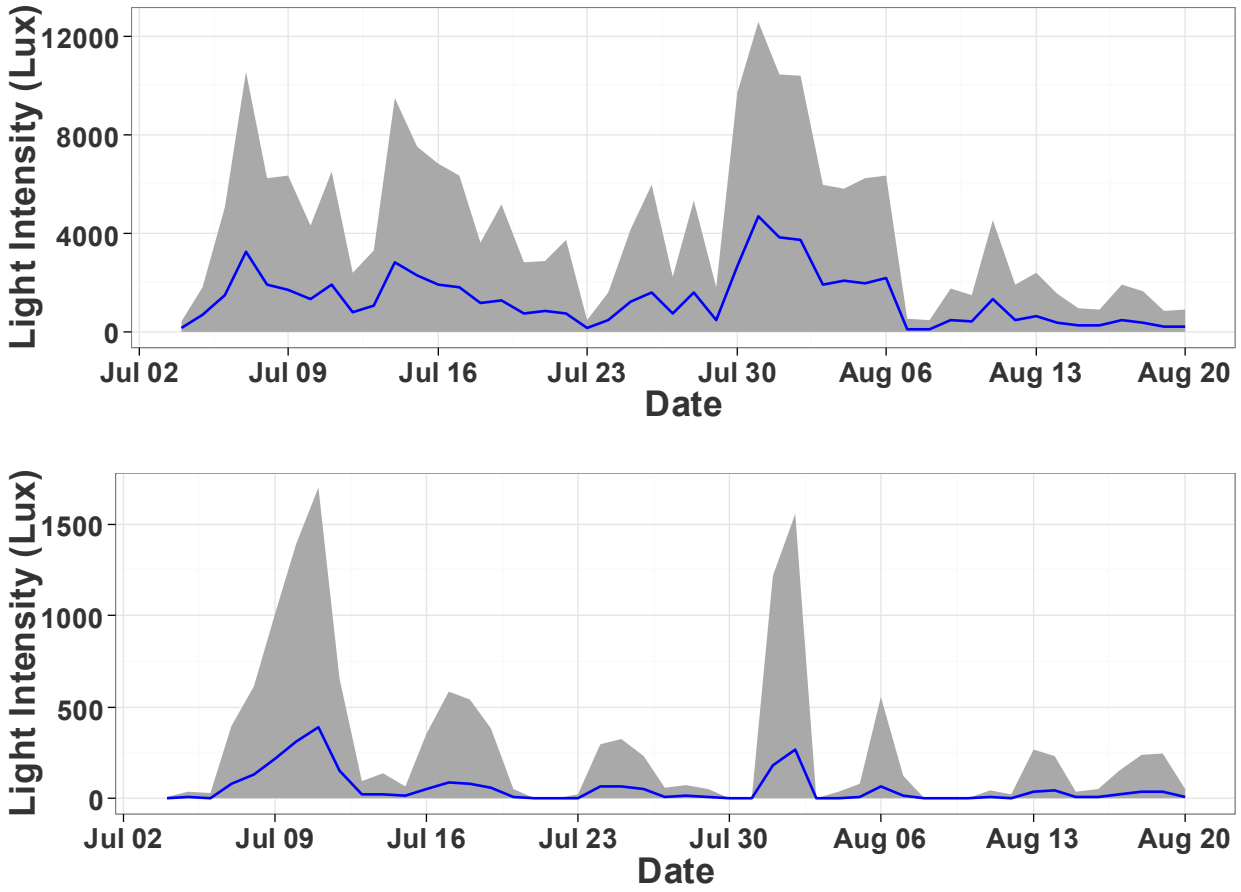

Figure 3-12: Light Logger data for Upstream (32L – top panel) and Downstream (102.5 R – bottom panel) light intensity data (Lux (1 lumen per m^2)) in side channels of the Peace River. The light loggers measured wavelengths between 400 and 700 nm, termed PAR (Photosynthetically Available Radiation)

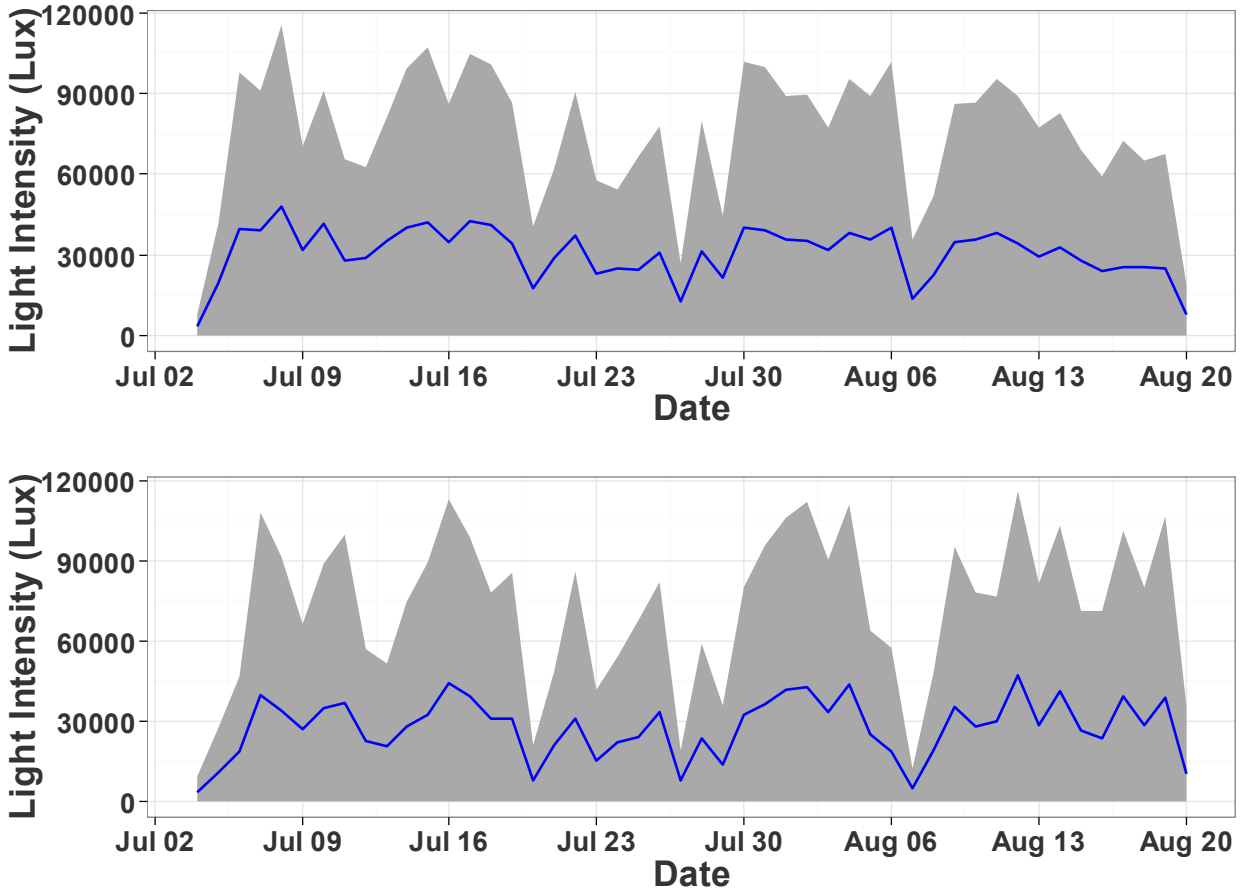

Figure 3-13: Light intensity data adjacent to side channel areas upstream (32L – top panel) and downstream (102.5 R – bottom panel) (Lux (1 lumen per m^2)) in the side channels of the Peace River. The light loggers measured PAR (400-700 nm).

That 6-7 mm of sediment accumulated in only 22 days (~0.37 mm/day), indicates that sediment accumulation is rapid. The results from the sediment settling experiment are presented in Figure 3-14. Initial sample turbidity was very high at >50 Nephelometric Turbidity Units (NTU) but heavy particles and clumps fell in seconds, resulting in rapidly declining turbidity. Turbidity continued to decline slowly over five days as all but clay-sized particles fell out of suspension. These results help explain the rapid sedimentation observed on the periphyton samplers. Light penetration increases with the inverse of turbidity. Based on this, the time to reach a turbidity that would not appreciably affect photosynthesis (<5 NTU) was 2 days. The actual settling time in slowly moving, cooler water in the side channels would likely be somewhat longer.

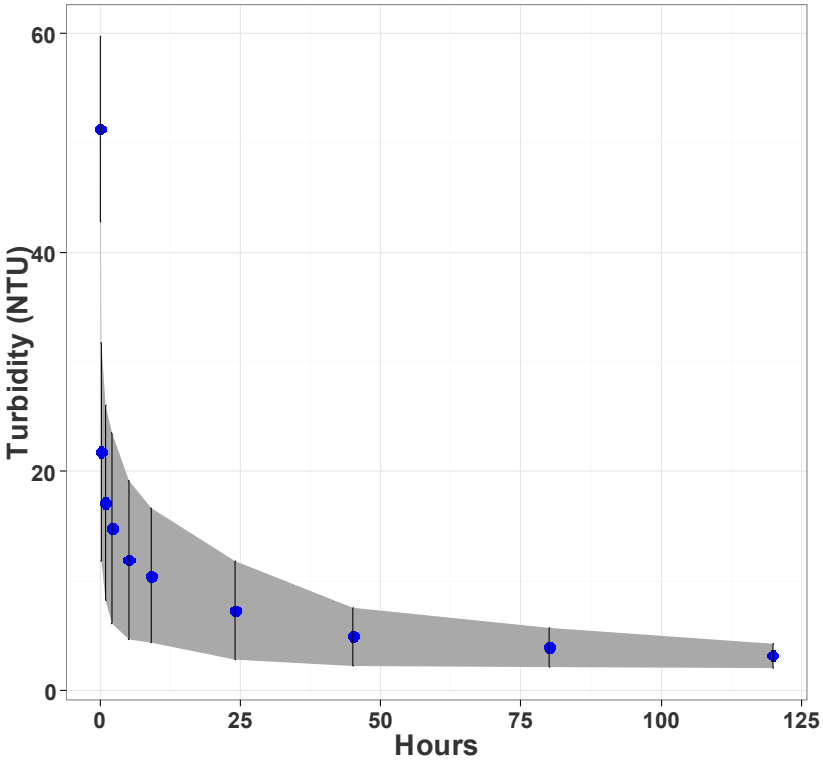

Figure 3-14: Peace River side channel sediment fall rate, showing decreasing turbidity over time

For reference, standard fall rates predict:

- sand particles (1mm dia.) settle by 10 cm in 1 second,
- silt particles (0.01mm dia) settle by 10 cm in 11 minutes, and
- clay particles (0.0001mm dia.) settle by 10 cm in 77 days.

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, a consequence of which has been increased sediment accumulation to the extent that significant vegetation encroachment and reduction in available fish habitat has occurred (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 in order to restore fish habitat and side channel connectivity to the mainstem channel, particularly at low flows. Key to the viability of fish habitat is the productivity of primary (e.g., periphyton) and subsequent trophic levels (e.g., benthic invertebrates), which fish populations depend on for food. To assess the success of proposed channel alterations on the productivity of these lower trophic levels three management questions have been proposed:

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 long-term goal of this study is to address all three management questions. The present report primarily focuses on the first, by characterizing the periphyton and benthic invertebrate communities within the side channels. The 2013 work program upon which this report is based aimed to collect baseline data on these communities and to characterize the present environmental variables and benthic habitat that are likely to influence them, and to assess the relationships among benthic community metrics and environmental and habitat variables. Understanding these relationships prior to commencement of excavation will help to better attribute any observed shifts in community structure or productivity to channel excavations, and to explain the mechanisms that may drive these shifts (e.g., changes in siltation levels, depth, available productive substrate area, etc.).

Specific tests of management questions 2 and 3 will follow after construction of the side channels over the next few years. Below is a summary and brief discussion of environmental and habitat characteristics of pre-enhancement side channels to the Peace River, and the community composition and productivity observed.

4.1 Physical Habitat Conditions

Benthic production is usually greatest during the summer period, 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 show that Peace side channels are the same temperature as mainstem areas, at least in the current sampling year.

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. In this study, samplers were deployed during the summer period, immediately following annual low flows in mid-June. Flows in 2013 were within the normal operating range. Summer sampling was chosen because selecting habitats in permanently submerged areas was achievable.

Hydro operations create a ramping pattern on a daily basis, similar to other systems such as the Middle Columbia River (MCR) below the Revelstoke Dam. 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. In the Peace River, there are higher flows from 9 a.m. to 9 p.m., while low flows typically occur between 11 p.m. and 7 a.m. The remaining periods are either ramping up to or down from low flows, noting that there is high variation in this daily trend. Samplers in this study were placed in areas that were permanently submerged 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 are all directly related to flows and subsequently affect benthic productivity.

The higher daily flows during the summer 2013 sampling period meant that side channels may be slightly deeper during daytime hours than at night. It is presumable that daily exposure of riverbed substrates has a similar adverse effect to that observed on the MCR (Schleppe *et al*. 2013), where productivity in varial zone areas is directly dependent on the total time submerged.

Peace side-channel samplers were deployed between 1.5 to 2 meters depth where they would remain submerged. 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 scattered light and reduced penetration within this productive zone, meaning that the most productive zones in Peace side channels were slightly shallower where light penetration was greater and the effects of turbidity were less. However, these more productive areas may occasionally be exposed as part of the operated flow regime. Differentiating between the effects of variable exposure and increased productivity at shallower depths would be difficult but this potential confounding effect should be considered in future interpretations. More detailed consideration for water depth and variable submergence through deployment of samplers in shallow and deep permanently submerged, and potentially variably submerged areas should occur to better quantify production in this narrow shoreline productive band.

4.2 Periphyton Production Summary

Suspended sediment likely greatly limited the summer 2013 periphyton side channel production in the Peace River. Prevalent periphyton species included those that grew *in situ* which are tolerant of low light conditions, and those imported from upstream sites. Periphyton community structure changes attributable to shading from the high and sustained sediments loads have been widely documented (Henley et al. 2010, Hoetzel and Croome 1994). Other Peace River system research determined that the large and fluctuating suspended sediment load reduced light penetration such that periphyton and submerged macrophyte populations were greatly reduced (Truelson and Warrington 1994).

In regulated rivers, the contribution to in situ periphyton production made by reservoir algae drifting into the river is significant (Larratt *et al*. 2013). If reservoir-produced algae are subtracted from the already low productivity estimates demonstrated in the 2013 data,

then it becomes clear that local algae productivity in these side-channel environments is extremely low relative to mainstem levels in the Peace and other larger BC rivers (Table 3.1), at least at the depths sampled in side channels.

The downstream 102.5R site experienced greater turbidity than the 32L site, likely resulting from suspended sediment inputs from the Halfway, Moberly, and Pine Rivers, tributaries to the Peace above these sites. Only one periphyton community metric, chlorophyll-a, was greater for the 102.5R sites. This suggests that photosynthetic bacteria are a significant contributor to productivity in turbid stretches of this river system.

Small increases in inorganic-based turbidity can adversely impact all components of primary productivity. Lloyd *et al*. (1987) found that an increase of only 5 NTU decreased primary production by 3 – 13 % and an increase of 25 NTU decreased primary production by up to 50%. Since turbidity measurements during the summer sampling period ranged from 2.85 – 83.2 NTU, a reduction of 7 to > 50% in primary productivity is predicted.

Table 3-1 presents the summer 2013 Peace side-channel periphyton data with typical data from large rivers. Metrics of the algal component of the periphyton would place the Peace River side-channel habitat in the stressed category. Diatom species richness was particularly low. Metrics that include all photosynthetic periphyton were closer to the typical range, reinforcing the importance of photosynthetic bacteria to this habitat. All metrics of periphyton growth were lower than those compiled on the Mid-Columbia River that experiences stress from regular habitat drying, and far below those compiled on the Lower Columbia River which is very productive (Larratt *et al.* 2013).

In summary, suspended sediment in the Peace River side-channel habitats affected periphyton community structure and productivity, based on summer 2013 data.

4.3 Invertebrate Production Summary

Peace River side channels were dominated by *Oligochaete* taxa, 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* or EPT taxa tend to be more predominant similar to mainstem samples from the Peace River (Table 4-1). These differences between the mainstem and side channels is likely due to the high relative turbidity, and subsequently high sediment deposition rates that create conditions most suitable for taxa such as *Oligogchaete*, which are typically collector-gather foragers associated with these finer sediments and lower oxygen environments (Rodriguez and Reynoldson 2011). Our habitat modelling data also suggests that factors such as light penetration and turbidity are important determinants of the productivity and diversity of the invertebrate community. Future years of this study will continue to investigate differences between side channels, treatments, 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. At the downstream sites (102.5L), Test locations had greater abundance, EPT Richness and %EPT than Control sites. These small differences may be the inputs the Pine River, immediately upstream of the Test side channel.

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) E*nchytraeidae* (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)
Cheakamus River	–	1252 (±1149)	6	–	*Ephemeroptera* *Plecoptera* *Diptera* w/o *chironomi*ds

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.

		Correlation Coefficients					
Explanatory Variable	**VIF**	**Substrate score**	**Mean silt depth**	**D90 (cm)**	**Turbidity (NTU)**	**Mean daily max. temp.**	**Light PC1**
Substrate score	**2.72**	1.00	-0.24	0.27	-0.39	0.57	0.26
Mean silt depth	**1.50**	-0.24	1.00	-0.22	0.53	0.05	-0.44
D90 (cm)	**1.90**	0.27	-0.22	1.00	-0.64	-0.06	0.57
Turbidity (NTU)	**4.30**	-0.39	0.53	-0.64	1.00	0.22	-0.66
Mean daily max. temp.	**2.61**	0.57	0.05	-0.06	0.22	1.00	0.05
Light PC1	**2.24**	0.26	-0.44	0.57	-0.66	0.05	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.

		Correlation Coefficients				
Explanatory Variable	**VIF**	**Substrate score**	**D90 (cm)**	**Compaction**	**Mean daily max. temp.**	**Light PC1**
Substrate score	***2.87***	1.00	0.35	0.67	0.62	0.34
D90 (cm)	***1.95***	0.35	1.00	0.59	0.04	0.62
Compaction	***2.75***	0.67	0.59	1.00	0.29	0.58
Mean daily max. temp.	***1.77***	0.62	0.04	0.29	1.00	0.16
Light PC1	***1.87***	0.34	0.62	0.58	0.16	1.00

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

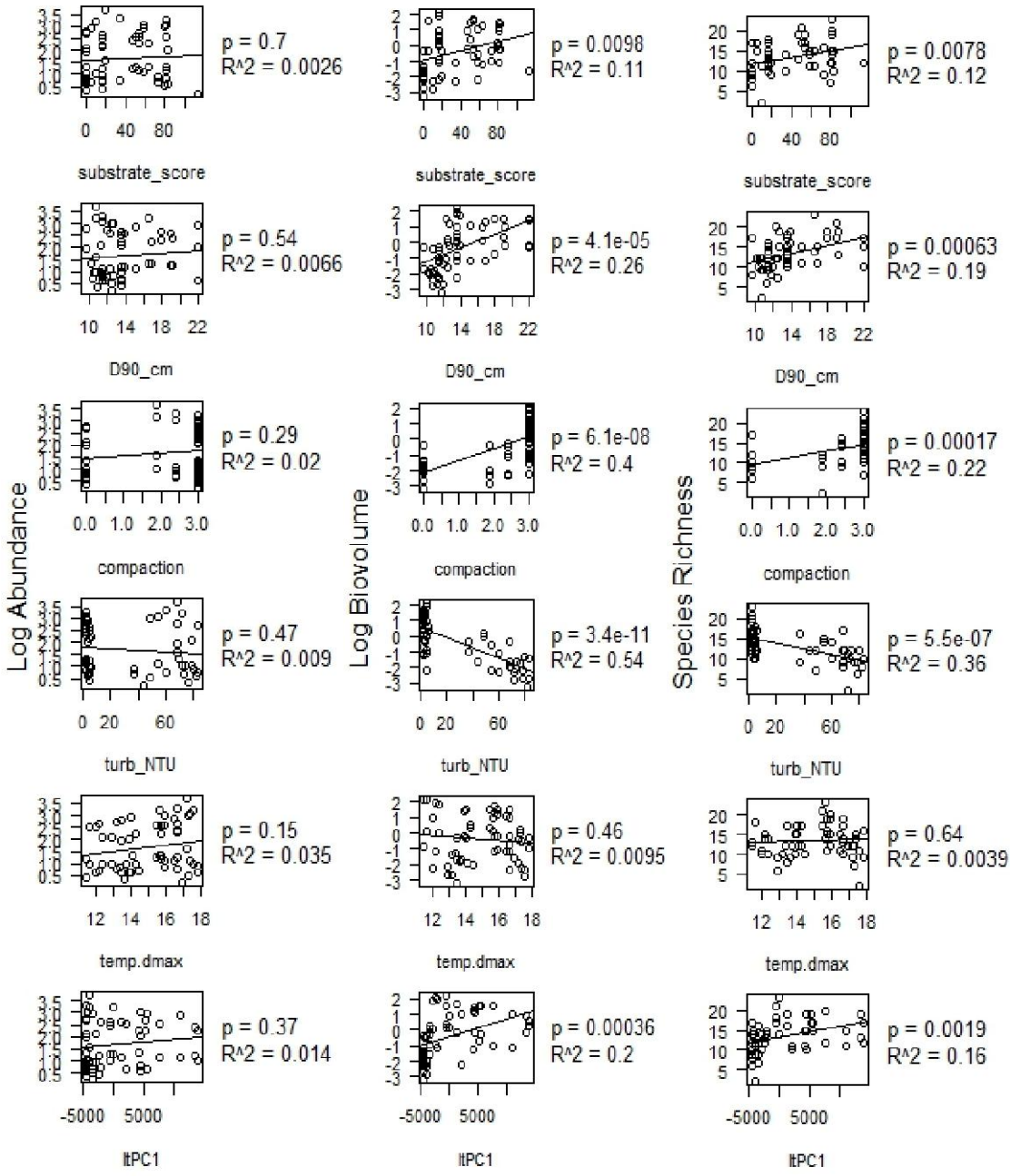

Figure A-3-1: Biplots of periphyton response variables (Log abundance and biovolume, and Species richness) and explanatory variables including D90 (D90_cm), substrate compaction, water turbidity (turb_NTU), mean maximum daily water temperature (temp.dmax), and light PC1 (ltPC1)included in linear mixed effects models.

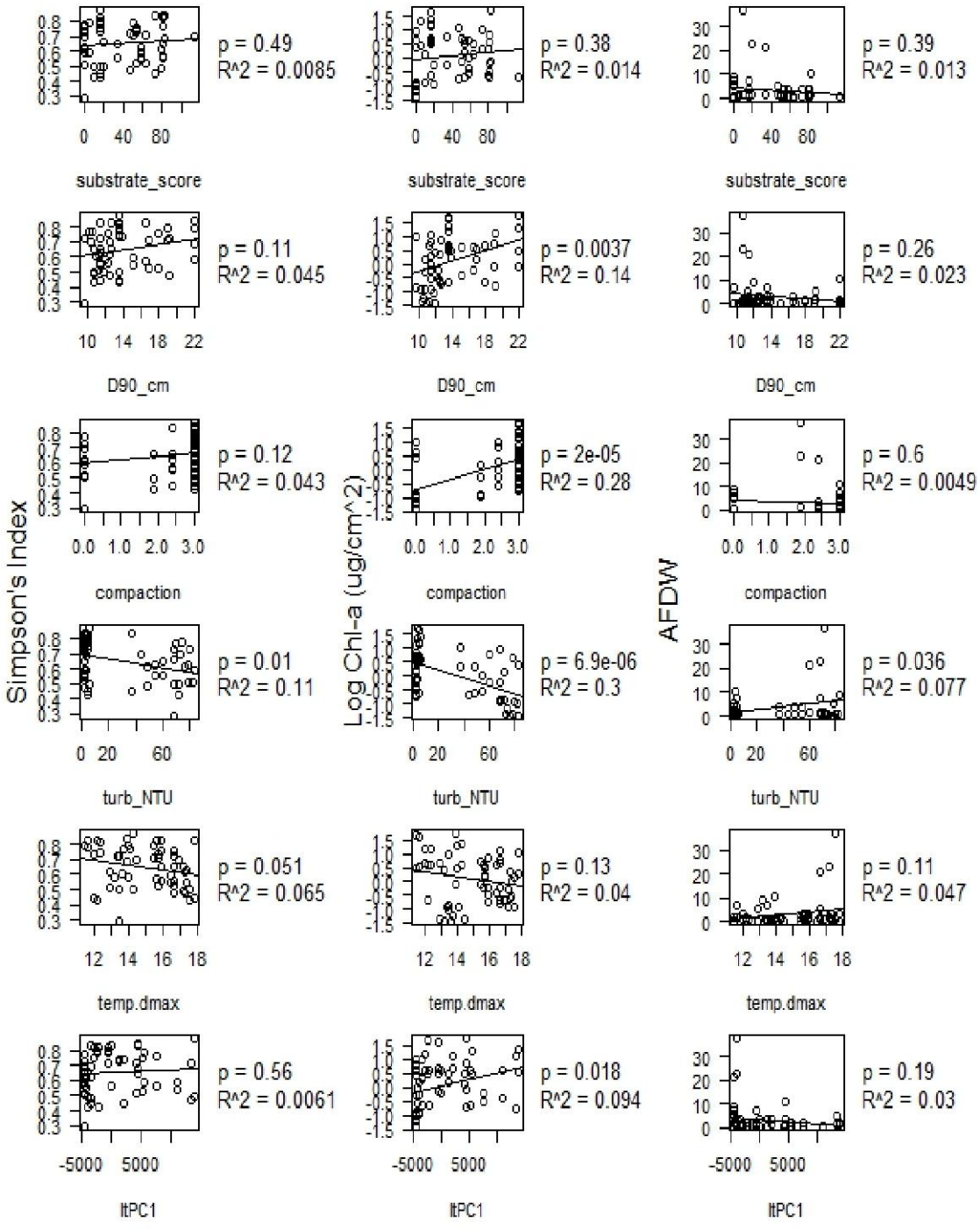

Figure A-3-2: Biplots of periphyton response variables (Simpson's Index, Log Chlorophyll-a, and AFDW) and explanatory variables including D90 (D90_cm), substrate compaction, water turbidity (turb_NTU), mean maximum daily water temperature (temp.dmax), and light PC1 (ltPC1) included in linear mixed effects models.

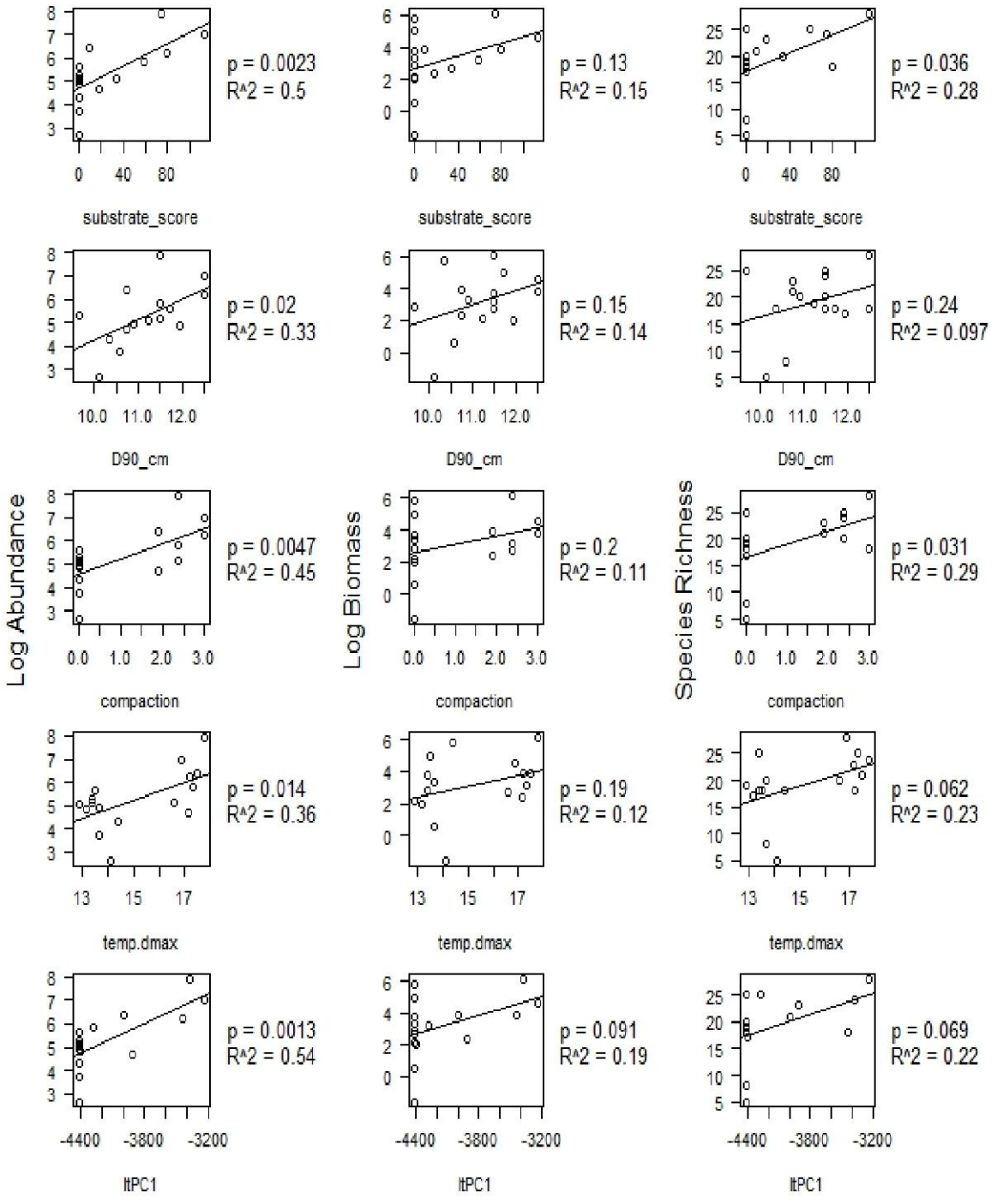

Figure A-3-3: Biplots of benthic invertebrate response variables (Log abundance, Log biomass, Species richness) and explanatory variables including D90 (D90_cm), substrate compaction, mean maximum daily water temperature (temp.dmax), and light PC1 (ltPC1) included in multiple linear regressions.

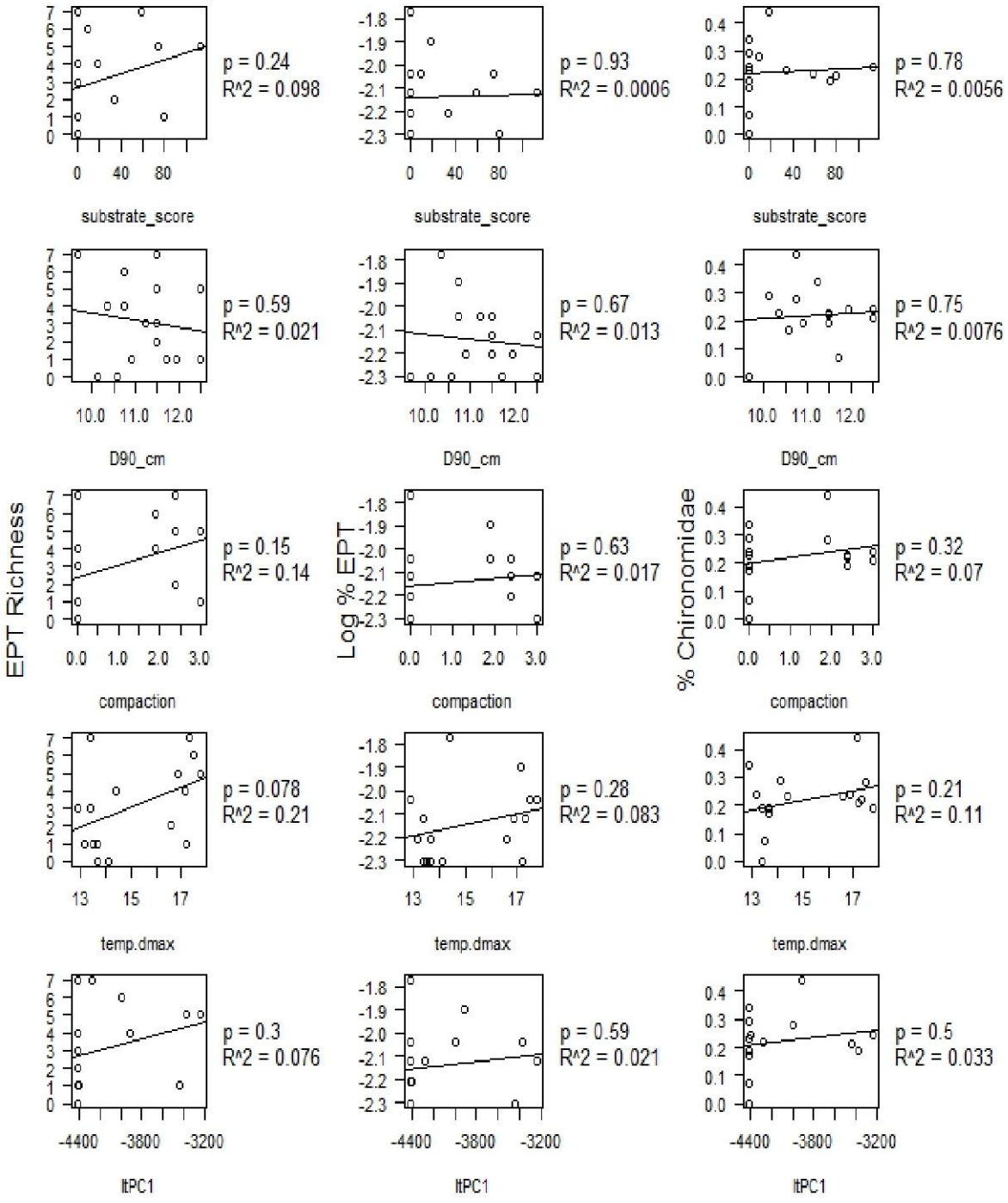

Figure A-3-4: Biplots of benthic invertebrate response variables (EPT richness, Log % EPT, and % Chironomidae) and explanatory variables including D90 (D90_cm), substrate compaction, mean maximum daily water temperature (temp.dmax), and light PC1 (ltPC1) included in multiple linear regressions.

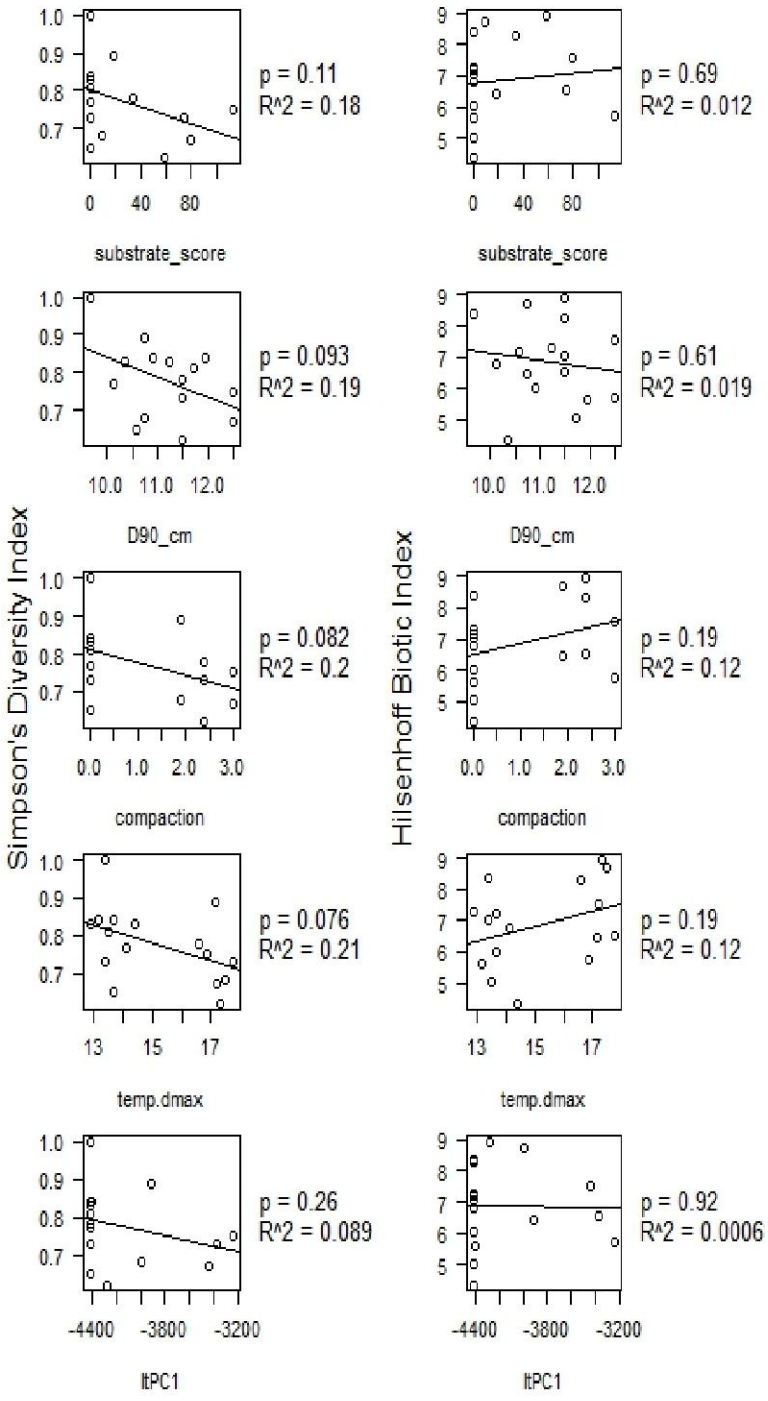

Figure A-3-5: Biplots of benthic invertebrate response variables (Simpson's Diversity Index and Hilsenhoff Biotic Index) and explanatory variables including D90 (D90_cm), substrate compaction, mean maximum daily water temperature (temp.dmax), and light PC1 (ltPC1) included in multiple linear regressions.

Appendix 4: Protocols for Benthic Invertebrate Sample Processing and Biomass Analysis

Ecoscape – Peace River Project 2013

Cordillera Consulting

On August 29, 2013, 34 samples were delivered to Cordillera Consulting from Ecoscape Environmental Consultants Ltd. When samples arrive at Cordillera Consulting they are logged into a proprietary software data base (INSTAR1) and the client generated sample information is recorded along with a Cordillera Consulting number for cross reference. The client representative is notified of the arrival of the shipment. The samples are checked that all sites and replicates recorded on field sheets or packing lists have been delivered intact and with adequate preservative. Attention is given to those samples which have been collected using more than one jar and the jars numbers are also recorded in INSTAR1. If there are any missing, mislabeled or extra samples Cordillera Consulting will contact the client immediately to confirm the total numbers and correct names on the sample jars.

After sieving the contents, each sample was assigned a distinct Cordillera Consulting code. See table below for summary:

Site	Sample	CC#	Date	Size	# of Jars
32L C	S1	CC140546	8/21/2013	250µM	1
32L C	S2	CC140547	8/21/2013	250µM	1
32L C	S3	CC140548	8/21/2013	250µM	1
32L C	S4	CC140549	8/21/2013	250µM	1
32L C	S5	CC140550	8/21/2013	250µM	1
32L C	S6	CC140551	8/21/2013	250µM	1
32L C	S8	CC140552	8/21/2013	250µM	1
32L C	S9	CC140553	8/21/2013	250µM	1
32L M	S1	CC140554	8/21/2013	250µM	1
32L M	S2	CC140555	8/21/2013	250µM	1
32L M	S3	CC140556	8/21/2013	250µM	1
32L M	S4	CC140557	8/21/2013	250µM	1
32L M	S5	CC140558	8/21/2013	250µM	1
32L M	S6	CC140559	8/21/2013	250µM	1
32L M	S7	CC140560	8/21/2013	250µM	1
32L M	S8	CC140561	8/21/2013	250µM	1
32L M	S9	CC140562	8/21/2013	250µM	1
102.5R C	S1	CC140529	8/20/2013	250µM	1
102.5R C	S2	CC140530	8/20/2013	250µM	1
102.5R C	S3	CC140531	8/20/2013	250µM	1
102.5R C	S4	CC140532	8/20/2013	250µM	1
102.5R C	S5	CC140533	8/20/2013	250µM	1
102.5R C	S6	CC140534	8/20/2013	250µM	1
102.5R C	S7	CC140535	8/20/2013	250µM	1
102.5R C	S8	CC140536	8/20/2013	250µM	1
102.5R C	S9	CC140537	8/20/2013	250µM	1
102.5R M	S1	CC140538	8/20/2013	250µM	1
102.5R M	S2	CC140539	8/20/2013	250µM	1
102.5R M	S3	CC140540	8/20/2013	250µM	1
102.5R M	S4	CC140541	8/20/2013	250µM	1
102.5R M	S5	CC140542	8/20/2013	250µM	1
102.5R M	S6	CC140543	8/20/2013	250µM	1
102.5R M	S7	CC140544	8/20/2013	250µM	1
102.5R M	S9	CC140545	8/20/2013	250µM	1

The contents were checked for appropriate preservation and the labeling, number of jars per sample and codes were verified. The preservative was rinsed out and replaced with 80% ethanol and the sample was elutriated to remove inorganic material. The elutriate was examined under low power magnification to ensure the removal of molluscs and trichopteran cases.

At the beginning of the sorting process each sample was examined and evaluated for an estimation of total invertebrate numbers. If the total number of invertebrates was estimated to be greater than 600 then the subsampling protocol was followed. The Marchant box is used for subsampling and a minimum number of invertebrates for subsampling set at 300. The table below is a summary of the level of subsampling applied to each sample.

Site	Sample	CC#	250 micron fraction	
			% Sampled	# Invertebrates
102.5R C	S1	CC140529	100%	208
102.5R C	S2	CC140530	100%	15
102.5R C	S3	CC140531	100%	74
102.5R C	S4	CC140532	100%	51
102.5R C	S5	CC140533	100%	143
102.5R C	S6	CC140534	100%	187
102.5R C	S7	CC140535	100%	182
102.5R C	S8	CC140536	100%	294
102.5R C	S9	CC140537	100%	143
102.5R M	S1	CC140538	11%	321
102.5R M	S2	CC140539	31%	362
102.5R M	S3	CC140540	64%	341
102.5R M	S4	CC140541	100%	366
102.5R M	S5	CC140542	100%	194
102.5R M	S6	CC140543	100%	136
102.5R M	S7	CC140544	54%	352
102.5R M	S9	CC140545	100%	219
32L C	S1	CC140546	33%	319
32L C	S2	CC140547	12%	59
32L C	S3	CC140548	54%	353
32L C	S4	CC140549	32%	371
32L C	S5	CC140550	30%	362
32L C	S6	CC140551	30%	401
32L C	S8	CC140552	18%	346
32L C	S9	CC140553	41%	371
32L M	S1	CC140554	100%	163
32L M	S2	CC140555	100%	176
32L M	S3	CC140556	52%	363
32L M	S4	CC140557	33%	354
32L M	S5	CC140558	32%	350
32L M	S6	CC140559	24%	351
32L M	S7	CC140560	21%	330
32L M	S8	CC140561	18%	360
32L M	S9	CC140562	30%	329

Removal of Invertebrates

Using a gridded Petri dish, fine forceps and a low power stereo microscope (Olympus, Nikon, Lieca) the sorting technicians removed the invertebrates and sorted them 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. Total numbers excluded organisms from Porifera, Nemata, Platyhelminthes, Ostracoda, Copepoda, Cladocera and terrestrial drop-ins such as aphids. These organisms were removed and counted but they were not included towards the total count.

- Where specimens were broken or damaged, only heads were counted.
- The number of organisms removed were recorded manually on a bench sheet. The number of organisms in each family or order were also recorded at this time.
- The groups of invertebrates and numbers of each group were entered into INSTAR1
- They are stored in 80% ethanol in separate vials (according to family/order) and an interior label using heavy laser paper is made using site names, date of sampling, site code numbers and portion subsampled. This information is also recorded on the laboratory bench sheet and on the database.
- 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 also labeled and preserved in separate jars.

Taxonomic Effort

The next procedure was the identification to genus-species level where possible. The Standard Taxonomic Effort lists compiled by SAFIT (Richards et al 2011) was used as a guideline for what level of identification to achieve where the condition and maturity of the organism enables.

Appendix 1 lists the major reference texts used for identification, though other online keys and journal publications may also be used.

- Organisms from the same families/order were kept in separate vials in 80% ethanol and labeled with an interior label of laser paper. Where numbers of organisms in a family or genus was large (>30) it merited a separate vial.
- Chironomidae will be identified to genus/species level using slide mounts. CMC-10 will be used to clear and mount the slide.
- Oligochaetes were identified to family/genus level with the aid of slide mounts. CMC-10 was used to clear and mount the slide.
- Decapoda, Amphipoda and Isopoda were identified at family/genus/species level where possible.
- Nemata remained at the phylum level.
- Hydrachnidae were identified at the family/genus level.

Sorting Efficiency

Ten samples were selected at random for resorting analysis to measure the effectiveness of the sorters. A different sorter from the original sorter did the resort.

All of the resorted samples were above 95% efficiency of invertebrate removal and so achieved industry standards.

There were three samples resorted: 102.5R C S4, 102.5R M S7, and 32L M S3.

Site	Original Sorting	Resort	% Efficiency
102.5R C, S4	42	1	97.62
102.5R M, S7	321	4	98.75
32L M, S3	333	11	96.70

Biomass Analysis

Biomass was measured using a digital biomass technique based on the use of length-dry biomass regressions found in the literature.

The digital biomass process starts with identification to the genus/species level. Once identification is completed the specimens are put into a small Petri dish in 70% ethanol. An Olympus SZX16 stereo microscope in conjunction with an Infinity2-C3 microscope mounted camera and Lumenera software are used to capture images of invertebrates in the samples. These images are then imported into a proprietary program, developed in house with help from SageKey Software, that allows for a length to weight conversion to take place. This program interprets data involved in the naming of the image file to determine the magnification used when the photo was taken. This allows the program to properly determine how long the line segments drawn on the invertebrate are in millimetres (.001 mm). Each drawn line is assigned a taxonomic identification from the sample that the program incorporates into a formula that then calculates a dry mass (DM) value in milligrams. The formula, $DM = aL^b$, incorporates length L (mm) of the invertebrates modified by constants, *a* and *b,* which are related to body shape. The constants for this process are taken from literature by A.C. Benke et al (1999), Sample et al (1993) and Smockl (1993).

The body length and taxa information is managed by the program software to create a spreadsheet showing total biomass persample, having taken subsample size, magnification, average body length and numbers of individuals into consideration. The program's layout is shown below in figure 1.

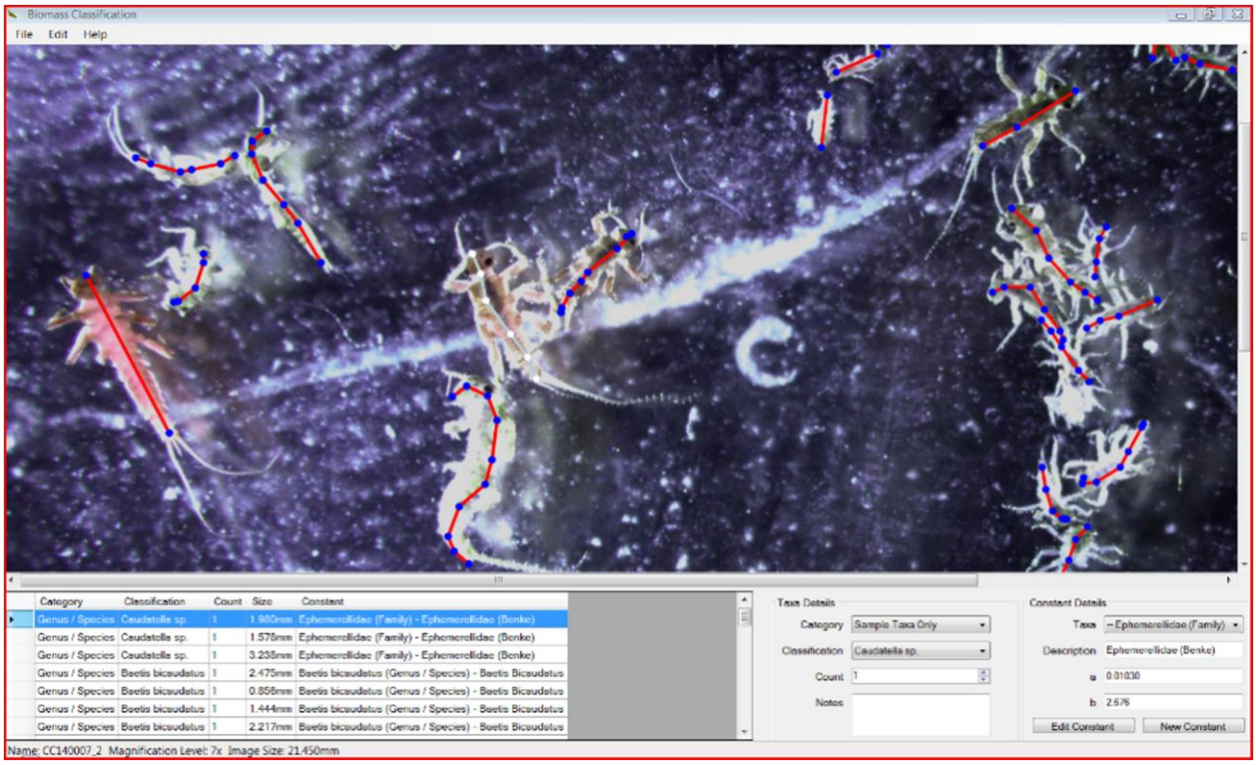

Figure 1 shows the layout of the Biomass App. It shows the lines drawn in red on various Ephemeroptera. It also shows the size in mm, as well as the values for the constants a and b.

Where there are 2-10 individuals in a taxa group, all individuals will be measured. Where there are more than 10 individuals in a taxa group a minimum of 10 measurements will be taken to calculate an average. Where there are more than 50 individuals in a taxa group the program can calculate the average.

There are no published length- dry mass regressions for oligochaetes or mites. Cordillera Consulting has calculated a simple constant which is multiplied by the number of individuals in the sample. This constant is based on the assumptions that the mites and Oligochaete families are of uniform length/diameter. This may be an advantage for the worms which are often found in pieces but the method assumes that the whole worm existed in the sample when it was first collected.

A record of the constants used to determine the dry mass is available upon request.

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Appendix 4-1

Keys used for Identification of Freshwater Benthic Invertebrates

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