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MACTAQUAC AQUATIC ECOSYSTEM STUDY

PRELIMINARY CHARACTERIZATION OF PLANKTON COMMUNITIES IN THE MACTAQUAC HEADPOND AND DOWNSTREAM SAINT JOHN RIVER

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TABLE OF CONTENTS

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EXECUTIVE SUMMARY

This report provides a general overview of the diversity and spatial variation the plankton communities and their associations with the environmental parameters in the Mactaquac Head Pond (HP) and downstream Saint John River (RIV) to the city of Fredericton measured from June to October in 2015 and 2016. Most of the water quality conditions of the HP and RIV sites are similar in both the HP stratification and non-stratification periods. The differences when observed (DO, conductivity and temperature) are most probably related to the two different habitats, e.g., differences in water depth and flow that would affect the physico-chemical processes. There were an estimated 341 phytoplankton and 73 zooplankton species observed. In 2016, the average number of phytoplankton cells in the HP habitat is 1.98E+09± 3.63E+09 cells/m^3 and that in RIV habitat is 4.08E+08± 2.76E+08 cells /m^3 ($p > 0.05$). The H' index of diversity for phytoplankton ranged from 0.17 to 2.78, in which the average values for the HP and RIV sites are 1.5±0.5 and 2.0±0.4, respectively ($p < 0.05$). During the non-stratification time in the HP, a series of statistical tests show that the mixing of water columns can lead to the mixture of the phytoplankton communities in both abundance and taxa richness (p's > 0.05). Similarly, during HP stratification, the difference in water quality conditions among layers was not enough to cause significant variation of the phytoplankton communities inhabiting each layer in terms of the taxa richness and number of cells ($p > 0.05$). Zooplankton analyses will be complete in spring, 2017. The non-significant results of the statistical tests ($p >0.05$) support the hypothesis that in the main river after the MD, the river plankton community are mostly supplemented by those from the MH. However, ANOSIM analysis showed that the variation of the plankton assemblages between the HP and RIV is significantly different with either of the variations within each habitat ($p <0.05$). Based on DCA and RDA analysis, we found the significant importance of the temperature, conductivity, and DO for the phytoplankton community structure ($p <0.05$). The zooplankton assemblage had a strong association with temperature, conductivity, and pH ($p <0.05$).

1. INTRODUCTION

Freshwater plankton are small organisms at the base of aquatic food webs where they play an essential role for the ecological functions of reservoir and river ecosystems (Likens 2010; Wetzel 2001). Plankton biology and ecology are well studied for lakes, rivers, and lake-river interactions (e.g., Jones 2010; Likens 2010; Wetzel 2001).

Phytoplankton, or algae, are highly diverse in freshwater bodies, displaying effective response mechanisms to environmental changes through the utilization of various adaptive strategies. As a photoautotrophic organism, algae capture light to convert inorganic elements into organic compounds and thus represent the basis of most all aquatic food webs; they also produce oxygen (Krienitz 2009). Conversely, excessive algal blooms or extreme production of algae can negatively affect fish and macroinvertebrates creating poisonous or bioactive substances causing death or disease, or altering habitat, e.g., changes in water chemistry and water clarity affecting photosynthetically active radiation (PAR) and ultraviolet (UV) penetration. Other major challenges of algal blooms include toxicity to animals including humans and thus affecting recreational activities such as fishing, boating, swimming. Blooms can also threaten water supplies, increasing the cost of water treatment and management (Burkholder 2009).

Zooplankton comprise four main groups: Protozoa, Rotifera, Copepoda, and Cladocera. They can be herbivores, carnivores, or omnivores, inhabiting multiple trophic levels in lacustrine ecosystems (Sterner 2009). Zooplankton function as a crucial intermediate trophic stage in the energy flow from primary producers to top consumers such as fish and larger aquatic animals (Sterner 2009). It has been demonstrated that a change in zooplankton composition and/or abundance can influence trophic structure in lake ecosystems, including affecting nitrogen and phosphorous (Andersen & Hessen 1991; Downing & McCauley 1992; Williamson & Reid 2010).

Plankton are well studied in standing waters such as lakes and reservoirs. The dynamic flowing waters of rivers are less suited to pelagic plankton production and species composition, and abundance is typically related to benthic production and occurrences of either standing water, e.g., inlets, or slow flow conditions (Basu et al. 2000; C. Reynolds 2000; Wetzel 2001). Studies of plankton in large river systems are few in the Atlantic Canada region (Locke & Klassen 2010). Only the studies of Aubé et al. (2005); Duerden (1973); and Watt and Duerden (1974) exist and focus on plankton of impounded water bodies in the region. The Saint John River (SJR), the longest river in the Atlantic Canada at ~ 650km long, has contributed considerably to the development of agriculture, forestry, transportation, and electricity in the region (Cunjak & Newbury 2005). The river has five major hydropower dams, the largest is the Mactaquac Hydroelectric Facility and Dam (MD) built in late 1960s (Cunjak & Newbury 2005; Watt 1973). The study of plankton in the SJR consists of a brief description of diversity, biomass, seasonal patterns, and relationships with some environmental parameters in association with the water-mixing period for the MD reservoir in the early 1970s (Watt 1972, 1973; Watt & Duerden 1974). There has yet to be assessments of the temporal and spatial plankton distributions in SJR, e.g., the

seasonal vertical distributions associated with stratification and mixing, or any possible effects of the MD on downstream plankton communities.

This report is a part of the MAES project and aims to characterize plankton communities of the Mactaquac Head Pond and downstream SJR from the MD to the City of Fredericton. It is the first comprehensive research on the SJR plankton communities since the 1970s.

This report comprises the following:

1. Descriptions of the plankton communities: biodiversity, and spatial variations in HP and downstream SJR.
2. The relationship between the plankton communities and environmental parameters.

2. METHODOLOGY

1.1. FIELD WORK

From 2014 to 2016, a total of 17 sites were investigated for to assess plankton abundance and diversity and the physico-chemical characteristics of the reservoir (N = 13, HP habitat) and river (N = 4, RIV habitat) (Figure 1 and Table 1). More details about the features of collecting sites could be assessed via the MAES web pages in Canadian Rivers Institute website (http://canadarivers-gis.maps.arcgis.com/home/index.html).

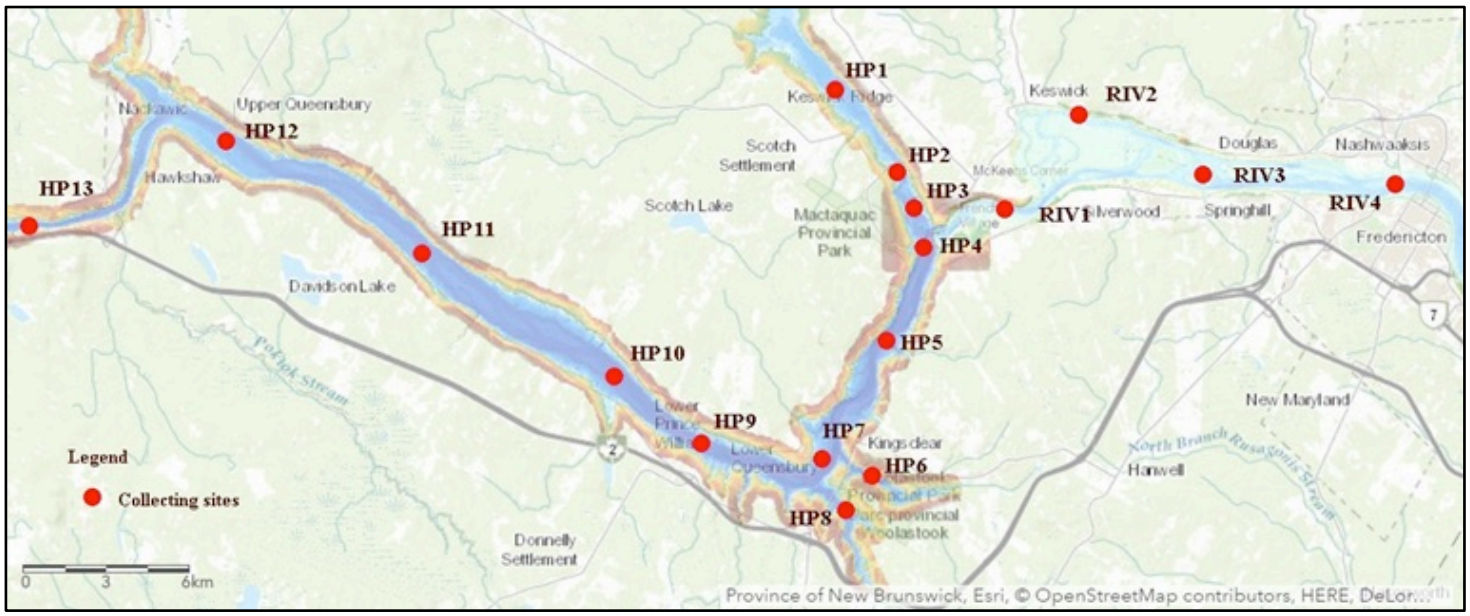

Figure 1. The map showing the collection sites in the studied area of the Mactaquac Head Pond (HP) and Saint John River (RIV) from 2014-16.

Table 1. Characteristics of the study sites in the Mactaquac Head Pond (HP) and Saint John River (RIV).

No.	Site		Coordinates		Limnology survey			Plankton survey		
	New names	Other names	Latitude	Longitude	2014	2015	2016	2014	2015	2016
1.	HP1	HP30-C	46.00012	-66.9173	x	x	---	x	x	---
2.		HP30-L	46.0016	-66.9152	x	x	---	---	---	---
3.		HP30-R	45.99953	-66.9185	x	x	---	---	---	---
4.	HP2	HP1	45.97403	-66.88643	---	---	x	---	---	x
5.	HP3	HP35-C	45.99953	-66.91852	---	x	---	---	x	---
6.		HP35-L	45.96067	-66.87749	---	x	---	---	---	---
7.		HP35-R	45.95911	-66.88314	---	x	---	---	---	---
8.	HP4	HP40-L	45.94762	-66.8739	x	x	---	---	---	---
9.		HP40-C	45.94717	-66.8739	x	x	---	x	x	x
10.		HP40-R	45.94644	-66.8711	x	x	---	---	---	---
11.		HP2	45.94891	-66.87474	---	x	---	---	x	---
12.	HP5	HP50-R	45.92163	-66.8933	x	---	---	---	---	---
13.		HP50-C	45.91996	-66.8904	x	---	---	---	---	---
14.		HP50-L	45.91889	-66.8879	x	---	---	---	---	---
15.		HP3	45.91681	-66.89414	---	---	x	---	---	x
16.	HP6	HP20-L	45.87516	-66.8995	x	---	---	---	---	---
17.		HP20-C	45.87588	-66.8992	x	---	---	---	---	---
18.		HP20-R	45.87644	-66.8986	x	---	---	---	---	---
19.	HP7	HP60-R	45.87978	-66.9179	x	x	---	---	---	---
20.		HP60-C	45.88094	-66.9211	x	x	---	---	x	---
21.		HP60-L	45.88185	-66.9247	x	x	---	---	---	---
22.	HP8	Longs-C	45.86466	-66.9132	x	x	---	---	x	---
23.	HP9	HP4	45.88589	-66.97754	---	---	x	---	---	x
24.	HP10	HP70-C	45.90372	-67.0154	x	x	---	x	x	---
25.		HP70-R	45.90101	-67.0166	x	---	---	---	---	---
26.		HP70-L	45.90701	-67.0127	x	---	---	---	---	---
27.	HP11	HP10-C	45.94509	-67.1053	x	x	---	---	x	---
28.		HP10-R	45.94331	-67.1076	x	x	---	---	---	---
29.		HP10-L	45.94793	-67.1022	x	x	---	---	---	---
30.	HP12	HP80-L	45.98351	-67.1967	x	x	---	---	---	---

No.	Site		Coordinates		Limnology survey			Plankton survey		
	New names	Other names	Latitude	Longitude	2014	2015	2016	2014	2015	2016
31.		HP80-C	45.98052	-67.1975	x	x	---	x	x	---
32.		HP80-R	45.97913	-67.1998	x	x	---	---	---	---
33.	HP13	Lotic-R	45.97913	-67.1998	x	---	---	---	---	---
34.		Lotic-C	45.95523	-67.2883	x	x	---	---	---	---
35.		Lotic-L	45.95695	-67.2881	x	---	---	---	---	---
36.	RIV1	---	45.9611	-66.83986	---	x	x	---	x	x
37.	RIV2	---	45.98984	-66.80491	---	---	x	---	---	x
38.	RIV3	RIV2	45.98984	-66.80491	---	x	x	---	x	x
39.	RIV4	---	45.96766	-66.66050	---	x	x	---	x	x

Notes: C-center; L-left; R-right; x-conducting survey

We determined the thermal stratification period in the HP begins in July and lasts until September (2014 and 2015 results). The strongest stratification occurred from HP3 to HP12 (Figure 1). Preliminary analyses indicated that the plankton communities were >65% similar in term of taxa richness and abundance in both the HP or RIV habitats. We intensified sampling to fewer sites in 2016: 4 sites in the HP and 4 sites in the RIV - HP2, HP4, HP5, HP9, RIV1, RIV2, RIV3, and RIV4 (Table 2).

Table 2. Field sampling protocol for 2016

Site	Stratification period		Non-stratification period	
	Reservoir	Downstream	Reservoir	Downstream
	HP2, HP3, HP5, HP9	RIV1, RIV2, RIV3, RIV4	HP2, HP3, HP5, HP9	RIV1, RIV2, RIV3, RIV4
Month	July August		June November	
Method	Sample 3 water layers by Schindler-Patalas trap: Epilimnion, Metalimnion, Hypolimnion.	Sample 2 layers by Schindler- Patalas trap: Surface, Bottom.	Sample by vertical towed method: Tow plankton net from bottom to the surface at a consistent rate.	Sample by vertical towed method: Tow plankton net from bottom to the surface at a consistent rate.
Environmental parameters	- T^0C, pH, turbidity, Depth, Conductivity, Salinity, DO, Secchi depth, T-N, T-P.	- T^0C, pH, turbidity, Depth, Conductivity, Salinity, DO, and Secchi depth, T-N, T-P.	- T^0C, pH, turbidity, Depth, Conductivity, Salinity, DO, Secchi depth, T-N, T-P.	- T^0C, pH, turbidity, Depth, Conductivity, Salinity, DO, and Secchi depth, T-N, T-P.
	- Chlorophyll-a, Phycocyanin	- Chlorophyll-a, Phycocyanin	- Chlorophyll-a, Phycocyanin	- Chlorophyll-a, Phycocyanin

Depth and other environmental parameters were measured using a YSI 6600 V2 Sonde coupled with various probes connected to a YSI 650 handheld unit which displays profile data (Chateauvert 2015), including Temperature (^{0}C), pH, turbidity (NTU), Depth (m), Conductivity (µS/cm), Salinity (ppt), Dissolved Oxygen (mg/L). Secchi disk depth is also recorded at every site (1 cm).

At each site, water samples were also collected and sent for analyses of Total Dissolved Phosphorus (TDP), Soluble Reactive Phosphorus (SRP), Nitrite+Nitrate, Ammonia (NH_3), and Total Dissolved Nitrogen (TDN) (Biogeochemical Analytical Service Laboratory, University of Alberta, http://www.biology.ualberta.ca/basl). Pigment concentrations, Chlorophyll-a and Phycocyanin were measured directly in the field using the AMISCIENCE® Handheld Fluorometer (http://www.amiscience.com). In addition, the pigments were determined in vitro by the fluorescence method in the laboratory (Arar & Collins 1997).

Plankton samples are collected from either individual water layers during the stratification period or by a single vertical tow to create a consolidated vertical sample in non-stratification time. During stratification, each layer (epi-, meta-, and hypolimnion) was sampled using three Schindler-Patalas plankton trap samples that were combined into a single sample. The volume capture of the trap is 12L with Nitex® filter net and 35µm mesh size. The layer was identified using the YSI Sonde and the targeted sample position was the middle of the thermal layer. In the non-stratified period, an integrated water column sample was collected using a conical plankton net with 35µm mesh. The net was deployed about 1 m above the substrate and retrieved at a consistent rate of ~15 cm/s (Chateauvert 2015; Keen 2013). An additional weight can be added to the trap and plankton net to ensure the vertical-towed process in deeper waters (typically > 10 m) or in the river locations where the velocity can cause some effects on the towing process. The towed sample volume, V, was calculated as: $V = \pi * r^2. * d$, where r = radius of the net rim, d = depth that the net was pulled. Plankton samples were stored in pre-labelled plastic jars (125 or 500 mL) preserved in full Lugol's solution with a final concentration 1%.

1.2. LABORATORY ANALYSES

In the first two years (2014 and 2015), plankton samples were identified to the species level or other higher taxonomic forms and numerated by EcoAnalysts, Inc., USA. The 2016 samples were identified and quantified in house at CRI@UNB, Department of Biology, Fredericton. The plankton samples are identified to the species or genus level based on various key documents (e.g., Baker 2012; Bellinger & Sigee 2010, 2015; Brandlova et al. 1972; Chengalath 1971; Haney ; Lerback 2013; Nuttall 1971; Prescott 1964, 1980; Serediak & Huynh 2011; Smith 1978; Suárez-Morales & Reid 1998; Suthers & Rissik 2009; Thorp & Covich 2001; Wehr & Sheath 2003; Witty 2004). The zooplankton density (individuals/m^3) is enumerated by applying the chamber-based counting method (APHA 2005; Stemberger 1979). The quantification of phytoplankton abundance (number of natural units/m^3 and number of cells/ m^3) is achieved by the Utermohl

method (AWWA 2010; Utermöhl 1958; Weber 1973). The plankton counting error is less than 20% (AWWA 2010; Harris et al. 2000).

1.3. STATISTICAL ANALYSIS AND BIO-INDEX CALCULATIONS

Characterizations of plankton communities were described as: Taxa richness= number of species; Shannon-Weaver Index (H') = biodiversity index; and Pielou (J') = evenness index (Krebs 1989). These indexes are calculated for the individuals/m^3 for zooplankton and the cells/m^3 for phytoplankton. The uncertain taxa of plankton were excluded in the statistical analysis and index calculations.

1.3.1. Variation among water layers:

We used two-way ANOVAs to test the hypothesis that there is difference in plankton communities among three water layers in the HP (epi-, meta-, and hypo-limnion) and between the surface and bottom layers in RIV habitat (during the stratification period). When the ANOVA assumptions are strongly violated, we use the non-parametric tests, including the two-way ANOVA equivalent Scheirer-Ray-Hare Test with the Bonferroni correction; one-way ANOVA equivalent Kruskal-Wallis or Mann-Whitney-Wilcoxon tests (Dytham 2011).

1.3.2. Variation between head pond and river habitats:

We used a set of one-way ANOVAs to assess the potential effect of the head pond plankton community on the river community by comparing the two sites, one directly upstream of the Mactaquac Dam (HP4) and one downstream SJR (RIV1) in term of the taxa richness and abundance (Figure 1). Proper non-parametric testes will be performed in case the ANOVA assumptions are violated. Additionally, the ANOSIM (Analysis of Similarity) was applied to detect the difference between the two habitat plankton assemblages.

1.3.3. Plankton and water conditions:

Relating plankton communities to the water quality conditions was conducted using a combination of DCA (Detrended Correspondence Analysis) and RDA (Redundancy Analysis) based on species scores for centering and symmetry scaling (Quinn & Keough 2002). To avoid model overfitting in RDA analysis, we applied the rule that the number of environmental variables was reduced to ½ the numbers of the species or collecting sites, dependent on which is smaller. Environmental variables were tested by Pearson Correlation Analysis such that correlations with $r>0.60$ resulted in one of the two variables being removed (Draper & Smith 1998). Furthermore, after RDA performance, only variables with VIF (Variance Inflation Factor) < 10 were retained in the analysis (Tu et al. 2005).

1.3.4. Summary

The plankton abundance (cells/m^3 for phytoplankton and individuals/m^3 for zooplankton), and environmental parameters (except pH) were transformed prior by the formula of $\log10(X + 1)$ to

reduce the effects of extreme values and the unit differences of environmental variables. In ANOSIM analysis, the plankton abundance data is ranked by the Bray-Curtis similarity process. The significance of RDA model and ANOSIM was achieved by using per permutation tests with 999 trials. We set $\alpha = 0.05$.

Statistical analyses and indices for phytoplankton calculations are based on the 2016 data. We exclude data collected in June for RDA analysis because we lacked conductivity and turbidity measures. Zooplankton analyses won't be complete until spring 2017. In the analyses of this report, data of 6 sites collected in October and November, 2015 are included (HP1, HP3, HP10, RIV1, RIV3, and RIV4). The software of R program v.3.3.2 coupled with various packages, Primer™ v.6, Microsoft® Excel™ v.2010 were used for the analyses. We report averages ± 1 standard deviation.

3. RESULTS

3.1. WATER CONDITIONS

3.1.1. Depth

During the stratification time, the depth of the upper MD habitat (HP) had a high range from 13.8m (HP1) to 39.4m (HP5), whereas, the range of the RIV habitat is from 2.2m (RIV3) to 4.7m (RIV4). In non-stratification time, the depth in the HP habitat varies from 13.7m (HP1) to 38.0m (HP5) and in the RIV habitat is about 4.4 m (RIV2) to 7.1m (RIV1). Table 3 provides more details.

Table 3. Depth (m) variation in the collecting sites between the stratification and non-stratification time.

Site	Stratification time	Non-Stratification time
HP1	13.8	13.7
HP2	19.7	19.1
HP3	27.1	---
HP4	37.5	35.1
HP5	39.4	38.0
HP6	24.5	---
HP7	37.9	---
HP8	26.1	---
HP9	35.3	34.5
HP10	33.8	29.1
HP11	29.3	---
HP12	23.0	---
HP13	27.0	---
RIV1	3.4	7.1
RIV2	3.4	4.4

Site	Stratification time	Non-Stratification time
RIV3	2.2	6.8
RIV4	4.7	5.7

3.1.2. Temperature

The average temperature in the head pond sites = 19.9 ±1.2^{o}C during the stratification period and 12.8±3.1 ^{o}C during the non-stratification period (Table 4). Temperature for the river sites averaged 21.0±0.4 ^{o}C and 12.6±1.0 ^{o}C in stratification and non-stratification periods, respectively.

Table 4. Water column temperature (^{0}C) among the collecting sites during stratification and non-stratification periods in the Mactaquac Head Pond (HP) and SJR (RIV) – see also Figure 1.

	Stratification time			Non-Stratification time		
Site	**Min (^{0}C)**	**Max (^{0}C)**	**Average (^{0}C)**	**Min (^{0}C)**	**Max (^{0}C)**	**Average (^{0}C)**
HP1	15.3	24.6	19.7	10.3	11.1	11.0
HP2	15.1	25.2	20.9	15.4	17.2	15.6
HP3	8.8	21.8	19.4	---	---	---
HP4	10.5	24.1	18.2	9.4	16.9	12.9
HP5	10.6	24.3	18.9	11.4	17.6	14.9
HP6	15.2	24.4	20.2	---	---	---
HP7	11.2	23.3	19.6	---	---	---
HP8	17.0	24.5	20.8	---	---	---
HP9	11.0	24.7	17.4	12.0	18.1	14.9
HP10	14.8	22.1	20.2	6.6	9.3	7.6
HP11	12.6	22.6	20.6	---	---	---
HP12	15.4	23.2	21.4	---	---	---
HP13	17.0	23.9	21.0	---	---	---
RIV1	20.4	22.8	21.2	12.3	15.9	13.7
RIV2	20.0	22.7	21.2	10.3	18.2	11.3
RIV3	19.8	24.0	21.1	11.3	15.1	12.5
RIV4	19.0	23.2	20.5	10.3	15.3	12.9

3.1.3. Conductivity

The average conductivity for the head pond is averaged 133.4 ± 32.1 µS/cm during the stratification period and 113.2± 18.9 µS/cm during the non-stratification period. In the river habitats, the average = 123.6 ±38.9 µS/cm and 108.5 ±19.5 µS/cm for the stratification and non-stratification periods, respectively (Table 5).

Table 5. Conductivity (µS/cm) variation among the collecting sites during stratification and non-stratification periods in the Mactaquac Head Pond (HP) and SJR (RIV)–see also Figure 1.

	Stratification time			Non-Stratification time		
Site	**Min (µS/cm)**	**Max (µS/cm)**	**Average (µS/cm)**	**Min (µS/cm)**	**Max (µS/cm)**	**Average (µS/cm)**
HP1	52.0	89.0	73.4	75.2	80.1	79.0
HP2	83.8	349.6	210.3	69.6	114.5	112.1
HP3	95.1	123.1	116.6	---	---	---
HP4	92.0	423.6	157.4	75.5	130.1	119.3
HP5	92.3	334.8	149.3	79.0	117.8	111.7
HP6	96.0	125.0	109.1	---	---	---
HP7	99.4	139.0	120.9	---	---	---
HP8	110.0	140.0	125.0	---	---	---
HP9	93.2	232.8	160.6	92.1	124.5	121.2
HP10	109.0	138.0	128.2	130.2	139.0	135.7
HP11	105.6	138.0	123.3	---	---	---
HP12	112.9	142.0	128.0	---	---	---
HP13	111.2	145.0	132.5	---	---	---
RIV1	113.7	368.0	181.5	70.8	127.9	120.3
RIV2	96.2	104.6	97.8	56.0	83.0	79.4
RIV3	106.9	109.8	107.9	71.8	128.3	117.8
RIV4	105.9	109.3	107.2	70.6	126.4	116.5

3.1.4. Dissolved Oxygen

The Dissolved Oxygen (DO) measurements of the collecting sites in two seasons are provided in the table 6. In the HP sites, the DO averages of the stratification and non-stratification time are 6.4 ± 0.6 mg/L and 8.5±1.4 mg/L. These values in the RIV sites are 8.5±0.5 mg/L (stratification period) and 9.5±0.5 mg/L (non-stratification period).

Table 6. DO (mg/L) variation among the collecting sites during stratification and non-stratification periods in the Mactaquac Head Pond (HP) and SJR (RIV)–see also Figure 1.

	Stratification time			Non-Stratification time		
Site	Min (mg/L)	Max (mg/L)	Average (mg/L)	Min (mg/L)	Max (mg/L)	Average (mg/L)
HP1	0.7	9.7	5.4	9.0	10.2	9.3
HP2	5.4	9.5	7.5	7.6	10.3	8.2
HP3	1.6	8.5	6.8	---	---	---
HP4	3.5	9.8	7.1	3.5	9.8	8.3
HP5	3.4	9.5	7.0	2.8	10.6	6.8
HP6	2.6	10.0	5.9	---	---	---
HP7	2.2	9.6	6.2	---	---	---
HP8	2.7	9.6	6.3	---	---	---
HP9	5.8	8.8	7.1	2.7	12.1	7.7
HP10	0.2	8.8	5.8	10.0	11.3	10.8
HP11	0.2	8.4	5.9	---	---	---
HP12	0.3	8.5	6.1	---	---	---
HP13	0.2	9.4	6.1	---	---	---
RIV1	7.8	8.9	8.5	8.5	11.2	9.0
RIV2	6.7	8.5	8.1	9.0	10.1	10.0
RIV3	8.9	9.4	9.1	8.7	11.4	9.3
RIV4	7.6	8.4	8.1	9.7	11.0	9.9

3.1.5. pH

The variation of pH among the collecting sites are shown in the table 7. During the stratification time, the average values of HP and RIV habitats are 7.2 ± 0.2 and 7.2±0.2. In contrast, those values in non-stratification time are 6.9±0.2 and 6.8±0.9.

Table 7. pH variation among the collecting sites during stratification and non-stratification periods in the Mactaquac Head Pond (HP) and SJR (RIV) – see also Figure 1.

	Stratification time			Non-Stratification time		
Site	Min	Max	Average	Min	Max	Average
HP1	6.0	8.1	7.0	6.8	7.3	7.1
HP2	6.7	7.9	7.1	6.6	8.3	6.7
HP3	6.2	7.9	7.2	---	---	---
HP4	6.2	8.3	7.1	6.2	8.2	7.0
HP5	6.2	8.1	7.2	6.2	8.6	6.8
HP6	6.7	8.4	7.4	---	---	---
HP7	6.4	8.4	7.2	---	---	---
HP8	6.6	8.4	7.3	---	---	---

	Stratification time			Non-Stratification time		
Site	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**
HP9	6.2	7.4	6.7	6.2	7.9	6.7
HP10	6.8	7.9	7.4	6.9	7.3	6.9
HP11	6.2	8.0	7.2	---	---	---
HP12	6.0	8.6	7.2	---	---	---
HP13	6.4	8.3	7.4	---	---	---
RIV1	7.1	8.0	7.4	6.1	8.8	7.7
RIV2	7.1	7.6	7.3	5.1	7.5	5.5
RIV3	7.1	7.4	7.2	6.8	7.9	7.0
RIV4	6.1	7.8	6.9	6.3	7.6	6.9

3.1.6. Turbidity

In the studied area, the average of the turbidity (Turbid) of the HP sites is 1.3±0.5 ppt in the stratification months, whereas the value of RIV sites is 1.1±0.4 ppt. In the non-stratification months, those values of the HP and RIV sites are 0.9±0.4 and 1.3±0.3 ppt, respectively. Table 8 provides more details about the recorded turbidity parameter.

Table 8. Turbidity (ppt) variation among the collecting sites during stratification and non-stratification periods in the Mactaquac Head Pond (HP) and SJR (RIV)–see also Figure 1.

	Stratification time			Non-Stratification time		
Site	**Min (ppt)**	**Max (ppt)**	**Average (ppt)**	**Min (ppt)**	**Max (ppt)**	**Average (ppt)**
HP1	0.3	4.7	1.5	1.3	2.1	1.5
HP2	0.0	2.2	0.7	0.5	1.3	0.8
HP3	0.4	31.1	0.9	---	---	---
HP4	0.0	4.5	0.8	0.0	1.7	0.8
HP5	0.0	3.4	1.2	0.2	1.7	0.6
HP6	0.9	15.4	1.7	---	---	---
HP7	0.3	7.5	1.4	---	---	---
HP8	0.4	5.5	1.6	---	---	---
HP9	0.0	1.3	0.4	0.1	1.7	0.6
HP10	1.4	4.5	1.9	0.7	1.7	1.1
HP11	0.4	3.6	1.4	---	---	---
HP12	0.9	4.5	1.7	---	---	---
HP13	0.9	6.5	1.8	---	---	---
RIV1	0.3	1.0	0.5	0.2	1.4	0.9
RIV2	0.9	2.0	1.6	1.4	2.0	1.7
RIV3	0.1	2.5	1.2	0.2	2.0	1.4
RIV4	0.2	3.0	1.0	0.2	9.2	1.2

3.1.7. Salinity

The salinity (Sal) was measured at some collecting sites from 2014 to 2016 and displayed in the table 9. Of which, the average value of HP habitat in stratification period is 0.09±0.01 ppt and in non-stratification period is 0.05±0.01 ppt. The average of the RIV sites is 0.06±0.01 ppt recorded in the stratification months and 0.05±0.01 ppt in non-stratification months.

Table 9. Salinity (ppt) variation among the collecting sites during stratification and non-stratification periods in the Mactaquac Head Pond (HP) and SJR (RIV)–see also Figure 1.

	Stratification time			Non-Stratification time		
Site	**Min (ppt)**	**Max (ppt)**	**Average (ppt)**	**Min (ppt)**	**Max (ppt)**	**Average (ppt)**
HP10	----	---	---	0.06	0.07	0.06
HP9	0.04	0.11	0.08	0.05	0.06	0.06
HP5	0.04	0.16	0.08	0.05	0.06	0.05
HP4	0.04	0.20	0.11	0.05	0.06	0.06
HP2	0.04	0.17	0.10	0.05	0.05	0.05
HP1	---	---	---	0.03	0.04	0.04
RIV1	0.05	0.18	0.09	0.05	0.06	0.06
RIV2	0.04	0.05	0.05	0.04	0.04	0.04
RIV3	0.05	0.05	0.05	0.05	0.06	0.06
RIV4	0.05	0.05	0.05	0.05	0.06	0.06

3.2. PHYTOPLANKTON

3.2.1. Biodiversity

The total number of phytoplankton species recorded was 341, including 152 Chlorophyta, 62 Bacillariophyta, 82 Cyanophyta, 17 Chrysophyta, 14 Cryptophyta, 6 Euglenophyta, 4 Rhodophyta, and 4 Dinophyta. In the head pond, there were 13 (HP8) to 185 (HP4) species; the number of species in the river ranged from 140 (RIV2) to 171 (RIV4). In 2016, we observed 288 phytoplankton species, of which the variation of taxa richness, number of cells, and H' and J indexes was shown in the Figure 2, 3 and 4, and Table 10.

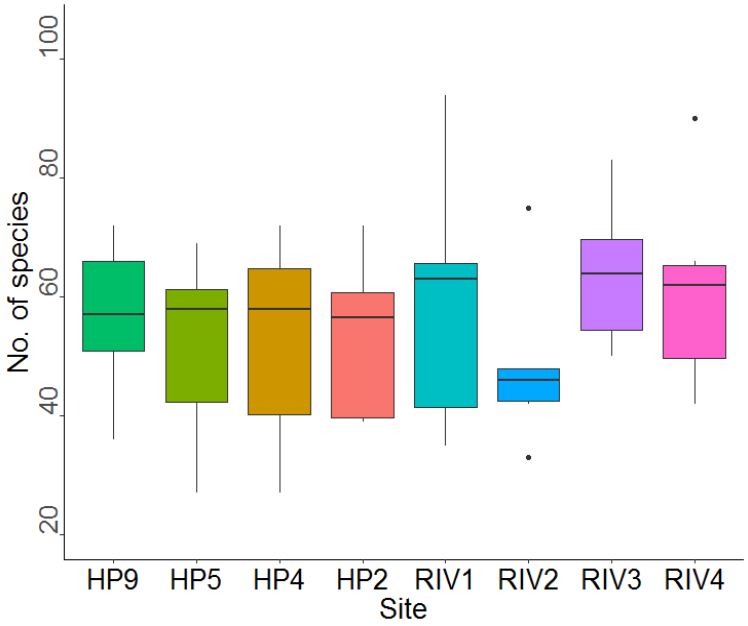

Figure 2. Variation of the species number among the collecting sites in 2016.

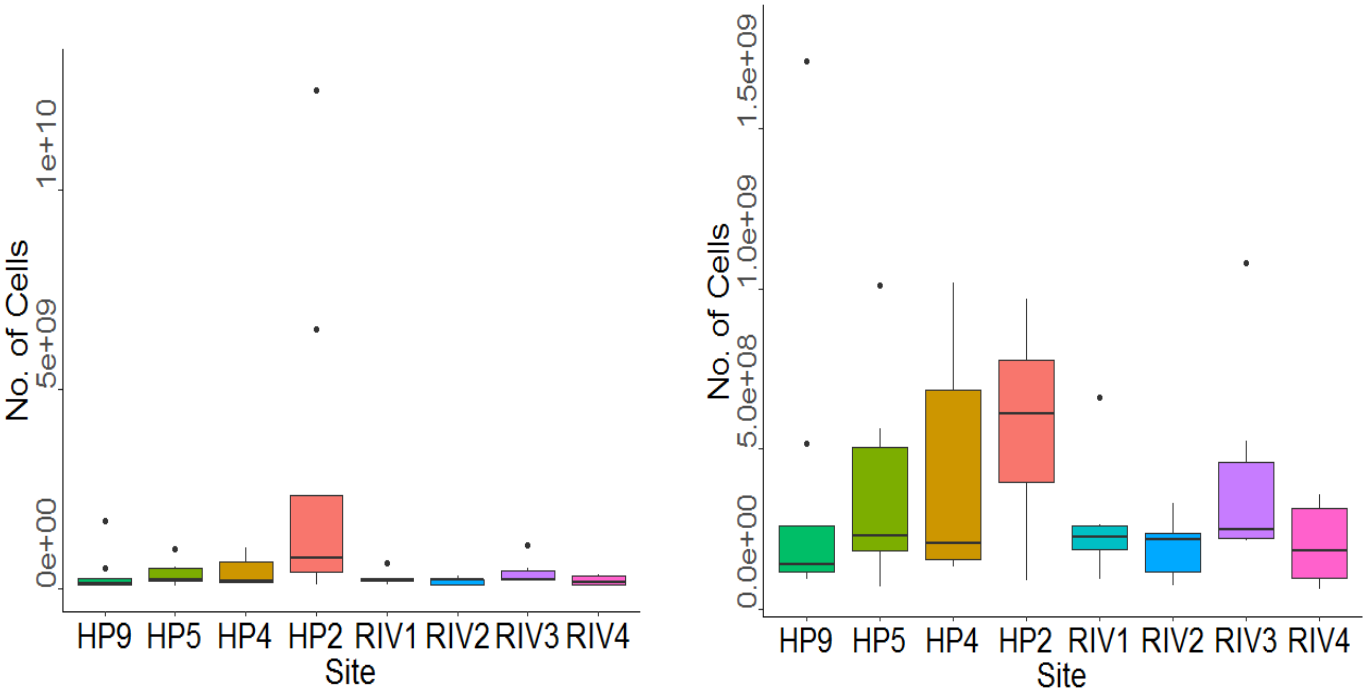

Figure 3. The number of cells/m^3 estimated among the collecting sites of 2016 – all data (left panel) and after removing the outliers at HP2.

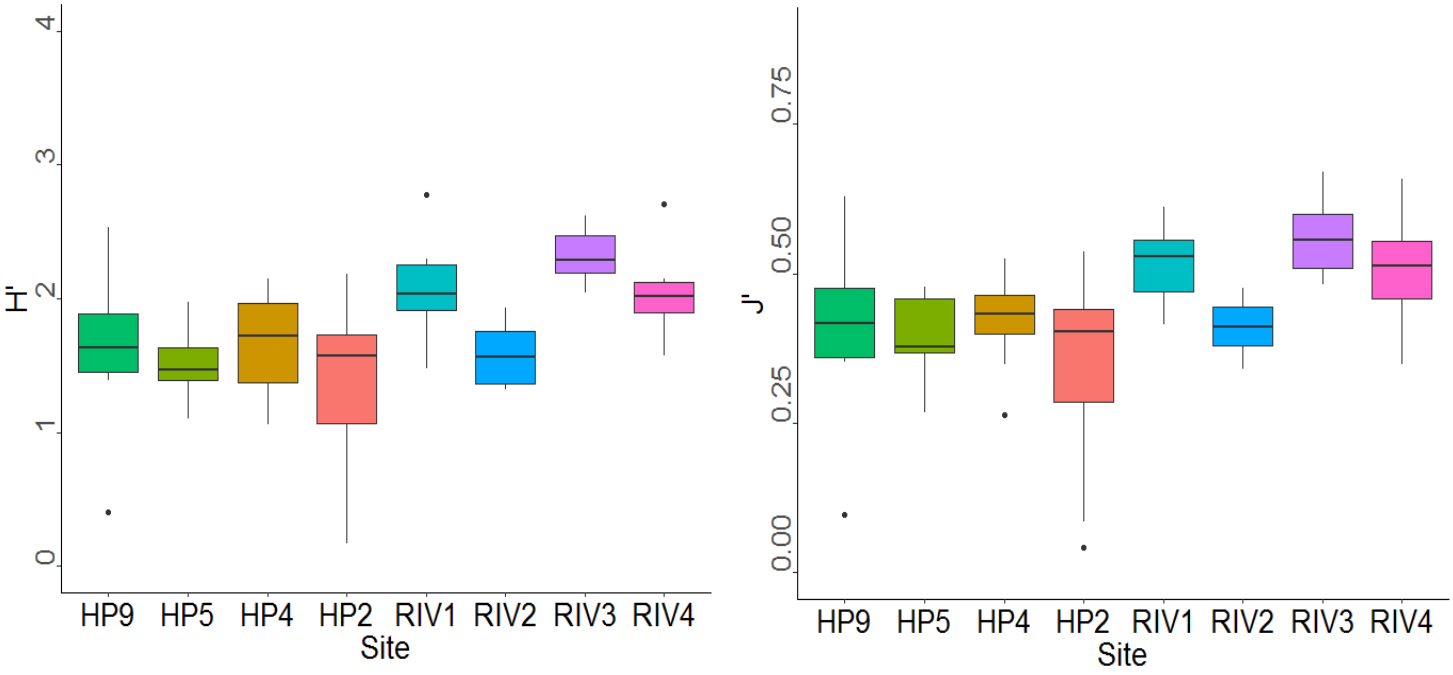

Figure 4. The variations of the H' and J' indices of diversity among the collecting sites in 2016.

Table 10. The testing results, using One-way ANOVA or Kruskal-Wallis test, for the difference of the taxa richness, number of cells, J and H' indexes between HP and RIV habitats based on the 2016 samples.

	Stratification time	**Non-stratification time**
Taxa richness	H= 0.03, 1 d.f., p>0.05	$F_{1,14}$=4.64, p < 0.05
Number of cells	H= 1.90, 1 d.f., p>0.05	H= 0.04, 1 d.f., p>0.05
J index	H= 8.56, 1 d.f., p<0.05	H = 3.19, 1 d.f., p>0.05
H' index	H= 6.45, 1 d.f., p<0.05	H = 4.42, 1d.f., p <0.05

3.2.2. Variation of phytoplankton

Different among Epi-. Meta-, and hypo-limnion: No interactions were detected in the Scheirer-Ray-Hare Test between the water layers and sites in terms of the taxa richness or number of cells. The test also revealed no significant differences in the taxa richness or the number of cells among the water layer. However, a significant variation was recorded in term of the number of cells among the HP sites (Table 11).

Table 11. The results of the Scheirer-Ray-Hare Test for the difference of the water layers (Epi: Epilimnion, Meta: Metalimnion, Hypo: Hypolimnion) in the HP habitats based on samples from 2016.

	Scheirer-Ray-Hare Test
Taxa richness	Layer: H= 0.43, 1 d.f., p>0.05
	Site: H= 0.31, 1 d.f., p>0.05
	Interaction: H= 0.05, 1 d.f., p>0.05
Number of cells	Layer: H= 2.53, 1 d.f., p>0.05
	Site: H= 8.81, 1 d.f., p<0.05
	Interaction: H= 0.03, 1 d.f., p>0.05

Phytoplankton variation among the HP sites: Even the above Scheirer-Ray-Hare Test showed the significant difference among sites in the stratification time (Table 11), further Mann-Whitney-Wilcoxon Tests with the Bonferroni correction (α level = 0.05/6= 0.008) revealed no significant variations among the HP sites in stratification time. Similarly, during non-stratification, no significant differences were detected. Table 12 shows the more detail about these tests.

Table 12. The results of one-way ANOVAs and Mann-Whitney-Wilcoxon tests with the Bonferroni correction (α level = 0.008) for the difference among the HP sites.

	Stratification time	**Non-stratification time**
Taxa richness	$F_{3,28}$=0.211, p>0.05	$F_{3,4}$=0.14, p>0.05
Number of cells	HP2-HP4: W= 35, p>0.008	$F_{3,4}$=0.64, p>0.05
	HP2-HP5: W= 27, p>0.008	
	HP2-HP9: W= 34, p>0.008	
	HP4-HP5: W= 18, p>0.008	
	HP4-HP9: W= 32, p>0.008	
	HP5-HP9: W= 32, p>0.008	

Different between surface and bottom layers in river habitats: Based on the Scheirer-Ray-Hare Test, no significant interactions or differences were observed between surface and bottom samples of the phytoplankton in the river locations (Table 13).

Table 13. The results of the Scheirer-Ray-Hare Test for the difference between surface and bottom in the river habitats sampled in 2016.

	Scheirer-Ray-Hare Test
Taxa richness	Layer: H= 0.10, 1 d.f., p>0.05
	Site: H= 1.17, 1 d.f., p>0.05
	Interaction: H= 0.00, 1 d.f., p>0.05
Number of cells	Layer: H= 0.01, 1 d.f., p>0.05
	Site: H= 1.17, 1 d.f., p>0.05
	Interaction: H= 0.06, 1 d.f., p>0.05

Variation along the RIV: No significant differences were found among the RIV sites in terms of the taxa richness and the number of cells from the above Scheirer-Ray-Hare Test (Table 13). The same results were recorded during the non-stratification time and shown in table 14.

Table 14. One-way ANOVA results of testing the variation along the SJR.

	Non-stratification time
Taxa richness	$F_{3,4}$=0.49, p=0.78
Number of cells	$F_{3,4}$=1.08, p=0.45

Influence of the dam on river plankton: We found no significant differences between the two sites, HP4 and RIV1, in both of stratification and non-stratification periods in terms of the taxa richness and the number of cells. Table 15 provides more details. However, regarding to the whole habitat variation, the result from ANOSIM analysis (p < 0.05) indicated that there was a significant difference between HP and RIV phytoplankton assemblages.

Table 15. The results of the One-way ANOVAs testing the difference between two sites, HP4 and RIV1, in 2016.

	Stratification time	**Non-stratification time**
Taxa richness	$F_{1,6}$=0.08, p > 0.05	$F_{1,2}$=0.18, p > 0.05
Number of cells	$F_{1,6}$=4,24, p > 0.05	$F_{1,2}$=0.84, p > 0.05

In DCA analysis, as the value of the first axis length is < 2 (DCA1 = 1.84), we apply RDA for the next analysis. We remove the environmental parameters of Depth, Sal and pH as these are highly correlated with other parameters (r> 0.6), the remaining parameters for the RDA analysis include Temp, Cond, DO, and Turbid. The first three RDA axes can explain ≈ 89.40% of constrained variance whereas only 15.08% of unconstrained variance is explained by these first

three axes. The ANOVA test shows 3 significant results for Temp ($F_{1,43}$ = 1.71, p < 0.05), Cond ($F_{1,43}$ = 2.47, p < 0.05), and DO ($F_{1,43}$ = 1.80, p < 0.05) but Turbid ($F_{1,43}$ = 1.42, p < 0.05). The RDA plot is illustrated in Figure 5.

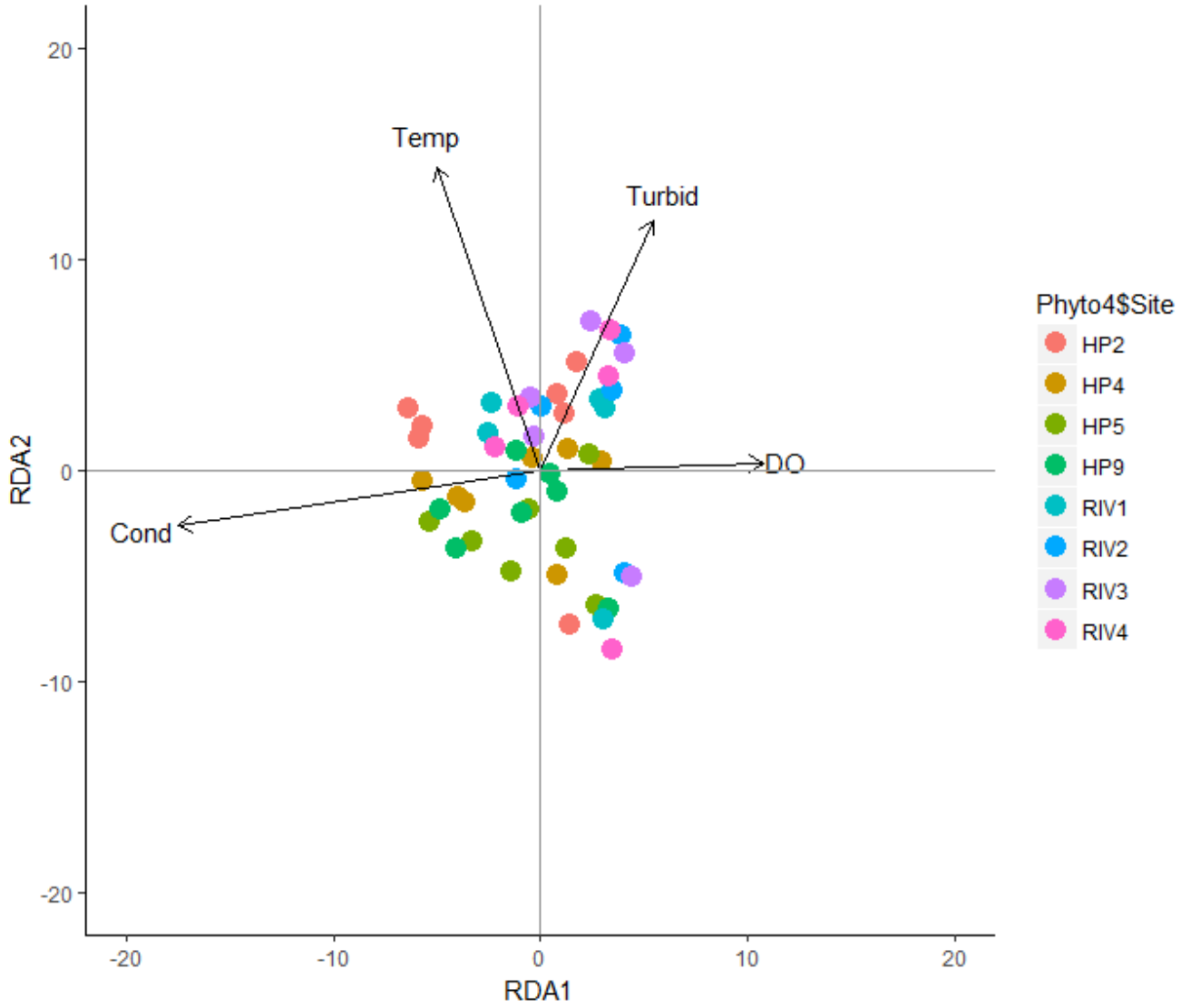

Figure 5. Plot for the RDA analysis between the phytoplankton communities and four selected environmental parameters (Cond = Conductivity, Temp = Temperature, DO= Dissolved Oxygen and Turbid = Turbidity).

3.3. ZOOPLANKTON

3.3.1. Biodiversity

The total species number of zooplankton recorded in the studied area = 73, including 2 phyla, e.g., Rotifera, 43 species (59%) and Arthropoda, 30 species (41%). The species numbers vary from 15 (HP13) to 46 (HP4) in the HP sites and from 12 (RIV3) to 18 (RIV1) in the RIV sites.

3.3.2. Variation of zooplankton

No significant results of the ANOSIM were found for the zooplankton assemblages among the layers, e.g., in HP: R = -0.38, $p > 0.05$; in RIV: R = -0.19, $p > 0.05$. By contrast, we found a significant difference between HP and RIV habitats with R = 0.59, $p < 0.05$.

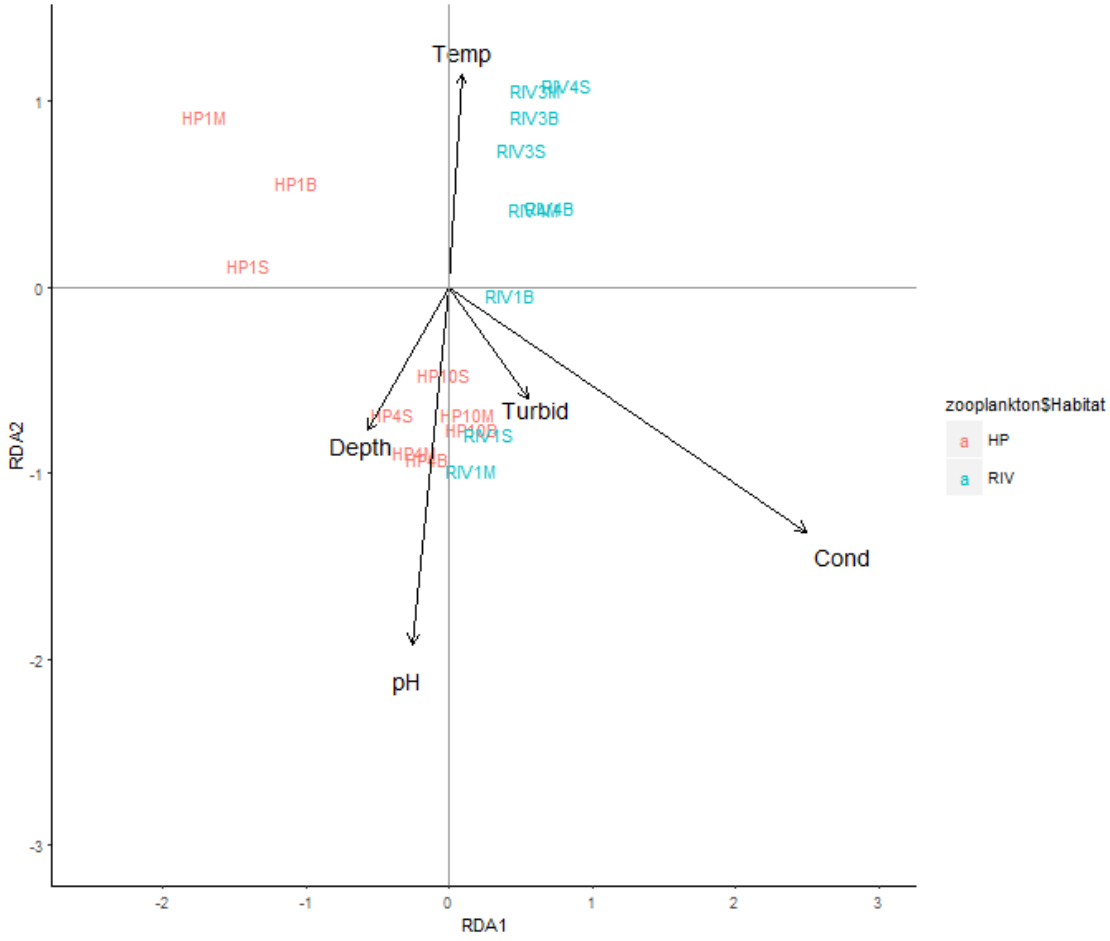

Figure 6. Plot for the RDA analysis between the zooplankton communities and selected environmental parameters (Cond: Conductivity, Turbid: Turbidity, Temp: Temperature).

The values of the first DCA length is 2.09, we apply RDA for the further multivariate analysis. Correlation analysis showed high correlations between Conductivity and Salinity (r>0.6); other high correlations were DO with both Temperature and Turbidity (r>0.6). Consequently, we remove both DO and Sal. The first three RDA axes can explain 94.30% of constrained variance and 56.25% unconstrained variance. The test of significance shows that Temp ($F_{1,12}$= 3.32, p<0.05), Cond ($F_{1,12}$= 9.89, p<0.05) and pH ($F_{1,12}$= 4.23, p<0.05) contribute significantly to the explanation of the zooplankton variance in the RDA axes but Depth and Turbid (p>0.05). Figure 6 illustrates the RDA plot for the zooplankton.

4. DISCUSSION

Head Pond and River Environments:
Average temperatures in the head pond tend to be lower than in river sites which reflects the deeper water, layering/isolation, and insolation effects in the head pond. The DO levels in the river are higher and more vertically stable than those in the head pond. This reflects the mixing (flowing and shallower water column). The remaining parameters were as would be expected for reservoir and river environments (e.g., Watt 1973; Watt & Duerden 1974; Wetzel 2001).

Biodiversity: The Plankton Communities
The number of phytoplankton species, about 314 species, was higher than reported in the early 1970s, i.e., only 128 phytoplankton (Watt 1973, 1974). Among the phytoplankton, we observed a number of cyanobacteria some species which have been linked to harmful blooms (Paerl et al. 2001). For example, there is an apparent outlier with the number of the cells recorded at head pond site HP2, the area where was recorded an algal blooming about five years ago (J. O'Keefe, NB Environment, pers. comm.), which appears to be a possible blooming of *Aphanocapsa holsatica*. This species favors to the habitat of short, nutrient rich columns (Reynolds et al. 2002).

The number of the zooplankton species found in our study is higher than reported in the 1970s (Watt & Duerden 1974) with a significant supplement of Rotifers, which was excluded in the 1970s research. We observed 73 species in comparison to 53 species revealed in the whole SJR report in 1970s, of which more than 18 species commonly found in the studied area. We have yet to complete the full zooplankton taxonomy and abundance analyses, but already the number of species and abundance appears to have increased over time.

Effects of Stratification
In both head pond and river habitats, full mixing of the water column was suggested because the plankton distribution is vertically homogenous. Similarly, during the stratification period, the thermal difference of among water layers was not enough to cause significant differences of the phytoplankton communities in terms of the taxa richness and number of cells. We might expect a

significant difference in zooplankton communities in stratification time in the HP when water columns were strongly categorized.

Plankton distribution patterns along RIV and HP habitats

In both habitats, the water columns are not static; there are continuous movements of water within the two habitats at most of the sites, even in the HP. Consequently, no significant differences were found in terms of the taxa richness and number of phytoplankton cells. Zooplankton, on the other hand, might have a different distribution pattern and the result will be revealed after the completion of laboratory work.

The effect of the reservoir on the river:

The non-significant results of the ANOVA tests ($p>0.05$) support the hypothesis that river plankton community are mostly supplemented by the Mactaquac Generating Station, at least in the main river and within 20 km of the dam. Nevertheless, the plankton communities depend on the distance from the dam and physical conditions of the littoral zones and backwaters, e.g., water velocity, depth, and macrophyte occurrence (e.g., Walks & Cyr 2004). Normally, large plankton assemblages occur in impoundments with lower concentrations in low-flow margins of running waters, like rivers and streams (e.g., Rojo et al. 1994). Once in the river, the riverine plankton rely on other physical factors, e.g., water velocity and water turbidity influencing UV permeation. Additionally, Jones (2010) found a spatial relationship between the distance of a plankton community from the reservoir and the reservoirs influence on that population, i.e. communities further downstream of a reservoir are less influenced than those proximal to the reservoir. Additionally, the SJR is provided by a plankton supplement to the SJR from the Keswick River. Consequently, a different plankton assemblage of the RIV habitat to that in the HP habitat is established possibly resulting from the variation of the physiochemical conditions along the river reach we studied, from the MD to the city of Fredericton, coupled with the plankton contribution of the Keswick River.

Essential environmental parameters:

Physiochemical parameters play an essential role in controlling the plankton dynamics in freshwaters (Wetzel 2001). In the studied area, we found the significant importance of the Temp, Cond, and DO with the phytoplankton pattern. However, these parameters contribute a small percentage to variance of the phytoplankton, suggesting that other factors might play an more important role. We might expect more significant results when Nitrogen and Phosphorus components are included in the RDA analysis as in the freshwater, phosphorus is the limiting growth factor and nitrogen is the essential part of the phytoplankton dynamics and productivity (Raven & Maberly 2009; C. S. Reynolds 2009). Investigations by Watt (1972, 1973) revealed significant correlations between phosphorous concentration and the maximum phytoplankton population density as well as the % biomass of *Dinobryon sertularia* and *D. bavaricum* in the MH. Moreover, changes of the phytoplankton also reply on the dynamics of zooplankton (Sterner

2009), we will add species number and abundance of zooplankton as two additional factors in further analysis.

The RDA analysis reveals that the zooplankton assemblage has a strong association with Temp, Cond and pH. However, the result might be changed as this is the primary analysis based on one fieldwork sampling. Further RDA will be applied to the full dataset from 2016 fieldwork. As zooplankton feed mostly on the phytoplankton, an ecological factor, we can see those factors of the number of the phytoplankton natural units or cells, and chlorophyll-a (Sterner 2009), possibly play a role on the distribution patterns of the zooplankton communities. Additionally, depth might also have a significant impact on the migration ability of the zooplankton and contribute to the distribution patterns.

Ongoing laboratory analyses:
As some laboratory work and analysis are ongoing and will be complete later in 2017.

- biovolume estimation for phytoplankton.
- taxonomy and numeration of zooplankton samples collected in 2016.
- measure the pigment concentrations, i.e., Chlorophyll-a and Phycocyanin.
- determine the trophic status of HP and SJR based on phytoplankton bioindicators and concentrations of the nitrogen and phosphorus components.
- perform full statistical analysis for zooplankton rerun statistical analysis for phytoplankton in association with the ecological factors.

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