Benthic Invertebrate Communities in the Ramsey Lake Watershed

Report Prepared by: C. Sarrazin-Delay
Cooperative Freshwater Ecology Unit, Vale Living with Lakes Centre
Laurentian University

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Vale Living with Lakes Centre, Laurentian University, 935 Ramsey Lake Rd., Sudbury, Ontario P3E 2C6
Phone: (705) 671-3861 Fax: (705) 671-3857

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1 Introduction

As the drinking water source for 40% of its residents, Ramsey Lake is a vital waterway to the city of Greater Sudbury. Covering 792 hectares, its shores are bordered by over 800 private homes as well as public spaces including Bell Park, Moonlight beach and Lake Laurentian Conservation Area (Figure 1). Ramsey Lake drains 43 km^2 and includes 13 sub-watersheds that supply water to the lake (CGS, 2014). It receives water from Minnow Lake and Frobisher Creek on the north shore and Laurentian Lake and a pond east of Laurentian Lake on the south shore. Bethel Lake also occasionally flows into Ramsey Lake during high water periods. The remainder of the drainage is from overland flow and groundwater seepage. The Ramsey Lake watershed drains into Lily Creek to eventually drain into Georgian Bay via the Spanish River.

Like many lakes in Greater Sudbury, Ramsey Lake was historically affected by local ore processing activities and by urbanisation in its watershed. Although Ramsey was never acidified, urban effects such as run-off from homes and roadways may be affecting the life in the lake. The effects of water quality threats can be understood by studying the benthic macroinvertebrate (BMI) communities in the lake and its tributaries.
Benthic invertebrates are small animals without backbones, like insects and snails that live at the bottom of lakes and streams. These animals are a link in the food chain that joins the vegetation with the fish. BMIs are used in water quality assessment because they:

- are easy to sample,
- are diverse,
- have known sensitivities to pollution,
- don’t travel very far in their lifetime and so indicate conditions at a specific site.

BMI assessments give a longer term view of the conditions at a site than water sampling which gives you a snapshot of conditions at a given time. By studying the BMI community at eight lake and seven stream sites, an integrative measure of the health of Ramsey Lake will be determined.

2 Methods

2.1 Study sites

Benthic macroinvertebrate (BMI) were sampled at fifteen sites in the Ramsey Lake watershed (Figure 1, Table 1). Stream BMI sampling was a 3-minute bank to bank kick-and-sweep with a 500 μm mesh D-frame net with 300 BMI extracted under a microscope as per the Canadian Aquatic Biomonitoring Network (CABIN) protocol (Reynoldson et al. 1999, Environment Canada, 2012). For in-lake sites, 3 replicates from multiple transects perpendicular to shore were sampled for 10 minutes (David et al 1998) with 100 BMI extracted from each replicate. Habitat characteristics were recorded for each site including those observed on-site (substrate, water depth etc.) and those extracted from maps and Geographic Information System (drainage area, stream order etc.). Watersheds were determined for each of the sites using Ontario Flow Assessment Techniques III, an online GIS application (OMNR, 2014). Surface water samples were taken and analyzed by the Ontario Ministry of the Environment and Climate Change’s laboratory for nutrients, metals and ions.

The sampling sites were located throughout the Ramsey Lake watershed. Streams flowing into the lake were sampled, as were the in-lake sites where those streams flow into Ramsey Lake. Sites on the south shore (Laurentian Creek, LauC1, LauC2, RL@LauC and Laurentian East Creek, LauEC, RL@LauEC) drain sub-watersheds of the Lake Laurentian Conservation Area with minimal urban development. Bethel Lake, on the other hand, has received sewage in the past and is eutrophic; a sample was taken in Bethel Lake (BetL) and in Ramsey Lake near Bethel Lake (RL@BetL). Sites on the north shore (Frobisher Creek, FroC, RL@FroC and Minnow Creek, MinC, RL@MinC) drain sub-watersheds with some urban development. An in-lake sample was also collected near an unsupervised beach of Bell Park (RL@BellP) where a storm drain releases water into the lake. At its western end, the lake drains into Lily Creek. There, an in-lake site (RL@LilC) was sampled as was Lily Creek at two locations (LilC1, LilC2).

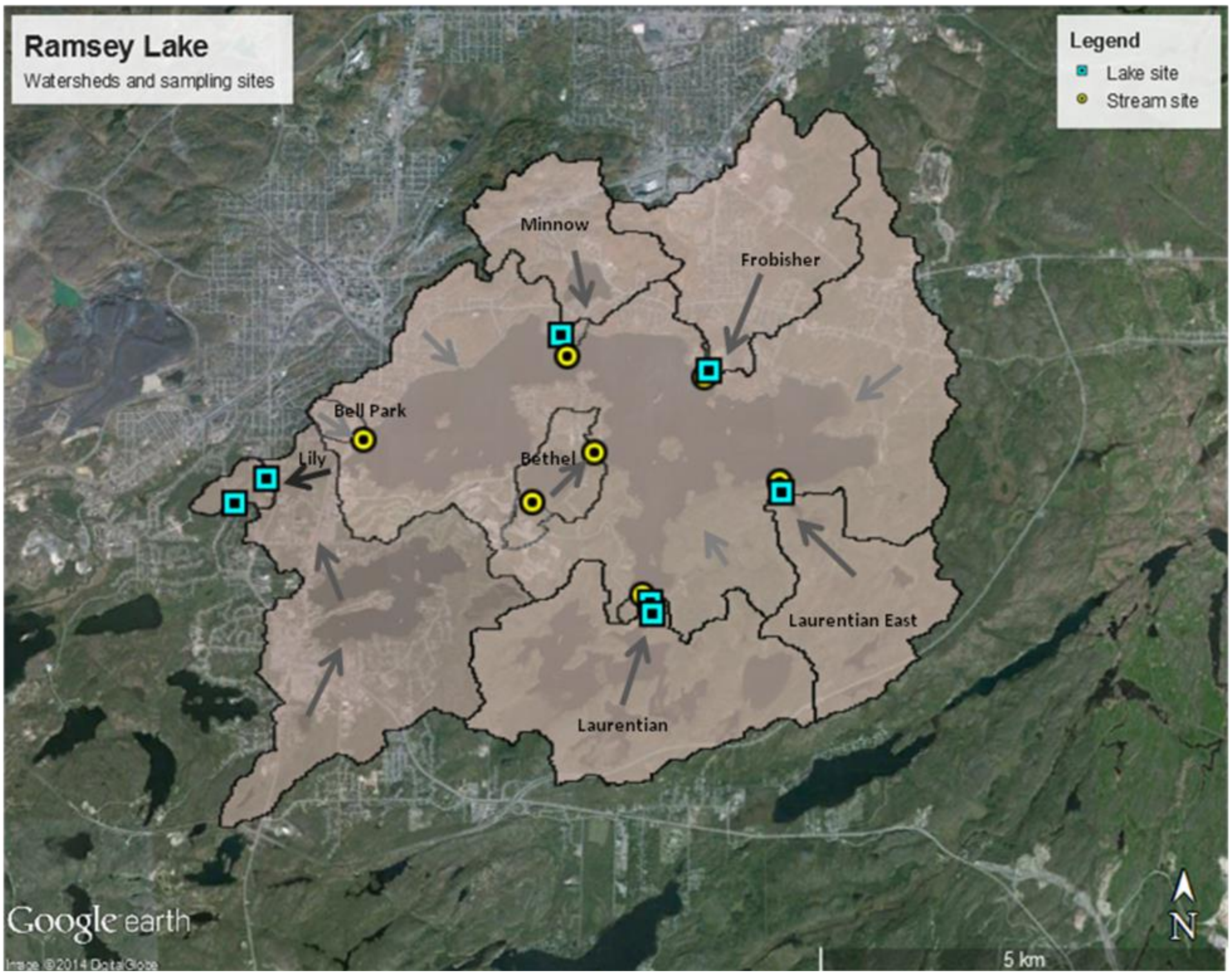


Figure 1 Ramsey Lake watershed and sub-watersheds with locations of sites sampled in the fall of 2013. Arrows indicate direction of flow.

Table 1 Location of sites sample the fall of 2013 in the Ramsey Lake watershed.

Site	Name	Sample type	Inflow or Outflow	Latitude	Longitude
LauEC	Laurentian Creek East	Stream	Inflow	46.46978	-80.92530
RL@LauEC	Ramsey Lake @ Laurentian East Creek	Lake	Inflow	46.47036	-80.92519
LauC1	Laurentian Creek	Stream	Inflow	46.45700	-80.94558
LauC2	Laurentian Creek	Stream	Inflow	46.45761	-80.94614
RL@LauC	Ramsey Lake @ Laurentian Creek	Lake	Inflow	46.45778	-80.94642
BetL	Bethel Lake	Lake	Inflow	46.46869	-80.96500
RL@BetL	Ramsey Lake @ Bethel Lake	Lake	Inflow	46.47419	-80.95511
FroC	Frobisher Creek	Stream	Inflow	46.48317	-80.93681
RL@FroC	Ramsey Lake @ Frobisher Creek	Lake	Inflow	46.48244	-80.93756
MinC	Minnow Creek	Stream	Inflow	46.48707	-80.96043
RL@MinC	Ramsey Lake @ Minnow Creek	Lake	Inflow	46.48690	-80.86050
RL@BellP	Ramsey Lake @ Bell Park	Lake	Inflow	46.47558	-80.99189
RL@LilC	Ramsey Lake @ Lily Creek	Lake	Outflow	46.47183	-80.97306
LilC1	Lily Creek	Stream	Outflow	46.47128	-81.00733
LilC2	Lily Creek	Stream	Outflow	46.46853	-81.01233

2.2 Reference Condition Approach and Test Site Assessment

To determine the expected BMI community at a particular Ramsey Lake watershed site, the Reference Condition Approach (RCA) (Bailey *et al* 2004) was used. Variation in BMI communities at reference sites with little human impacts was used to establish what is normal under natural conditions. Reference sites were selected from a the Cooperative Freshwater Ecology Unit's (CFEU) Freshwater Invertebrate Network of Northern Ontario (FIRNNO) database (Sarrazin-Delay et al. 2006) to most closely match the Ramsey Lake sites in habitat characteristics. This database includes BMI and water chemistry data for over 600 reference and impaired sites throughout Northern Ontario (Figure 2).

Selection of reference sites was done statistically to incorporate multiple habitat variables (15 for lakes, 24 for streams; Appendix 10) in the selection process. Habitat variables known to affect BMI community composition were plotted (Figure 3, Principal Component Analysis) and those that explained most of the variation in the sites (on Axis 1 and 2 of PCA (Jackson, 1998)) were used to select 30 sites that plotted closest to the Ramsey site in question. These reference sites which have the most similarity to the Ramsey site in important habitat variables are their Nearest Neighbours (Linke, *et al*. 2005).

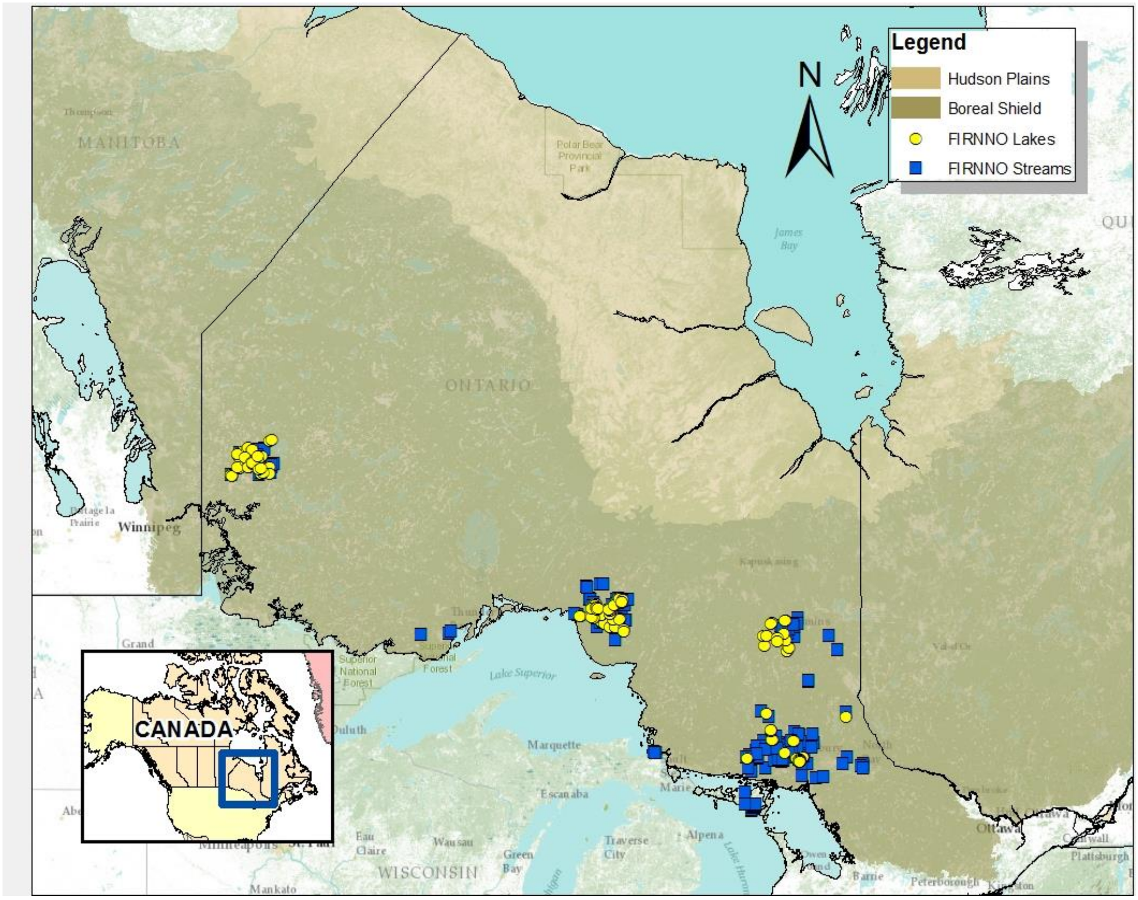


Figure 2 Map of FIRNNO lake and stream sites.

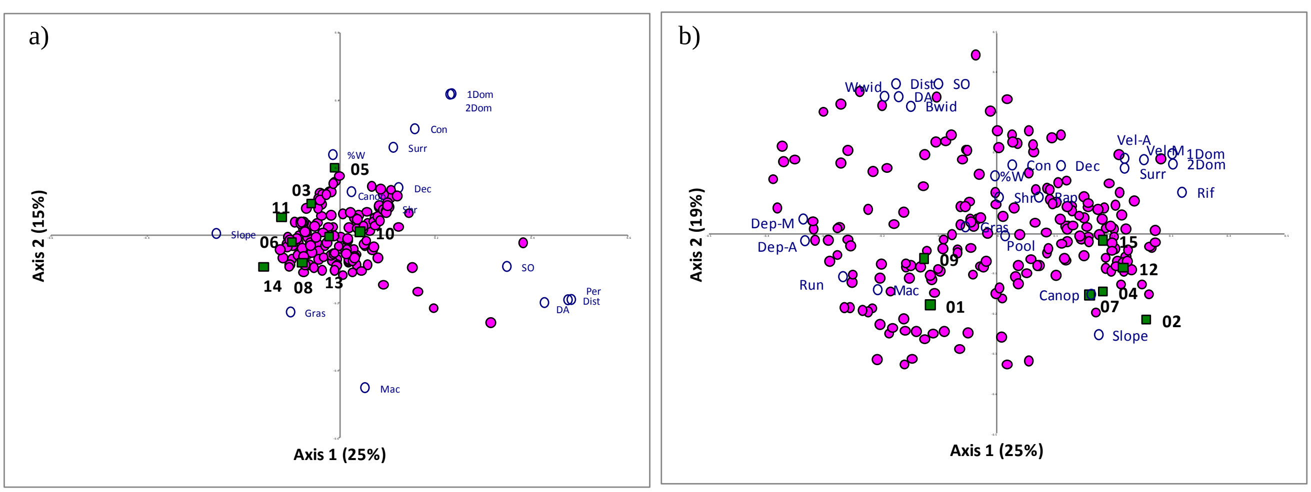


Figure 3 PCA plot of habitat variables (open circles) for Ramsey Lake watershed sites(squares) and FIRNNO reference sites (closed circles) for a) in-lake sampling sites (N-156) and b) stream sampling sites (N=200).Reference sites that are closest to a Ramsey site are similar in habitat and are selected to determine the expected BMI community. Refer to Appendix 10 for habitat variable abbreviations.

BMI data tend to include large number of entries making visualization of trends in community composition difficult. The BMI data are therefore summarized into metrics such as abundance, richness, diversity, %EPT and Correspondence Analysis (Table 2) and by comparing their value to NN reference site values, level of impairment of the BMI community can be determined. Abundance is the number of individual BMI in each sample; a higher than expected abundance can indicate enrichment whereas as low abundance can indicate other impacts. Richness is the number of families found in a sample; the lower the number of families, the more likely that a site is impaired. Low diversity is also an indication of an impaired site. When only one or two families dominate the BMI community (diversity =0), it is an indication of an impaired site with simplified food web whereas a community where several different families have a similar abundance (diversity =1) indicates a much more complex food web which is more resilient to disturbance. Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) are sensitive and a low proportion of these groups in the BMI community indicates an impaired site. Finally, correspondence analysis was used to determine the similarity of the BMI communities at multiple sites; BMI data for Ramsey Lake watershed sites and NN reference sites were plotted together and if the Ramsey site plots away from the reference site, it is an indication that it is impaired.

The metric values of each of the Ramsey Lake sites were compared to their Nearest Neighbour (NN) reference sites to determine the status of the benthic community. Test Site Assessment was used to determine if a Ramsey Lake watershed site's BMI community was significantly different from its NN reference sites (Bowman et al. 2003, Bowman and Somers 2006). If the metric value of a Ramsey sites falls outside of the normal range that includes 95% of the NN reference site values (Kilgour et al. 1998), it is considered impaired. This non-central test, (calculated with Excel's πface add-in; Lenth, 2003) where the Ramsey site metric value is compared to the range of values for the NN reference sites rather than the mean of the reference sites is more ecologically significant. BMI communities are naturally very variable and statistically comparing a metric value to the mean of reference sites would assess too many unimpaired sites as impaired.

Table 2 Metrics calculated to summarize the invertebrate data.

Metric	Description	Response to impairment
Abundance	Total number of individuals in the sample	Variable
Richness	Total number of families in the sample	Decrease
Diversity	Measure of relative abundance of the families	Decrease
%EPT	Proportion of Ephemeroptera, Plecoptera, Trichoptera in the sample	Decrease
CA1	Correspondance Analysis (Log(x+1), rares removed) Axis 1	Relative
CA2	Correspondance Analysis (Log(x+1), rares removed) Axis 2	Relative
CA3	Correspondance Analysis (Log(x+1), rares removed) Axis 3	Relative

3 Results and Discussion

3.1 Water chemistry

Some metal values exceeded the Provincial Water Quality Objective (PWQO, Table 3) at the Ramsey in-lake sites. Aluminum at the Bell Park site (RL@BellP) was double the allowable amount. All Ramsey Lake nickel and copper values were greater than PWQO contrary to the site within Bethel Lake (BetL) where these metals were closer to values seen in the reference lake sites. The Bethel Lake site (BetL) did however have elevated nutrients (N and TP) as did the Minnow Bay site (RL@MinC) on Ramsey Lake for TP and the Frobisher Creek Bay (RL@FroC) for inorganic nitrogen. All Ramsey watershed streams had nickel and copper values greater than PWQO; in fact these parameters were five times higher than allowable in the Laurentian East Creek (LauEC). Aluminum in Lily Creek (LilC2) was eight times the allowable amount. A low pH (6.3) was recorded at the Laurentian East Creek (LauEC) whereas the highest pH was recorded in Frobisher Creek (FroC). Frobisher Creek (FroC) also had among the highest values for calcium and sodium, nitrogen and dissolved organic carbon (DOC). DOC was also high at Laurentian East Creek (LauEC). The Ramsey stream phosphorus concentrations were generally higher than the reference sites with the exception of Frobisher Creek (FroC) which had slightly lower TP.

Table 3 Water chemistry parameters for Ramsey Lake watershed test sites and the mean of the FIRNNO reference sites. Metal values in grey shading exceed the Ontario Provincial Water Quality Objectives.

Site Codes	Lake or Stream	Ca mg/L	Na mg/L	pH	SO_4 mg/L	DOC mg/L	Inorganic N ug/L	TP ug/L	Al ug/L	Cu ug/L	Ni ug/L
LauEC	Stream	3.3	7.6	6.3	6.3	9.4	148	27.1	168.0	23.7	93.8
RL@LauEC	Lake	16.6	53.6	7.9	16.4	3.7	18	12.8	7.7	8.3	30.1
LauC1	Stream	3.6	18.0	6.5	5.1	5.4	46	26.1	41.4	12.5	38.0
LauC2	Stream	3.8	21.9	6.8	5.4	5.2	48	22.2	35.6	12.2	36.2
RL@LauC	Lake	13.9	30.5	7.7	16.3	3.7	16	12.6	6.4	9.0	32.3
BetL	Lake	15.6	32.8	7.8	5.8	6.5	56	36.3	11.5	2.5	19.7
RL@BetL	Lake	15.8	32.4	7.7	15.7	3.6	16	9.7	3.2	7.9	30.1
FroC	Stream	64.4	83.3	7.9	34.7	10.3	334	13.7	61.0	5.7	24.2
RL@FroC	Lake	17.6	61.7	7.9	16.7	3.7	40	11.5	9.5	7.8	28.7
MinC	Stream	18.2	93.4	7.6	17.8	4.9	60	23.3	32.5	8.1	34.2
RL@MinC	Lake	16.4	57.2	7.7	16.7	3.6	20	40.1	43.0	10.1	36.8
RL@BellP	Lake	17.9	59.6	7.8	17.8	3.6	16	17.9	147.0	10.1	33.0
RL@LilC	Lake	14.2	57.1	7.6	16.9	3.6	18	9.4	7.0	8.4	32.9
LilC1	Stream	20.4	69.7	7.1	17.6	4.7	28	24.5	24.5	2.5	23.0
LilC2	Stream	23.4	37.9	7.3	18.6	5.0	20	45.6	874.0	11.6	36.8
Ref Lake mean	N=156	4.9	7.7	6.9	4.8	5.8	29	10.8	27.9	1.4	3.3
Ref Stream mean	N=200	5.1	1.7	6.8	5.5	7.1	59	15.5	78.5	1.5	2.7

3.2 Benthic invertebrate community structure

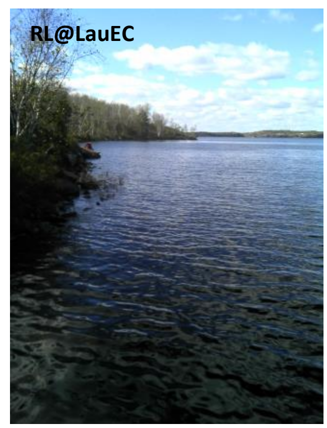
To characterize the Ramsey Lake watershed, stream and in-lake BMI communities were compared to those in minimally impacted sites with similar habitat. Ramsey Lake sites generally had similar metric values to their NN reference sites (Table 4). Although all the Ramsey sites had relatively low diversity, being dominated by tolerant Chironomidae and Hyalellidae comprising over 60% of their communities, none of the site values were significantly different to those calculated for their NN reference sites. Impairment at lake sites was more a factor of the community composition being slightly different than expected as detected by correspondence analysis. Each of the Ramsey Lake watersheds streams was evaluated as impaired or potentially impaired by at least one metric (Table 4).

Table 4 TSA of BMI metric for Ramsey Lake watershed sites and their NN reference sites. Shading indicates potential impairment (NCP 0.05-0.95) and dark shading indicates impairment (NCP >0.95) .

Site	Lake or Stream	Abundance	Richness	Diversity	%EPT	CA1 30NN	CA2 30NN	CA3 30NN
LauEC	Stream	2156	14	0.61	12	-0.73	0.17	1.58
30NN Mean		*4492*	*24*	*0.75*	*42*	*0.01*	*0.00*	*0.03*
RL@LauEC	Lake	10280	24	0.75	15	0.82	-2.66	-1.29
30NN Mean		*13211*	*24*	*0.71*	*16*	*-0.07*	*0.14*	*0.08*
LauC1	Stream	2031	16	0.81	23	-1.27	-0.44	-0.25
30NN Mean		*4249*	*25*	*0.78*	*49*	*0.09*	*0.05*	*0.11*
LauC2	Stream	1694	20	0.58	9	2.01	2.04	-1.13
30NN Mean		*4127*	*26*	*0.83*	*57*	*-0.06*	*0.04*	*0.07*
RL@LauC	Lake	16660	22	0.70	7	-0.76	0.62	-1.81
30NN Mean		11552	25	0.74	21	-0.02	-0.02	0.06
BetL	Lake	22000	22	0.76	14	0.27	-1.26	-2.39
30NN Mean		11669	24	0.70	19	0.03	0.03	0.10
RL@BetL	Lake	12980	26	0.70	3	-0.09	0.58	-1.18
30NN Mean		11694	24	0.72	19	0.05	0.00	-0.01
FroC	Stream	1981	13	0.30	6	0.00	0.00	0.00
30NN Mean		*5021*	*24*	*0.75*	*44*	*-0.09*	*-0.04*	*-0.07*
RL@FroC	Lake	13420	23	0.77	7	-0.12	0.04	2.37
30NN Mean		11607	24	0.73	21	-0.05	0.00	-0.05
MinC	Stream	956	17	0.84	26	-0.04	2.60	3.85
30NN Mean		*4783*	*24*	*0.75*	*44*	*0.00*	*-0.06*	*-0.03*
RL@MinC	Lake	8920	24	0.68	4	0.10	0.10	2.57
30NN Mean		13547	25	0.74	17	0.05	0.09	-0.05
RL@BellP	Lake	10040	21	0.76	17	0.39	0.94	0.60
30NN Mean		12074	25	0.71	19	-0.04	-0.03	0.06
RL@LilC	Lake	5681	23	0.63	9	-2.80	-0.24	-0.58
30NN Mean		11143	22	0.69	18	0.07	0.05	0.01
LilC1	Stream	8300	19	0.80	34	0.62	-2.51	0.40
30NN Mean		*6346*	*23*	*0.65*	*24*	*0.03*	*0.00*	*0.05*
LilC2	Stream	16260	23	0.72	6	-0.59	-0.71	-0.51
30NN Mean		*5873*	*22*	*0.64*	*17*	*0.05*	*-0.06*	*0.15*

3.2.1 Laurentian East Creek (LauEC)

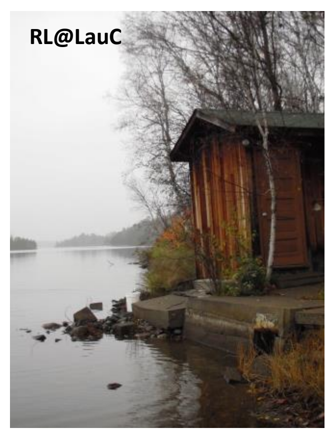
On the south shore, the Lake Laurentian Conservation Area (LLCA) is an undeveloped region that is dominated by wetlands. Two creeks drain the LLCA into Ramsey Lake, Laurentian Creek and Laurentian East Creek (Figure 1). Laurentian East Creek (LauEC) showed signs of impairment in the BMI community with low richness (14 families) in comparison to that expected (24) based on the range found at the NN reference sites (Table 4). Similarly, the proportion of sensitive EPT was much reduced at LauEC (12%) where 42% was expected. Laurentian East Creek is a headwater stream that drains a series of wetlands of low oxygen (4.5 mg/L) water high in organic acids (DOC 10.3 mg/L) reflected in the low pH (6.3) (Table 3). The wetland may also be storing historical loads of nickel and copper which are being carried downstream. Concentrations five times the PWQO for copper (24 ug/L) and nickel (94 ug/L) were measured in the Laurentian East Creek sample. In addition to the difficult chemical environment, there may be limited physical niches for BMI. Bedrock with sparse cobble within the stream paired with the shallow (average depth 9 cm), slow moving water (average velocity 0.04 m/s) may prevent more sensitive species from surviving once they colonize.



The lake site in which Laurentian East Creek drains (RL@LauEC) had expected values for abundance, richness, diversity and %EPT as these metrics were not significantly different from their NN reference site values (Table 4). As was the case for all the other Ramsey Lake sites, Laurentian East Creek Bay was dominated by scuds (Hyalellidae) and midges (Chironomidae). A difference in the community was, however, detected in the correspondence analysis as more sensitive dragonflies (Gomphidae) and mayflies (Heptageniidae) and tolerant dance fly larvae (Empididae) were collected than found in the NN reference sites (Table 4). The interstitial space between the cobble/boulder substrate and the overhanging shrubs with submerged branches seemed to offer ample suitable refugia for BMI. Elevated levels of metals (Ni - 30 ug/L and Cu – 8ug/L), sulphate ($SO_{4\,-}$ - 16ug/L) and sodium (53mg/L) (Table 3) may, however, have, had a negative effect on the BMI community.

Laurentian Creek (LauC1, LauC2)

Laurentian Creek also drains an area with little urban development, the Laurentian Lake sub-watershed (Figure 1). Nevertheless, Laurentian Creek sampled upstream and downstream of South Bay Road showed potential impairment owing to a lower than expected richness with 16 and 20 families at each of the sites (Table 4). In fact, Laurentian Creek downstream of South Bay Road (LauC2) was different from its NN reference streams for most metrics indicating an impaired BMI community. With low diversity (0.58) and low EPT (9%), it was dominated by tolerant midges (Chironomidae) and filtering black flies (Simuliidae) comprising 72% of the sample. Also, a much lower than expected proportion of Laurentian Creek's BMI community was represented by the net spinning caddisfly (Hydropsychidae). This relatively tolerant caddisfly was found at 95% of NN reference sites. The downstream site had a potentially challenging habitat for BMI with a 10 m drop in elevation in the 50 m between the road and the lake. Higher than PWQO concentrations for copper (12 ug/L) and nickel (37 ug/L) may also help explain the difference between the community in Laurentian Creek and the community expected in a similar stream (Table 3). The Laurentian Creek sites had the highest proportion of water in their watershed (38%), comprised mostly of Laurentian Lake, a shallow man-made lake (Pearson et al. 2002) high in organics which may bind metals. Further, sodium concentrations were higher than those found in reference streams, at 18 and 22 ug/L.



The corresponding lake site in Ramsey Lake (RL@LauC) was potentially impaired, supporting a different community than expected (CA3, Table 4). Although fewer sensitive mayflies (Leptophlebiidae, Caenidae, Ephemerellidae, Heptageniidae) and more tolerant dance flies (Empididae) and mites (Arrenuridae, Mideopsidae, Oxidae) were found than expected, the majority of the community structure was similar to the NN reference sites with scuds (Hyalellidae) and midges (Chironomidae) dominating the community. Scud/midge-dominated communities are not unusual in environments like Laurentian Bay with soft sediments and high macrophyte coverage (Mackie, 2004). Slight differences in community structure may be explained by the poor water quality; low oxygen (5.2 mg/L) with copper (9 ug/L) and nickel (32 ug/L) greater than the PWQO (Table 3). Metals were at slightly lower concentrations than the incoming stream sites as were sulphate and sodium which were, however, elevated relative to the reference site.

3.2.2 Bethel Lake (BetL)

Also draining into the south end of Ramsey Lake, Bethel Lake (Figure 1) has some urban impacts - notably sewage dumping up until a few years ago. The site within Bethel Lake (BetL) showed signs of enrichment both chemically (TP-36 ug/L; N-56 ug/L) and biologically with an abundance of 22000 BMI. High abundance is often a sign of enrichment (Mackie, 2004) thus potential impairment of the community was suspected as more individuals were collected than in the reference sites (11669 individuals; Table 4). In addition, the community in Bethel Lake was different from the NN reference sites with more tolerant mites (Arrenuridae), snails (Valvatidae) and water boatmen (Corixidae) and fewer sensitive mayflies (Leptophlebiidae, Ephemerellidae, Heptageniidae) than expected (CA3, Table 4). In contrast to the Ramsey Lake sites, Bethel Lake concentrations for nickel (20 ug/L) and Copper (2 ug/L) were at or below PWQO (Table 3). These metals, DOC (7 mg/L) and sulphate (6 mg/L) were in fact more similar to that found at the FIRNNO reference sites. It appears that enrichment plays an important role in determining the BMI community in Bethel Lake. The enrichment signal was further substantiated by the presence of considerable quantities of macrophytes and filamentous algae within a littoral zone which was blanketed by thick organic substrate. The legacy of enrichment from sewage (Pearson et al 2002) appears to shape the food web in Bethel Lake.

Separated by a wetland, the bay adjacent to Bethel Lake (RL@BetL) had a lower proportion of sensitive EPT (3%) (Leptoceridae, Polycentropodidae, Phrygaenidae, Caenidae, Hydroptilidae), and was dominated by tolerant scuds (Hyalellidae), midges (Chironomidae) and fingernail clams (Pisidiidae) (Table 4). Although a potential impairment was indicated by a lower proportion of EPT than the site's NN reference sites, the cause may be different from that which is driving the community in Bethel Lake. A wetland that separates Bethel Lake and Bethel Bay in Ramsey Lake seems to be efficiently capturing the nutrients which are in abundance in Bethel Lake proper (TP 9.7 ug/L and N 16 ug/L). Instead, elevated metal (Cu 7.9 ug/L and Ni 30 ug/L) and sulphate (15.7 ug/L) concentrations more typical of the other sites in Ramsey Lake were measured in Bethel Bay. These were well above the values seen in the reference sites and may help explain the impoverished BMI community.

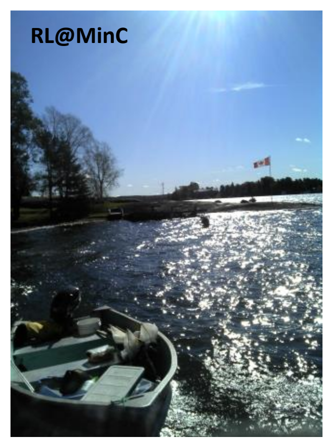
3.2.3 Frobisher Creek (FroC)

On the north shore of Ramsey Lake, more urban development is evident than on the south shore (Figure 1). Frobisher Creek's (FroC) watershed includes residential and industrial areas as well as 2km of Hwy 17E. An impaired BMI community was found at Frobisher Creek (FroC) with lower richness (13 families) and diversity (0.3) than at the NN reference sites (Table 4). The low diversity is evident when looking at the BMI community composition. It was dominated by filterers, the tolerant black flies (Simuliidae) and fingernail clams (Pisidiidae) making up 89% of the sample. Further potential impairment was apparent based on proportion of EPT with only 6% of the community composed of sensitive EPT families, notably only mayflies and caddisflies (Caenidae, Hydropsychidae, Hydroptilidae, Limnephilidae). Mayflies found at over 85% of the NN site (Heptageniidae, Ephemerellidae, Baetidae, Leptophlebiidae) were absent from the Frobisher creek sample as were amphipods. The Frobisher Creek site had good instream habitat with large cobble offering ample interstitial spaces for BMI but the complete lack of canopy offered little food for shredders like stoneflies which are deciduous tree leaf feeders (Mackie, 2004). Poor water quality in Frobisher Creek at the time of sampling (Na 83 mg/L, SO_4 35 mg/L, N 334 ug/L, DOC 10 mg/L and Ca 64 mg/L; Table 3) may have also contributed to the poor BMI community.

The Frobisher Bay (RL@FroC) in Ramsey Lake where Frobisher Creek drains showed impairment in the BMI community (CA3; Table 4). It was dominated by scuds (Hyalellidae) and midges (Chironomidae) as were the other Ramsey sites and NNs sites, which together with fingernail clams (Pisidiidae) comprised 78% of the community. It, however, had more snails (Physidae) and mites (Sperchontidae) than expected. Some mayfly families (Leptophlebiidae and Caenidae) that were found in all the NN reference sites were notably absent. Poor water quality from the inflow creek was diluted somewhat within the lake. Still, levels above those encountered in reference lakes for many parameters (Ni 29 ug/L, Cu 8 ug/L, Ca 18 mg/L, SO_4 17 mg/L, N 40 mg/L and Na 62 mg/L; Table 3) have likely led to impairment in the BMI community. In fact, in-lake sodium concentrations were the highest at the Frobisher Creek Bay. Further, the elevated concentrations of inorganic nitrogen could lead to algal blooms as encountered in the summer of 2013 (SDHU) thereby limiting the BMI community to those families that can tolerate the likely low oxygen concentrations in winter caused by the decomposition of the algae (Mackie, 2004). In addition to water quality issues, the Frobisher Bay shoreline is over-developed with riparian vegetation limited to lawn grasses without a tree canopy. Without a riparian buffer zone to shade the water and maintain cool temperatures, and stop chemicals including pesticides from entering the lake, BMI community would be impaired. Also, a silt/clay benthic area offers little refugia, though ample macrophytes were present to fill that role.

3.2.4 Minnow Creek (MinC)

Also on the north shore, Minnow Lake receives urban inputs including historical inputs of sawdust. Minnow Creek (MinC) drains Minnow Lake into Ramsey Lake. The BMI community was impaired at Minnow Creek with low richness (17) and differences in community composition (CA2 and CA3) together with more worms (Tubificidae) and fewer mayflies (Leptophlebiidae, Caenidae, Ephemerellidae, Heptageniidae) than expected. Minnow Creek had the highest sodium values (93 mg/L) of all sampling sites, much higher than the FIRNNO reference streams and those generally found in clean Ontario lakes of <1 mg/L (Neary et al 1990). Enrichment also seemed to be an issue in this small shallow (3m) lake. The stockpiles of organics still appear to affect Minnow Lake as spring phosphorus of 61 ug/L was recorded in Minnow Lake in 2012 (CGS, 2014). Minnow Creek, draining Minnow Lake, had equally poor water quality at the time of sampling. Historical smelting (SO_4 18 ug/L, Ni 34 ug/L and Cu 8 ug/L) confounded by enrichment (TP 23 ug/L) and elevated sodium (93 mg/L; Table 3) all likely contributed to the poor BMI community. Habitat was quite suitable to support a good BMI community with well-developed riparian vegetation and large substrate size to allow for sufficient refugia within the interstitial spaces, further pointing to a water chemistry issue in the case of Minnow Creek.

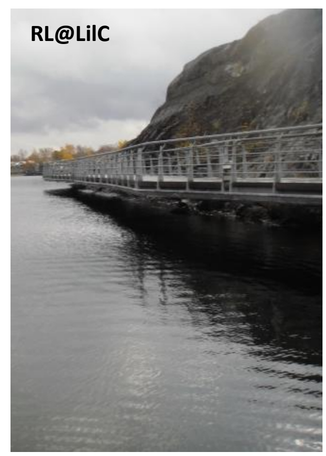


The proportion of sensitive mayflies, stoneflies and caddisflies (%EPT) was low at the Minnow Creek Bay (RL@MinC) with a small number of invertebrates from 5 relatively tolerant mayfly and caddisfly families (Caenidae, Polycentropodidae, Phryganidae, Leptoceridae, Molanidae). Impairment was detected in the BMI community with higher numbers of dragonflies (Aeshnidae) and mites (Sperchontidae) than at the NN reference sites (CA3; Table 4). Similarly to the NNs (mean 57%), the community was comprised mainly of scuds (Hyalellidae) and midges (Chironomidae)(77%). The low proportion of EPT and high proportion of tolerant scuds and midges may be due to enrichment from the receiving waters of Minnow Creek and Minnow Lake. With total phosphorus of 40 ug/L (Table 3) well above the NN mean and all the other sites on Ramsey, the site was eutrophic. High phosphorus can lead to algal blooms and subsequent depression of oxygen affecting sensitive BMI (Mackie, 2004). The Minnow Creek Bay site also had elevated metals (Ni 37ug/L, Cu 10ug/L), sodium (57mg/L) and sulphate (17mg/L), albeit at lower concentrations than the feeder stream having been diluted within the lake. This site had the additional challenge of poor habitat for BMI; the coarse sand and lack of macrophytes combined with sparse riparian vegetation dominated by grasses offered little in the way food and refugia for BMI.

3.2.5 Bell Park in Ramsey Lake (RL@BellP)

A sample was taken on the north-western shore of the lake near Bell Park (RL@BellP). The in-lake Bell Park site was the only site where no impairment in the BMI community was evident with none of the metrics outside the normal range (Table 4). Similarly to the other Ramsey Lake sites, a large proportion (64%) of the community was comprised of scuds (Hyalellidae) and midges (Chironomidae). Water chemistry here was similar to the other Ramsey sites with the additional issue of slightly elevated phosphorus and very elevated concentrations of aluminum (Table 3). The source of the water is the sub-watershed that includes portions of the park and a stretch of Paris Street, all of which drains directly into the lake through a storm conduit. The lack of a buffer zone allows water laden with metal-rich sediment to enter the lake and would presumably negatively affect the BMI community. Overhanging trees and vegetation within the lake may have buffered the negative effects of storm water inputs. The resulting community was not significantly different from it NNs.

3.2.6 Ramsey Lake outflow (RL@LilC)



At the western end of Ramsey Lake, the lake's outflow runs under Paris Street into an extensive cattail marsh with a defined channel, Lily Creek. The lake site at Ramsey's outflow near Science North (RL@LilC) had the lowest diversity although not significantly different from its NN reference sites. The community composition was, however significantly different with more tolerant mites (Sperchontidae, Lebertidae, Torrenticolidae) and dance fly larvae (Empididae) (CA1, Table 4) and a complete lack of two mayfly families (Leptophlebidae and Caenidae) present in all the NN reference sites. The quality of the water at the outflow site was similar to others in the lake with elevated metals and sodium (Table 3) which may have affected the BMI community.

Lily Creek, the only outflow for Ramsey Lake was sampled at 2 locations downstream of Ramsey Lake. LilC1 was 1km downstream of Ramsey Lake immediately downstream of Regent Street, having travelled through an extensive cattail marsh (Figure 1). LilC2 was 1.5 kms downstream of Ramsey Lake upstream of Martindale Road at Beverly Street. Being only half a kilometre apart, their habitat was similar (slow moving - 0.001 and 0.02 m/s and relatively deep 45 cm and 17 cm) although LilC1 had a cobble bottom likely from stray rocks from road construction whereas LilC2 had a gravel /silt bottom. Differences in water chemistry were observed between reference streams and Lily Creek (Table 3). Being immediately downstream of the large wetland of standing water, low oxygen (5.2 mg/L) was recorded at LilC1. Despite the water quality issues, the Lily Creek sites (LilC2, LilC1) were the only test stream sites to have similar richness values to their NNs reference streams.

There were, however, differences in the community composition in LilC1; dominated (52%) by midges (Chironomidae) and mayflies(Caenidae) with these mayflies (Caenidae) and water boatmen (Corixidae) being more numerous than at most of its NN reference sites (CA2; Table 4). Some mayfly families (Ephemerellidae and Leptophlebiidae) were, missing from LilC1 while they were found in all NN reference site.

Abundance was much higher in the furthest downstream Lily Creek site (LilC2) with over 16000 tolerant individuals captured. Dominated (63%) by midges (Chironomidae) and collector/gatherer beetle larvae (Elmidae), some mayflies families (Ephemerellidae) were absent from the sample. Erosion of fine substrate have caused high turbidity in this furthest downstream Lily Creek site (LilC2) which carried with it elevated aluminum (Table 3). The enrichment (TP 46 ug/L) resulting from suspended solids may have caused the increase in abundance of relatively tolerant BMI.

3.3 The Ramsey Lake watershed

The Ramsey Lake watershed has historically been altered by logging and mining, loss of riparian vegetation acidification and metal deposition as well as erosion and severely impacted water and sediment quality. Prior to disturbance in the early 1900s, pH of Ramsey Lake is estimated to have been 6.6 with an increase to 7-7.7 during the cultural disturbance of 1920-1980 (Dixit et al .1996). Despite receiving high loadings of airborne contaminants, pH has increased, possibly because of carbonate leaching of the watershed by acid rain (Kilham et al 1982). From rock etching evidence, glaciers are thought to have travelled in a southwest direction in Northern Ontario (Pearson, 2002). Glaciers have deposited limestone from Temiskaming shores in the northeast portion of the Ramsey watershed. It is possible therefore that Ramsey Lake receives groundwater with buffering capacity and so the lake has never acidified and had a pH as high as 7.9 in 2013. This elevated pH has provided some protection to the BMI community whereas in other lakes in the Greater Sudbury area, pH had dropped below 5.5 and aquatic life was reduced or even extirpated.

In the Sudbury Urban Lakes study done in 1990, a rocky area in Ramsey Lake was found to have 80% relatively tolerant Amphipods, Chironomids and worms (ACW) and 7% EPT (Smith, 1990). Rocky lake sites sampled in 2013 like those near Laurentian East (RL@LauEC), Bell Park (RL@BellP) and the outflow (RL@LilC) had 64-68% ACW and 9-17% EPT (Table 4). At a non-rocky area of Ramsey Lake, 97% of the community was ACW and 2% was EPT (Smith, 1990). Similar lake sites sampled here (RL@MinC, RL@BetL, RL@FroC, RL@LauC) had 65-88% ACW and 3-7% EPT. A decrease in tolerant scuds (Amphipoda), midges (Chironomidae) and worms

(Oligochaeta) and an increase in sensitive EPT at both rocky and non-rocky sites leads one to believe that Ramsey Lake's BMI community has improved since 1990.

Although the BMI community has improved, there are still impairments when compared to reference sites. As expected, all of the in-lake sites were dominated by scuds (Hyalellidae) and midges (Chironomidae). Fewer amphipods were, however, found in the streams with the exception of the outflow stream, Lily Creek (LilC2, LilC1) where both Hyalellidae and the more sensitive Crangonyxidae were found. Of note was the absence of some sensitive species in many lake and stream sites. Missing were some common mayflies and caddisflies but of particular concern was the complete lack of stoneflies in the streams. Shredders such as stoneflies (Plecoptera) feed on plant material and break it into smaller particles through their feeding and digestive process (Mackie, 2004). Shredding macroinvertebrates represent an important component of the biological processing of coarse particulate organic matter. Shredders are typically most abundant where there is a strong interaction between the riparian zone and the stream (Vannote et al., 1980). Many Ramsey Lake sites were limited by minimal riparian inputs from the surrounding shore.

In the sites entering Ramsey Lake from the north shore of the lake (Minnow, Frobisher), urban impacts were evident while on the south shore (Laurentian, Laurentian East) the legacy of mining in Sudbury was more prominent (Figure 1). The Bethel sites were distinguished by an enrichment signal. Sites sampled in the bays receiving water from inflows were more similar to their NN reference sites than the creeks from which the water is being received. Lakes tend to offer a more stable environment for BMI being less susceptible to extreme changes in water levels and flows whereas streams, especially small headwater streams suffer from more fluctuations in environmental conditions causing more chemical spikes followed by drift or kill episodes of BMI (Mackie, 2004). In addition, Ramsey Lake is ground water fed and offers dilution of stream water thereby reducing metal, nutrient and salt concentrations and increasing pH at the in-lake sites. The in-lake communities therefore emulate more closely those found at reference sites.

The BMI community continues to be impaired likely because of confounding impacts of multiple pollutants and physical alterations. The legacy of mining since the early 1800s of metals and sulphate contamination continue to impact the BMI community in Ramsey Lake. The release of stored acidity in wetlands, such as the ones in the southern watersheds of Laurentian and Laurentian East Creeks, can mobilize acid-soluble metals (Yan et al 1996) in sub-lethal or even lethal concentrations. Small headwater streams like those in the Ramsey Lake watershed are prone to drought induced acidification. Historical human-caused eutrophication (Dixit et al 1996) from raw sewage and sawdust also continues to impact Ramsey Lake; the organic matter continues to decompose using up oxygen and adding nutrients thereby affecting the BMI community.

With significant reductions of sulphur and metal emissions, acidification and metal dusting from the mining industry have reduced, but non-point sources of contamination from surface runoff continue. Road runoff is contaminated with oil, gasoline and de-icing salt. Sodium concentrations in surface waters of the Ramsey Lake watershed have increased since 1990 (Smith 1990) to over 50 mg/L at many lake sampling sites (Table 3). Particulates in road runoff from brake linings and tires accumulate in the sediments of receiving waters where they can reach concentrations orders of magnitude greater than those present in the overlying water. The organisms most at risk, therefore, will be BMI as they are exposed to both dissolved and deposited contaminants (Maltby, 1996). Road runoff also carries with it fine substrate (gravel/sand) that inundate larger substratum structure, such as cobble and snags, thereby reducing refuges for larger invertebrates (Mackie, 2004). In addition, lawn runoff can carry with it pesticides and nutrients (N and TP).

A healthy riparian community can help reduce the impacts of surface runoff on waterways. Unfortunately, many shorelines in the Ramsey Lake watershed lack the required riparian vegetation to sustain a healthy BMI community. Such vegetation lowers water temperatures through shading, acts as a nutrient buffer through uptake of nutrients from urban runoff, and provides habitat and food sources for invertebrates through leaf litter and twig deposition. The Ramsey Lake watershed has a young transitional forest which is generally sparse. On the north and west shores of the lake, the virtually complete lack of woody riparian vegetation is generally a function of urbanisation. The poor vegetated buffer strip at many sampling sites likely contributes to impoverished BMI communities.

4 Conclusions

The Ramsey Lake watershed continues to be impacted by historical chemical loads as well as effects of current urbanization. To quantify the impacts, Ramsey Lake watershed sites were compared to NN reference sites. The BMI community in inflow streams were impaired with multiple metric values different from reference sites. Lake sites tended to have similar metric values as the reference site with relatively tolerant scuds (Hyalellidae) and midges (Chironomidae) dominating both Ramsey and reference lake BMI communities. Impairment was more a factor of the community composition being slightly different than expected as detected by correspondence analysis. The outflow stream, Lily Creek also had some impairment in the BMI community. Of concern at all the Ramsey sites was the low proportion of sensitive species, mayflies and caddisflies, as well as complete lack of stoneflies.

Although improvements have occurred in the Ramsey Lake watershed, both biologically and chemically, a continued effort will be necessary to more closely match Ramsey BMI communities to those seen at reference sites. Possible strategies to improve habitat for BMI may include:

- Reduce salt use
- Encourage riparian vegetation
- Reduce nutrient load from lawn fertilizer, malfunctioning septic systems, and legacy sewage and sawdust loads, especially from Minnow Lake and Frobisher Creek
- Encourage sphagnum moss to help bind metals in wetlands in the Laurentian and Laurentian East sub-watersheds (as described by Szkokan-Emislon, 2014)
- Build catchment basin to filter water before it enters the lake, particularly at Bell Park and Minnow Creek

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7 Appendices

Appendix 1 - PCA ordination of water chemistry variables (open circles) for Ramsey in-lake test sites (03-14), and reference lake sites (closed circles, N=156). The first 3 axes of the PCA explained 68% of the variation (31%, 21% and 16%, respectively) in the 16 water chemistry parameters. Generally, Ramsey Lake watershed sites had higher pH, alkalinity, conductivity, ions (Na, Ca, Mg, SO_4), and metals (Cu, Ni) than the reference sites. 22

Appendix 2 - PCA ordination of water chemistry variables (open circles) for Ramsey stream test sites (squares, 01-15) and FIRNNO reference stream sites (closed circles, N=200). The first 3 axes of the PCA explained 58% of the variation (33%, 14% and 9%, respectively) in the 16 water chemistry parameters. Two inflows, Frobisher Creek (FroC) and Minnow Creek (MinC) as well as the two outflows, Lily Creek, had higher conductivity, alkalinity and ions (K, Ca, Mg, Na, SO4) than the other Ramsey watershed site and the reference sites. In contrast, the Laurentian sites were similar to reference for all parameters except for elevated copper and nickel........ 23

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Appendix 4 - CA ordination of BMI community structure for the outflow (RL@LauEC) Ramsey in-lake site (square) and its 30 NN reference sites (closed circles). Families are open circles. 25

Appendix 5 - CA ordination of BMI community structure for the outflow (RL@FroC) Ramsey in-lake site (square) and its 30 NN reference sites (closed circles). Families are open circles. 26

Appendix 6 - CA ordination of BMI community structure for the outflow (RL@LilC) Ramsey in-lake site (square) and its 30 NN reference sites (closed circles). Families are open circles. 27

Appendix 7 - CA ordination of BMI community structure for the Laurentian Creek (RL@LauC) Ramsey in-lake site (square) and its 30 NN reference sites (closed circles). Families are open circles. 28

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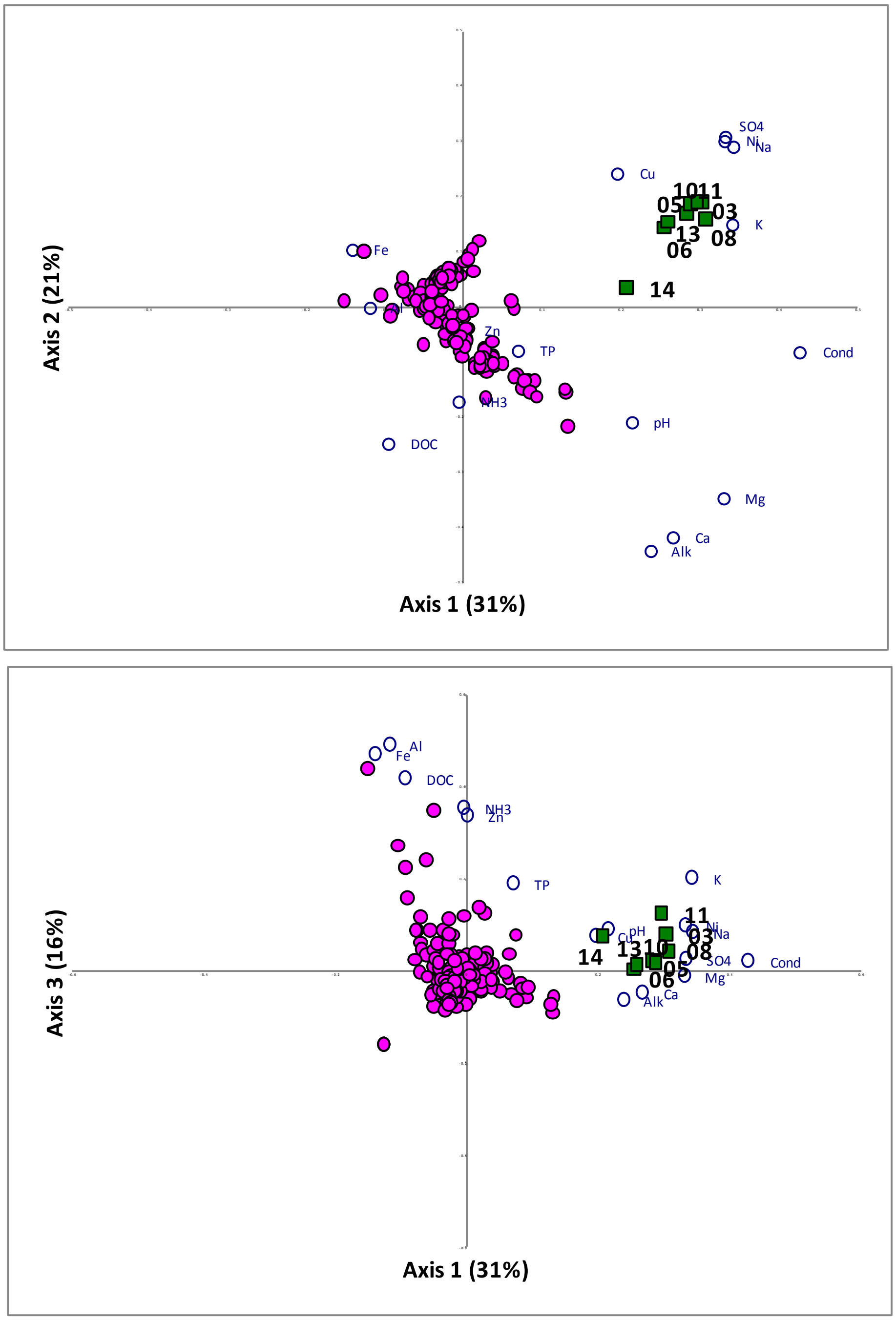

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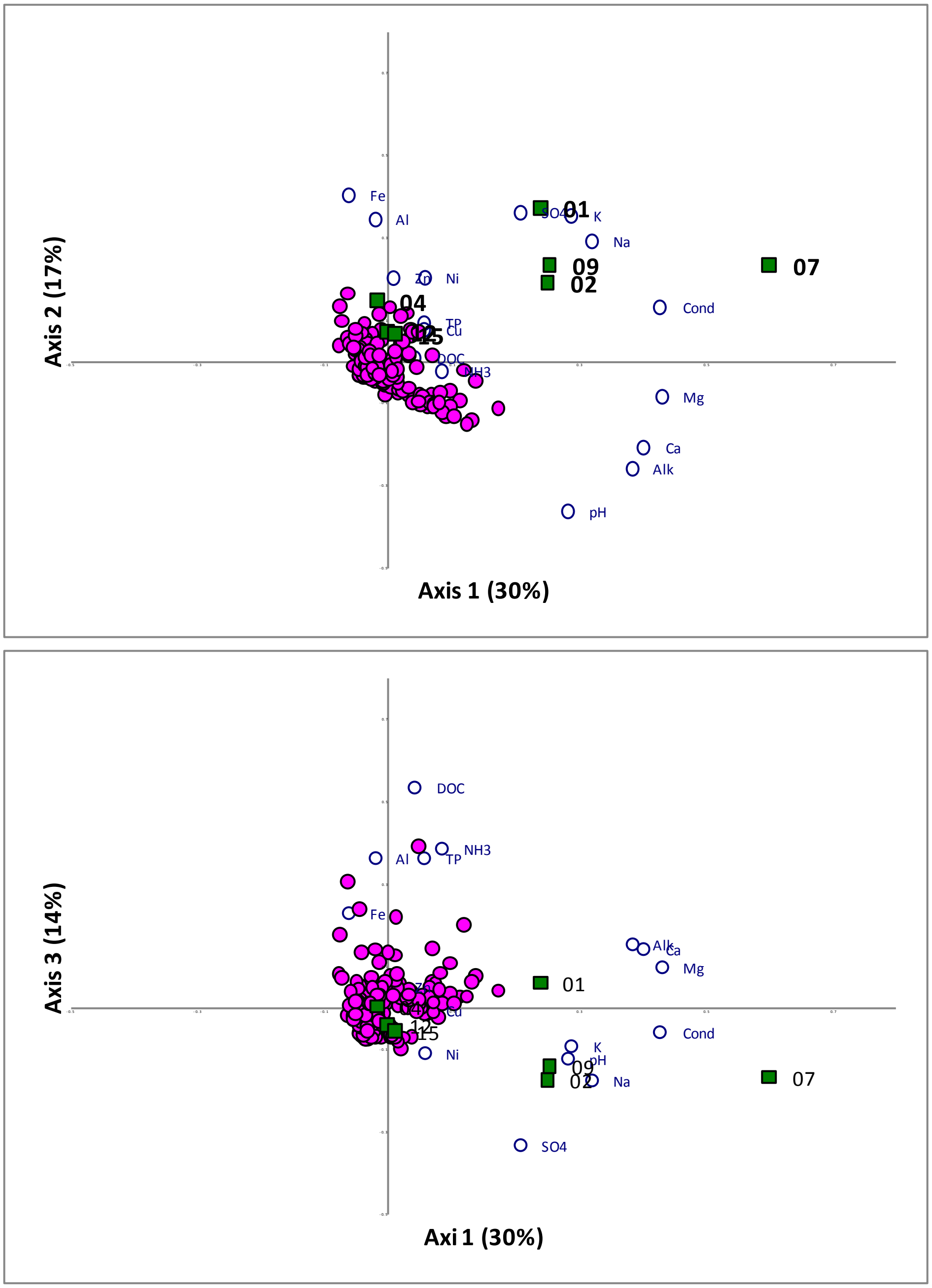

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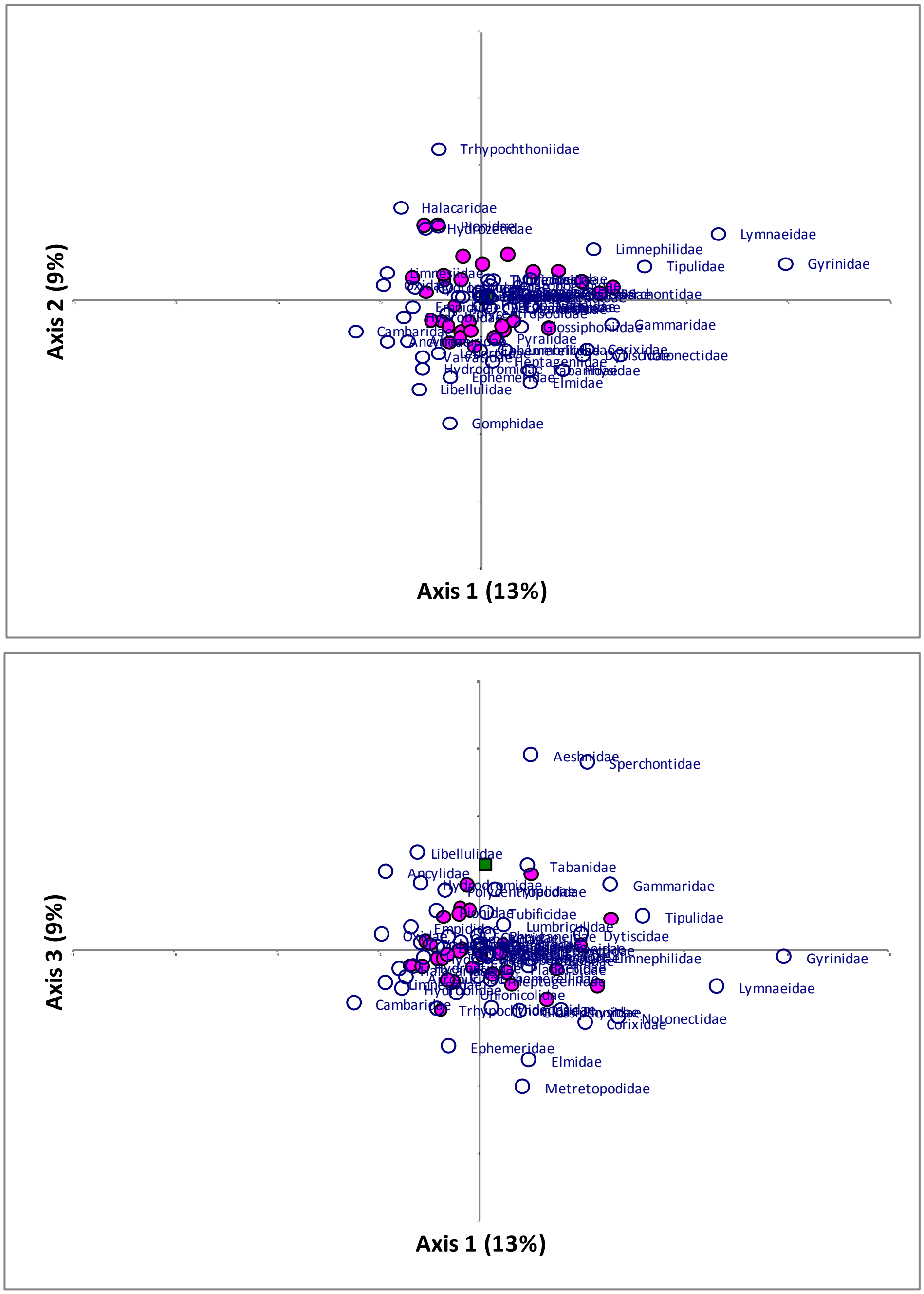
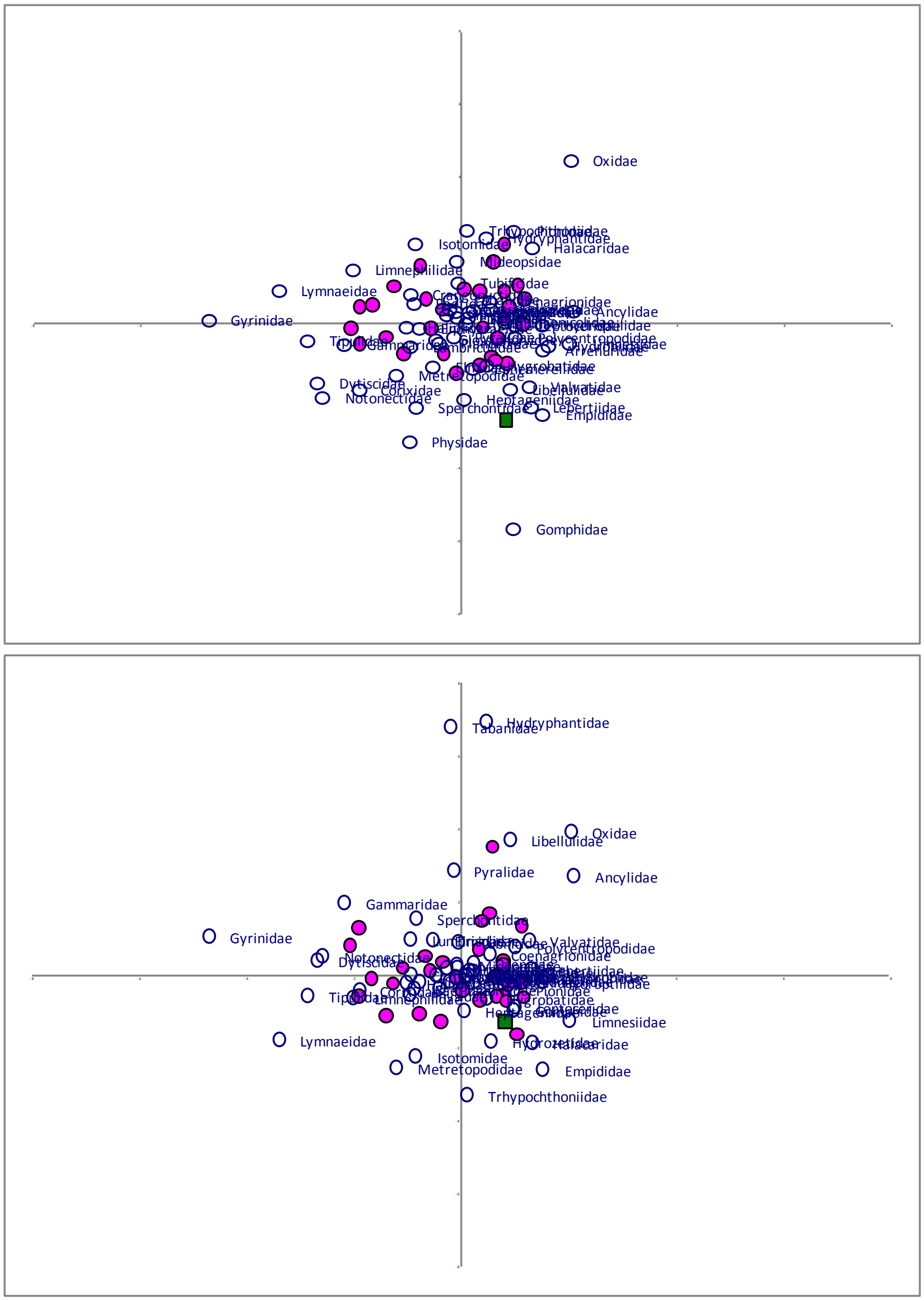
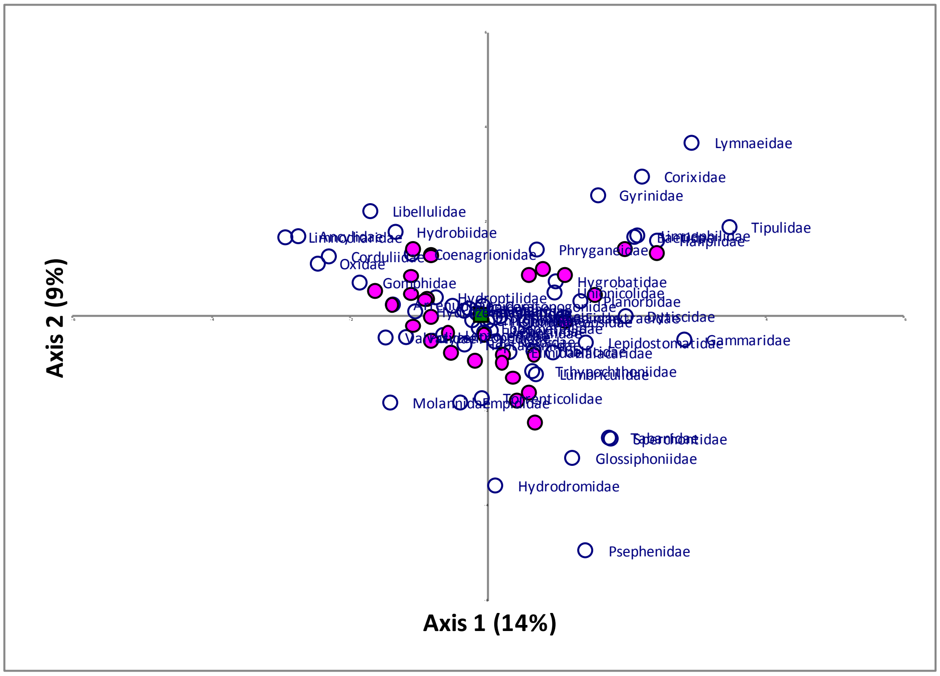
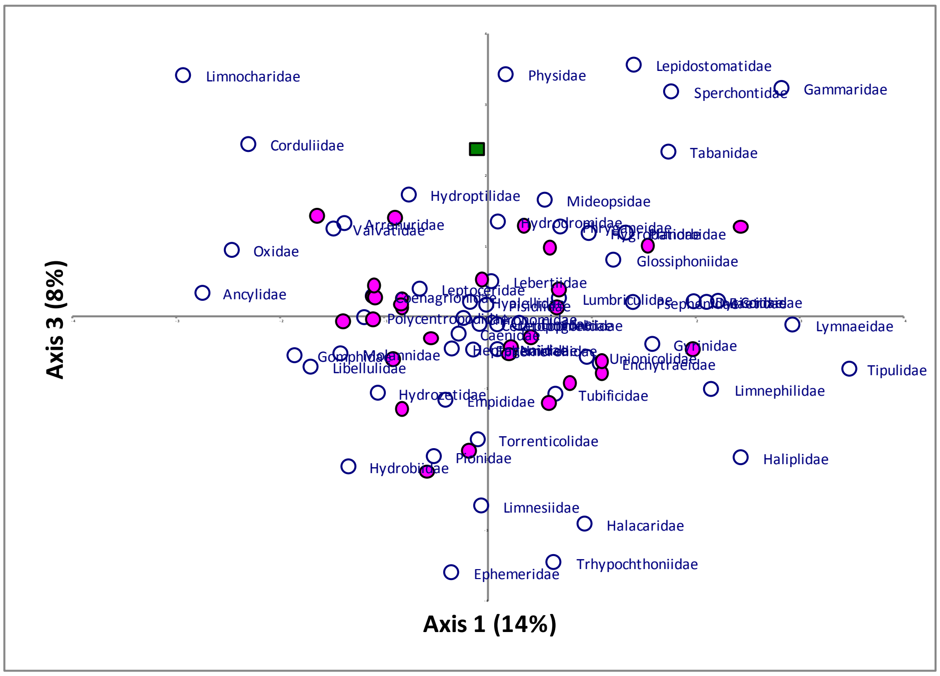


Appendix 3 CA ordination of BMI community structure for the outflow (RL@MinC) Ramsey in-lake site (square) and its 30 NN reference sites (closed circles). Families are open circles.

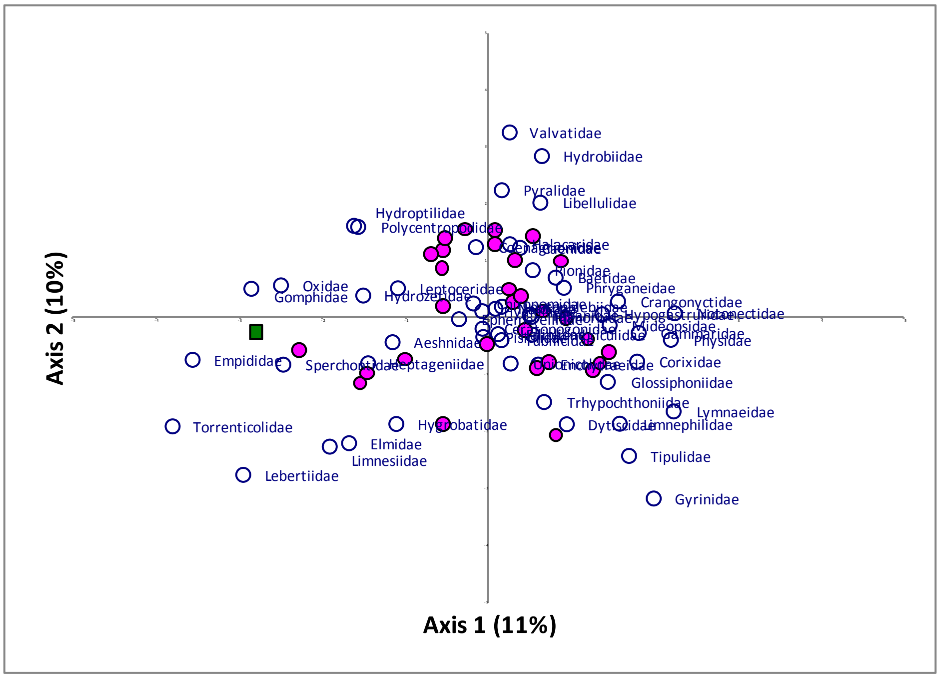


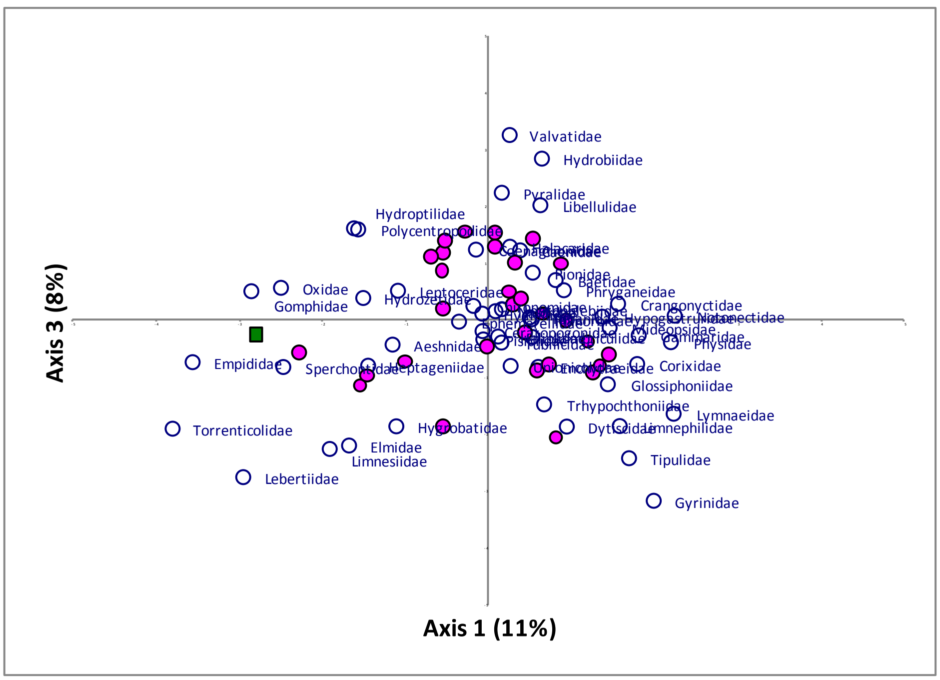
Appendix 4 CA ordination of BMI community structure for the outflow (RL@LauEC) Ramsey in-lake site (square) and its 30 NN reference sites (closed circles). Families are open circles.



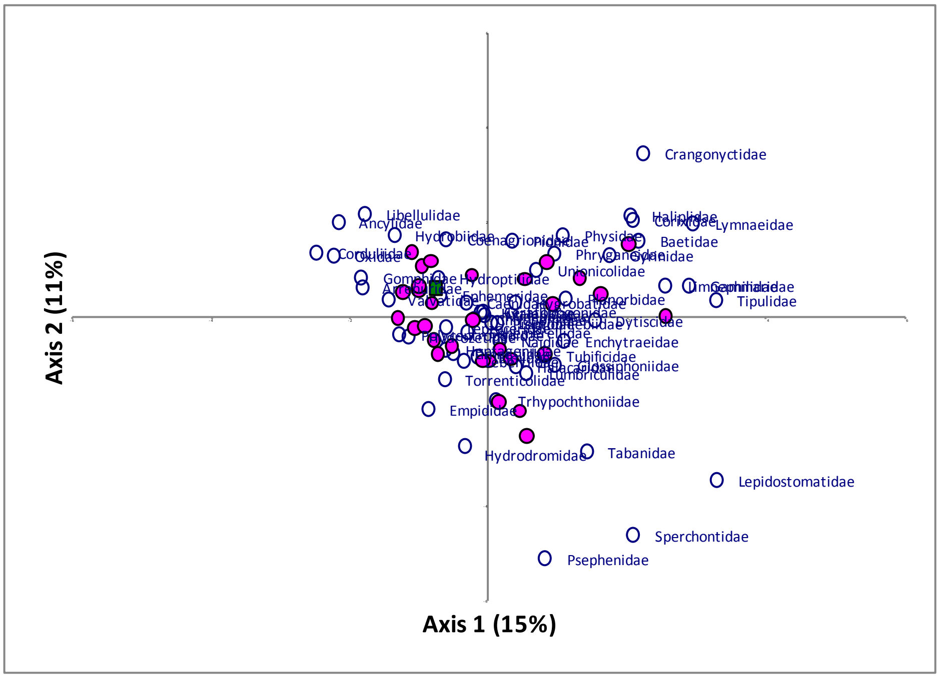


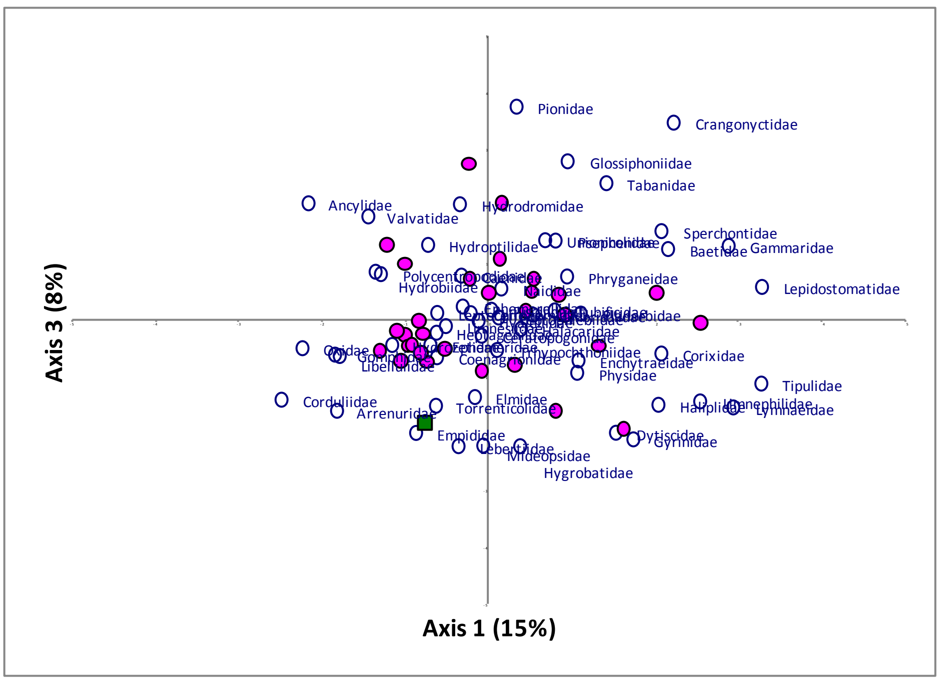
Appendix 5 CA ordination of BMI community structure for the outflow (RL@FroC) Ramsey in-lake site (square) and its 30 NN reference sites (closed circles). Families are open circles.



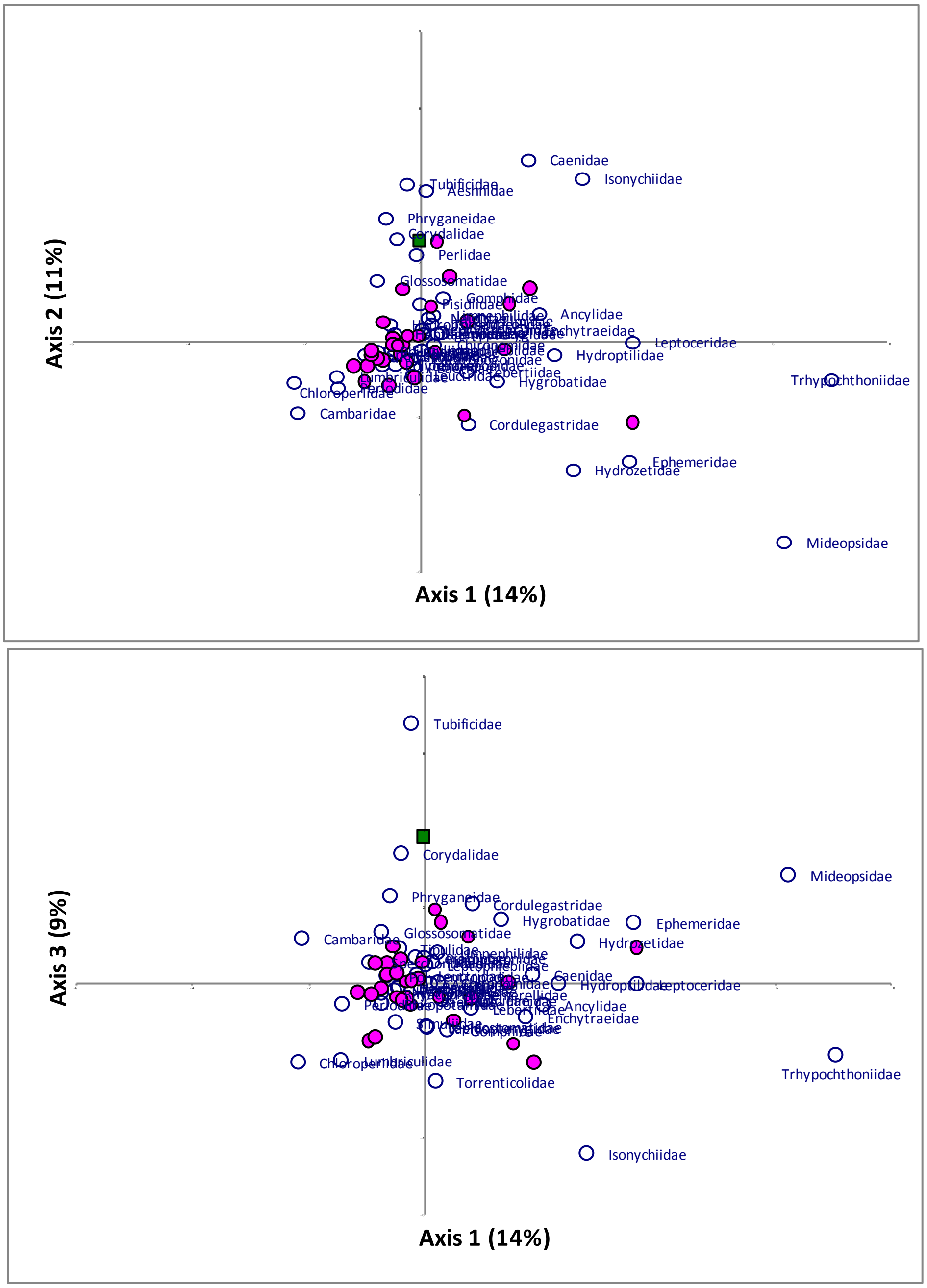


Appendix 6 CA ordination of BMI community structure for the outflow (RL@LilC) Ramsey in-lake site (square) and its 30 NN reference sites (closed circles). Families are open circles.

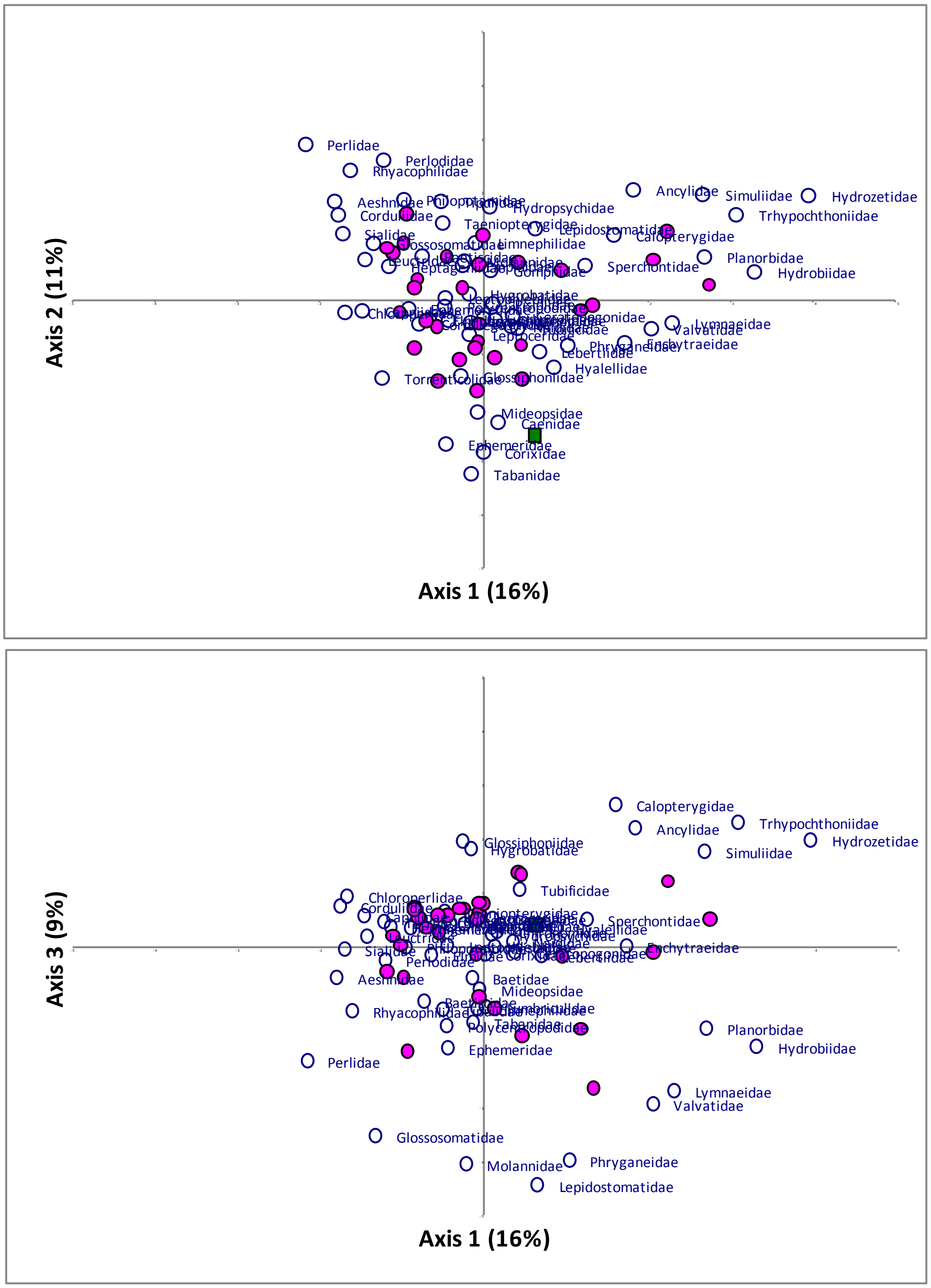




Appendix 7 CA ordination of BMI community structure for the Laurentian Creek (RL@LauC) Ramsey in-lake site (square) and its 30 NN reference sites (closed circles). Families are open circles.



Appendix 8 CA ordination of BMI community structure for the Minnow Creek (MinC) Ramsey stream test site (square) and its 30 NN reference **streams** (closed circle). Families are closed circles.



Appendix 9 CA ordination of BMI community structure for the Lily Creek (LilC1) Ramsey stream test site (square) and its 30 NN reference **streams** (closed circle). Families are closed circles.

Appendix 10 Ramsey watershed sites habitat data

	LauEC	LauC1	LauC2	FroC	MinC	LilC2	LilC1	RL@LauEC	RL@LauC	RL@FroC	BetL	RL@BetL	RL@MinC	RL@BellP	RL@LilC
	Laurentian East Creek	Laurentian Creek	Laurentian Creek	Frobisher Creek	Minnow Creek	Lily Creek	Lily Creek	Ramsey Lake @ Laurentian East Creek	Ramsey Lake @ Laurentian Creek	Ramsey Lake @ Frobisher Creek	Bethel Lake	Ramsey Lake @ Bethel Lake	Ramsey Lake @ Minnow Creek	Ramsey Lake @ Bell Park	Ramsey Lake @ Lily Creek
	RAM04	RAM12	RAM15	RAM07	RAM02	RAM01	RAM09	RAM05	RAM11	RAM08	RAM14	RAM06	RAM03	RAM13	RAM10
Latitude	46.46978	46.457	46.45761	46.48317	46.48707	46.46853	46.47128	46.470361	46.47558	46.4824	46.4687	46.4742	46.4869	46.4578	46.4718
Longitude	-80.9253	-80.9456	-80.9461	-80.9368	-80.9604	-81.0123	-81.0073	-80.92519	-80.99189	-80.9376	-80.965	-80.9551	-80.8605	-80.9464	-80.9731
Altitude	872	898	856	843	794	849	846	839	833	849	843	823	836	889	826
SO	1	2	2	1	1	2	2	1	2	1	1	1	1	2	2
Dist	5.1	6.08	6.2	4.8	3.18	13.27	16.56	5.2	0.75	4.99	0.68	2	3.2	6.3	15.2
DA	3.8	6.99	7	5.29	2.9	51.75	51	3.8	0.26	5.2	0.25	1.2	3	7	42.8
Slope	10.0	3.6	4.4	13.6	21.6	2.5	1.9	10.9	50.7	13.4	55.9	17.0	21.5	4.7	2.1
%W	28.2	38.1	38.0	11.9	7.2	27.7	29.2	28.3	0.0	12.1	0.0	30.4	8.0	18.2	30.8
Mac	0	0	0	0	0	3	3	0	1	4	4	2	0	4	4
Canop	4	4	3	0	4	1	0	1	2	0	0	0	0	0	0
Pool	1	0	0	0	0	0	0	NA	NA	NA	NA	NA	NA	NA	NA
Rap	0	0	0	0	0	0	0	NA	NA	NA	NA	NA	NA	NA	NA
Rif	1	1	1	1	1	0	0	NA	NA	NA	NA	NA	NA	NA	NA
Run	1	0	0	1	0	1	1	NA	NA	NA	NA	NA	NA	NA	NA
Con	1	0	1	1	1	0	1	1	0	0	0	0	1	1	0
Dec	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1
Gras	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Shr	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1
Dep-A	9.1	14.3	10.2	12.4	6.7	17.4	45.1	NA	NA	NA	NA	NA	NA	NA	NA
Dep-M	13	28	14	18	8	26	80	NA	NA	NA	NA	NA	NA	NA	NA
Vel-A	0.04	0.15	0.18	0.19	0.06	0.02	0.01	NA	NA	NA	NA	NA	NA	NA	NA
Vel-M	0.23	0.5	0.42	0.42	0.16	0.05	0.01	NA	NA	NA	NA	NA	NA	NA	NA
Bwid	2.1	5.5	13	2	1.8	7.3	10.5	NA	NA	NA	NA	NA	NA	NA	NA
Wwid	0.4	3.1	1.2	1.4	1	5.2	8	NA	NA	NA	NA	NA	NA	NA	NA
1Dom	6	8	7	7	6	2	7	8	6	1	0	1	2	1	7
2Dom	7	7	4	8	7	1	5	7	4	1	0	1	7	3	6
Surr	4	6	5	3	4	3	3	6	2	0	1	0	2	4	2

Appendix 11 Ramsey watershed sites water chemistry.

		Stream sites								Lake sites								
Water parameter	**Units**	LauEC	LauC1	LauC2	FroC	MinC	LilC1	LilC2	Ref Stream mean	RL@LauEC	RL@LauC	BetL	RL@BetL	RL@FroC	RL@MinC	RL@BellP	RL@LilC	Ref Lake mean
Alkalinity	**mg/L**	8.0	5.1	5.5	155.0	46.3	58.4	65.1	13.3	36.0	37.3	61.0	37.0	40.9	36.8	38.6	37.2	10.0
Ca	**mg/L**	3.3	3.6	3.8	64.4	18.2	20.4	23.4	5.1	16.6	13.9	15.6	15.8	17.6	16.4	17.9	14.2	4.9
K	**mg/L**	0.48	0.62	0.64	3.40	1.50	3.12	3.13	0.54	1.64	1.61	2.21	1.60	1.76	1.63	1.63	1.54	0.39
Mg	**mg/L**	1.41	1.49	1.54	19.20	4.99	6.08	7.26	1.47	5.22	5.30	6.19	5.33	6.05	4.74	5.11	5.17	1.42
Mn	**ug/L**	30.6	36.6	17.4	68.2	40.3	67.8	197.0	42.2	8.3	11.6	62.5	7.6	11.8	21.5	60.4	8.8	33.9
Na	**mg/L**	7.6	18.0	21.9	83.3	93.4	69.7	37.9	1.7	53.6	30.5	32.8	32.4	61.7	57.2	59.6	57.1	7.7
Cl	**mg/L**	9.0	32.9	35.7	302.0	148.0	118.0	122.0	1.5	88.2	91.0	50.2	90.6	98.6	89.5	91.7	89.9	13.3
pH		6.3	6.5	6.8	7.9	7.6	7.1	7.3	6.8	7.9	7.7	7.8	7.7	7.9	7.7	7.8	7.6	6.9
Si	**ug/L**	3.36	0.96	1.00	4.16	0.76	1.52	1.72	2.89	0.84	0.88	0.58	0.88	0.94	0.84	0.88	0.82	2.10
SO_4	**mg/L**	6.3	5.1	5.4	34.7	17.8	17.6	18.6	5.5	16.4	16.3	5.8	15.7	16.7	16.7	17.8	16.9	4.8
Conductivity	**uS/cm**	72.0	143.0	150.9	1390.0	651.0	557.0	589.0	50.9	416.0	417.0	302.0	417.0	456.0	418.0	434.0	421.0	81.6
Colour		103.0	63.0	58.3	34.6	28.6	45.8	121.0	56.1	14.0	16.2	25.0	10.8	13.2	12.4	13.2	12.2	37.9
DOC	**mg/L**	9.4	5.4	5.2	10.3	4.9	4.7	5.0	7.1	3.7	3.7	6.5	3.6	3.7	3.6	3.6	3.6	5.8
NH3	**ug/L**	30	28	22	20	20	22	16	18	14	14	54	12	32	16	14	16	15
NO2+NO3	**ug/L**	118	18	26	314	40	6	4	40	4	2	2	4	8	4	2	2	14
Inorganic N	**ug/L**	148	46	48	334	60	28	20	59	18	16	56	16	40	20	16	18	29
TKN	**ug/L**	548	428	407	396	338	353	496	304	309	305	616	292	339	286	289	300	295
TP	**ug/L**	27.1	26.1	22.2	13.7	23.3	24.5	45.6	15.5	12.8	12.6	36.3	9.7	11.5	40.1	17.9	9.4	10.8
Al	**ug/L**	168.0	41.4	35.6	61.0	32.5	24.5	874.0	78.5	7.7	6.4	11.5	3.2	9.5	43.0	147.0	7.0	27.9
Co	**ug/L**	1.0	0.5	0.5	0.5	0.5	0.5	1.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.2
Cu	**ug/L**	23.7	12.5	12.2	5.7	8.1	2.5	11.6	1.5	8.3	9.0	2.5	7.9	7.8	10.1	10.1	8.4	1.4
Fe	**ug/L**	1050.0	540.0	480.0	190.0	220.0	590.0	1490.0	461.3	30.0	50.0	70.0	15.0	40.0	90.0	240.0	15.0	300.4
Ni	**ug/L**	93.8	38.0	36.2	24.2	34.2	23.0	36.8	2.7	30.1	32.3	19.7	30.1	28.7	36.8	33.0	32.9	3.3
Zn	**ug/L**	6.0	2.4	2.7	4.2	5.3	7.1	7.8	2.8	1.0	1.0	1.0	1.0	1.0	2.1	3.9	1.0	1.6

Appendix 12 Benthic invertebrate community data

Order	Family	Stream							Lake							
	Site code	LauEC	LauC1	LauC2	FroC	MinC	LilC1	LilC2	RL@LauEC	RL@LauC	RL@FroC	RL@MinC	BetL	RL@BetL	RL@BellP	RL@LilC
	Name	Laurentian East Creek	Laurentian Creek	Laurentian Creek	Frobisher Creek	Minnow Creek	Lily Creek	Lily Creek	Ramsey Lake @ Laurentian East Creek	Ramsey Lake @ Laurentian Creek	Ramsey Lake @ Frobisher Creek	Ramsey Lake @ Minnow Creek	Bethel Lake	Ramsey Lake @ Bethel Lake	Ramsey Lake @ Bell Park	Ramsey Lake @ Lily Creek
	CABIN Code	RAM04	RAM12	RAM15	RAM07	RAM02	RAM09	RAM01	RAM05	RAM13	RAM08	RAM03	RAM14	RAM06	RAM11	RAM10
Hirudinea	Erpobdellidae	100	0	0	0	3	0	0	0	0	0	20	20	0	0	0
Hirudinea	Glossiphoniidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hirudinea	Hirudinidae	0	0	0	0	0	0	0	0	40	0	0	0	0	40	0
Hirudinea	Piscicolidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligocheata	Enchytraeidae	0	13	24	0	0	20	0	40	0	0	60	0	20	0	0
Oligocheata	Naididae	13	6	24	6	85	140	180	560	0	0	20	0	100	0	0
Oligocheata	Tubificidae	0	6	0	0	150	260	1180	0	0	0	860	0	440	0	0
Oligocheata	Lumbriculidae	0	0	0	0	0	0	0	0	0	180	40	0	100	0	0
Aelosomatida	Aeolosomatidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydracharina	Hydrozetidae	0	0	0	0	0	0	0	20	0	0	20	20	0	20	60
Hydracharina	Malaconothridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydracharina	Trhypochthoniidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydracharina	Arrenuridae	0	0	0	0	0	80	0	0	100	380	0	520	300	20	20
Hydracharina	Aturidae	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0
Hydracharina	Halacaridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydracharina	Hydrachnidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydracharina	Hydrodromidae	0	0	0	0	0	0	0	120	0	0	20	0	0	0	0
Hydracharina	Hydryphantidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydracharina	Hygrobatidae	0	0	0	0	0	0	0	140	680	820	160	0	600	1200	120
Hydracharina	Lebertiidae	0	0	0	6	0	20	0	140	0	20	0	0	20	0	57
Hydracharina	Limnesiidae	19	0	0	0	0	0	0	60	0	0	0	0	0	0	0
Hydracharina	Limnocharidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydracharina	Mideopsidae	6	0	0	0	0	20	0	0	40	20	0	0	0	0	0
Hydracharina	Neoacaridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydracharina	Oxidae	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0
Hydracharina	Pionidae	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0
Hydracharina	Sperchontidae	6	0	6	25	26	0	0	20	0	80	20	0	0	180	290
Hydracharina	Stygothrombidiidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydracharina	Torrenticolidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20
Hydracharina	Unionicolidae	0	0	6	0	0	20	0	0	0	0	0	20	0	0	0
Collembola	Entomobryidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Collembola	Hypogastruridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Collembola	Isotomidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Collembola	Onychiuridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Collembola	Poduridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 12 Benthic invertebrate community data (contn)

Order	Family	Stream							Lake							
	Site code	LauEC	LauC1	LauC2	FroC	MinC	LilC1	LilC2	RL@LauEC	RL@LauC	RL@FroC	RL@MinC	BetL	RL@BetL	RL@BellP	RL@LilC
	Name	Laurentian East Creek	Laurentian Creek	Laurentian Creek	Frobisher Creek	Minnow Creek	Lily Creek	Lily Creek	Ramsey Lake @ Laurentian East Creek	Ramsey Lake @ Laurentian Creek	Ramsey Lake @ Frobisher Creek	Ramsey Lake @ Minnow Creek	Bethel Lake	Ramsey Lake @ Bethel Lake	Ramsey Lake @ Bell Park	Ramsey Lake @ Lily Creek
	CABIN Code	RAM04	RAM12	RAM15	RAM07	RAM02	RAM09	RAM01	RAM05	RAM13	RAM08	RAM03	RAM14	RAM06	RAM11	RAM10
Collembola	Sminthuridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coleoptera	Chrysomelidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coleoptera	Curculionidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coleoptera	Dryopidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coleoptera	Dytiscidae	0	0	12	0	0	0	80	0	20	0	20	0	0	20	0
Coleoptera	Elmidae	0	0	0	0	0	0	2080	0	20	20	0	0	0	0	0
Coleoptera	Gyrinidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coleoptera	Haliplidae	0	0	0	0	0	80	0	0	20	0	20	100	20	60	166
Coleoptera	Hydraenidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coleoptera	Hydrophilidae	0	0	0	0	0	0	0	60	160	0	0	0	0	40	20
Coleoptera	Psephenidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coleoptera	Staphylinidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Athericidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Ceratopogonidae	50	194	141	6	68	80	160	40	1720	220	280	1320	140	200	179
Diptera	Chaoboridae	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0
Diptera	Chironomidae	1288	544	1071	31	235	2280	8140	1700	4780	3640	2620	7040	4320	3040	3387
Diptera	Culicidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Dixidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Dolichopodidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Empididae	213	0	0	0	32	0	60	1100	160	20	100	0	0	40	20
Diptera	Ephydridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Muscidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Psychodidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Ptychopteridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Sarcophagidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Sciomyzidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Simuliidae	6	444	141	1650	0	0	0	0	0	0	0	0	0	0	0
Diptera	Stratiomyidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Tabanidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Tanyderidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Thaumaleidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Tipulidae	0	6	24	0	21	0	0	20	0	0	0	0	0	0	0
Ephemeroptera	Ameletidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ephemeroptera	Baetidae	0	0	0	0	0	760	0	0	0	20	0	0	0	20	20
Ephemeroptera	Baetiscidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 12 Benthic invertebrate community data (contn)

Order	Family	Stream							Lake							
	Site code	LauEC	LauC1	LauC2	FroC	MinC	LilC1	LilC2	RL@LauEC	RL@LauC	RL@FroC	RL@MinC	BetL	RL@BetL	RL@BellP	RL@LilC
	Name	Laurentian East Creek	Laurentian Creek	Laurentian Creek	Frobisher Creek	Minnow Creek	Lily Creek	Lily Creek	Ramsey Lake @ Laurentian East Creek	Ramsey Lake @ Laurentian Creek	Ramsey Lake @ Frobisher Creek	Ramsey Lake @ Minnow Creek	Bethel Lake	Ramsey Lake @ Bethel Lake	Ramsey Lake @ Bell Park	Ramsey Lake @ Lily Creek
	CABIN Code	RAM04	RAM12	RAM15	RAM07	RAM02	RAM09	RAM01	RAM05	RAM13	RAM08	RAM03	RAM14	RAM06	RAM11	RAM10
Ephemeroptera	Caenidae	0	0	6	13	3	2040	700	40	0	20	20	2040	40	0	0
Ephemeroptera	Ephemerellidae	0	0	6	0	0	0	0	0	0	0	0	20	0	0	0
Ephemeroptera	Ephemeridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ephemeroptera	Heptageniidae	0	0	0	0	0	0	0	700	20	60	0	20	0	40	31
Ephemeroptera	Isonychiidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ephemeroptera	Leptohyphidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ephemeroptera	Leptophlebiidae	0	344	6	0	0	0	40	0	20	0	0	20	0	0	0
Ephemeroptera	Metretopodidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ephemeroptera	Siphlonuridae	0	0	0	0	0	0	0	0	0	0	0	200	0	0	0
Hemiptera	Belostomatidae	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0
Hemiptera	Corixidae	0	0	0	0	0	120	260	0	0	0	0	40	0	20	0
Hemiptera	Gerridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemiptera	Hydrometridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemiptera	Nepidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemiptera	Notonectidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemiptera	Pleidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemiptera	Veliidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemiptera	Noctuidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lepidoptera	Pyralidae	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0
Megaloptera	Corydalidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Megaloptera	Sialidae	0	0	0	0	0	0	20	0	0	0	0	0	0	0	20
Neuroptera	Sisyridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odonata	Aeshnidae	0	0	0	0	0	0	0	0	0	0	40	0	0	0	0
Odonata	Calopterygidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odonata	Coenagrionidae	0	0	0	0	0	360	1160	0	60	60	20	600	60	60	66
Odonata	Cordulegastridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odonata	Corduliidae	0	0	0	0	0	0	0	0	0	20	0	0	0	0	20
Odonata	Gomphidae	0	0	0	0	0	0	0	40	160	0	0	0	20	0	6
Odonata	Libellulidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odonata	Macromiidae	0	0	0	0	0	0	0	0	60	0	0	0	0	0	0
Plecoptera	Capniidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plecoptera	Chloroperlidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plecoptera	Leuctridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plecoptera	Nemouridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plecoptera	Perlidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 12 Benthic invertebrate community data (contn)

Order	Family	Stream							Lake							
	Site code	LauEC	LauC1	LauC2	FroC	MinC	LilC1	LilC2	RL@LauEC	RL@LauC	RL@FroC	RL@MinC	BetL	RL@BetL	RL@BellP	RL@LilC
	Name	Laurentian East Creek	Laurentian Creek	Laurentian Creek	Frobisher Creek	Minnow Creek	Lily Creek	Lily Creek	Ramsey Lake @ Laurentian East Creek	Ramsey Lake @ Laurentian Creek	Ramsey Lake @ Frobisher Creek	Ramsey Lake @ Minnow Creek	Bethel Lake	Ramsey Lake @ Bethel Lake	Ramsey Lake @ Bell Park	Ramsey Lake @ Lily Creek
	CABIN Code	RAM04	RAM12	RAM15	RAM07	RAM02	RAM09	RAM01	RAM05	RAM13	RAM08	RAM03	RAM14	RAM06	RAM11	RAM10
Plecoptera	Perlodidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plecoptera	Pteronarcyidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plecoptera	Taeniopterygidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	Brachycentridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	Dipseudopsidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	Glossosomatidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	Goeridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	Helicopsychidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	Hydropsychidae	244	6	6	75	235	0	0	0	0	0	0	0	0	0	0
Trichoptera	Hydroptilidae	6	0	0	13	0	0	20	160	620	220	0	420	20	180	191
Trichoptera	Lepidostomatidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	Leptoceridae	0	0	0	0	3	20	180	400	460	320	240	120	200	1420	204
Trichoptera	Limnephilidae	0	56	100	25	3	0	0	0	0	0	0	0	0	0	0
Trichoptera	Molannidae	0	0	0	0	0	0	0	20	0	0	40	0	0	0	0
Trichoptera	Odontoceridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	Philopotamidae	0	19	6	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	Phryganeidae	6	6	6	0	3	0	40	0	0	120	20	160	40	0	0
Trichoptera	Polycentropodidae	0	31	24	0	0	0	60	180	0	140	20	40	120	20	77
Trichoptera	Psychomyiidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	Rhyacophilidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	Sericostomatidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	Uenoidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda	Crangonyctidae	6	0	0	0	3	40	180	0	0	0	0	0	60	0	0
Amphipoda	Gammaridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda	Hyalellidae	0	6	6	0	0	1900	1040	4580	7420	4900	4220	7720	5500	3360	483
Decapoda	Cambaridae	0	0	0	0	0	0	20	0	0	0	0	0	20	0	0
Isopoda	Asellidae	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0
Hydrida	Hydridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusca	Unionidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusca	Pisidiidae	194	344	76	106	29	40	100	80	20	1940	20	400	700	40	206
Mollusca	Ancylidae	0	0	0	0	0	0	180	0	0	0	0	0	0	0	0
Mollusca	Lymnaeidae	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0
Mollusca	Physidae	0	6	0	19	21	0	20	40	0	40	0	0	20	0	0
Mollusca	Planorbidae	0	0	6	0	35	0	360	20	60	160	0	1020	60	0	20
Mollusca	Valvatidae	0	0	0	0	0	0	0	0	0	0	0	140	0	0	0