FINAL REPORT

PROJECT TITLE: Sustained Changes in Rainy Lake and Namakan Reservoir Benthic Macroinvertebrate Communities in Relation to the 2000 Rule Curve Changes

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Executive Summary

In 2000, the International Joint Commission (IJC) issued an Order prescribing the method of regulating the levels of the boundary waters of Rainy and Namakan lakes, which would be reviewed 15 years after its implementation, and was to include the system's ecology as monitored by natural resource managers. In response to the order, in 2004-2005, a comprehensive assessment using a Before- After Control-Impact (BACI) experimental design was performed in Rainy Lake and Namakan Reservoir to quantify possible changes in littoral zone benthic macroinvertebrate assemblages (McEwen and Butler 2008). The field design was patterned after a study on sites established in Voyageurs National Park by Kraft (1988) and conducted in 1984-1985, results of which served as the "Before" data. Results from the 2004-2005 served as the "After" data and demonstrated changes in macroinvertebrate community structure in Namakan Reservoir ("Impact" sites) relative to Rainy Lake ("Control" sites) at 1-2 meter depths, but not at 3-5 meter depths (McEwen and Butler 2010). Research reported on in this current report gives results on a second "After" study where data were collected during 2012-2013 at the same sites as before to determine if the changes documented in 2004-2005 were sustained over longer time scales and/or now include changes in deeper areas of the littoral zone of Namakan Reservoir. We report effects in 2012-2013 consistent with the changes reported from the early 2004-2005 analysis. In particular, in the shallow depths (1, 2 m), we found sustained significant differences in community structure since the implementation of the 2000 rule-curve. We also found a significant increase in the diversity for Namakan Reservoir's shallow sites relative to Rainy Lake's sites in the 2012-2013 data, which was not detected during the 2004-2005 study. Also for the first time, we saw a significant change in the structure of the benthic community at the deeper depths as determined by ordinated community scores (3-5 m).

There was a shift at these deeper depths in Namakan Reservoir from small bodied detritivores such as chironomids, snails, amphipods, oligocheates, and mayflies of the genus *Caenis* to greater representation of large-bodied animals such as the mayfly *Hexagenia limbata* and alderfly *Sialis* sp. These changes at the deeper depths in Namakan Reservoir, which were not manifest during the 2004-2005 study, are consistent with a macroinvertebrate community that continues to become more similar to Rainy Lake, the control site, which was one of the goals for the implementation of the 2000 rule curve.

In addition to replicating the design used earlier, efforts were made to document the composition and abundance of aquatic insects emerging from the predominant aquatic vegetation beds in each bay and types and relative abundances of macroinvertebrates occurring on submerged wood substrates near areas where benthic samples were collected. These efforts were focused on vegetation and wood in the 1-2 meter depth zones. Composition of insects emerging from vegetation beds was very similar both qualitatively and quantitatively from bay to bay, but some of the existing variability could be partially attributed to differing vegetation and substrate types. Insects emerging from vegetation beds in each bay represented a subset of the more common taxa occurring in transect samples, and no taxa were restricted only to weed beds. Taxa occurring on wood substrates consisted of sprawling and grazing taxa that use wood as a non-specific solid substrate, combined with a smaller number that are known to gouge wood substrates, bore into wood of varying degrees of decomposition, or are xylophagic. Analysis of similarities showed no substantive differences for sites within Rainy Lake and Namakan Reservoir (= within-reservoir similarities) relative to comparisons of sites across the two reservoirs (= across-reservoir similarities) for either emergence from vegetation or on submerged wood substrates, which is consistent with our other results that indicate soft sediment communities of the two systems are also not different.

In sum, there was no evidence that Namakan Reservoir (i.e., “Impact” site) is reverting to its previous macrobenthic community structure as existed under the pre-2000 rule curve, and observed changes in 2012-2013 relative to earlier studies were consistent with the goal of managing water-levels to achieve more naturally structured macroinvertebrate community. In fact, the two systems, Namakan Reservoir and Rainy Lake, continue to become more similar as more time passes from the implementation of the 2000 rule curve. Additionally, quantitative baseline data have been collected for aquatic invertebrates on submerged wood and patterns of emergence from zones of aquatic vegetation, which will be useful for future studies on macroinvertebrate responses to water-level management regimes.

Introduction

Background

Voyageurs National Park (VNP) is a system dominated by six major water bodies that, for management purposes, are split into two different systems: Rainy Lake and “Namakan Reservoir.” The latter system is comprised of five connected water bodies: Namakan, Sand Point, Kabetogama, Crane, and Little Vermilion lakes. Since the early 1900s, water levels in these water bodies have been controlled by regulatory dams at Squirrel and Kettle Falls on Namakan Lake’s northwest end and a hydroelectric dam at the outlet of Rainy Lake (Fig. 1). These lakes all once existed as natural water bodies, but at present, they function as larger reservoirs that are regulated to satisfy a variety of water users. While the dams have always been owned and operated by private industry, these waters are shared by Canada and the United States, with the International Joint Commission (IJC) having regulatory authority. The IJC uses “rule curves” or bands of permitted high- and low-water levels through the year to regulate this system of lakes.

In 2001, the IJC issued an Order prescribing the method of regulating the levels of the boundary waters of Rainy Lake and Namakan Reservoir, consolidating and replacing a number of previous orders and supplementary orders, most recently put into effect in 1970 (International Joint Commission 2001). Rule curves in force from 1970 to 2001 (here-after “1970 Rule-Curve”) allowed larger-than-natural lake-level fluctuations on Namakan Reservoir (2.5 meters) to maintain less-than-natural fluctuations in Rainy Lake (1.1 meters). The timing of water-level fluctuations under the 1970 Rule-Curve differed substantially from what was found in natural lake systems, particularly for Namakan Reservoir, which rose later and stayed higher longer than would have been the case under a natural regime, according to historical modeling (Flug 1986).

In both Rainy Lake and Namakan Reservoir, under the 2000 plan (hereafter “2000 Rule-Curve”), a gradual summer drawdown was initiated instead of holding water stable during the summer; however, this change was much more pronounced in Namakan Reservoir compared to Rainy Lake as both the magnitude of drawdown and timing of spring refill remained essentially unchanged from the 1970 Rule-Curve in Rainy Lake (Fig. 2).

The change in rule-curves in the “Consolidated Order” (effective on February 28, 2001) that replaced the 1970 Order contained the following provision: “*This order shall be subject to review 15 years following adoption of the Commission's Supplementary Order of 5 January 2000, or as otherwise determined by the Commission. The review shall, at a minimum, consider monitoring information collected by natural resource management agencies and others during the interim that may indicate the effect of the changes contained in the Supplementary Order of January 5, 2000*.”

In response to the order, in 2004-2005, a comprehensive assessment using a Before-After Control-Impact (BACI) experimental design was performed in Rainy Lake and Namakan Reservoir to quantify possible changes in littoral zone benthic macroinvertebrate assemblages (McEwen and Butler 2008) associated with the change in rule curves. The field design was patterned after a study by Kraft (1988) conducted in VNP lakes during 1984-1985, results of which served as the “Before” data. Results from the 2004-2005 study served as the “After” data where Rainy Lake was considered the “control” system and Namakan Reservoir the “impact” system. The original justification for choosing Rainy Lake as a control was that *“Kraft was unable to contrast his benthic community data from Namakan lakes with either their pre-impact condition, or with a natural reference site, but instead used Rainy Lake as a reference.”* In short, because Kraft (1988) used Rainy Lake as a reference site, future studies would depend on that legacy to make statistical comparisons. McEwen and Butler (2008) previously acknowledged limitations in using Rainy Lake as a "control" in the strict sense of the term, but justified its applicability to a BACI design where in their technical report they stated that *"Since 2000, the new rule curves have reduced winter drawdown in Namakan from 2.5 to 1.5 meters, and allow the reservoir to be refilled to capacity at the end of May instead of the later part of June; in both Rainy Lake and Namakan Reservoir a gradual summer drawdown was initiated instead of hold(ing) water stable during the summer (Kallemeyn et al. 2003). The magnitude of drawdown and timing of spring refill remained essentially unchanged from the 1970 rule-curve in Rainy Lake. For this reason, the relevant parameters of interest with respect to the change of rule curve in comparing Namakan Reservoir and Rainy Lake are limited to the change in the magnitude of winter drawdown and the timing for when the reservoir is filled to capacity in the spring*." We also note that the appropriateness of using Rainy Lake as a control in this study was acknowledged by the original publication of the technical document (McEwen and Butler 2008) and journal publication in Freshwater Biology (McEwen and Butler 2010) after rounds of rigorous anonymous reviews by peers. Perfect "controls" or studies for that matter do not exist and are especially difficult to implement in environmental research and simple solutions to these problems do not exist.

In any respect, determining the validity of Rainy Lake as a control was outside of the scope of this current work and so was identifying new systems that could potentially serve as a more proper control. The charge for the current research team under their agreed-upon scope of work with the IJC was to *"… make the same contrast with results from McEwen and Butler (2010), again using sites in three areas of Namakan Reservoir versus sites in Rainy Lake, in* *order to test for differences between lakes for temporal changes associated with the altered rule curves."*

The results of the 2004-05 study as reported in McEwen and Butler (2008) and then again in McEwen and Butler (2010) demonstrated changes in macroinvertebrate community structure in Namakan Reservoir ("Impact" sites) relative to Rainy Lake ("Control" sites) at 1 and 2 meter depths, but not at 3-5 meter depths (McEwen and Butler 2010). Benthos of Namakan Reservoir showed lower overall abundance, more larger-bodied taxa, and an increase in non-insect invertebrates relative to 1984-1985. The authors concluded "*Changes in benthic community of Namakan may reflect cooler water in spring and early summer as well as lower resource availability (both autochthonous production and allochthonous in puts) under the new regime*." The authors also state that they "*were able to detect a signal related to change in water-level management despite sampling only (being) the third and fourth year following the implementation of the new rule curve*" at the shallowest depths, and speculated that there may be "*greater community change over time that may possibly extend to deeper depths."* The 2012-2013 study was designed to determine if the changes documented in 2004-2005 were sustained over longer time scales (11 and 12 years) after the implementation of the 2000 Rule-Curve) and/or included changes in deeper areas of the littoral zone of Namakan Reservoir.

In addition to replicating the study of 2004-2005, the IJC acknowledged and requested that future assessments of possible changes related to the modified rule curve should include efforts "*to obtain a more complete picture of the possible effects of the water level changes associated with the 2000 rule curves will require sampling additional habitats since invertebrates exhibit distinct habitat preferences. For the other habitats, however, comparisons of results from Namakan Reservoir and Rainy Lake with those from naturally regulated* *reference lakes will be required to determine if the one-meter reduction in the over-winter drawdown on Namakan Reservoir has resulted in the restoration of a more diverse littoral community*.”

Although funding limitations prevented work on other “reference sites,” after discussion of this request, it was agreed upon by the IJC that standardized assessments of immature aquatic invertebrates on submerged, water-logged wood substrates and emergence of adults from beds of floating and emergent vascular hydrophytes would be included during June and August assessments during both years of the project. Prior to the 2012-2013 study, no data existed regarding the influence of vegetational shifts on composition and aquatic insect emergence in Namakan Reservoir, although Wilcox and Meeker (1992) speculated that the presence of macrophytes should foster higher diversity and abundance of fauna. Samples collected during 2012-13 on these habitats provided a first descriptive look at these invertebrate communities and facilitated development of a set of data that will be used in future inferential studies should rule curves be modified again. All field sampling of wood substrates and emergence from beds of vascular hydrophytes were conducted during the same months and within two-weeks of the benthic sampling. Ferrington and student assistants performed sampling of emerging insects and immature aquatic macroinvertebrates on wood substrates.

The IJC agreed upon four primary objectives in this study, and they are listed verbatim from the scope of work.

Objective 1: Assess change in the benthic fauna of Rainy Lake and three Namakan Reservoir lakes that may be a consequence of the new rule curves. Better understand how the benthic community of these lakes varies with respect to water chemistry, depth, sediment characteristics, macrophytes, and season, in addition to potential effects of differing water-level regimes.

Objective 2: Determine if benthic invertebrate communities at shallow depths (1, 2 m) in Namakan Reservoir have become even more similar to communities in Rainy Lake since McEwen and Butler (2010). While benthic communities at 1 and 2 meters were statistically different between Namakan Reservoir and Rainy Lake before the 2000 rule curve, they were not statistically different after. A result of increased similarity or no difference between the 2004-05 data would indicate a community that continues to homogenize between the two systems. A result of decreased similarity may indicate either large year-to-year variability or a reversion to pre-2000 rule curve conditions and cast doubt on whether the rule curve is effective at constraining the benthic community.

Objective 3: Determine if community changes found by McEwen and Butler (2010) have increased over time at 3, 4, and 5 meter depths. A result of increased similarity between the invertebrate communities of Rainy Lake and Namakan Reservoir sampled during the 2012-2013 effort as compared to the similarity between the invertebrate communities of Rainy Lake and Namakan Reservoir sampled during 1984-85, would indicate a community that has become more homogenous between the two systems (Namakan Reservoir and Rainy Lake). A result of no change or decreased similarity may indicate large year-to-year variability or that invertebrates at 3-5 meter depths are not influenced by water-level management, or that not enough time has accumulated to facilitate changes to the benthic community.

Objective 4: Determine the extent to which changes in community structure may have occurred (a) among aquatic insects emerging from within beds of aquatic vegetation and (b) among aquatic macroinvertebrates associated with wood substrates under the new management regime.

Methods

The study reported on here was conducted during 2012-13 and used the same experimental design employed for the 2004-05 study. We were charged by the IJC to "…*repeat the McEwen and Butler (2010) study, following the study design and methods in nearly all details*". Adherence to the design of that earlier study provided a previously vetted set of methodologies (McEwen and Butler 2008; McEwen and Butler 2010) and provided the most statistical power to demonstrate continued and/or more pronounced effects of the 2000 rule-curve change on benthic community structure in Namakan Reservoir that were unique relative to Rainy Lake. Consequently, the same research team leaders cooperated in field work, laboratory sample processing, specimen identification and quantification, data analysis, and interpretation of results. Each team leader supervised the same tasks as previously and, to the extents practical, performed their respective tasks independently.

In addition to replicating the study of 2004-2005, we sampled water-logged wood substrates and trapped adults emerging from beds of submerged, floating, and emergent vascular hydrophytes during June and August in both 2012 and 2013. The IJC acknowledged that *"to obtain a more complete picture of the possible effects of the water level changes associated with the 2000 rule curves will require sampling additional habitats since invertebrates exhibit distinct habitat preferences."* Results from emergence trapping and wood substrates in Namakan Reservoir and Rainy Lake were to be compared to existing literature on other regulated reference lakes of similar water quality, size and depth to describe how the change in approach to regulating water in Namakan Reservoir may be structuring the littoral community. In addition, with this sampling approach, we would obtain a data set that could serve as a basis for quantifying the extent to which changes in community structure may occur if vegetation continues to be modified in the 1.25-2.0 meter depth zone in the future. This is especially important as a recent study of aquatic vegetation patterns in lakes of VNP showed measurable changes in composition at 1.25-2.0 meter depths (Meeker and Harris 2011).These authors present strong arguments that the vegetational changes can also be expected have a significant impact on macroinvertebrate community structure and dynamics.

Field Methods

Objectives 1-3

We sampled in five locations--- two bays in Rainy Lake and one in each of the Namakan Reservoir lakes (Kabetogama, Namakan, and Sand Point). These locations were well-documented in Kraft (1988) and McEwen and Butler (2010). We used the same timing for field sampling as used by McEwen and Butler (2010). A comparison of sampling is shown below.

Kraft (1988)	Jun-83	Aug-84	Jun-85	Aug-85
McEwen and Butler (2010)	Jun-04	Aug-04	Jun-05	Aug-05
Ferrington and McEwen (Current Study)	Jun-12	Aug-12	Jun-13	Aug-13

Kraft (1988) and McEwen and Butler (2010) sampled each site at five depths (1-5m) whenever possible. Sampling sites were located as close as possible to the prior site locations using maps and GPS coordinates collected in June 2004 (McEwen and Butler 2008). McEwen and student assistants performed four rounds of field sample during (1) 8-10 June 2012, (2) 20-22 August 2012, (3) 10-12 June 2013, and (4) 13-15 August 2013 of invertebrates at these sites. During the first field sampling effort (June 2012), the GPS receiver we used malfunctioned, and subsequently, we needed to rely on maps and prior knowledge to locate sites. Later, we determined that we misidentified where sampling sites were located within both Black Bay (Rainy Lake) and Junction Bay (Namakan). Samples taken during June 2012 were from different locations than those taken in August 2012 and June/August 2013. We assumed that because samples were selected in the same bay that these data were exchangeable even though at different coordinates.

As was done in earlier studies, we collected three replicate samples from soft sediments at each depth with an Ekman grab, and live-washed contents through a 0.59 mm mesh. Washed samples were initially preserved in 5% formalin and then switched to 70% ethanol until processed by Ferrington's lab at the University of Minnesota. We collected an additional sample at each site/depth for analysis of sediment characteristics (organic content, sediment particle size, and water saturation potential). Further, for each sample taken at 1-2 meter depths, we assessed the occurrence, composition, and abundance of macrophytes (no macrophytes have been observed in the 3-5 meter depths at any sites). Macrophytes were sampled in a standard semi-quantitative manner that has been used for shallow lake monitoring by the MN Department of Natural Resources for decades (Jessen and Lound 1962). Samples were collected with a weighted plant rake along four 90-degree compass directions from an anchored boat. Each macrophyte was identified in the field to the lowest practicable taxonomic unit and was given one point for its occurrence in each of the four rake samples. A fifth point was scored if a taxonomic unit was highly abundant in all four rake samples. For each site, we scored for taxon richness, which was the total number of taxonomic units identified at the site, and average rake abundance, which we scored as the sum of the total points divided by taxon richness for the same site. Sediment organic content was determined using a loss-on-ignition protocol where sediment samples were dried and then burned at 550 °C for four hours. The difference between the pre-burn and post-burn dry mass was attributed to combusted organic content. The inorganic sediments that remained were saturated with water for 24 hours. Supernatant water that was not absorbed by the sediments was removed with a pipette, and the saturated inorganic sediments were weighed. The difference between post-burn dry mass and post-burn wet mass was used to derive a percent saturation value. We determined average sediment particle size using chemical and physical separation procedures (Kettler and Gilbert 2001). Additional data were collected, including the distance of each site from the nearest shore and the slope at each site, using the on-site depth measurements and distance to shore (i.e., slope = depth/distance to shore). Readers should consult McEwen and Butler (2008) for more details.

Objective 4

One week after each of the benthic sampling events by McEwen, Ferrington performed sampling of immature aquatic invertebrates on submerged or water-logged wood substrates and emergence of adults from beds of submerged, floating, and emergent vascular hydrophytes in locations located at less than one kilometer away from the transect. Samples of emerging insects and macroinvertebrates on wood substrates were collected 19-22 June 2012, 15-19 August 2012, 13-16 June 2013, and 17-20 August 2013. At all sample sites, the collections of submerged wood substrates were completed after collection of emerging insects was completed.

Emerging insects were sampled using floating emergence traps. All the collections from vegetation using emergence traps were taken in areas where the water depth did not exceed two meters. The trap design consisted of six inverted funnels attached to a floating wood frame. Each funnel was 15 cm in diameter and funneled emerging insects into a removable collection jar.

Traps were staked in place in each bay over the predominant vegetation types at water depths greater than one meter but less than two meters closest to areas where the benthic transects were located. Traps remained in place for two days at each site on each sample date, and then samples were retrieved. Insects trapped in the jar were field-preserved with 80% ethanol and returned to lab for counting and identification. At each site, emergence trapping was completed before wood substrates were sampled.

Wood substrates were sampled at each sample site from water depths up to 1.5 meters. Wood was located, and a sample jar placed over the end of the piece of wood, which was carefully removed and sawed into sections of 12-15 cm lengths. Water was decanted through a sieve to retain detached specimens, and 80% ethanol was added as preservative. Wood was sampled from areas close to the places where emergence trap and benthic samples were taken for each site. Wood was difficult to locate at Black Bay, where small, recently-downed branches were the primary type of wood sampled. At Moxie and Sand Point, most of the wood that was sampled was from active or recently abandoned beaver lodges and had been stripped of bark. At the other two sites, older and partially decomposed wood was common, and some samples were taken of wood in differing degrees of decomposition.

In the lab, each sample of wood was carefully observed under 6X magnification, and macroinvertebrates were removed for identification and counting. Sections of wood with bark on them were stripped of the bark, and stripped wood was inspected for xylophagic larvae of Diptera that bore into wood. Softer (partially) decomposed wood samples were broken apart and checked for boring larvae.

To gather evidence of how the macroinvertebrates were using the submerged wood substrate (e.g., as a physical substrate and grazing periphyton versus gouging wood or burrowing into the wood by masticating the tissues), up to a total of five specimens of each taxon were dissected, and the functional feeding status was determined based on gut contents classified into (1) primarily periphyton (= grazer), (2) at least some visible wood particles in the gut (shredder), (3) observed in burrows or gouging into wood (= xylophage), or (4) remains of invertebrate prey (= predator)

Laboratory Processing Methods

Objectives 1-3

All benthic samples were preprocessed in McEwen's laboratory at Minnesota State University Moorhead before being sent for identification to Ferrington's laboratory at the University of Minnesota. At the McEwen lab, formalin was drained from the samples though a 0.59 mm or finer sieve. Flotation in 80% saturated sucrose solution (Anderson 1959) was used to separate the majority of specimens from the sample residue. Residue was examined visually in white plastic sorting trays for any specimens that failed to float. The samples were scanned for removal with fine-tipped forceps of all macroinvertebrate organisms that were visible without magnification. This included immatures of Odonata, adults of most Coleoptera, immatures of most Coleoptera, all Hemiptera (including Pleidae and small Corixidae), all Ephemeroptera, Trichoptera, Diptera, Megaloptera, and annelids. All specimens from a single grab sample were placed into one vial along with 70% ethanol and transferred to the University of Minnesota.

At the Ferrington lab, specimens were transferred to separate vials according to order or family and stored in 70% ethanol. Identification with finer resolution was accomplished by removing specimens from the vials and placing them into Syracuse dishes (when specimens were small) or petri dishes (when specimens were larger) for sorting. Each organism was identified to genus using the appropriate identification guide. If it was obvious that two or more species were present, they were sorted and identified or, when identification was not practical, were given a numerical code. Each identified taxon was stored in 70% ethanol in a new vial with a label to include: locality, identification including family, genus and species (when practical), the name of the person performing the identification, and the date of the identification. Counts were made of each taxon, and records were archived for back-up and later analysis. Voucher specimens were also preserved for each taxon that had been identified from this location for the first time.

Taxonomic identification and specimen curation in Ferrington's lab followed standard operating procedures that were spelled out in detailed documents that all laboratory personnel were required to read and sign. This ensured that all samples and specimens were processed in a consistent manner. A voucher collection was prepared and comparisons made to archived specimens retained by VNP from the earlier studies. In many cases, we identified specimens to the same degree of taxonomic resolution as McEwen and Butler (2010), but with a higher degree of taxonomic resolution than Kraft (1988). When necessary, the more finely resolved taxonomy was reduced to the same taxonomy as the data used in the earlier BACI analyses. The higher resolution data from emergence traps of adults from the vascular hydrophyte beds were used to generate biodiversity information from the wood substrates and the site in Rainy Lake for contemporary comparisons between the two water bodies and for comparison with other data in similar systems. No sample processing for data collected as part of Objective 4 was done at the McEwen laboratory but was done exclusively at the Ferrington laboratory.

Quantitative & Statistical Methods

General

We applied statistical analyses to test for significant change in benthic invertebrate density, diversity, and community structure and drew inferences about the relationship of any differences detected between locations over time. Under our scope of work provided by the IJC we were charged to "*…apply statistical analyses to test for statistically significant change in benthic invertebrate density of abundant taxa, diversity and community structure, and draw inferences about the cause of any differences detected between locations and over time*."
Our statistical analyses followed very closely those found in McEwen and Butler (2010).

Univariate statistical tests were applied to overall density, species richness, Simpson's diversity, and Pielou's evenness. Mixed linear models were used, extending the BACI experimental design to more than one "After" period, while also taking into account measured environmental factors as covariates (i.e., year, month, bay, macrophyte diversity, macrophyte site occupancy, slope, distance from shore, sediment organic content, and depth). We used the covariates in the model to control for these variables that might have an influence on our measured output and subsequently reduce our power to detect the BACI effect, which was of primary interest. To choose the appropriate number of covariates, we began with an additive global model that included all covariates and used Akaike model selection with small sample size correction (AICc) to choose the nested model that was most parsimonious. Only additive combinations of environmental covariates were considered. We relied on the R package `glmulti,` which iteratively used an exhaustive screening algorithm to find the most parsimonious combination of variables to explain responses. Treatment effects of interest were (A) "period" as a random factor with three levels: (1) B=1984-85, (2) A1=2004-05, and (3)

A2=2012-13, and (B) “system” with respect to drawdown regime as a fixed factor, having two levels: (1) Rainy Lake as a control and Namakan Reservoir as the impact system. We determined the 2000 Rule-Curve to have a positive ecological effect if two conditions were met: (1) there was an interaction between A and B and (2) that interaction was such that the two systems (i.e., Rainy Lake and Namakan Reservoir) have become more similar to one another in the response of interest. As agreed upon with the IJC, our assumption was that Rainy Lake operated under a more natural water-level fluctuation regime than did Namakan Reservoir under the 1970 Rule-Curve. Given Namakan Reservoir had its water-level fluctuation regime changed to match more closely that in Rainy Lake under the 2000 Rule-Curve, a general homogenization was expected between faunal characteristics in Rainy Lake and Namakan Reservoir.

This same modeling approach was used for multivariate response measures, which allowed us to assess impacts on the entire community at once. Community-level data from complex natural systems are sometimes difficult to evaluate rigorously with traditional statistical tests due to large numbers of response variables (i.e., species) and complex interactions among response variables (ter Braak 1994). Constrained ordination (distance-based redundancy analysis = dbRDA; Legendre and Anderson 1999) was used to test multivariate hypotheses using the same model structure for predictor variables as used for our univariate analysis. The db-RDA determines *F* statistics and subsequent *p*-values using a permutation procedure, which can be specified as “free”, where all elements in the species response matrix are freely exchanged, or “restricted” under specified conditions. We restricted permutations to be exchanged only within sampling periods (Month-Year), which is more conservative than freely exchanging sites but takes into account better the potential additional variability associated with the time variable.

We used Nonmetric Multidimensional Scaling (NMDS) as an indirect gradient analysis method to visualize resulting changes in community structure.

In our approach, we made multiple comparisons (testing multiple taxa for response), and when doing multiple tests, the risk of making Type I errors (e.g., concluding there is a BACI effect when one really has not occurred) becomes inflated. Many researchers advocate using some type of correction for doing multiple tests to control for this experiment-wise error rate, but this is not without controversy (e.g., Moran 2003, Nakagawa 2004). While using an experiment-wise correction does reduce the chance of making Type I errors, it inflates the chance of making a Type II error (e.g., concluding there is no BACI effect when one really has occurred). Here, we take the approach of reporting raw *p*-values and indicate tests that would still be significant after a correction after using a sequential Bonferroni correction by using the asterisk (*) and allow the reader to draw conclusions (Holm 1979). Raw data were transformed as needed to meet assumptions associated with the specific tests used.

We also report general descriptive summaries for the macroinvertebrate communities to provide readers with extra information, but we warn that any pattern not supported with a statistical analyses should be interpreted with caution. We sampled only a small fraction of the benthic communities in these systems, and while we hope these samples are representative of the larger population of potential samples, we really cannot suppose that our sample estimates indicate anything about the larger population without statistical support. Statistical support provides evidence that patterns we see related to the rule-curve change are something other than random patterns that result from our sampling design. We also do not provide inferential statistical output for the emergence trap or the wood substrate collections because there were no similar data collected for these habitats under the 1970 Rule-Curve. Following provides additional methods that are specific for each of the four objectives.

Objective 1

Variance partitioning was accomplished using scores from a db-RDA and then separately for the univariate measures of density, species richness, Peilou's evenness, and Simpson's diversity index on two separate data sets. The first data set, which we named "Long term" was the full complement of species as initially defined by Kraft (1988), which included the set of 55 taxonomic units (Table 1) that were used in the 2004-05 BACI analysis and then again in the current analysis (see Objectives 2 and 3). Even though in 2004-05 and then again in 2012-13, we identified animals to a finer taxonomic resolution, we aggregated our taxonomic list, which included 184 taxonomic units to match Kraft's (1988) to make them comparable. In the 2012-2013 samples, we found many taxa that had not been previously accounted for in any of the VNP lakes (Table 2). To use the more finely taxonomically resolved data, we performed a second variance partitioning with db-RDA on the 184 taxonomic units identified in the 2012-13 data, a data set we distinguish as "Short Term" given that it is comprised only of the two most recent years of activity. While we had finely resolved taxonomy also for the 2004-2005 data collection, we did not have exactly comparable environmental data, and therefore, we left them out. The variance partitioning model for both the Long- and Short- Term data sets included, as predictors, sediment characteristics (average particle size, percent organic matter as determined by loss-on-ignition, percent water saturation potential), macrophyte characteristics (number of different species present, average point value for species present from the plant rakes), location effects (distance to the nearest shore, bottom slope, bay, lake, depth), and time effects (year and month).

For the 55 taxonomic unit analysis, we also included a BACI term to determine the proportion of variance explained by that interaction relative to the rest of the variables. We considered sample units to be sites, which were location- and time-specific (e.g., Site 1 was the one meter depth in Black Bay during June 2012). Univariate summaries were made of these sites for taxon richness (i.e., total number of taxonomic units per site), density (i.e., number of total animals per square meter), evenness (i.e., Peliou's evenness = $H'/\ln(S)$ where $H'=\Sigma(p_i\ln[p_i])$ such that p_i is the proportion of the i^{th} species and S is the species richness), and Simpson's diversity index (i.e., $1-\Sigma(p_i^2)$).

We performed an ANOVA and partitioned variance using the sum of the squared errors (SSE) from the output for each term, respectively. The amount of unexplained variance remaining after including all of the terms of our model could be extracted by using the residual SSE from the output. We first divided the total variance into an "explained" and "unexplained" proportion and represented these differences as a pie-chart. We then built plots showing the proportion of the explained variance ("constrained variance") that could be attributed to each of the terms in our model as a cumulative line plot.

Objective 2

We extracted from our data matrix of site-by-taxa and site-by-environmental variables only sites that were located at 1 and 2 meter depths. Prior to testing for the effect of a treatment (BACI), we built a covariate model to account for potential confounding environmental variables influencing our response of interest (i.e., the BACI effect). A global model was used and all possible additive combinations of covariates were subjected to an AICc analysis to choose the most parsimonious model of the group. The selected covariates were then used in a model designed to test for the BACI effect. The global model we built used year as a random factor (Year), month as a fixed factor (Month), bay as a random factor (Bay), macrophyte abundance as the sum of points for all macrophtyes collected at sites (MacAbund), macrophtye diversity as the number of macrophyte taxonomic units collected at sites (MacDiv), slope at the site (Slope), the distance to the nearest shore from the site (dShore), the organic content of the sediment determined using loss-on-ignition method (Organic), and depth as a fixed factor (Depth). The full model then was

$$Y \sim Year+Month+Bay+MacAbund+MacDiv+Slope+dShore+Organic+Depth$$

where Y was one of our one of four univariate responses including taxon richness, abundance, evenness, and Simpson's diversity index or the community-derived Principle Coordinate Analysis (PcoA) scores used as an input for the db-RDA for multivariate responses. Once the covariates were selected, we built a model to account for them while simultaneously testing the response of interest, which was a BA × CI effect where BA was a factor with three levels, which we symbolize as B, A1, and A2 such that

B = "Before" data (1984-1985)

A1 = First set of "after" data (2004-2005)

A2 = Second set of "after" data (2012-2013)

The CI term in the model assigned Rainy Lake sites as the control (C) and Namakan Lake sites as the impact (I) sites. The full model then would be given as

$$Y \sim BA+CI+(BA\times CI)+\text{Error(Covariates)}$$

If the term $BA\times CI$ was significant, we concluded there was an impact on the macroinvertebrate responses associated with the implementation of the 2000 rule curve change; however, this test does not give information on which combinations of time-systems were different. Subsequently, for any significant *BA*×*CI* effect, we used a post-hoc analysis comparing the BACI response between B vs. Al, B. vs. A2, and Al vs. A2. The post-hoc analysis including additional statistical tests and graphical displays of data to observe effect sizes.

Objective 3

We extracted from our data matrix of site-by-taxa and site-by-environmental variables only sites that were located at 3-5 meter depths. As before, sites were location- and time-specific (e.g., Site 1 was the three meter depth in Black Bay during June 2012). Univariate summaries were made in the same way as they were for the shallow depths for species richness, density, evenness (i.e., Peliou's evenness, species richness, and Simpson's diversity index). Again, prior to testing for the effect of a treatment (BACI), we built a covariate model to include account for confounding environmental variables influencing our response of interest (i.e., the BACI effect). A global model was used and all possible additive combinations of covariates were subjected to an AICc analysis to choose the most parsimonious model of the group. The selected covariates were then used in a model designed to test for the BACI effect. The global covariate model was the same as for the shallow depths except that it did not include terms for macrophytes, given that we never observed them at depths of 3-5 meters at our sites (see Objective 2).

Objective 4

No comprehensive quantitative data for aquatic insects emerging from shallow littoral areas of VNP existed prior to this project. Similarly, no historical data were available for composition and abundance of aquatic invertebrates on submerged wood substrates. Therefore, the results for Objective 4 will serve as estimates of variability of emergence from shallow-water vegetation zones and of the importance of submerged wood as substrates for aquatic invertebrates under the present rule curve conditions. These data also will provide a basis for comparisons into the future.

Identification of specimens collected from benthic transects was limited to genus level, except for selected groups where only family or order level could be consistently achieved. Genus-level identifications were consistently achieved for immature stages of all aquatic insects on submerged wood substrates. Consequently, to compare results of emergence and utilization of submerged wood substrates to results of transect samples, we used genus level identifications of all taxa collected in emergence traps and from submerged wood substrates.

We report the results for Objective 4 at the following spatial and temporal scales to provide detailed views of insect emergence and use of submerged wood substrates: (1) summarized across all bays and all sample dates, (2) all bays 2012 versus 2013, (3) June versus August sample dates across both years, (4) by individual bays comparing 2012 versus 2013, and (5) among bays based on results for both 2012 and 2013. Data summaries are reported for each bay in appendix tables, arranged by estimated emergence density/square meter/day.

We summarized results based on both composition and estimated abundance. Similarity of emergence using compositional data was quantified using Jaccard’s Coefficient of Similarity (=JAC), and similarities using estimated abundance were calculated with Whittaker’s Percentage Similarity Index (=WPS). These two approaches provide complementary views of similarity that are considered to be qualitative (JAC) and quantitative (WPS).

The JAC is calculated as

$$\mathrm{JAC} = a/a+b+c$$

where a = number of taxa shared by the two units being compared (e.g., years, months, or bays), b= number of taxa in the first of the two units compared but absent from the second unit, and c= number of taxa in the second of the two units but absent from the first unit.

The WPS is calculated as

$$\text{WPS}= \Sigma \min [\, p_{iJ} \text{ or } p_{iK} \,]$$

where n_{iJ} is the number of specimens of species i in sample J, n_{iK} is the number of specimens of the same species i but in sample K, N is the total number of specimens in the respective sample J or K, $p_{iJ} = n_{iJ}/N_J$ and $p_{iK} = n_{iK}$.

These two similarity coefficients can vary between 0.0 (no overlap) to 1.0 (complete overlap) and were multiplied by 100 to convert the coefficient to a percentage similarity measure, which we reported in this document. The values were used to assess for bay-to-bay similarities as a function of the two different reservoirs. Similarities among sites in different bays were used as contrast for within bay similarities. This approach is not robust for our sample design because only one within-reservoir comparison of bays can be calculated for Rainy Lake. However, three within-reservoir comparisons can be calculated and averaged for bays located in Namakan Reservoir. The two sets of within-reservoir bay comparisons can also be averaged to compare with the similarities of bays that are located within the two different reservoirs (= cross-reservoir comparisons). A difference in composition and/or abundances related to differing reservoir management should appear as lower average similarity of cross-reservoir bay-to-bay comparisons when compared to the within-reservoir average similarities. See Van Sickle (1997) for more detail on this approach.

Results and Discussion

Objective 1: Assess change in the benthic fauna of Rainy Lake and three Namakan Reservoir lakes that may be a consequence of the new rule curves. Better understand how the benthic community of these lakes varies with respect to water chemistry, depth, sediment characteristics, macrophytes, and season, in addition to potential efforts of differing water- level regimes.

Sediment characteristics (average particle size, percent organic matter as determined by loss-on-ignition, percent water saturation potential), macrophyte characteristics (number of different species present, average point value for species present from the plant rakes), location effects (distance to the nearest shore, bottom slope, bay, lake, depth), and time effects (year and month) collectively explained 25-50% of the total variability in our response variables (Fig. 3). We refer to this “explained variance” as the constrained variance and found that for the Long-Term dataset, the BACI term accounted for 5.4% of the constrained variance. This means that even in the midst of all the potential factors that influence the structure of the macroinvertebrate community, the influence from the rule-curve regime registers as being important. The average proportion of variance explained from most-to-least can be ranked as *Year* > *Macrophyte Density* > *Bay* > *System* (*Rainy* or *Namakan*) > *Rule Curve* (*1970* vs. *2000*) > *Sediment Particle Size* > *Depth* > *Sediment Organic Content* > *Month* > *Distance from the Shore* > *Macrophyte Diversity* > *Sediment water holding potential* > *Slope* . Of these terms, macrophyte density may be the most likely to respond to water-level regulation. For the more recent (Short-Term) dataset, the ranking for explained variance was *Macrophyte Diversity* > *Bay* > *System* (*Rainy* or *Namakan*) > *Month* > *Depth* > *Sediment Organic Content* > *Slope* > *Year* > *Macrophyte Density* > *Sediment*

Particle Size > *Distance from the Shore* > *Sediment water holding potential* . Interestingly, both macrophyte measurements made up a large part of the constrained variance, but it was the *density* of macrophytes in the Long-Term data set, while it was the *diversity* of macrophytes in the Short-Term data set. From both of the Short-Term and Long-Term perspectives, factors that can be influenced by water- level regulation are limited to macrophyte and sediment characteristics, and of these, it appears that macrophytes are a more important influence on measures of benthic invertebrate communities. These results further support the importance of knowing how macroinvertebrates are associated with macrophytes (see Objective 4). While explaining 25-50% of the total variance in any measure is low if the goal is to explain 100% of the variability, this amount of variance is relatively high when compared to typical amounts of variance explained in ecological studies, which tend to fall within the range of 2 – 7% (Moller and Jennions 2002). Variables that we did not measure that likely account for much of the unexplained variance include species-species interaction (e.g., predation pressure by fishes) and both demographic and environmental stochasticity, all of which are inherently a part of structuring ecological communities.

Objective 2: Determine if benthic invertebrate communities at shallow depths (1, 2 m) in Namakan Reservoir have become even more similar to communities in Rainy Lake since McEwen and Butler (2010). While benthic communities at 1 and 2 meters were statistically different between Namakan Reservoir and Rainy Lake before the 2000 rule curve, they were not statistically different after. A result of increased similarity or no difference between 2004-05 data and the proposed data would indicate a community that continues to homogenize between the two systems. A result of decreased similarity may indicate either large year to year variability or a reversion to pre 2000 rule curve conditions and cast doubt on whether the rule curve is effective on constraining the benthic community.

Univariate Community Structure

For our four univariate measures, including taxon richness, density, evenness, and diversity, the most parsimonious covariate models were as follows:

1. *Taxon richness ~ Year + Month + Macrophyte Abundance + Depth*
2. Ln(*Density*) ~ *Year + Bay*
3. *Pielou's evenness ~ Bay*
4. *Simpson's diversity ~ Bay*

This indicates that if we take the system as a whole (i.e., Rainy Lake and Namkan Reservoir together) Pielou's evenness and Simpson's diversity are different from bay-to-bay but not necessarily over time at the scale of month or year. We also conclude that these measurements are not responsive to macrophytes. The same could be said about the density of organisms in the shallow littoral habitats, with the exception that there is a year-to-year effect. For taxon richness, there also was background year-to-year variability that was important but so was month, macrophyte abundance, and depth. There were slightly more TUs found in samples taken in August relative to June, at high macrophyte abundances, and at the 1-m relative to the 2-m depths.

After controlling for these covariates, we found no evidence to suggest a BACI effect on taxon richness ($F_{2,110}$=0.07, p=0.930), the natural log abundance ($F_{2,110}$=0.14, p=0.870), or evenness, although evenness had a significance level near the $\alpha = 0.05$ threshold ($F_{2,111}$=2.98, p=0.055). A post-hoc test was performed on B vs. A1, B. vs. A2, and A1 vs. A2. We found no BACI impact on B vs. A1 ($F_{1,73}$=0.16, p=0.690), but both B vs. A2 ($F_{1,73}$=5.57, p=0.021) and A1 vs. A2 ($F_{1,73}$=6.82, p=0.011) did have a BACI impact. We consider this to be evidence that there has been a lagged effect on species richness for Namakan only manifest in the recent rather than earlier data.

We did find that Simpson's diversity index did have a significant BACI signal (Fig. 4), suggesting that this measure has been affected by the change in the rule curve over time ($F_{2,111}$=3.78, p=0.026). Simpson's diversity is a measurement that takes into account both species richness and evenness at the same time. It can be interpreted as the probability that a random selection of two individuals from a community is comprised of two different species. This probability depends both on how many different species there are in a community and on how evenly those species are distributed. If in a community the *abundance* of rare species is low even if there are a high number of species, Simpson's diversity penalizes. The probability of getting different species only increases when all species increase to have an equal distribution to one another. Communities that have higher diversity measures tend to function at a higher level in provisions of ecological services.

In samples collected under the 1970 Rule-Curve, Simpson's diversity was higher on average for Rainy Lake sites compared with Namakan Lakes. Since the implementation of the 2000 Rule-Curve, the average Simpson's diversity has become more similar between Rainy Lake and Namakan Reservoir. In fact, in 2013, Namakan had a Simpson's diversity higher than Rainy for the first time in our time series. We consider this consistent with the new rule curve having a positive effect in bringing the two communities in Namakan and Rainy to be more similar. There was a significant BACI effect on the community structure in the shallow depths associated with the implementation of the 2000 rule curve ($F_{2,106}$=1.300, p=0.007) . A post-hoc analysis indicated that the differences were manifest between B and A1 ($F_{1,69}$=1.770, p=0.001*). There was no difference in community structure between the 2004-05 and 2012-13 data sets ($F_{1,69}$=0.960, p=0.470). While there was not a significant difference between B and A2 ($F_{1,69}$=1.270, p=0.060), the p-value was low enough to suspect a significant result would occur if more samples would have been collected. The NMDS analysis and subsequent plot shows that Namakan Reservoir and Rainy Lake communities have progressively become more similar since the 2000 rule curve went into effect (Fig. 5). This figure also shows that communities for both Rainy Lake and Namakan Reservoir showed change not related to the rule curve. The strength of the BACI design is that these changes that are unassociated with the rule curve are captured by the control system (i.e., Rainy Lake) and effectively accounted for. What is important in the ordination plot is not just the time effect (the movement of parallel lines on the plot) but the interaction between time and system. We were most interested in how the distance between the control and impact sites change over time.

While whole community responses are complex, a few patterns were suggested by the ordinary. The ordination suggested that Rainy Lake has been more characterized by large-bodied carnivores and has more insects relative to noninsects over all time periods. The genera *Sialis* and *Hexagenia* have historically been found in the shallows of Rainy Lake more so than Namakan Reservoir sites. On the other hand, the Namakan Reservoir sites have been characterized by more amphipods and chironomids. As these systems have continued to become more similar to one another, there has been a gradual replacement of amphipods and chironomids by larger-bodied animals such as *Sialis* and *Hexagenia*. In a disturbance context, smaller animals like amphipods and chironomids, which can often have multiple generations within a year, are more resilient to high levels of stress brought on by extreme water-level fluctuation, as occurred at Namakan Reservoir prior to the 2000 rule-curve implementation. Larger bodied insects, which have one or even two year life cycles may not be able to recover under such conditions, and therefore, may have been at a disadvantage under the prior rule curve. These factors follow basic *r*- and *K*-selection theory from ecology (Chiu and Kuo 2012).

Descriptive Summaries

Over all sampling periods 44,797 individual animals were collected in 360 grab samples at the 1 and 2 meter depths, resulting in an average catch per unit effort (CPUE) of 125 animals (range = 6-871 individuals) per grab in the shallow littoral zone sites. We found that density was highly skewed, yielding a median CPUE of 80 individuals per grab (Fig. 6).

In the shallow water littoral sites, individuals were represented by 55 unique taxonomic units (TUs). On a per grab basis, this equated to approximately 12 TUs on average (Range: 3-22 TUs) with a distribution that appeared Normal (Fig. 7). Of the 55 TUs collected in the shallow littoral soft sediment habitats, 11 were represented by a single individual. These communities were dominated by chironomids (41%), amphipods (21%), fingernail clams (8%), oligochaetes

(7%) and snails (5%). Together these five TUs represent 82% of all individuals collected in these habitats. All other TUs had relative densities of less than 5% of the total catch.

Following is a description of the response of each of these abundant taxa in terms of their relative abundance and site occupancy over time and system. By relative abundance, we mean the proportion of individuals in an average grab sample that belong to a taxonomic unit, and by site occupancy, we mean the proportion of all grab samples in which at least one individual of a taxonomic unit is present.

Chironomidae

Chironomids (Order Diptera, Family Chironomidae) are a dominant freshwater aquatic insect group commonly known as “midges” or “lake flies.” Of the 120 samples (three grabs pooled per site-time) collected over the entire course of the study from 1984 through 2013, there was 100% occupancy at sites for chironomids, meaning there was at least once individual chironomid larva in every single grab made over the course of the study. The number of individuals ranged from 11 to 9,960 larvae (Mean = 1,914, SD=2,059) m^2. On average, approximately 40% (SD=8%) of all individuals in an average grab sample from the shallow depths were chironomids. Namakan Reservoir had higher relative abundances of chironomids compared to Rainy Lake for the 1984-85 and 2004-05 period but not for the 2012-13 period. If chironomids are indicative of stressed systems because they are good colonizers, able to adapt a generalist strategy in exploiting resources, then whatever factor caused separation under the 1984-85 sampling regime is apparently being mitigated. For the first time in our samples, we find Rainy Lake to feature chironomids in a higher relative abundance than Namakan Reservoir, where relative densities have remained rather stable over the sampling periods (Fig. 8).

While Kraft (1988) did not identify chironomids to the genus-level for the majority of his samples, he did for a subset of samples collected at various depths in Moxie and Harrison Bays, finding shallow water fauna dominated by *Tanytarsus* sp. (13%) and *Procladius* sp. (11%). Other important genera, which together accounted for the top 50% of all chironomids collected in the shallow littoral sites, included *Polypedilum* sp. (10%), *Cladotanytarsus* sp., and *Pseudochironomus* sp. (10%). In both 2004-05 and 2012-13, chironomids were identified to genera in all samples, and we found a similar result to Kraft (1988), with the top two most abundant genera being *Procladius* sp. (20%) and *Tanytarsus* sp. (15%). We did find a slightly different group rounding out the top 50% of individuals, which included *Pseudochironomus* sp. (9%) and *Dicrotendipes* sp. (8%) in the 2004-05 samples and only *Pseudochironomus* sp. (16%) in the 2012-13 samples. We suggest that the shallow water chironomid communities are dominated by the three genera *Procladius* sp., *Pseudochironomus* sp., and *Tanytarsus* sp. and that these genera are becoming homogenized in terms of relative abundance and site occupancy between Rainy Lake and Namakan as time passes from the implementation of the 2000 Rule-Curve.

Amphipoda

Amphipods were the second most abundant group of animals in the shallow littoral soft sediments, representing on average 21% of all animals collected. They were particularly abundant at Moxie Bay in Namakan Reservoir and Black Bay in Rainy Lake. While the median number of amphipods collected in the shallow littoral zone was 43 individuals m^{-2}, based on a sample collected at the 1-m depth at Moxie Bay in August 1984, we estimated 20,566 individuals m^{-2} present. While numbers would never be found this high under the 2000 Rule-

Curve, amphipods were still abundant at the shallow Moxie sites where we found 7,206 individuals m^{-2} in August 2012 and 5,710 individuals m^{-2} in August 2013. The most abundant reported amphipods in Rainy Lake were from Black Bay 1-m depth during August 1985, where 2,942 individuals m^{-2} were collected. It has not been uncommon to find estimates above 2,000 individuals m^{-2} in any of the samples from Black Bay. There has been a general decline of amphipods since the 2000 rule-curve implementation in both Namakan and Rainy Lake, but the two systems have become more similar in terms of the relative abundance (Fig. 9). The relative abundance differed by 24% in 1984-85 and then 20% and 12% in 2004-05 and 2012-13, respectively. Amphipods have always been relatively ubiquitous in both systems, where they have occurred in 56% to 88% grab samples in the shallow littoral zone over the duration of the entire study. We did not identify all amphipods to genus, although Kraft (1988) reported finding both *Gammarus* and *Hyalella* sp., which agrees with our personal observations.

Sphaeriidae

Mollusks in the group Sphaeriidae are known by the common name “fingernail clam” due to their small size. These clams showed a high occupancy in both Rainy Lake (86%) and Namakan Reservoir shallow littoral sites (92%). There has been a general increase in the relative density of fingernail clams in both systems (Fig. 10). During the 1984-85 study under the 1970 Rule-Curve, the relative frequency was approximately the same in Namakan Reservoir as it was in Rainy Lake, but differences began to appear in the 2004-05 when fingernail clams became relatively more important in Rainy Lake sites compared with Namakan Reservoir sites; however, in the 2012-13 fingernail clams became more frequent in Namakan Reservoir in comparison with Rainy Lake. We interpret the lack of a consistent pattern for relative frequency and the general stability in measures of site occupancy to mean that, although these animals are important in these systems, they do not appear to be responding the implementation of the 2000 rule curve.

While Kraft identified all fingernail clams to the general category "Sphaeriidae," in both the 2004-05 and 2012-13 samplings, genus level identifications were made. We found Sphaeriidae to be dominated by two genera, *Pisidium* sp. and *Sphaerium* sp. For all fingernail clams collected in 2004-05, 55% and 18% were *Pisidium* sp. and *Sphaerum* sp., respectively. These relative positions were reversed in the 2012-13 where we found that 79% of fingernail clams were *Sphaerium* sp. and 21% were *Pisidium* sp. We also found 27% of Sphaeriidae to be *Musculium* sp. during the 2004-05 but less than 1% in 2012-13. We conclude that the fingernail clams, particularly the two genera *Pisidium* sp. and *Sphaerium* sp., are both ubiquitous and relatively abundant in the shallow littoral zone of these lakes, but they have yet to show a response to the 2000 Rule-Curve in the shallow littoral sites.

Oligochaeta

Aquatic segmented worms (Phylum Oligochaeta) were found in 100% of samples collected from shallow water littoral samples in Rainy Lake during 1984-85 and in 94 % of samples in both 2004-05 and 2012-13. They were never found at 100% occupancy in Namakan sites but became much more ubiquitous following the implementation of the 2000 rule curve, where the number of samples they were found in approximately doubled (Fig. 11). In particular, while these animals were found in only 25% of Namakan samples during the 1984-85 period, they were found in 92% and 83% of samples under the post 2000 rule curve implementation.

Relative frequencies of oligocheates in grab samples have been declining on both systems over time; however, the decline has been more pronounced in Rainy Lake, and the dissimilarity in relative frequency between the systems has been lessened at each sampling bout after the 2000 rule curve implementation. Under the 1970 Rule-Curve, there was a difference of 16% in relative frequencies, which was lessened to 11% under the 2004-05 samples, and then that difference was reduced to 1% under the 2012-13 sampling regime. This is consistent with the 2000 Rule-Curve having a homogenizing impact on the systems. Additional taxonomic resolution was not achieved under any of the sampling regimes. Classification to “Oligochaeta” was the lowest practicable level for this study under all sampling periods.

Gastropoda

Aquatic snails were found in 86% of grab samples over all periods even though they were not particularly abundant, except in Rainy Lake during the 2004-05 collections, where approximately 25% of all animals collected were snails in the shallow water sites. Gastropods have always occurred at more sites in Namakan Reservoir than in Rainy Lake (Fig. 12). These occupancy differences, which were as high as 13% (i.e., 13% more sites were occupied in Namakan than were in Rainy Lake) during the 1970 Rule-Curve, were reduced to 11% during the 2004-05 sampling period and then to 4% under the 2012-13 sampling period. Over time then, the systems appear to be becoming more homogenous in occupancy scores for gastropods, which again is consistent with the 2000 Rule-Curve having a homogenizing impact on the two systems.

Kraft (1988) did not report genus-level information on gastropods. Gastropods were identified to genus level (sometimes species level) for the 2004-05 and 2012-13 data. A total of seven genera were found in 2004-05, with the majority being *Amnicola* sp. (83%) and *Valvata* sp. (17%). The rest of the genera during 2004-05 made up less than 1%. A total of 10 genera were found in 2012-13, but the majority by relative abundance were *Galba* sp. (65%), followed by *Valvata* sp. (15%).

Rare Taxa

We identified 50 rare taxa, which we defined as those that contributed less than 5% to the total relative abundance on average. The combined abundance of all of these did not reveal any clear patterns in their average composite relative frequency or site occupancy in response to the change in the rule curve (Fig. 13). Of these 50 rare taxa, six were found to comprise 78% of the total abundance for just the rare species, with the most abundant rare TU being the mayfly *Caenis* sp. (Fig. 14). The average relative abundance for any one of these TUs was 0.65%, but a few were found to have a relative abundance larger than 5% for at least one sampling date. This included *Caenis* sp., *Chaoborus* sp., Ostracoda, and Isopoda.

The case of the Isopoda is interesting in that it occurred in relatively high abundances in Rainy Lake, being present in 34% of samples, with an average relative abundance over all sampling periods of 4% . This animal had not ever been found in Namakan Reservoir until the 2012-13 study. Isopods found in the 2012-13 Namakan samples were restricted to Moxie 1-m and Junction 1-m depths, where in August 2013, we found 431 individuals per m^2 and 57 individuals per m^2, respectively. Kraft (1988) speculated that isopods were sensitive to the 1970 Rule-Curve. Their appearance in Namakan is consistent with the hypothesis that the 2000 Rule-Curve is helping to foster conditions that make the environment in Rainy Lake and Namakan Reservoir more similar.

While the composite average occupancy was between 20 and 35%, some of the TUs did show a higher occupancy, suggesting that they were ubiquitous but rather rare where they occurred. Each of the following TUs had average site occupancy above 50%: Ceratopoginadae (75%), *Caenis* sp. (59%), *Chaoborus* sp. (56%), *Hexagenia* sp. (55%), and leeches (50%). Ten additional TUs had average site occupancy scores between 25-50%. The remaining 34 TUs had site occupancies less than 25%.

Objective 3: Determine if community changes founds by McEwen and Butler (2010) have increased over time at 3,4, and 5 meter depths. A result of increased similarity between the invertebrate communities of Rainy Lake and Namakan Reservoir sampled during the proposed 2012-2013 effort as compared to those sampled during 1984-85, would indicate a community that has become more homogenous between the two systems (Namakan Reservoir and Rainy Lake). A result of no change or decreased similarity may indicate large year to year variability or that invertebrates at 3-5 meter depths are not influenced by water-level management, or that not enough time has accumulated to integrate changes to the benthic community.

Univariate Community Structure

The most parsimonious covariate models for univariate community measures in the deep littoral habitats were as follows:

1. *Taxon Richness ~ Year+Bay+Depth+Slope+Distance from Shore*
2. Ln(*Density*) ~ *Year+Bay+Depth+Slope+Distance from Shore*
3. *Evenness ~ Year+Month+Bay+Depth+Distance from Shore*
4. *Simpson's Diversity ~ Year+Month+Bay+Depth*

Univariate summaries of the benthic community in the deep littoral zone were more responsive to environmental covariates than were the shallow littoral communities. Taxon richness and abundance increased from 3 to 5 meters, while evenness and diversity were highest at the deepest depths. This suggests that, while there are more taxa in the 3 and 4-m depths, individuals are more evenly distributed at the 5-m depth. We found that steeper slopes furthest away from the shore had higher overall abundances and diversity. We speculate that the steeper slopes lead to heterogeneity in deposition of sediments, which may lead to more niches for a higher variety of organisms. On the other hand, both Simpson's diversity and evenness were highest at flatter slopes closer to the shore and in August relative to June.

After controlling for covariates, we found no evidence to suggest a BACI effect on any of the four univariate measures, including species richness ($F_{2,140}$=1.09, p=0.340), the natural log abundance ($F_{2,140}$=2.64, p=0.075), Pielou's evenness ($F_{2,140}$=0.85, p=0.430), or Simpson's Diversity Index ($F_{2,141}$=3.78, p=0.810). The 2000 Rule-Curve appears to have not altered these measurements in the deeper littoral sediments.

Multivariate Community Structure

For the deeper littoral zone samples, AICc chose as most parsimonious, a whole community response to the following set of environmental variables:

PcoA1~Year+Organic Content + Depth

This is to suggest that TUs are sorting themselves in the environment according to the organic content of sediment and depth, primarily, but that other factors such as month, slope, and distance from shore, likely do not have a strong structuring force. There was also a "year" effect, suggesting a general lack of stability in what taxonomic units are more or less important on a year-to-year basis.

After controlling for the environmental covariates, we found a significant BACI effect on the community structure in the deeper depths associated with the implementation of the 2000 rule curve ($F_{2,142}$=1.250, p=0.034) , which is a new result that differs from the previous analysis on just the 2004-2005 data sets. A post-hoc analysis indicated that the differences were manifest between B and A1 ($F_{1,95}$=1.480, p=0.019) and between B and A2 ($F_{1,95}$=1.400, p=0.039), but there was no difference between the 2004-05 and 2012-13 data sets ($F_{1,95}$=0.900, p=0.560).

The NMDS plot shows that Namakan Reservoir and Rainy Lake communities have become more similar since the 2000 rule curve implementation and statistically so since the samples taken during the 2004-2005 study at the depths of 3-5 meters, and that the communities in A2 became even more similar since A1 samples (Fig. 15). In particular, the Rainy Lake sites have had more large carnivorous insects than Namakan Reservoir sites historically. In the 2012-13 samples, not only have the Namakan Reservoir sites become more associated with these groups, but they show more of them on average than the Rainy sites. These results are consistent with the long tradition in ecology that points to relationships between food-chain length and disturbance (e.g., Post 2002, McHugh et al. 2010).

Descriptive Summaries

Over the entire duration of all three sampling periods, 30,653 individual animals were collected in 468 grab samples at the 3, 4, and 5 meter depths, resulting in an average catch per unit effort (CPUE) of 65 animals (range = 1-357 individuals) per grab in the deep littoral zone sites. We found that density was highly skewed, yielding a median CPUE of 49 individuals per grab (Fig. 16).

In the deep water littoral sites, individuals were represented by 36 unique taxonomic units (TUs). On a per grab basis, this equated to approximately 9 TUs on average (Range: 2-15 TUs), with a distribution that appeared Normal (Fig. 17). Of these 36 unique TUs, six TUs were represented by a single individual. If we use a relative frequency of 5% as a cutoff for “rare” TUs, we find these communities to be dominated by chironomids (48%), oligocheates (10%), fingernail clams (10%), amphipods (7%), phantom midges (7%), and the burrowing mayfly, *Hexagenia limbata* (6%). Together, these six TUs represent 88% of the individuals collected in these habitats.

Following is a description of the response of each of these abundant taxa in terms of their relative abundance and site occupancy over time and system. By relative abundance, we mean the proportion of individuals in an average grab sample that belong to a taxonomic unit, and by site occupancy, we mean the proportion of all grab samples in which at least one individual of a taxonomic unit is present.

Chironomidae

Chironomids (Order Diptera, Family Chironomidae) are a dominant freshwater aquatic group. Of the 276 samples that were collected over the entire course of the study from 1984 through 2013, there was 100% occupancy in all grabs, meaning there was at least one individual. The number of individuals ranged from 11 to 6,537 larvae (Mean = 1,123, SD=1,168) m^2.

On average, approximately 45% (SD=7%) of all individuals in an average grab sample from the deeper depths were chironomids. Namakan Reservoir has always had more chironomids than Rainy Lake at the deeper littoral sites, but the difference between Namakan and Rainy Lake has become reduced for each sampling regime (Fig. 18). The relative abundance was 16% higher in Namakan Reservoir relative to Rainy Lake during the 1984-85 period but then 11 and 4% in 2004-05 and 2012-13, respectively. We consider this to be consistent with a homogenizing of Namakan Reservoir with Rainy Lake.

While Kraft (1988) did not identify chironomids to the genus-level for the majority of his samples, he did for a subset of samples collected at various depths in Moxie and Harrison Bays, finding deep water fauna dominated by *Procladius* sp. (23%), *Glyptotendipes* sp. (21%), and

Tanytarsus sp. (15%) species. In both the 2004-05 and the 2012-13 samplings, chironomids were all identified to genus, and we found a similar result to Kraft (1988), with the exception that *Chironomus* sp. instead of *Glytotendipes* sp. We found the top three most abundant genera to be *Procladius* sp. (29%), *Chironomus* sp. (21%), and *Tanytarsus* sp. (15%) in the 2004-05 samples and *Procladius* sp. (29%), *Chironomus* sp. (15%), and *Tanytarsus* sp. (11%) in the 2012-13 samples respectively. We found both *Chironomus* sp. and *Glytotendipes* sp. at *Namakan* and Rainy Lake sites, and whether Kraft's pre-2000 rule curve data would have shown similar results when sampling across all sites is impossible to know. We suggest that the deep water chironomid communities were dominated then by the three general *Procladius* sp., *Chironomus* sp., and *Tanytarsus* sp. and that these genera comprise a more similar proportion of individuals in samples from Rainy Lake and Namakan Reservoir under the 2000 rule curve than they did under the 1970 rule curve.

Oligochaeta

The second most abundant group in the deep water littoral zone was aquatic segmented worms (Phylum Oligochaeta). These animals were found in 63% of samples collected from deep water littoral samples in Rainy Lake during 1984-85, but in 100 % of samples in both 2004-05 and 2012-13. They were not as ubiquitous in Namakan samples, where they were never found at 100% occupancy but became more ubiquitous following the implementation of the 2000 rule curve, where the number of samples they were found in approximately doubled. There has been a trend to increasing similarity between Namakan Reservoir and Rainy Lake for the relative frequencies of oligochaetes (Fig. 19). This shift toward similarity may be an important driver in showing significant results under the 2000 rule curve relative to the 1970 rule curve. Additional taxonomic resolution was not achieved under any of the sampling regimes. Classification to "Oligochaeta" was the lowest practicable level for this study.

Sphaeriidae

Fingernail clams had an average relative frequency that was the same as for the segemented worms (10%), but they were more variable in site-regime and in occupancy (Fig. 20). According to the relative frequency, if using 5% as a cut-off for rare species, we would call fingernails rare in Rainy but common in Namakan; however, even though they were not abundant, they were ubiquitous in both systems occurring in on average 80% of samples and never in fewer than 67% of samples for a site-time combination. The difference between Rainy Lake and Namakan Reservoir looks to have remained consistent over all sampling periods for relative abundance and occupancy.

While Kraft identified these only to Sphaeriidae in both the 2004-05 and 2012-13 samples, a finer scale taxonomic resolution was used. The vast majority of these animals belonged to the genus *Sphaerium* sp. (81%), followed by *Pisidium* sp., which comprised 81% and 19% of all Sphaeriidae in 2012-13, respectively. Making up less than 1% of these organisms were *Musculium* sp. (5 individuals), *Obovaria* sp., and *Utterbackia* sp., each yielding a single individual. These densities were similar to those found in 2012-13, where only three species were identified but where *Pisidium* sp. (56%) was the most abundant followed by *Sphaerium* sp. and *Musculium* sp., which both had a relative frequency of 22%. We conclude that the fingernail clams, particularly the three general *Pisidium* sp. and *Sphaerium* sp., are both ubiquitous and relatively abundant in the deep littoral zone of these lakes.

Amphipoda

Amphipods tend to be more common in shallow littoral than deep littoral zones but still show up as important TUs at 3-5 meter depths. Namakan Reservoir has always maintained higher relative abundances of amphipods relative to Rainy Lake. In 2012-13, amphipods became much less represented in samples from Namakan, where relative densities went from 12 and 16% in 1984-85 and 2004-05, respectively, to rare at 2% in 2012-13 (Fig. 21). Amphipods have always been rare (less than 5% relative abundance) in Rainy Lake, even though they may occur in low number at low to moderate site occupancies. Amphipods were not well-represented in terms of either relative abundance or occupancy in 2012-13 in Rainy Lake and look to be becoming less abundant but in a similar number of plots in Namakan Reservoir.

Chaoboridae

Phantom midges (Order Diptera, Family Chaoboridae) have a relative abundance of 7% but have an occupancy that suggests they are ubiquitous in deep littoral water sediments. The largest differences between Rainy Lake and Namakan Reservoir that occurred after the implementation for the 2000 rule curve were in relative abundance (Fig. 22). Phantom midges had a relative abundance of 14% in Rainy Lake deep water sediments and less than half that at 6% for Namakan Reservoir. The largest difference occurred during the 1970 rule curve, where the difference in relative abundance amounted to 8% by dropped to no difference in 2004-05 and an actual reversal in 2012-2013, where it was 1% more abundant in the Namakan samples compared with the Rainy Lake samples. After implementation of the 2000 rule curve, there was less than a 1% difference in the relative abundance of phantom midges. With the exception of the 2004-05 samples, they were found in 100% of the deep water littoral zone sediments. On average, including 2004-05, occupancy was 92% and still high for Namakan at 80% for occupancy. Both occupancy and relative abundance increased in the 2012-13 samples relative to the 2004-05 samples. All Chaoboridae were identified to the genus *Chaoborus.*

Hexagenia limbata

The burrowing mayfly (Order Ephemoptera, Family Ephemeridae) *Hexagenia limbata* is another important animal that favors deep water littoral zone habitats. These larvae are larger on average compared with other benthic invertebrates. They also tend to be quite mobile and are likely an important source of food for fishes due to their size and catchability. They werefound in nearly 100% of samples and comprised on average 6% of the total individuals in a grab but found to be more abundant in Rainy Lake (10%) relative to Namakan Reservoir (5%). The difference in the relative abundance between the two systems was cut in half, where it was a 6% difference in relative abundance, during 1984-85 and then 3 and 4% in the 2004-05 and 2012-13 period respectively (Fig. 23). This reduction is consistent with a change in rule curve leading to a homogenization of the Namakan and Rainy Lake.

Rare Taxa

For the deep water littoral zone, the average relative density of rare taxa was 11%, and the average site occupancy was 30% (Fig. 24). There were 30 TU found in the deep littoral zone that had average relative densities that were less than 5% Of these rare taxa, a group of six taxa comprised 85% and the rest combined less than 15% (Fig. 25). Both *Sialis* sp. and the Ceratopogindae, although not particularly abundant, were ubiquitous in being found in 74% and

72% of grab samples taken, respectively. The rest of the rare taxa were found in less than half of the samples.

Objective 4: To determine the current patterns of insect emergence from vegetation beds and aquatic macroinvertebrates in submerged wood substrates and to use the results from Namakan Reservoir and Rainy Lake for comparison with those from naturally regulated reference lakes to determine if the one-meter reduction in the over-winter drawdown on Namakan Reservoir has resulted in the restoration of a more diverse littoral community. Both the emergence sampling and the assessments of macroinvertebrates on wood were performed in the 1.0-2.0 meter depth.

Emerging Insects

Composition: A total of 42 genera of aquatic insects were collected in emergence traps (Appendix Table 3). Chironomidae were the most rich (36 genera), followed by Ephemeroptera and Ceratopogonidae (2 genera each), Trichoptera and Chaoboridae (one genus each). Chironominae were represented by 23 genera (Chironomini = 17 genera, Tanytarsini = 5 genera and Pseudochironomini = one genus), Orthocladiinae by 7 genera and Tanypodinae by 6 genera. No specimens of Diamesinae, Prodiamesinae or Podonominae were detected.

Variation in composition during 2012 versus 2013 was minimal when considered across all sample sites, with 39 taxa detected in 2012 and 36 taxa detected in 2013. JAC of year-to-year similarity was 78.6%. Six of the taxa detected during only one year were represented by only a single specimen each (*Culicoides*, *Conchapelopia/Thienemannimyia* gr., *Paralauterborniella*, *Paratendipes*, *Stempellina* and *Stenochironomus*) and when deleted from the calculation of similarity, resulted in year-to-year JAC Similarity of 83.3%.

Considered across all bays and both years, emergence in August (40 genera) was more genus-rich than June (33 genera). Thirty one of the genera were detected during both months (JAC = 73.3%). Genera emerging from vegetation beds formed a subset of the taxa found in benthic transect samples. At the generic-level none of the taxa emerging from vegetation beds were only collected from the beds.

Black Bay had the greatest generic richness when considered over both years (30 genera), however the year-to-year richness differed substantially (28 genera in 2012 versus 19 genera in 2013). The JAC similarity for the two years was 56.7% and was lowest compared to patterns seen over the two years in other bays. The 17 taxa detected during both years were among the most abundant taxa in each year. In addition, the similarity of emergence composition during June versus August (of both years) was low, with the JAC = 43.3%.

Twenty-eight genera were detected during the study at Harrison Bay. Year-to-year differences were minimal in terms of generic richness (27 genera in 2012 versus 23 genera in 2013), and 21 genera were detected both years. The JAC Similarity was 72.4%. By contrast, the similarity of emergence composition in June (both years) versus August (both years) was lower at JAC = 58.6%.

Twenty-seven genera were detected during the study at Junction Bay. Year-to-year differences were minimal in terms of generic richness (23 genera in 2012 versus 25 genera in 2013), and 21 genera were detected both years. The JAC Similarity across years was highest of all bays at 75.0%. By contrast, the similarity of emergence composition in June (both years) versus August (both years) was lower at JAC = 60.7%.

Twenty-nine genera were detected during the study at Moxie Bay. Year-to-year differences were minimal in terms of generic richness (24 genera in 2012 versus 26 genera in 2013), and 22 genera were detected both years. The JAC Similarity across years was the second highest of all bays at 73.3%. By contrast, the similarity of emergence composition in June (both years) versus August (both years) was lower at JAC = 63.3%.

Twenty-eight genera were detected during the study at Swanson Bay. Year-to-year differences were minimal in terms of generic richness (25 genera in 2012 versus 24 genera in 2013), and 21 genera were detected both years. The JAC Similarity across years was intermediate of all bays at 72.4% and was identical to the similarity across years for Harrison Bay. By contrast to all other bays, the similarity of emergence composition in June (both years) versus August (both years) in Swanson Bay was the same as the year-to-year similarity at JAC = 72.4%.

Abundance: The average total emergence density across all bays totaled 195 adults/square meter/day. Appendix Table 3 lists the genera sorted by average density across all bays. Twelve of the 14 most- abundant genera occurred in all five bays. The remaining two genera were common in four of the five bays (*Nanocladius* not detected in Black Bay, *Pseudochironomus* not detected in Junction Bay). At genus-level, 13 of the 14 most abundant genera were Chironomidae. The only non-chironomid among the most-abundant genera was the mayfly *Caenis*. Seven genera were detected only in one bay, and all of them were only detected on one sample date.

Year-to-year similarity of emergence across all sample dates and bays based on estimated emergence densities was high (WPS = 89.5%), as was the similarity of emergence by month when calculated at the same scale for all bays over both years (WPS = 84.6).

Emergence density was lowest in Black Bay (124 adults/square meter/day). Emergence traps in this bay were situated in areas of emerging reeds and rushes, with moderate abundance of submerged vegetation. The substrates near where traps were located consisted of large amounts of bedrock and large broken rock, with small amounts of finer substrates and organic matter mixed among the rocks. No efforts were taken to measure the relative amounts of the differing substrate types, but this site clearly had the lowest amounts of fine bottom substrates, which likely accounts for the lower emergence abundance densities. Consequently, a large percent of specimens emerging at this site would likely occur on rocks or the surfaces of the aquatic plants rather than associated with finer lake-bottom sediments. The WPS similarity of emergence for 2012 versus 2013 was lowest of all bays at 75.7%. By contrast, the similarity of emergence densities in June (both years) versus August (both years) was substantially lower at WPS = 47.9%.

Emergence density in Harrison Bay was second lowest of all bays (188 adults/square meter/day) but was not substantially different from densities at all remaining bays (other than Black Bay). The emergence traps in this bay were situated over solid substrates consisting of sand, gravels, and clay, with larger rounded boulder interspersed within the weed bed. Although not common in emergence, the abundance of *Hexagenia* was greatest in Harrison Bay. The WPS similarity of emergence for 2012 versus 2013 was next to intermediate of all bays at 80.5%. By comparison, the similarity of emergence densities in June (both years) versus August (both years) was lower at WPS = 61.8%.

Emergence density in Junction Bay was greatest of all bays (226 adults/square meter/day) but was not substantially different from densities at Moxie Bay and Swanson Bay. The emergence traps in this bay were situated over solid substrates consisting of sand, gravels, and clay, with very slight accumulations of fine particulate organic matter within the weed bed. The WPS similarity of emergence for 2012 versus 2013 was next to the highest of all bays at 83.0%. By comparison, the similarity of emergence densities in June (both years) versus August (both years) was slightly lower at WPS = 76.9%.

Emergence density in Moxie Bay was not substantially different from densities at Junction Bay and Swanson Bay. The emergence traps in this bay were situated over very thick and extensive accumulations of fine particulate organic matter within the weed bed. The substrate conditions were very similar to substrate conditions where emergence trap samples were collected in Swanson Bay. The WPS similarity of emergence for 2012 versus 2013 was the highest of all bays at 84.6%. By comparison, the similarity of emergence densities in June (both years) versus August (both years) was slightly lower at WPS = 75.9%.

Emergence density in Swanson Bay was third greatest of all bays (214 adults/square meter/day) but was not substantially different from densities at Junction Bay and Moxie Bay. The emergence traps in this bay were situated over very thick and extensive accumulations of fine particulate organic matter within the weed bed. The substrate conditions were very similar to substrate conditions where emergence trap samples were collected in Moxie Bay. The WPS similarity of emergence for 2012 versus 2013 was intermediate of all bays at 79.1%. By comparison, the similarity of emergence densities in June (both years) versus August (both years) was lower at WPS = 70.4%.

Bay-to-Bay Comparisons: The JAC and WPS similarities of emergence of all combinations of bays are presented in Tables 7 and 8. Based on compositional data, emergence from Moxie Bay and Swanson Bay was most similar at JAC = 78.8%. These two bays had the most similar substrate conditions and vegetational compositions, and are in differing reservoirs. The two bay-to-bay comparisons with the least similar emergence composition are Harrison Bay and Swanson Bay (JAC = 56.8%) and Junction Bay and Swanson Bay (JAC = 58.3%). Harrison Bay and Swanson Bay are in different reservoirs, but Junction Bay and Swanson Bay are in the same reservoir. Substrate conditions among the two sets of bay with least similar emergence differed substantially, but vegetation composition was somewhat similar, suggesting that substrate conditions are likely to be more influential than vegetation or reservoir in determining taxonomic composition of emergence.

Based on abundance of emerging aquatic insects, Harrison Bay and Black Bay were most similar at WPS = 71.4%. Junction Bay and Moxie Bay (WPS = 51.0%) and Harrison Bay and Moxie Bay (WPS = 54.1%) were least similar in terms of abundance of aquatic insects emerging. Junction Bay and Moxie Bay are in the same reservoir, and Harrison Bay and Moxie Bay are in different reservoirs, but both bay comparisons have contrasting substrate conditions and vegetational compositions, suggesting that both of the factors are more important in explain variation of emergence abundances compared to potential reservoir-related effects.

Analyses of similarities of sites classified by reservoir does not show strong differences that would correspond to the Rule Curve conditions. Although limited by a single within-reservoir similarity for Rainy Lake, the JAC of Black Bay versus Harrison Bay (JAC = 59.4%) is less than both the average within similarities of Namakan Reservoir Sites (JAC = 66.1%) and the mean of all cross classification comparisons of bays in Rainy Lake to bays in Namakan Reservoir, which average to JAC of 64.1%. Therefore, it appears that taxonomic composition of aquatic insects emerging from vegetation beds in the 1-2 meter depth zones is not strongly different across the two reservoirs under the present Rule Curve conditions.

Analysis of similarities based on the abundances of emerging aquatic insects classified by reservoir also shows very little support for potential differences that would correspond to the Rule Curve conditions. For Rainy Lake, the WPS of Black Bay versus Harrison Bay (WPS = 71.4) is higher than the average within similarities of Namakan Reservoir Sites (WPS = 58.6%) and the mean of all cross classification comparisons of bays in Rainy Lake to bays in Namakan Reservoir, which average to WPS of 64.0%. However, when the two within-reservoir averages are averaged (WPS = 65%) the result is nearly identical to the average of the across-reservoir bay-to-bay similarities. Therefore, it appears that abundance composition of aquatic insects emerging from vegetation beds in the 1-2 meter depth zones is not strongly different across the two reservoirs under the present Rule Curve conditions.

Macroinvertebrates on Submerged Wood

Composition: The macroinvertebrates occurring on wood substrates are listed by bay in Appendix Table 4. A total of 50 taxa of macroinvertebrates were collected from wood. Chironomidae were the most rich (26 genera), followed by Gastropoda (6 genera, including one represented only by small specimens not identifiable to genus), Trichoptera (4 genera, including two represented by small specimens not identifiable to genus). Chironominae were represented by 16 genera (Chironomini = 12 genera, Tanytarsini = 3 genera and Pseudochironomini = one genus), Orthocladiinae by 7 genera and Tanypodinae by 3 genera. No specimens of Diamesinae, Prodiamesinae or Podonominae were detected.

All taxa that were common on wood substrates were also collected from benthic samples. Three less abundant taxa, *Lymnaea*, *Brillia*, and a single larva resembling *Xylotopus*, were not detected in benthic samples collected during this project. The *Brillia* (two specimens) and *Xylotopus* larvae were all very small, probably late first or early second instars. Larvae of both of these genera are known to occur on submerged wood (*Brillia*) or bore into decomposing wood (*Xylotopus*) but have only been reported from lotic habitats in the United States. *Brillia*, however, was reported from South Indian Lake in Manitoba (Rosenberg et al. 1980). Both genera were collected from wood with advanced decay from an abandoned beaver dam, and their presence in littoral areas of the bay was unexpected.

In August 2013, a growth of freshwater sponge was observed on wood of an abandoned beaver dam in Swanson Bay as the last sample of wood was being processed. Some of the sponge tissue was removed and preserved. Larvae of *Xenochironomus*, *Conchapelopia/Thienemannimyia* gr. sp., and *Polypedilum* were associated with the tissue. Larvae of *Xenochironomus xenolabis* are known to forage on sponge tissue, and the other two genera were common on sponges collected from a variety of habitats in Kansas (Ferrington, 1987).

In August 2013, a small ball-shaped growth of Bryozoa was observed on floating wood while anchoring the emergence traps at Moxie Bay. The bryozoan was retrieved and inspected. Larvae of *Glyptotendipes* and *Parachironomus* were associated with the tissues of the bryozoan. Both of these genera have been previously collected from *Pectinatella* (Ferrington, personal observations), and larvae of *Parachironomus pectinatellae* were described by Dendy & Sublette (1959) from Bryozoa.

Variation in composition of macroinvertebrates in wood substrates during 2012 versus 2013 was moderate when considered across all sample sites, with 38 taxa detected in 2012 and 45 taxa detected in 2013. JAC of year-to-year similarity was 64.4%. Six of the taxa detected during only one year were represented by only a single specimen each (*Helobdella stagnalis/modesta*, *Glyphopsyche*, *Agabus*, *Endochironomus*, *Paralauterborniella,* and *Xylotopus*) and when deleted from the calculation of similarity resulted in year-to-year JAC Similarity of 79.1%. The 22 most abundant macroinvertebrates collected from wood substrates were detected during both years.

Variation in composition of macroinvertebrates on wood substrates during June (both years) versus August (both years) was relatively high when considered across all bays. The JAC similarity of June versus August emergence was 87.3%.

The generic richness of macroinvertebrates on wood substrates in Black Bay when considered over both years was low (30 genera), but the year-to-year richness did not differ substantially (27 genera in 2012 versus 23 genera in 2013). The JAC similarity for the two years was 66.7% and was intermediate when compared to patterns seen over the two years in other bays. Seven genera were represented by only a single specimen and when deleted from the analysis the JAC similarity increased to 87%, which was the highest JAC of all bays. The twenty taxa detected during both years were among the most abundant taxa in each year on wood substrates in this bay.

Thirty genera were also detected during the study at Harrison Bay. Year-to-year differences were minimal in terms of generic richness (28 genera in 2012 versus 24 genera in 2013), and 22 genera were detected both years. The JAC Similarity was 73.3%. Four genera were represented by only a single specimen, and when deleted from the analysis, the JAC similarity increased to 84.6%. Twenty taxa detected during both years were among the most abundant taxa in each year on wood substrates in this bay.

Thirty-two genera were detected on wood substrates during the study at Junction Bay. Year-to- year differences were minimal in terms of generic richness (26 genera in 2012 versus 24 genera in 2013) but only 18 genera were detected both years. The JAC Similarity across years was next to the lowest of all bays at 56.2%. However, eight genera were represented by only a single specimen, and when deleted from the analysis, the JAC similarity increased to 75%. The 18 taxa detected during both years were among the most abundant taxa in each year on wood substrates in this bay

Thirty genera were detected on wood substrates during the study at Moxie Bay. Year-to-year differences were substantial and were greater than for all other bays in terms of generic richness (18 genera in 2012 versus 27 genera in 2013), and only 15 genera were detected both years. The JAC similarity across years was lowest of all bays at 50%. Seven genera were represented by only a single specimen, and when deleted from the analysis, the JAC similarity only increased to 65.2%, which also was the lowest adjusted JAC of year-to-year similarity of all bays.

Swanson Bay had the greatest generic richness when considered over both years (34 genera); however, the year-to-year richness differed substantially (22 genera in 2012 versus 32 genera in 2013). The JAC similarity for the two years was 58.8% and was next to the intermediate compared to patterns seen over the two years in other bays. However, eight genera were represented by only a single specimen, and when deleted from the analysis, the JAC similarity increased to 76.9%. The 22 detected during both years were among the most abundant taxa in each year.

Abundance: Abundances of macroinvertebrates on wood substrates were highly variable across individual samples by collection date and bay. In four of the five bays, wood substrates in one-to-two meter depths were difficult to locate near the areas where benthic transect samples were collected and, when located, were highly variable in terms of physical condition and degree of decomposition. This was especially the case in Black Bay, Moxie Bay, and Swanson Bay. Consequently, it was not possible to stratify wood into different class of estimated time in water, degree of decomposition, and associations of wood with differing lake-bottom substrate conditions, all of which can potentially influence the use of the substrate by macroinvertebrates.

The similarity in abundance of aquatic macroinvertebrates on submerged wood substrates during 2012 versus 2013 was high when considered across all sample sites. The WPS of year-to-year similarity was 83.9%. In addition, when considered across both years, the WPS similarity of invertebrates on submerged wood substrates in June versus August was high at 89.2%.

During summer of 2012 in Black Bay, the wood substrates that were sampled were from recently fallen branches with bark still relatively intact, and although saturated, most had no noticeable softening of the fibers. During 2013, however, several older and larger wood substrates were located and sampled. The bark on these pieces was more worn or missing in several pieces, which may have influenced the variability of macroinvertebrates. In both years the wood sampled from this bay was located in areas of large cobble, boulder, or layered, broken bedrock, and portions of the wood were in contact with the rock surfaces. The WPS similarity of abundance in 2012 versus 2013 was 75.7%

Wood substrates were most common and easily located at Harrison Bay, where randomly chosen pieces of wood had markedly different degrees of bark losses and amount of softening due to time in water and associated degrees of decomposition. The WPS similarities of macroinvertebrate abundance on submerged wood substrates for 2012 versus 2013 in Harrison Bay was 78.5%

At Junction Bay the wood substrates were collected in areas with firm lake bottom substrates consisting of mud and or mud/clay-like mixtures. Compared with Black Bay, there was less rock or cobble, and compared with Swanson Bay and Moxie Bay, there was substantially less accumulation of soft organic matter. The wood was partially in contact with lake-bottom substrates and more highly variable in terms of decomposition and loss of bark. The WPS similarities of macroinvertebrate abundance on submerged wood substrates for 2012 versus 2013 in Junction Bay was 75.9%

Wood sampled in both Moxie Bay and Swanson Bay was taken from near abandoned beaver lodges and had been stripped of all bark by the beaver. Consequently, the heterogeneity of the surface of the substrates differed markedly from wood collected at the other bays. The sections of wood sampled were not in contact with lake-bottom substrates, which at both of these sites consisted of large amounts of organic matter. Both abandoned beaver lodges were also situated close to dense stands of cattails. Most of the wood had well-developed periphyton growth. The WPS similarities of macroinvertebrate abundance on submerged wood substrates for 2012 versus 2013 in Moxie Bay and Swanson Bay were 75.3% and 78.0%, respectively.

To gather evidence of how the macroinvertebrates were using the submerged wood substrate (e.g., as a physical substrate and grazing periphyton versus gouging wood or burrowing into the wood by masticating the tissues), up to a total of five specimens of each taxon were dissected and the functional feeding status was determined based on gut contents classified into (1) primarily periphyton (= grazer), (2) at least some visible wood particles in the gut (shredder), (3) observed in burrows or gouging into wood (= xylophage), or (4) remains of invertebrate prey (= predator). Appendix Table 4 provides a summary of these findings.

Bay-to-Bay Comparisons: The JAC and WPS similarities of macroinvertebrates on submerged wood substrates for all combinations of bays are presented in Tables 9 and 10. Based on compositional data, emergence from Black Bay and Swanson Bay was most similar at JAC = 68.4%. These two bays had dissimilar substrate conditions and are in different reservoirs. The two bay-to-bay comparisons with the least similar emergence composition were Harrison Bay and Swanson Bay (JAC = 52.4%) and Harrison Bay and Moxie Bay (JAC = 58.3%). Harrison Bay and Swanson Bay, are in different reservoirs, as are Harrison Bay and Moxie Bay. Substrate conditions among the two sets of bay-to-bay comparisons with least similar emergence differed substantially, but vegetation composition was somewhat more similar, suggesting that substrate conditions are likely to be more influential than vegetation or reservoir in determining taxonomic composition of macroinvertebrates on submerged wood substrates.

Based on abundance of macroinvertebrates on submerged wood substrates, Harrison Bay and Swanson Bay were most similar at WPS = 80.8%. Junction Bay and Moxie Bay (WPS = 63.7%) and Black Bay and Moxie Bay (WPS = 66.0%) were least similar in terms of abundance of macroinvertebrates on submerged wood substrates. Junction Bay and Moxie Bay are in the same reservoir, but Black Bay and Moxie Bay are in different reservoirs. Both bay comparisons have contrasting substrate conditions and vegetational compositions, suggesting that both of these factors are more important in explaining variation of abundances of macroinvertebrates on submerged wood substrates compared to potential reservoir-related effects.

Analysis of similarities of sites classified by reservoir does not show strong differences that would correspond to the Rule Curve conditions. Although limited by the single within-reservoir similarity for Rainy Lake, the JAC of Black Bay versus Harrison Bay (JAC = 66.7%) is slightly greater than both the average within similarities of Namakan Reservoir Sites (JAC = 61.3%) and the mean of all cross classification comparisons of bays in Rainy Lake to bays in Namakan Reservoir, which also average to JAC of 61.3%. Therefore, it appears that taxonomic composition of aquatic insects on submerged wood substrates in the 1-2 meter depth zones is not strongly different across the two reservoirs under the present Rule Curve conditions.

Analysis of similarities based on the abundances of macroinvertebrates on submerged wood substrates classified by reservoir also shows only very weak support for potential differences that would correspond to the Rule Curve conditions. For Rainy Lake, the WPS of

Black Bay versus Harrison Bay (WPS = 78.7) is higher than the average within similarities of Namakan Reservoir Sites (WPS = 68.6%) and the mean of all cross classification comparisons of bays in Rainy Lake to bays in Namakan Reservoir, which average to WPS of 74.6%. However, when the two within-reservoir averages are averaged (WPS = 64%), the result is less than the average of the across-reservoir bay-to-bay similarities. Therefore, it appears that abundance composition of macroinvertebrates on submerged wood substrates in the 1-2 meter depth zones is not strongly different across the two reservoirs under the present Rule Curve conditions.

Rosenberg et al. (1980, 1984) studied emergence of chironomids from littoral regions of the newly formed reservoir, South Indian Lake, in Manitoba, and their study is most comparable in design and type of lentic system relative to other studies in the literature of chironomids in lentic habitats in North America. At the genus-levels, their results correspond well to the taxonomic compositions and relative abundances of chironomid genera detected in all bays of this study. Although the generic richnesses are comparable, the abundances detected on both sample dates during both years for four of our five bays appear to be higher than recorded from littoral regions of South Indian Lake. No statistical comparisons, however, can justifiable be made between the two studies, so the higher numbers recorded in this study may not be significant. In addition, it is difficult to generalize across an entire emergence season based on two sample dates from only two months in each of two year.

Final Remarks: Composition of insects emerging from vegetation beds was very similar qualitatively and quantitatively from bay-to-bay. Year-to-year similarity was strongly related to reduced generic richness in 2013 in some bays.

Insects emerging from vegetation beds in each bay represented a subset of the more-common taxa occurring in transect samples, and no taxa were restricted only to weed beds. A recommendation for future studies would be to concentrate emergence trap sampling over vegetation types that are shown to be the most influenced by changes in the rule curve. This should be done in consultation with principal investigators conducting future vegetation surveys and with a special focus on Black Bay to develop a better predictive capacity to understand the year-to-year variability of emerging insects.

Taxa occurring on wood substrates consisted largely of sprawling and grazing taxa that use wood as a non-specific solid substrate (= grazers and predators), combined with a smaller number that are known to gouge wood substrates (shredders), bore into wood of varying degrees of decomposition, or are xylophagic. The abundances of macroinvertebrates were quite variable across all samples but, in some instances, were remarkably high. This was especially the case for Chironomidae taxa (e.g., *Corynoneura* and *Thienemanniella*), with small grazers taxa being very common on wood from beaver lodges that was stripped of bark by beaver. Partially decomposed wood with most bark still in place had higher numbers of collector taxa than other categories of wood. Wood in the most advanced stages of decay (but still solid enough to be removed from the water without breaking) had the highest incidence of gouging or xylophagic taxa. However, these last two categories of taxa were the least abundant when considered across all samples of wood.

Because of the difficulty locating substantial amounts of wood that are easy to stratify into different classes of estimated time in water, degree of decomposition, and associations of wood with differing lake-bottom substrate conditions (all of which can potentially influence the use of the substrate by macroinvertebrates), it is recommended that future studies include placement of retrievable wood substrates into the bay in areas with similar substrate compositions. Wood should be selected with regard to species of tree, degree of decomposition and presence or absence of bark. Wood should be placed into each bay at predetermined intervals before removal so that a variable placement, simultaneous retrieval approach can be used to minimize macroinvertebrate variability as a consequence of differences in wave action, lake levels and seasonal water temperatures.

Summary & Conclusion

Objective 1

The composition and structure of macroinvertebrate communities are influenced by time (year and month), location (depth, distance from shore, and bottom slope), sediment composition (organic content, water saturation potential, and sediment particle size), and macrophtye presence (macrophyte diversity and abundance). For covariates that likely would respond to water-level management, macrophyte abundance and diversity both seem to play an important role in structuring macroinvertebrate communities. The variance associated directly with the change in the rule curve accounted for 5.4% of the explained variance. If the goal of the 2000 rule curve implementation was to elicit a change in community structure for the macroinvertebrate community, we consider this result to be consistent with that goal.

Objective 2

There was a significant change of the community as measured by Simpson's Diversity and multivariate community structure as determined by ordination scores ($p < 0.05$) in the 1 and 2 meter shallow littoral sites. If stakeholders were concerned that measured differences in macroinvertebrate communities in McEwen and Butler (2010) attributed to the 2000 Rule-Curve would reverse after a longer time period (i.e., 12 and 13 years after the implementation of the 2000 Rule-Curve rather than 4 and 5 years after the implementation of the 2000 Rule-Curve), the results reported on here show just the opposite. We find sustained and even amplified differences in communities based on the 2012-13 samples. We think that given even more time under the current rule-curve regime, communities in Rainy Lake and Namakan Reservoir will become even more similar. If the goal of the 2000 rule curve implementation was to create macroinvertebrate communities in Namakan Reservoir that would become more similar to those of Rainy Lake, we consider these results to be consistent with that effect.

Objective 3

We found a significant effect associated with the rule curve change for multivariate community structure as measured by community ordination scores. In general, the communities in Rainy Lake and Namakan Reservoir in the post-2000 rule curve era have become more similar relative to the pre-2000 rule curve. This result is a new finding that was unable to be demonstrated in McEwen and Butler (2010), but one that was speculated as a probable outcome if the 2000 Rule-Curve remained in operation. We suspect that if the 2000 Rule-Curve continues to be in force into the future, further homogenization in community structure will occur within these deep littoral zone sites. Again, if the goal of the 2000 Rule-Curve implementation was to create macroinvertebrate communities in Namakan Reservoir that would become more similar to those of Rainy Lake, we consider these results to be consistent with that effect.

Objectives 4

Composition of insects emerging from vegetation beds was very similar qualitatively and quantitatively from bay to bay and was influenced by reduced generic richness in 2013 in some bays. Insects emerging from vegetation beds in each bay represented a subset of the more-common taxa occurring in transect samples, and no taxa were restricted only to weed beds. A recommendation for future studies would be to concentrate emergence trap sampling over vegetation types that are shown to be the most influenced by changes in the rule curve.

Taxa occurring on wood substrates consisted largely of sprawling and grazing taxa that use wood as a non-specific solid substrate (= grazers and predators), combined with a smaller number that are known to gouge wood substrates (shredders), bore into wood of varying degrees of decomposition, or are xylophagic. The abundances of macroinvertebrates were quite variable across all samples, but in some instances were remarkably high. This was especially the case for Chironomidae that are small grazers taxa, which were very common on wood from beaver lodges that was stripped of bark by beaver.

Because of the difficulty locating substantial amounts of wood that are easy to stratify into different classes of estimated time in water, degree of decomposition and associations of wood with differing lake-bottom substrate conditions, all of which can potentially influence the use of the substrate by macroinvertebrates, we recommend that future studies include placement of retrievable wood substrates into the bay in areas with similar substrate compositions.

At the genus levels, our results correspond well to the taxonomic compositions and relative abundances of chironomid reported by Rosenberg at al. (1980, 1984). Although generic richnesses are comparable, the abundances detected on both sample dates during both years for four of our five bays appear to be higher than recorded from littoral regions of South Indian Lake.

Additional Comments and Discussion

Individual species are influenced by a myriad of environmental variables, variables that themselves may be affected by water-level regulation. These variables include rates, location, and spatial distribution of depositional materials, sheer forces resulting from a combination of wave action and water level, temperature and oxygen, redistribution of nutrients, and more. At the same time, species are also impacted by interactions, including mutualisms, competition, predation, and more, and each participating species in these species-species interactions is also potentially influenced by water-level management regimes. Finally, species are influenced by their own evolutionary history and life histories, which give animals different abilities and strategies for reproduction, dispersal, and survivorship in the face of a changing biotic and abiotic environment. Operating on all of these is water-levels. While a direct linkage between water-level management on a population of macroinvertebrates is desirable, ecology complicates such direct associations. The multivariate method of analysis provided here provides a glimpse of the macroinvertebrate community as an emergent property, whereby all of these three major influencing factors (i.e., abiotic, species-species, and life-history) in ecology have an influence. Unfortunately, this leaves us frustrated because clean and clear population-level patterns cannot be pointed to for helping inform decisions. This is the best we can do.

We have pre-defined Rainy Lake as the “ideal” system, and we judge whether the water-level management regime is beneficial by noting whether a change in Namakan has become more similar to Rainy Lake. The evidence provided by our analysis and in this report does not disprove the hypothesis that Namakan Reservoir and Rainy Lake have become more similar. Of course, this does not prove it as a factor, but our analysis does support the proposition that the 2000 Rule-Curve has benefited the aquatic macroinvertebrate communities at Voyageur’s National Park. Based on our evidence and professional opinions, we think it is most prudent to retain the 2000 Rule-Curve and think there is a better probability than not that if the 1970 Rule-Curve is reestablished that these systems, Namakan Reservoir and Rainy Lake, will begin to become less similar.

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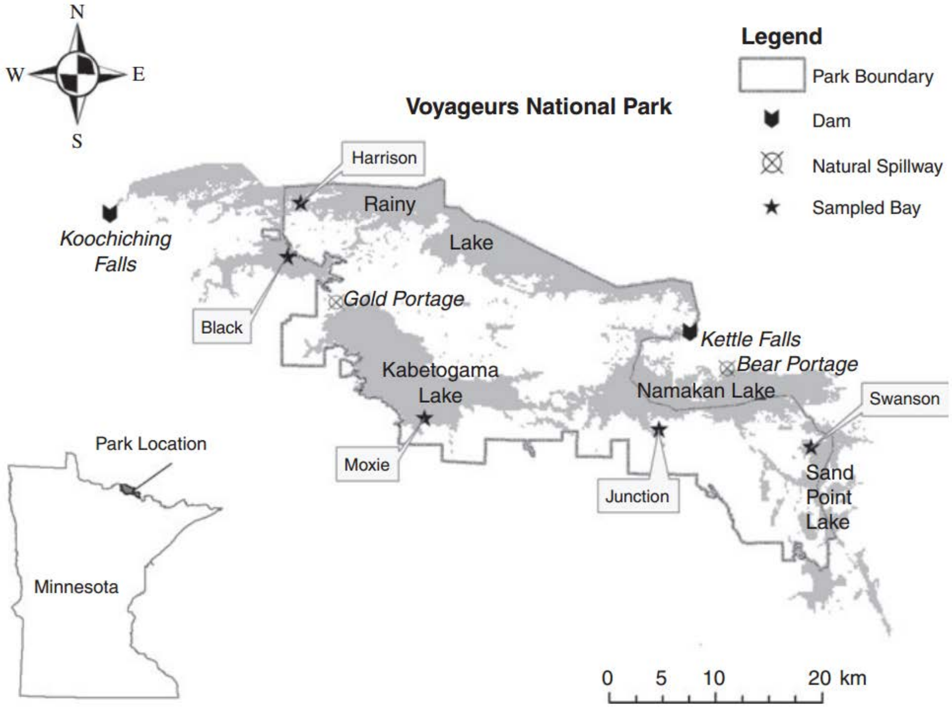

Figure 1. Voyageurs National Park on the northeastern border of Minnesota. Water flows from Kabetogama and Sand Point lakes into Namakan Lake through a control dam at Kettle Falls into Rainy Lake where outflow is used for hydroelectricity generation at Koochiching Falls in International Falls, Minnesota. Macroinvertebrate sampling sites included in Rainy Lake: Harrison and Black Bays, and in Namakan Reservoir: Moxie Bay in Kabetogama Lake, Junction Bay in Namakan Lake proper, and Swanson Bay in Sand Point lake. Figure reprinted from McEwen and Butler (2010).

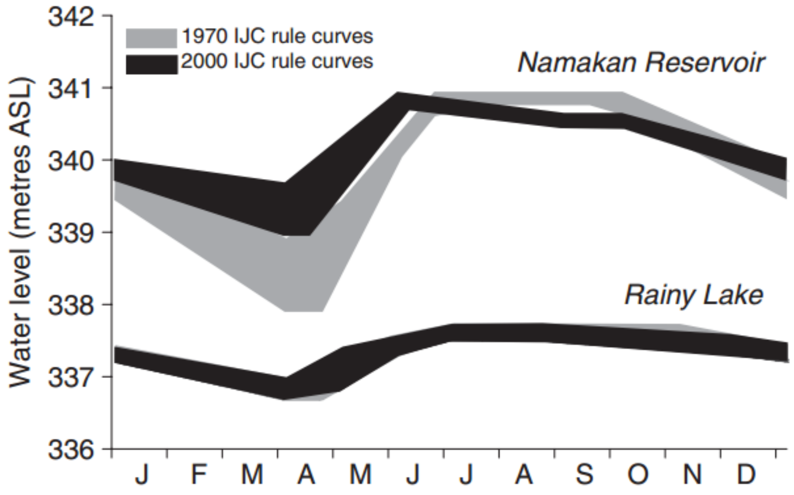

Figure 2. Comparison of the 1970 and 2000 rule curves for water level management at Voyageurs National Park issued by the International Joint Commission. Under the 1970 rule curve ruling (i.e., gray shade) Namakan Reservoir had a winter drawdown of 2.5 m while Rainy Lake had a winter drawdown of 1.1 m. Maximum water levels did not occur until the end of June under the 1970 rule curve for both systems. The 2000 rule curve ruling (i.e., black shade) reduced winter drawdown in Namakan to 1.1 m and allowed the reservoir to refill to capacity at the end of May instead of June. Both Namakan Reservoir and Rainy Lake changes between 1970 and 2000 were restricted to gradual summer release instead of maintain steady levels as was the case under the 1970 reviews. Figure reprinted from McEwen and Butler (2010).

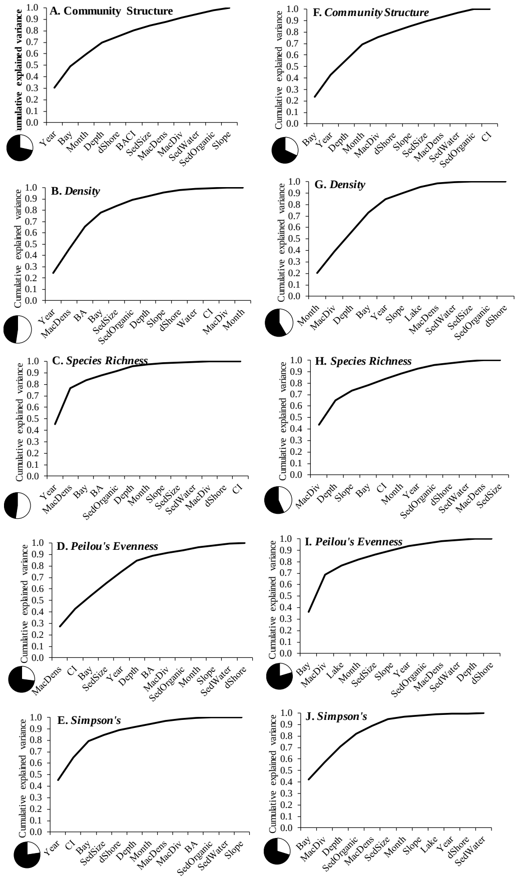

Figure 3. Variance partitioning for multivariate community structure and four univariate macrobenthic invertebrate community summaries. Pie chart in the lower left corner of subplots indicate the ratio of the unexplained (black fill) and total explained (white fill) proportion of variance based on the SSE. Cumulative plots indicate the contribution of modeled factors to the explained proportion of variance with the variables explaining most variance listed in order from left to right on the x-axes. Plots in the left panel (A-F) come from a coarse taxonomic resolution (55 total species) that is given over the entire study period and includes data from 1984-85, 2004-05, and 2012-13. Plots in the right panel (G-J) come from a finer taxonomic resolution (185 total species) but only for the most recent sampling period (2012-13).

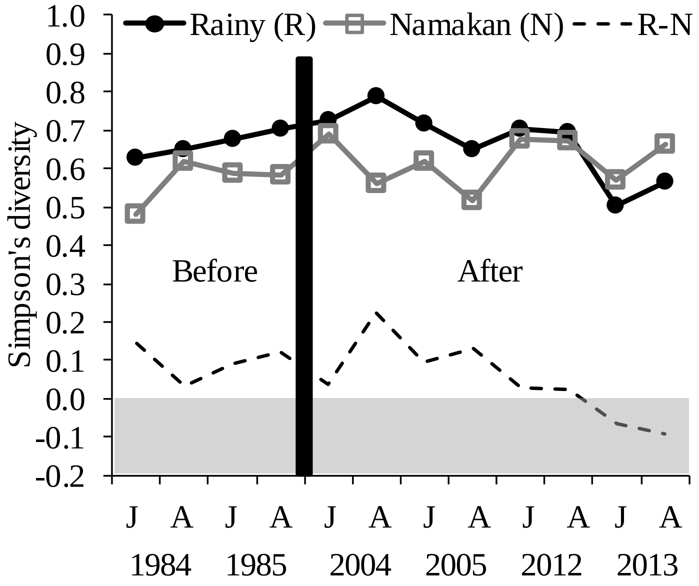

Figure 4. Interaction plot for BACI effect on Simpson's diversity index at shallow depths (1 and 2 m) after accounting for covariates year, month, macrophyte abundance, and depth. Solid vertical bar separating "Before" from "After" periods indicates the implementation of the 2000 rule curve. Time series shows months (J=June, A=August) for each year. Systems are shown as Rainy Lake for the control (solid circle markers), Namakan Reservoir for the impact (hollow square markers, and the difference between Rainy Lake and Namakan (dashed line - no marker). The shaded gray area represents time periods where the impacted site shows higher diversity index than the control area. Since August 2004, the diversity indices for the two systems have gradually been becoming more similar to one another.

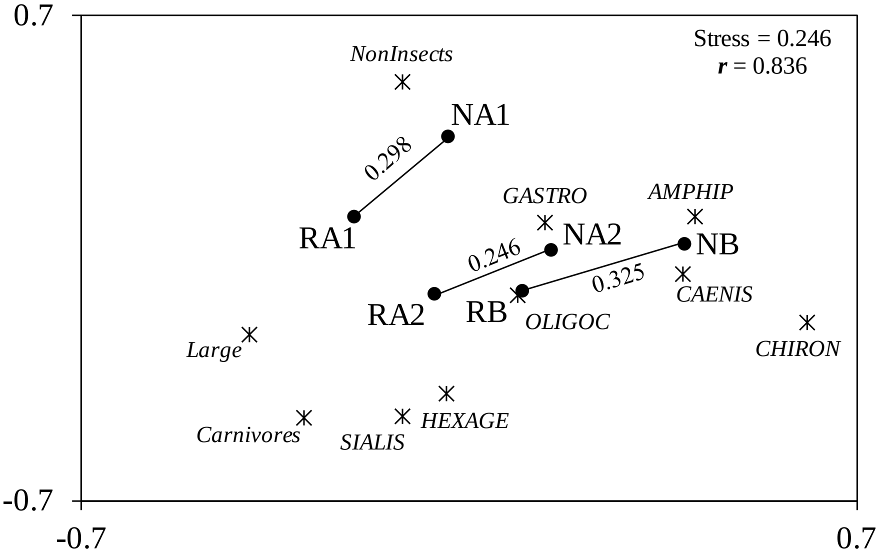

Figure 5. Nonmetric multidimensional ordination plot for centroid scores by groupings for Namakan and Rainy samples taken in shallow littoral zone (i.e., 1 & 2 m) depths during 1984-85 (NB, RB), 2004-05 (NA1, RA1), and 2012-13 (NA2, RA2). Lines drawn between centroids show ecological distance using a Euclidean measure during each sampling event where smaller distances indicate greater community similarity for macroinvertebrates. Taxonomic units are plotted as asterisks with italicized labels. Only taxonomic units proposed by Kraft (1985) to be most susceptible to drawdown and composite ratios for Large bodied organisms (Large:Small), Carnivores (Carnivores: Detritivores), and NonInsects (NonInsect:Insect) proposed to be influenced by water -level fluctuation by McEwen and Butler (2010) . The correlation coefficient (*r*) applies to the two-dimensional ordinated distance matrix correlated with the full data distance matrix. If communities are changing in concert to the rule curve change, we expect to see the distances between N and B to get closer over time, which is the case (i.e., NA2 andRA2 are closest and NB and RB are the farthest). The movement of the lines over space and time represents time-dependent shifts that are not associated with the change in the rule curves.

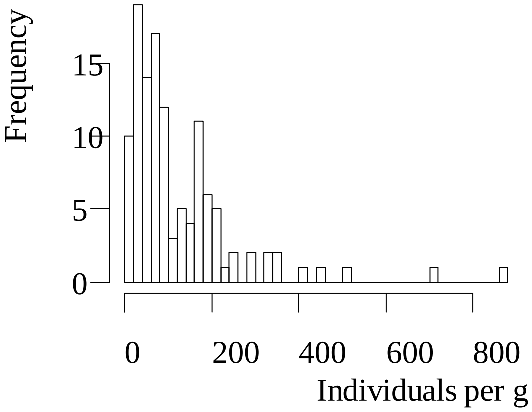

Figure 6. Catch per grab sample at the shallow littoral soft sediment sites combined over the three sampling periods: 1984-85, 2004-05, and 2012-13.

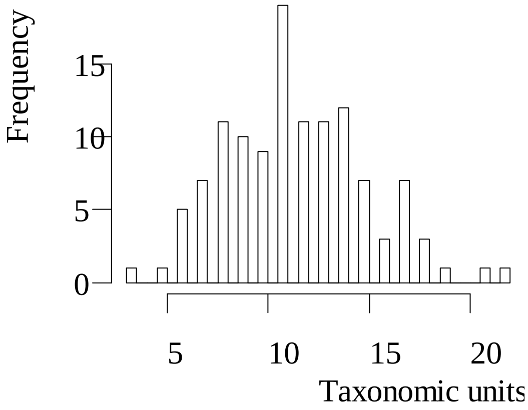

Figure 7. Taxonomic units per grab sample at the shallow littoral soft sediment sites combined over the three sampling periods: 1984-85, 2004-05, and 2012-13.

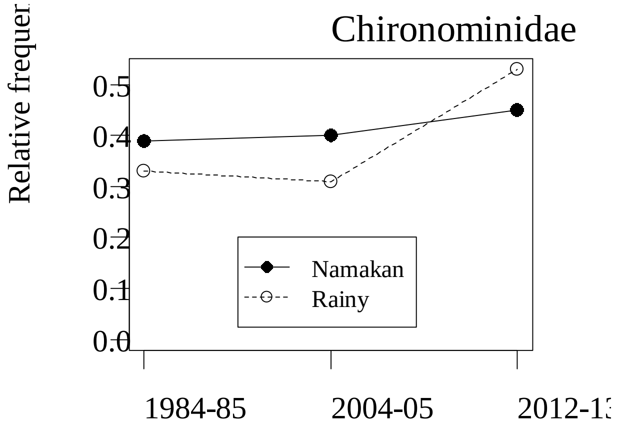

Figure 8. Relative frequency or average proportion of individuals that were chironomids in an average grab sample at the shallow littoral soft sediment sites combined over the three sampling periods: 1984-85, 2004-05, and 2012-13.

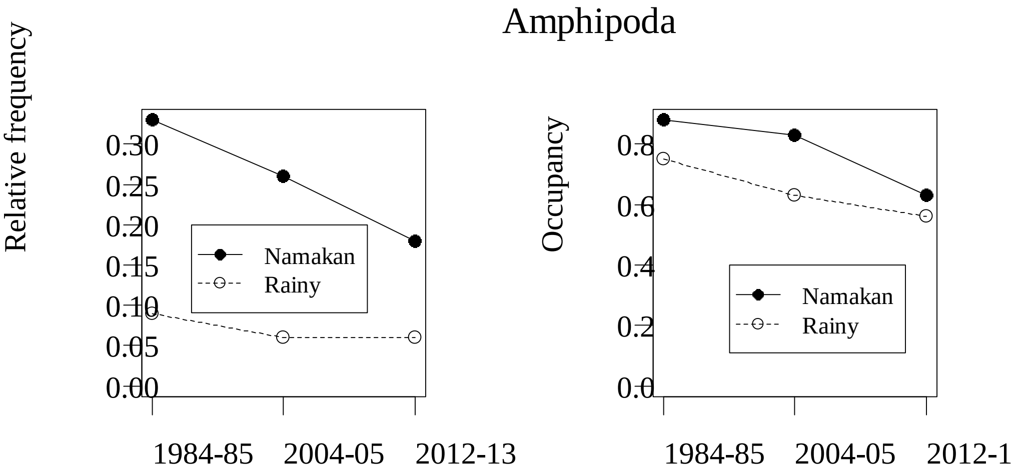

Figure 9. Left plot shows the relative frequency or average proportion of individuals that were amphipods in an average grab sample at the shallow littoral soft sediment sites, and the right plot shows the occupancy or the proportion of grab samples that contained at least one amphipod.

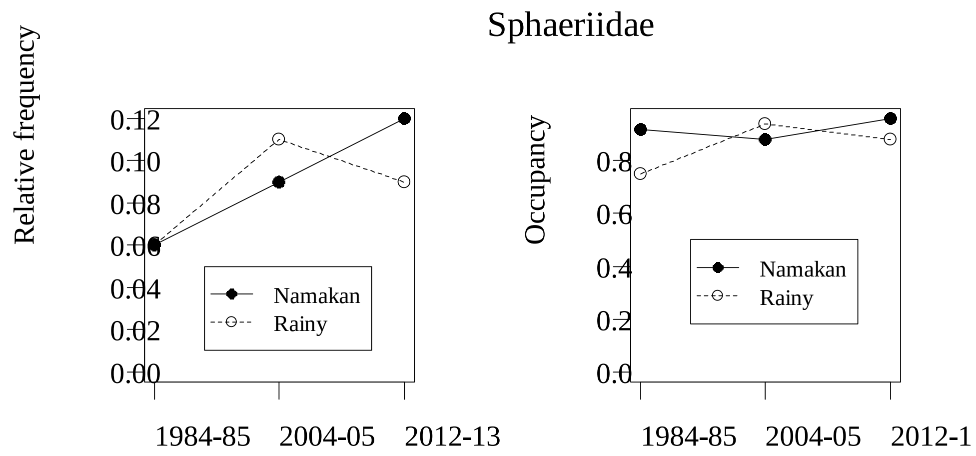

Figure 10. Left plot shows the relative frequency or average proportion of individuals that were Sphaeriidae in an average grab sample at the shallow littoral soft sediment sites, and the right plot shows the occupancy or the proportion of grab samples that contained at least one Sphaeriidae.

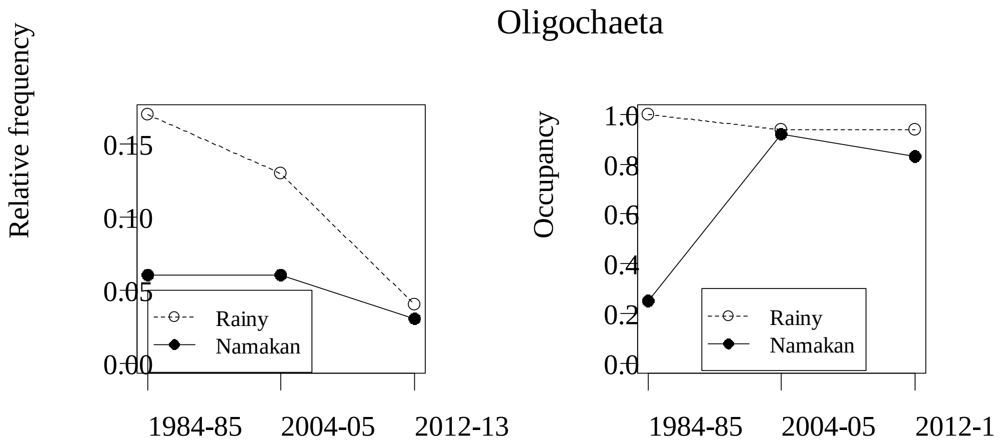

Figure 11. Left plot shows the relative frequency or average proportion of individuals that were Oligochaeta in an average grab sample at the shallow littoral soft sediment sites, and the right plot shows the occupancy or the proportion of grab samples that contained at least one Oligochaeta.

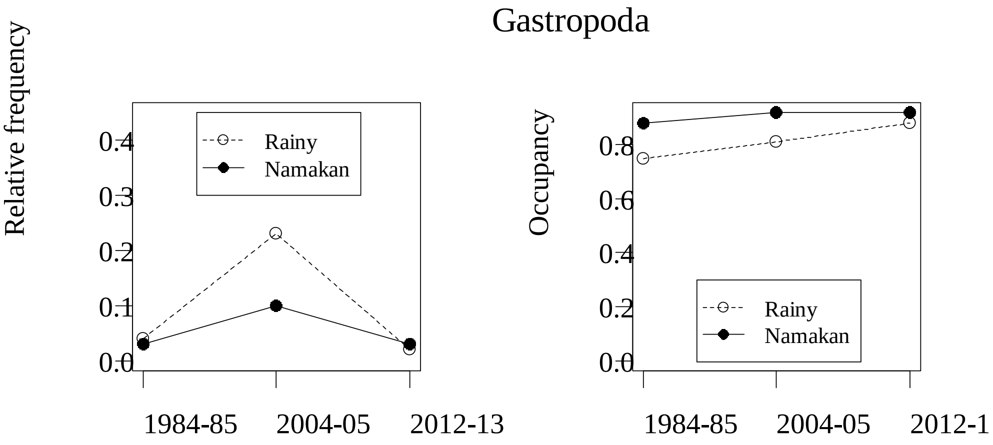

Figure 12. Left plot shows the relative frequency or average proportion of individuals that were gastropods in an average grab sample at the shallow littoral soft sediment sites, and the right plot shows the occupancy or the proportion of grab samples that contained at least one gastropods.

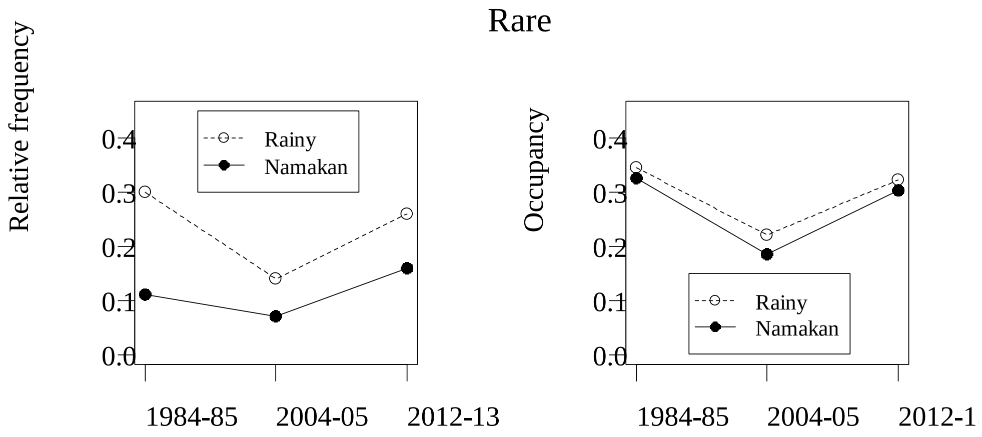

Figure 13. Left plot shows the relative frequency or average proportion of combined individuals that found in with a relative abundance of less than 5% (i.e., rare taxa) in an average grab sample at the shallow littoral soft sediment sites, and the right plot shows the occupancy or the proportion of grab samples that contained at least one rare taxon individual.

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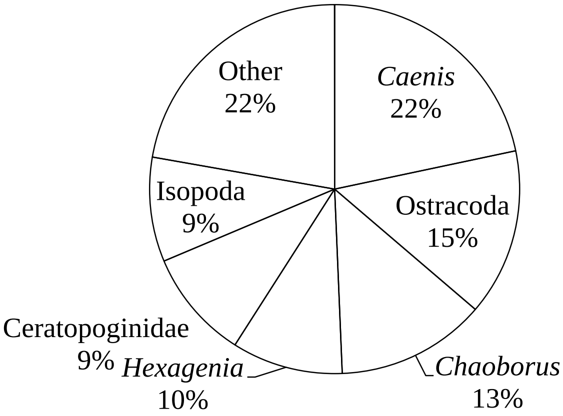

Figure 14. Proportional distribution of rare taxa defined as any taxonomic unit with an average relative abundance less than 5% for all sampling periods. The category “Other” includes all taxa that that fail to represent 5% of the rare taxa (i.e., 5% of 5%).

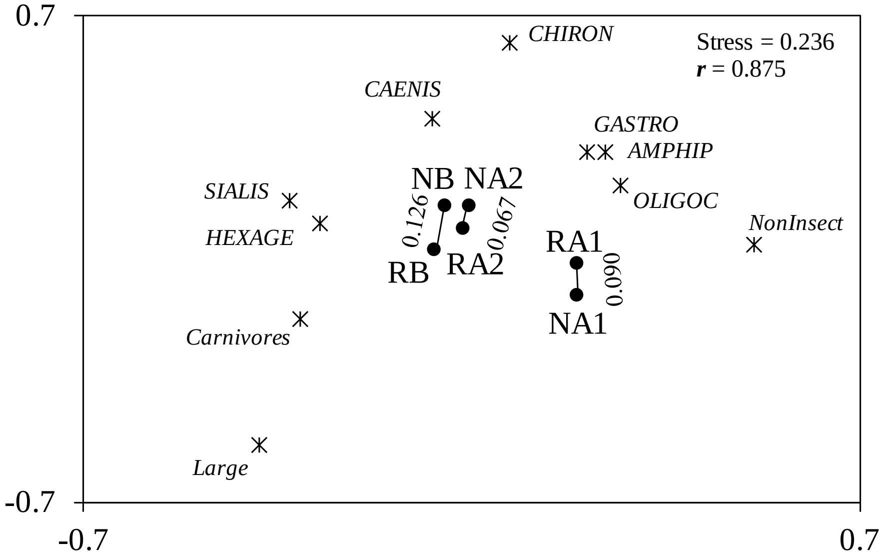

Figure 15. Nonmetric multidimensional ordination plot for centroid scores by groupings for deep littoral zone (i.e., 3, 4, and 5 m) depths in Namakan and Rainy samples taken in 1984-85 (NB, RB), 2004-05 (NA1, RA1), and 2012-13 (NA2, RA2). Lines drawn between centroids show ecological distance using a Euclidean measure during each sampling event where smaller distances indicate greater community similarity for macroinvertebrates. Taxonomic units are ploted as asterisks with italicized labels. Only taxonomic units proposed by Kraft (1985) to be most susceptible to drawdown and composite ratios for Large bodied organisms (Large:Small), Carnivores (Carnivores: Detritivores), and NonInsects (NonInsect:Insect) proposed to be influenced by water-level fluctuation by McEwen and Butler (2010) . If communities are changing in concert to the rule curve change, we expect to see the distances between N and B to get closer over time, which is the case (i.e., NA2 andRA2 are closest and NB and RB are the farthest). The movement of the lines over space and time represents time-dependent shifts that are not associated with the change in the rule curves.

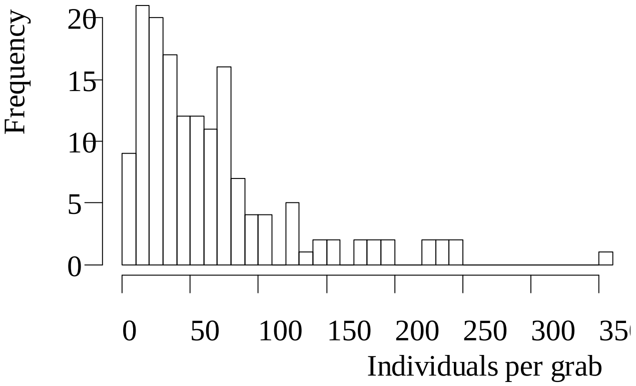

Figure 16. Catch per grab sample at the deep littoral soft sediment sites combined over the three sampling periods: 1984-85, 2004-05, and 2012-13.

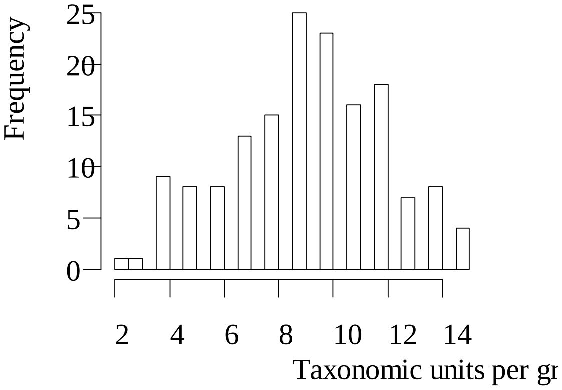

Figure 17. Taxonomic units per grab sample at the shallow littoral soft sediment sites combined over the three sampling periods: 1984-85, 2004-05, and 2012-13.

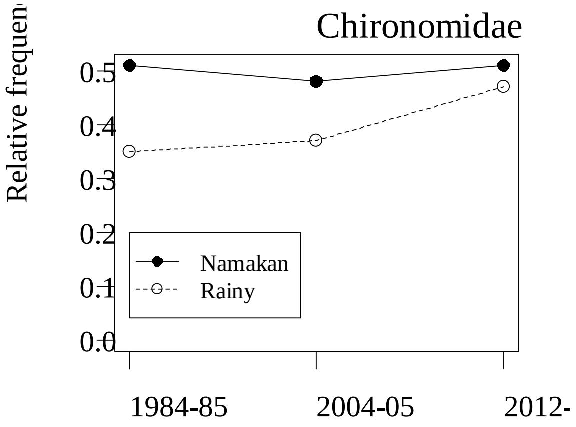

Figure 18. Relative frequency or average proportion of individuals that were chironomids in an average grab sample at the deep littoral soft sediment sites combined over the three sampling periods: 1984-85, 2004-05, and 2012-13.

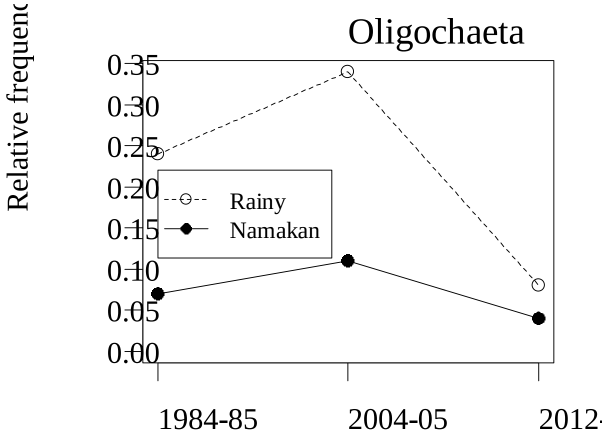

Figure 19. Relative frequency or average proportion of individuals that were oligochaetes in an average grab sample at the deep littoral soft sediment sites combined over the three sampling periods: 1984-85, 2004-05, and 2012-13.

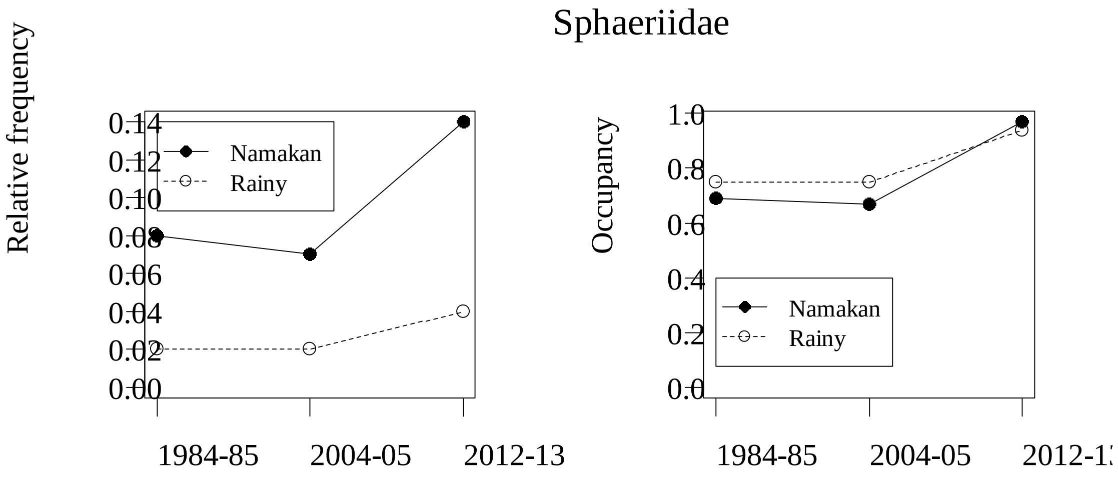

Figure 20. Left plot shows the relative frequency or average proportion of individuals that were Sphaeriidae in an average grab sample at the deep littoral soft sediment sites, and the right plot shows the occupancy or the proportion of grab samples that contained at least one Sphaeriidae.

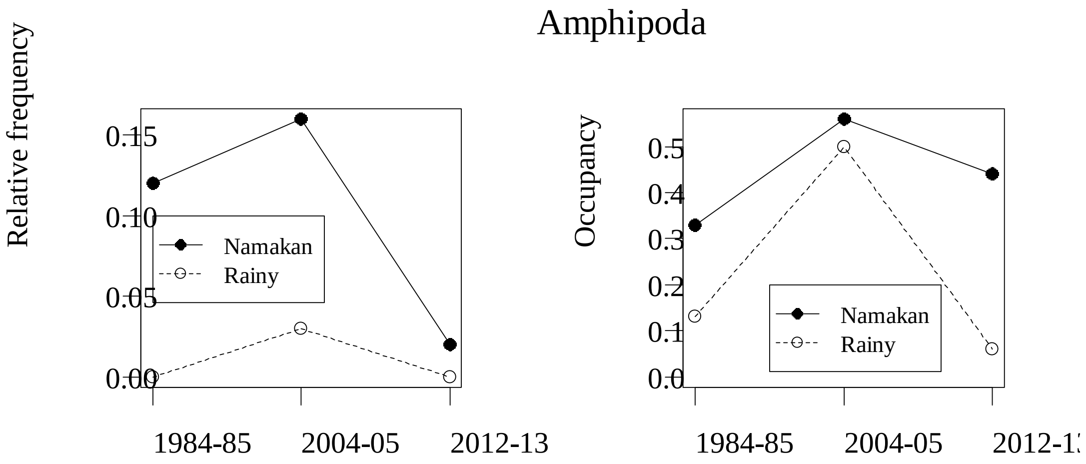

Figure 21. Left plot shows the relative frequency or average proportion of individuals that were Amphipoda in an average grab sample at the deep littoral soft sediment sites, and the right plot shows the occupancy or the proportion of grab samples that contained at least one Amphipoda.

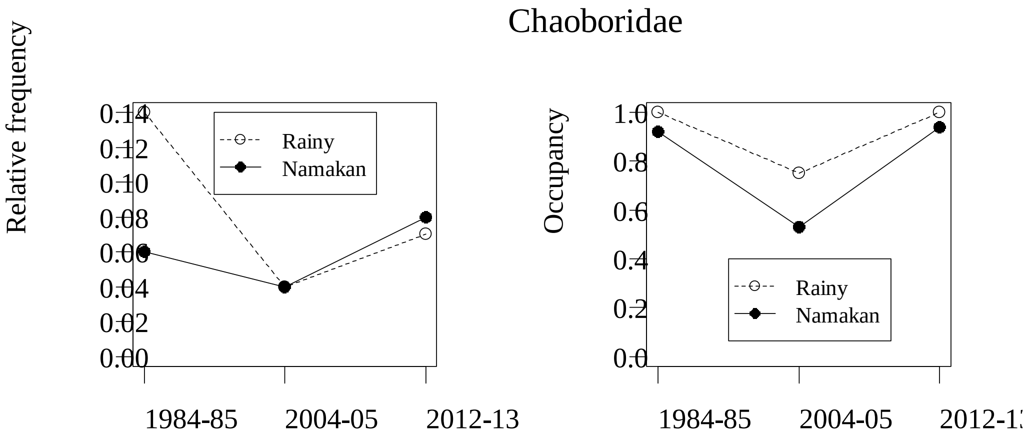

Figure 22. Left plot shows the relative frequency or average proportion of individuals that were Chaoboridae in an average grab sample at the deep littoral soft sediment sites, and the right plot shows the occupancy or the proportion of grab samples that contained at least one Chaoboridae.

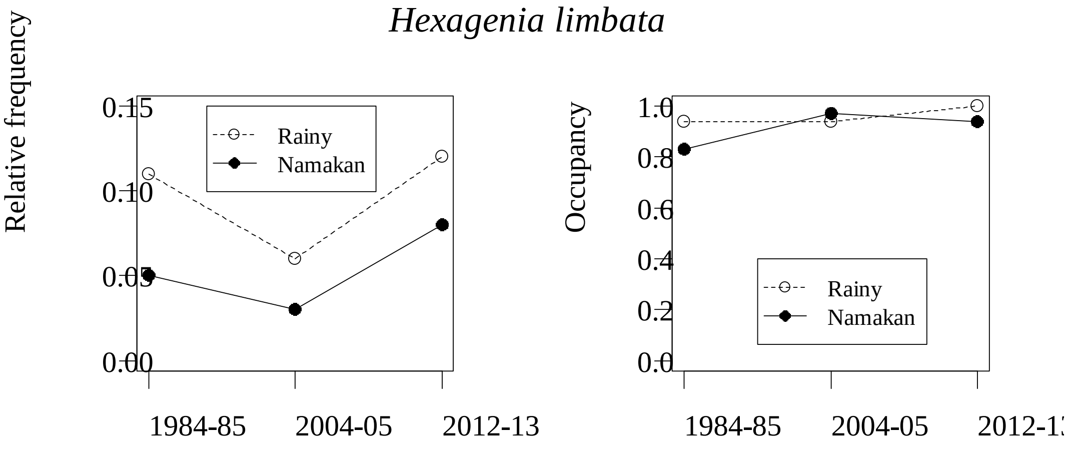

Figure 23. Left plot show the relative frequency or average proportion of individuals that were *Hexagenia limbata* in an average grab sample at the deep littoral soft sediment sites, and the right plot shows the occupancy or the proportion of grab samples that contained at least one *Hexagenia limbata*.

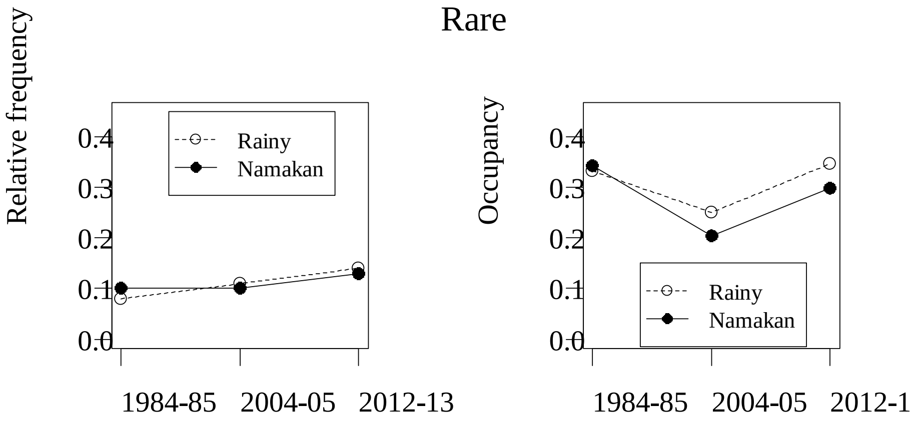

Figure 24. Left plot shows the relative frequency or average proportion of combined individuals that found in with a relative abundance of less than 5% (i.e., rare taxa) in an average grab sample at the deep littoral soft sediment sites, and the right plot shows the occupancy or the proportion of grab samples that contained at least one rare taxon individual.

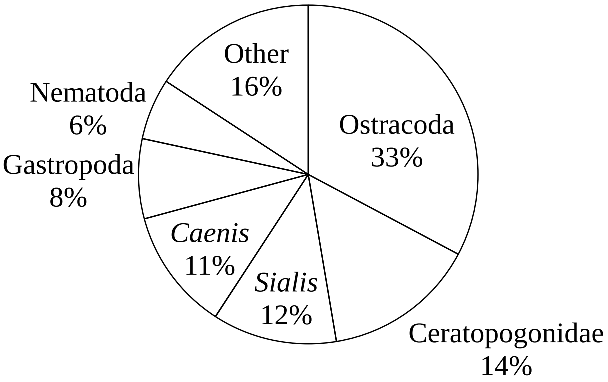

Figure 21. Proportional distribution of rare taxa defined as any taxonomic unit with an average relative abundance less than 5% for all sampling periods. The category “Other” includes all taxa that that fail to represent 5% of the rare taxa (i.e., 5% of 5%).

Table 1. Taxonomic units used in the BACI analysis. Even though taxa were identified to a finer resolution in 2004-05 and 2012-13, we clumped to original taxa specified by Kraft (1988) for comparability. Size class designations were assigned based on the median asymptotic length of 15 mm where those less than this threshold were classified as small and those larger as large. Trophy is major feeding style, although the category detritivore is probably better described as herbivore-detritivore.

SuperGroup	Phylum	Class	Order	Family	Genus	Symbol	Size Class	Trophy
Non-Arthropoda	Porifera					PORIFE	Small	Detritivore
	Platyhelminthes	Tubellaria				TUBELL	Large	Carnivore
	Nematomorpha					NEMMOR	Small	Carnivore
	Nematoda					NEMATO	Small	Detritivore
	Annelida	Clitelata	Oligochaeta			OLIGOC	Large	Detritivore
			Hirudinea			HIRUDI	Large	Carnivore
	Mollusca	Gastropoda				GASTRO	Small	Detritivore
		Pelecypoda	Veneroida	Sphaeriidae		SPHAER	Small	Detritivore
Arthropoda	Arthropoda	Arachnida	Trombidiformes	Hydracarina		HYDRAC	Small	Carnivore
		Crustacea	Amphipoda			AMPHIP	Small	Detritivore
			Isopoda			ISOPOD	Large	Detritivore
			Ostracoda			OSTRAC	Small	Detritivore
			Spinicaudata			SPINIC	Large	Detritivore
		Insecta	Coleoptera	Chrysomelidae	*Donacia*	CHRDON	Small	Detritivore
				Dytiscidae	*Hydroporus*	DYTHYD	Large	Carnivore
				Elimidae	*Dubiraphia*	DUBIRA	Small	Detritivore
				Gyrinidae	*Gyrinus*	GYRGYR	Large	Carnivore
				Haliplidae	*Haliplus*	HALHAL	Small	Detritivore
			Diptera	Ceratopogonidae		CERATO	Large	Carnivore
				Chaoboridae	*Chaoborus*	CHAOBO	Small	Carnivore
				Chironomidae		CHIRON	Small	Detritivore
				Tabanidae	*Chrysops*	TABCHR	Small	Carnivore
				Tephriidae		TEPHRI	Small	Carnivore
				Tipulidae		TIPULI	Large	Detritivore
			Ephemeroptera	Baetidae	*Callibaetis*	CALLIB	Small	Detritivore
				Baetiscidae	*Baetisca*	BAETIS	Small	Detritivore
				Caenidae	*Caenis*	CAENIS	Small	Detritivore
				Ephemeridae	*Hexagenia*	HEXAGE	Large	Detritivore
				Ephemerillidae	*Eurylophella*	EURYLO	Large	Detritivore
				Heptageniidae	*Macdunoa*	HEPMAC	Large	Detritivore
			Hemiptera	Aphididae		APHIDI	Small	Carnivore
				Corixidae		CORIXI	Small	Detritivore
			Lepidoptera	Pyralidae		PYRALI	Large	Detritivore
			Megaloptera	Sialidae	*Sialis*	SIALIS	Large	Carnivore
			Neuroptera	Sisyridae	*Climacia*	CLIMAC	Small	Carnivore
			Odonata	Coenagrionidae	*Enallagma*	ENALLA	Large	Carnivore
				Corduliidae	*Tetragoneuria*	TETRAG	Large	Carnivore
				Gomphidae	*Agriogomphus*	ARIGOM	Large	Carnivore
				Gomphidae	*Gomphus*	GOMGOM	Large	Carnivore
				Libelluidae	*Ladona*	LIBUND	Large	Carnivore
					Leucorrhinia	LEUCOR	Large	Carnivore
					Perithemis	PERITH	Large	Carnivore
				Macromiidae	*Didymops*	DIDYMO	Large	Carnivore
			Trichoptera	Hydroptilidae	*Agraylea*	HYDAGR	Small	Detritivore
					Oxyethira	HYDOXY	Small	Detritivore
				Leptoceridae	*Mystacides*	LEPMYS	Small	Detritivore
					Nectopsyche	LEPNEC	Small	Detritivore
					Oecetis	LEPOEC	Small	Carnivore
					Triaenodes	LEPTRI	Large	Detritivore
				Limnephilidae	*Limnephilus*	LIMLIM	Large	Detritivore
				Molannidae	*Molanna*	MOLMOL	Large	Detritivore
				Phryganeidae	*Banksiola*	PHRBAN	Large	Detritivore
					Phryganea	PHRPHR	Large	Detritivore
				Polycentropodidae	*Cernotina*	POLCER	Large	Carnivore

Table 2. New taxonomic units identified in 2012-13 not previously reported in McEwen and Butler (2010). Site names are given as Bay-Depth (e.g., B1 = Black Bay 1 m). The remaining bays are Harrison (H), Junction (J), Moxie (M), and Swanson (S).

Classification					Rainy Lake								Namakan Reservior														
Phylum	Class	Order	Family	Genus	B1	B2	B3	H1	H2	H3	H4	H5	J1	J2	J3	J4	J5	M1	M2	M3	M4	M5	S1	S2	S3	S4	S5
Annelida	Polychaeta	Canalipalpata	Sabellidae	*Manayunkia*	1	5		3	9	53	173	273	4	11	27	97	1								5		
Arthropoda	Crustacea	Cladocera	Cercopagididae	*Bythotrephes*		1					3			1		2					2	1					
	Insecta	Coleoptera	Dytiscidae	*Agabus*														1									
			Haliplidae	*Peltodytes*												1											
		Diptera	Chironomidae	*Cladotanytarsus*	1	24	3	88	19	62	42	12	23	49	31	46	2	97	14	3	3	1	22	13	9	3	
				Cryptochironomus	1	3	4	8	3			2	5	1	11	7	8	21	17	7	12	5	2	24	1		2
				Heterotrissocladius											1	1		1									
				Nanocladius	2	1		2	3					1	1		1	8	5	1			2	1	2	1	
				Paracladopelma		2	1		3			4	1	2	5	4	5	4	8	54	28	12		1	7	11	3
				Tanypus				3	6	3			5	3		3	29						3	23	1	1	
				Thienemanniella						1														3			
		Ephemeroptera	Baetidae	*Fallceon*	2													3	1								
			Ephemeridae	*Ephemera*						1						1				1		1			1		
			Leptophlebiidae	*Asioplax*																1							
				Habrophlebia																							1
			Siphloneuridae	*Parameletus*						1																	
				Siphloneurus						1																	
		Lepidoptera	Crambidae	*Neargyractis*															5								
		Lepidoptera	Crambidae	*Parapoynx*				2																			
		Lepidoptera	Pyralidae	*Acentria*									1					4	22								
		Neuroptera	Sisyridae	*Sisyra*				1																			
		Odonata	Corduliidae	*Epitheca*	1			2	1				2	2		1				1			1	1			
			Corduliidae	*Somatochlora*									1														
		Trichoptera	Dipseudopsidae	*Phylocentropus*				1	2	4	2		2	1	5	2	4	3	2	2					1	6	4
		Trichoptera	Leptoceridae	*Ceraclea*	1											1							1	2			
		Trichoptera	Limnephilidae	*Glyphopsyche*	2			1																			
		Trichoptera	Molannidae	*Molannodes*														1	4	1			3	1	2	1	
		Trichoptera	Phryganeidae	*Agrypnia*				3		1								4	3				3				

Table 3. Estimated emergence densities of aquatic insects emerging from vegetation beds at Voyageurs National Park (2012-2013).

VOYAGEURS NATIONAL PARK 2012-2013			Black Bay	Harrison Bay	Junction Bay	Moxie Bay	Swanson Bay	Average
Estimated densities of insects emerging from aquatic vegetation.			Average Project	Average Project	Average Project	Average Project	Average Project	Across all Bays
		EMERGENCE TOTALS BY BAY	Density per	Density per	Density per	Density per	Density per	Both Months
Order	Family	Genus	Sq Meter	Sq Meter	Sq Meter	Sq Meter	Sq Meter	Both Years
Diptera	Chironomidae	*Procladius*	18.3	26.3	10.9	17.1	29.7	20.5
Diptera	Chironomidae	*Tanytarsus*	8.6	18.3	21.1	10.3	26.8	17.0
Diptera	Chironomidae	*Cladotanytarsus*	12.0	20.0	24.0	9.7	7.4	14.6
Diptera	Chironomidae	*Corynoneura*	1.7	7.4	33.1	12.6	14.9	13.9
Diptera	Chironomidae	*Ablabesmyia*	12.0	17.1	16.6	10.9	13.1	13.9
Diptera	Chironomidae	*Polypedilum*	10.9	8.0	5.1	24.6	19.4	13.6
Diptera	Chironomidae	*Cricotopus/Orthocladius*	8.6	13.1	13.1	14.9	13.1	12.6
Diptera	Chironomidae	*Parakiefferiella*	0.6	10.9	20.6	2.9	13.1	9.6
Diptera	Chironomidae	*Paratanytarsus*	10.9	8.0	12.6	8.0	1.7	8.2
Diptera	Chironomidae	*Nanocladius*	0.0	10.9	15.4	1.7	9.7	7.5
Diptera	Chironomidae	*Dicrotendipes*	6.0	5.7	6.3	13.1	4.6	7.1
Diptera	Chironomidae	*Pseudochironomus*	2.9	2.9	0.0	14.3	11.4	6.3
Ephemeroptera	Caenidae	*Caenis*	3.4	2.9	13.7	5.7	2.9	5.7
Diptera	Chironomidae	*Cryptotendipes*	6.4	3.4	2.3	4.6	9.7	5.3
Diptera	Chironomidae	*Chironomus*	3.4	0.0	0.0	16.3	5.7	5.1
Diptera	Chironomidae	*Glyptotendipes*	0.6	0.6	1.7	18.2	0.6	4.3
Diptera	Chironomidae	*Cryptochironomus*	1.1	2.3	0.0	9.1	5.1	3.5
Diptera	Chironomidae	*Cladopelma*	3.4	5.1	1.7	0.0	6.3	3.3
Diptera	Chironomidae	*Endochironomus*	0.6	0.0	2.3	8.6	4.6	3.2
Diptera	Chironomidae	*Parachironomus*	1.7	0.0	4.6	8.8	0.6	3.1
Diptera	Chironomidae	*Thienemanniella*	1.1	1.1	2.9	1.7	8.0	3.0
Diptera	Chironomidae	*Labrundinia*	0.6	3.4	5.1	0.0	0.0	1.8
Diptera	Ephemeridae	*Hexagenia*	0.6	4.8	1.1	1.1	0.0	1.5
Diptera	Chironomidae	*Pagastiella*	0.0	6.3	0.6	0.0	0.0	1.4
Diptera	Chaoboridae	*Chaoborus*	0.0	0.0	6.3	0.0	0.0	1.3
Diptera	Chironomidae	*Psectrocladius*	0.0	3.4	0.6	0.6	1.1	1.1
Trichoptera	Leptoceridae	*Oecetis*	1.7	0.0	1.1	1.1	1.4	1.1
Diptera	Chironomidae	*Clinotanypus*	1.7	0.0	1.1	1.1	0.6	0.9
Diptera	Chironomidae	*Phaenopsectra*	1.1	0.6	0.0	1.1	0.6	0.7
Diptera	Chironomidae	*Microtendipes*	0.6	0.6	0.6	1.7	0.0	0.7
Diptera	Chironomidae	*Paracladopelma*	1.7	0.0	0.0	0.6	0.6	0.6
Diptera	Ceratopogonidae	*Bezzia/Palpomyia*	0.6	2.3	0.0	0.0	0.0	0.6
Diptera	Chironomidae	*Apedilum*	0.0	1.1	0.0	0.6	0.6	0.5
Diptera	Chironomidae	*Stempellinella*	0.0	0.6	1.1	0.0	0.0	0.3
Diptera	Chironomidae	*Tanypus*	0.0	0.0	0.0	0.0	1.1	0.2
Diptera	Chironomidae	*Heterotrissocladius*	0.0	0.6	0.0	0.6	0.0	0.2
Diptera	Chironomidae	*Paralauterborniella*	0.0	0.0	0.0	0.0	0.6	0.1
Diptera	Ceratopogonidae	*Culicoides*	0.0	0.6	0.0	0.0	0.0	0.1
Diptera	Chironomidae	*Conchapelopia/Thienemannimyia* gr.	0.0	0.0	0.0	0.6	0.0	0.1
Diptera	Chironomidae	*Paratendipes*	0.0	0.0	0.6	0.0	0.0	0.1
Diptera	Chironomidae	*Stempellina*	0.6	0.0	0.0	0.0	0.0	0.1
Diptera	Chironomidae	*Stenochironomus*	0.6	0.0	0.0	0.0	0.0	0.1

Table 4. Abundances of aquatic macroinvertebrates occurring on submerged wood substrates at Voyageurs National Park (2012-2013).

VOYAGEURS NATIONAL PARK: 2012-2013			**Functional**	**Project Totals**	**Project Totals**	**Project Totals**
Aquatic Macroinvertebrates on Wood Substrates		**2012-2013**	**Feeding**	**All Sites**	**All Sites**	**All Site**
		ANNUAL TOTALS	**Group**	**Both Months**	**Both Months**	**Both Months**
Order	**Family**	**Genus**	**Classification**	**2012**	**2013**	**Both Years**
Diptera	Chironomidae	*Corynoneura*	**Grazer**	217	166	383
Diptera	Chironomidae	*Polypedilum*	**Grazer/Shredder**	141	156	297
Diptera	Chironomidae	*Thienemanniella*	**Grazer**	129	135	264
Diptera	Chironomidae	*Glyptotendipes*	**Shredder**	114	96	210
Diptera	Chironomidae	*Cricotopus/Orthocladius*	**Grazer/Shredder**	71	94	165
Ephemeroptera	Caenidae	*Caenis*	**Grazer**	82	51	133
Diptera	Chironomidae	*Dicrotendipes*	**Grazer/Shredder**	65	65	130
Amphipoda	Gammaridea		**Grazer**	70	59	129
Diptera	Chironomidae	*Tanytarsus*	**Grazer**	61	57	118
Diptera	Chironomidae	*Paratanytarsus*	**Grazer**	44	58	102
Gastropoda		*Ferrissia parallelus*	**Grazer**	65	33	98
Diptera	Chironomidae	*Nanocladius*	**Grazer**	35	46	81
Diptera	Chironomidae	*Ablabesmyia*	**Predator**	28	49	77
Diptera	Chironomidae	*Parakiefferiella*	**Grazer**	33	20	53
Coleoptera	Haliplidae	*Peltodytes*	**Grazer/Shredder**	37	9	46
Diptera	Chironomidae	*Phaenopsectra*	**Shredder**	24	22	46
Turbellaria	Planariidae (?)	Unknown	**Grazer**	34	11	45
Gastropoda		*Promenetus exacuous*	**Grazer**	23	3	26
Diptera	Chironomidae	*Endotribelos*	**Shredder**	11	11	22
Hirudinea		*Erpobdella punctata*	**Grazer**	15	4	19
Megaloptera	Sialidae	*Sialis*	**Predator**	10	5	15
Ephemeroptera	Baetidae	*Fallceon (?) (early instars)*	**Grazer**	8	6	14
Diptera	Chironomidae	*Stenochironomus*	**Xylophagic**	0	10	10
Diptera	Chironomidae	*Conchapelopia/Thienemannimyia* gr.	**Predator**	0	9	9
Trichoptera	Hydropsychidae	Unknown (early instars)	**Filterer**	7	1	8
Ephemeroptera	Ephemerillidae	*Eurylophella*	**Grazer**	5	3	8
Diptera	Chironomidae	*Chironomus*	**Grazer**	6	2	8
Diptera	Chironomidae	*Cladotanytarsus*	**Grazer**	6	2	8
Diptera	Chironomidae	*Labrundinia*	**Grazer**	0	7	7
Gastropoda		*Planorbella trivolvis*	**Grazer**	5	1	6
Oligochaeta		(Oligochaeta)	**Grazer**	6	0	6
Odonata	Coenagrionidae	*Coenagrion/Enallagma*	**Predator**	2	4	6
Isopoda		(Isopoda)	**Grazer**	3	2	5
Trichoptera	Limnephilidae	Unknown *(Chilostigma?,* early instar)	**Grazer**	0	5	5
Diptera	Chironomidae	*Microtendipes*	**Shredder**	4	1	5
Gastropoda		Unknown gastropod (immature)	**Grazer**	0	3	3
Trichoptera	Leptoceridae	*Oecetis*	**Grazer**	2	1	3
Diptera	Chironomidae	*Nilothauma*	**Shredder**	1	2	3
Gastropoda		*Stagnicola*	**Grazer**	0	2	2
Coleoptera	Gyrinidae	*Gyrinus*	**Predator**	0	2	2
Diptera	Chironomidae	*Brillia*	**Shredder**	0	2	2
Diptera	Chironomidae	*Pseudochironomus*	**Grazer**	1	1	2
Diptera	Chironomidae	*Stictochironomus*	**Shredder**	1	1	2
Hirudinea		*Helobdella stagnalis/modesta*	**Grazer**	0	1	1
Trichoptera	Limnephilidae	*Glyphopsyche*	**Grazer**	1	0	1
Coleoptera	Dytiscidae	*Agabus*	**Predator**	0	1	1
Diptera	Chironomidae	*Endochironomus*	**Shredder**	1	0	1
Diptera	Chironomidae	*Paralauterborniella*	**Grazer**	1	0	1
Diptera	Chironomidae	*Xylotopus (?) (early instar)*	**Xylophagic**	0	1	1

Table 5. Similarity of aquatic insects emerging from vegetation beds at differing temporal scales.

Scale of Comparison	**Cumulative Results**	**JAC Similarity**	**WPS Similarity**
All sites, by year	All sites 2012 vs All sites 2013	78.6%	89.5%
All sites, by month	June (12 + 13) vs Aug (12 + 13)	73.3%	84.6%
By individual bay (Rainy)			
Black Bay	2012 vs 2013	56.7%	75.7%
Harrison Bay	2012 vs 2013	72.4%	80.5%
By individual bay (Namakan)			
Junction Bay	2012 vs 2013	75.0%	83.0%
Moxie Bay	2012 vs 2013	73.3%	84.6%
Swanson Bay	2012 vs 2013	72.4%	79.1%
By individual bay (Rainy)			
Black Bay	June (12 + 13) vs Aug (12 + 13)	43.3%	47.9%
Harrison Bay	June (12 + 13) vs Aug (12 + 13)	58.6%	61.8%
By individual bay (Namakan)			
Junction Bay	June (12 + 13) vs Aug (12 + 13)	60.7%	76.9%
Moxie Bay	June (12 + 13) vs Aug (12 + 13)	63.3%	75.9%
Swanson Bay	June (12 + 13) vs Aug (12 + 13)	72.4%	70.4%

Table 6. Similarity of aquatic invertebrates on submerged wood substrates at differing temporal scales

Scale of Comparison	**Cumulative Results**	**JAC Similarity**	**WPS Similarity**
All sites, by year	All sites 2012 vs All sites 2013	64.4%	83.9%
All sites, by month	June (12 + 13) vs Aug (12 + 13)	87.3%	89.2%
By individual bay (Rainy)			
Black Bay	2012 vs 2013	66.7%	75.7%
Harrison Bay	2012 vs 2013	73.3%	78.5%
By individual bay (Namakan)			
Junction Bay	2012 vs 2013	56.2%	75.9%
Moxie Bay	2012 vs 2013	50.0%	75.3%
Swanson Bay	2012 vs 2013	58.8%	78.0%
By individual bay (Rainy)			
Black Bay	June (12 + 13) vs Aug (12 + 13)	63.3%	76.6%
Harrison Bay	June (12 + 13) vs Aug (12 + 13)	78.6%	82.1%
By individual bay (Namakan)			
Junction Bay	June (12 + 13) vs Aug (12 + 13)	62.5%	80.6%
Moxie Bay	June (12 + 13) vs Aug (12 + 13)	50.0%	78.6%
Swanson Bay	June (12 + 13) vs Aug (12 + 13)	58.8%	81.1%

Table 7. Bay-to-Bay comparison of the composition of emergence of aquatic insects as calculated with JAC. (JAC percent similarity shown in table cells below the diagonal. Rank of JAC similarity shown in corresponding table cells above the diagonal).

	Black Bay	Harrison Bay	Junction Bay	Moxie Bay	Swanson Bay
Black Bay	-----	8	6 (tie)	2	3
Harrison Bay	59.4%	-----	5	4	10
Junction Bay	61.1%	62.8%	-----	6 (tie)	9
Moxie Bay	71.4%	63.9%	61.1%	-----	1
Swanson Bay	68.6%	56.8%	58.3%	78.8%	-----

Table 8. Bay-to-Bay comparison of the abundance of aquatic insect emergence as calculated with WPS. (WPS percent similarity shown in the table cells below the diagonal. Rank of WPS similarity shown in the corresponding table cells above the diagonal).

	Black Bay	Harrison Bay	Junction Bay	Moxie Bay	Swanson Bay
Black Bay	-----	1	8	6	4
Harrison Bay	71.4%	-----	3	9	2
Junction Bay	56.9%	70.2%	-----	10	7
Moxie Bay	63.8%	54.1%	51.0%	-----	5
Swanson Bay	67.8%	71.2%	59.2%	65.5%	-----

Table 9. Bay-to-Bay comparison of the composition of aquatic insects on submerged wood substrates as calculated with JAC. (JAC percent similarity shown in table cells below the diagonal. Rank of JAC similarity shown in corresponding table cells above the diagonal).

	Black Bay	Harrison Bay	Junction Bay	Moxie Bay	Swanson Bay
Black Bay	-----	3	2	6	1
Harrison Bay	66.7%	-----	5	9	10
Junction Bay	67.6%	63.2%	-----	8	4
Moxie Bay	62.2%	53.8%	59.0%	-----	7
Swanson Bay	68.4%	52.4%	65.0%	60.0%	-----

Table 10. Bay-to-Bay comparison of the abundance of aquatic insects on submerged wood substrates as calculated with WPS. (WPS percent similarity shown in the table cells below the diagonal. Rank of WPS similarity shown in the corresponding table cells above the diagonal).

	Black Bay	Harrison Bay	Junction Bay	Moxie Bay	Swanson Bay
Black Bay	-----	2	4	9	3
Harrison Bay	78.7%	-----	5	6	1
Junction Bay	76.4%	74.2%	-----	10	8
Moxie Bay	66.0%	72.5%	63.7%	-----	7
Swanson Bay	78.0%	80.8%	70.6%	71.4%	-----