

Do long-term macrophyte management efforts in inland lakes effect system wide biotic richness and diversity?

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INTRODUCTION

Lake Moraine (42° 50' 47" N, 75° 31' 39" W), in Madison County in east-central New York State, is an artificially raised impoundment originally formed by the damming of a valley by the deposition of glacial moraine. This 106 ha (261 acre) water body comprises two distinct basins separated by Madison County Rt. 87 traversing a causeway between them. A submerged culvert under the highway joins the north and south basins. The northern basin occupies 32 ha (79 acres), has a maximum depth of about 3.7 m (12 feet) and a mean depth of 1.1 m (3.7 feet). This study, and most human activity, focuses upon the southern basin which occupies 74 ha (182 acres), has a maximum depth of 13.7 m (45 feet) and a mean depth of 5.4 m (17.7 feet) (Harman et al. 2003). The lake is dimictic and eutrophic, as reflected by low transparency, high productivity of algae and vascular plants and hypolimnetic oxygen depletion during summer stratification. Phosphorus appears to be limiting (Harman 1978; Oglesby 1975). Agricultural activities and residential development are believed to be primarily responsible for the bulk of the phosphorus loading (Hohenstein et al. 1997). Excessive algal and submergent macrophyte growth, primarily Eurasian water milfoil, has chronically impaired recreational activities (Anon 1991; Harman et al. 1997).

Eurasian water milfoil (*Myriophyllum spicatum*) is a non-native aquatic macrophyte which was introduced into North American waters in the late 19th century (Reed 1977). From the Chesapeake Bay, it has spread throughout North America including many northeastern lakes. It out-competes native species because of its tendency to grow quickly after spring ice out. By the time spring growth is initiated by native plants they are already partially shaded by the milfoil, and are quickly further deprived of sunlight by the thick canopy that milfoil soon forms at the surface of the water (Lord 2004). *Myriophyllum* may produce flowers in the late growing season and later seeds, but in Lake Moraine, it reproduces by asexual fragmentation and expansion of root crowns and runners, a typical situation in northeastern lakes (Aiken et. al. 1979).

Moraine Lake was dammed and managed as a source of water for the NYS Erie Canal system, which officially opened in 1825. Water levels have been artificially controlled since that time. In recent years winter draw down of *ca.* 1.5 m (5 feet) has been annually undertaken for the convenience of cottage owners and protection of their properties (Staley 2004). Management of *M. spicatum* has been the a priority of the Lake Moraine Association, and before it by the American Management Association, both of which have developed long

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histories of in-lake plant control activities, physical, chemical and biological. Initial efforts in the 1940s to manage aquatic plants involved physical methods including mechanical harvesting. That method has been used, with few exceptions, annually in Lake Moraine until quite recently (Lord 2003). The annual lowering of water levels, as mentioned above, has also been recognized as inhibiting to plant growth (Harman 1978). The first chemical methods used to control macrophyte growth were implemented in the late 1940s (Anon. 1996). Initially, copper sulfate (CuSO_4) was used as a non-selective herbicide (Kastens 1974). It has been frequently used since the 1970s for control of planktonic algae. In 1972-73 Diquat (1,1'-ethylene-2,2'-bipyridylium dibromide salt [$\text{C}_{12}\text{H}_{12}\text{N}_2\text{Br}_2$]) was used for control of planktonic algae (Kastens 1974). Simazine (6-chloro- N_2N_4 -diethyl-1,3,5-triazine-2,4-diamine [$\text{C}_7\text{H}_{12}\text{ClN}_5$]) was used in 1974-75 for algae and macrophyte control (Harman 1978). Anecdotal data indicates the use of additional herbicides in the 1980s (Anon., 1991). In 1996, fluridone (1-methyl-3-phenyl-5(3-(trifluoromethyl)phenyl)-4(1H)-pyridinone [$\text{C}_{19}\text{H}_{14}\text{F}_3\text{NO}$]) was applied throughout the littoral regions of both basins (Harman et al. 2002); in 2001, this product was re-applied throughout the littoral zone of the south basin only (Harman et al. 2002). The north basin was left untreated at that time to provide an area for biocontrol efforts.

There are three herbivorous insects in the Northeast that have been considered for Eurasian milfoil management. The aquatic macrophyte moth (*Acentria ephemerella*), the milfoil weevil (*Euhrychiopsis lecontei*) and the milfoil midge (*Cricotopus myriophylli*) have shown some potential (Sheldon 1997; Johnson et al. 1998; Lord 2003). Between 30 June 1998 and 18 July 2000, 13,000 weevils were released in the three sites in the north basin of Lake Moraine (Harman and Albright 2002). Hand pulling by SCUBA divers was employed in a small area of the south basin near the culvert under the causeway in 2002 in order to remove plants developing from fragments exported from the untreated north basin (Lord 2004).

We hypothesized that the taxonomic richness and diversity of aquatic communities (macrophytes, zooplankton, macrobenthic invertebrates and fish) in the main (south) basin of Lake Moraine have been negatively impacted by at least 60 years of a diversity of macrophyte and algae control methods, including herbicide use, to control Eurasian milfoil and associated noxious plants. To test this hypothesis we compared classic limnological water quality characteristics, richness and selected indicators of diversity of the above-mentioned taxocenes in the south basin of Lake Moraine with those in Hatch Lake, a nearby lake of similar size, morphology and biota that, to the best of our knowledge, has not been subjected to any herbicides or other macrophyte control activities (the surface elevation of Hatch Lake is lowered <1 m during winter periods (Lord 2004)). Table 1 provides data comparing the limnological characteristics of Moraine and Hatch Lakes as well as relevant hydrological attributes of their respective watersheds.

We felt that if any community in Lake Moraine exhibited taxa richness that significantly deviated from that found in Hatch Lake, particularly less richness, either a documented logical explanation would be needed, or further work would have to be carried out to ascertain the reasons for the differences. We felt that if all communities

Lake Basin	Lake Moraine	Hatch Lake
Location	42°50'47"N, 75°31'39"W	42°50'06"N, 75°40'67"W
Surface area	106 ha (262 acres)	54 ha (133 acres)
Maximum depth	13.7 m (45 feet)	18 m (60 feet)
Mean Depth	5.4 m (17.7 feet)	10.4 m (25.2 feet)
Thermal Regimen	dimictic	dimictic
Secchi transparency	3.5 m ¹	4.3 m ²
Oxygen	Epilimnion - 12 mg/l ¹ Hypolimnion - 0.2 mg/l ¹	Epilimnion. - 11.9 mg/l ² Hypolimnion - 1.3 mg/l ²
Total Phosphorus	North basin - 25ug/l ¹ South Basin - 38ug/l ¹	18 ug/l ²
Nitrite + nitrate	North Basin - 0.230 mg/l ¹ South basin - 0.740 mg/l ¹	0.083 mg/l ²
Calcium	25.7mg/l ¹	28.1mg/l ²
pH	Epilimnion - 8.7 ¹ Hypolimnion - 7.2 ¹	Epilimnion - 9.0 ² Hypolimnion - 7.1 ²
Conductivity	Epilimnion - 270 us/cm ¹ Hypolimnion - 325 us/cm ¹	Epilimnion. - 213 us/cm ² Hypolimnion - 215 us/cm ²
Trophic status	Eutrophic	Eutrophic
Watershed		
Area	1,217 ha (3,006 acres)	345 ha (852 acres)
Bedrock	Panther Mt. Shales and SS	Panther Mt. Shales and SS
Soils	glacial till, moraine	glacial till, moraine
Elevation	1200 - 1720' above msl	1480 - 1740 above msl
Ann. Phos. loading	6.5 kg/ha/yr	2.3 kg/ha/yr

¹Measured 29 May 03

²Measured 28 May 03

Table 1. The limnological and watershed characteristics of Lake Moraine and Hatch Lake, Madison County, NY.

exhibited similar taxonomic richness and diversities within ranges explained by other phenomena (e.g., impacts from top predators cascading down trophic levels creating differences in zooplankton community structure) it could be assumed that plant management efforts did not impart any lasting impacts.

The phytoplankton community was excluded from this work because their ephemeral and patchy occurrence through the period of study precluded adequate sampling within the constraints of our methodologies. Furthermore, since CuSO₄ was applied to Moraine Lake during the course of study, short-term impacts on target algal species would certainly have masked the long-term impacts we were attempting to observe.

METHODS

Measurements of temperature, pH, oxygen and conductivity, taken with a Hydrolab Scout 2™ multiprobe digital multiprocessor at 1 m increments from the surface to the bottom in both lakes during summer stratification. Secchi transparency was also recorded. In Hatch Lake collections were made on 28 May 2003 at 5:15 pm. On 29 May 2003 at 10:00 am the same procedure was repeated on the southern basin of Lake Moraine. Water samples from both lakes were brought back to the lab where they were analyzed for nitrites +nitrates, total

phosphorous and calcium. Nitrogen compounds were measured using the cadmium reduction method (APHA 1989), total phosphorous using the single reagent ascorbic acid method following persulfate digestion (APHA 1989) and calcium using the EDTA titrimetric method (APHA 1989).

Macrophyte biomass was evaluated in Lake Moraine at four permanent sampling sites. Five replicate samples were taken at each site on 30 July 2003. A weighted line marked at 1 m intervals was randomly tossed from a boat and allowed to settle to the bottom to ascertain intrasite replicate sample locations. Divers equipped with snorkels, masks and 0.32 m diameter nets collected the samples. The nets were lowered so that any macrophytes beneath them were collected, but roots and dead plant parts were discarded. The samples were bagged and put on ice until they were returned to the laboratory. In the laboratory, samples were rinsed, identified by species, and separated according to Crow and Hellquist (2000a; 2000b). The plants were dried in an oven at 105° C for approximately 24 hours and were weighed. At Hatch Lake, 20 random sites with no replicates were sampled on 16 July 2003. The collecting process was identical to that performed at Lake Moraine. After the data from each lake were compiled, the Shannon-Weaver Index was applied as a measure of diversity. The Index, expressed as the ratio H'/H'_{max} , is obtained by calculating $(p_i \log(p_i)) / \sum(p_d (\log(p_d)))$, where p_i refers to the proportion of the i^{th} species, and p_d refers to a theoretical species whose population has the maximum amount of diversity possible (Cole 1979). All calculations were made using base 10 logarithms. The smaller the resultant numbers the higher the diversity. Relevant to this study are the similarities between the results for each community from both Lake Moraine and Hatch Lake.

Zooplankton samples were obtained at Lake Moraine on 26 June 2003 and at Hatch Lake on 10 July 2003 using a 0.25 m diameter plankton net with a 147 micron mesh towed approximately 1 m below the surface about 160 m (500 ft). The sample was transferred into a vial and 5 ml of 5% formalin were added as a fixative. In the lab, the samples were diluted from 5 ml to 25 ml using 70% ethyl alcohol. The solutions were shaken to ensure thorough mixing and pipetted onto Sedgewick-Rafter cells for identification according to Pennak (1989). The zooplankton were identified to sub-order (copepods) or genus or species (cladocera, rotifera) then counted and measured using an ocular micrometer. This process was performed in triplicate. Corresponding proportions of cladocera, copepoda and rotifera, and their mean lengths, are provided.

On 17 June 2003 qualitative samples of macrobenthic invertebrates were obtained from Lake Moraine to develop a taxonomic richness somewhat representative of the easy to collect, although potentially uncommon species, found in several of the microhabitats characteristic of the lake. Using a triangle net and hand picking and scraping rocks, eulittoral organisms were gathered and preserved in 70% ethyl alcohol. A 15x15 cm Ekman dredge was used to obtain invertebrates from deeper substrates at suitable locations. On 26 June 2003, additional quantitative and qualitative samples were obtained from Moraine Lake. Qualitative samples were obtained in the same manner as on 17 June 2003. Quantitative samples were taken from sediment collected at four sites with an Ekman dredge. The substrate was then filtered using a 500 um sieve. A profundal quantitative sample was taken in the middle of the lake with a 23x23 cm Ekman dredge. The samples were stored in bottles with 70% ethyl alcohol for analysis in the laboratory. On 10 July 2003 quantitative and

qualitative samples were collected from Hatch Lake in the same manner as was used in Lake Moraine. In the laboratory, benthic specimens were identified using dichotomous keys from Peckarsky et al. (1990) and Merritt and Cummins (1996). Quantitative samples were air dried in the lab for 15 minutes and then weighed using an electronic balance. Wet weights were put into a spreadsheet in Microsoft Excel and the Shannon-Weaver Index for these values was calculated.

On 1 July 2003 a 200 foot haul seine was towed to capture fish at four sites in the lower basin of Lake Moraine. The net was dragged behind a John Boat in a semicircle from and back to the shoreline. When both ends of the net were on the shore, they were walked toward each other and then hauled to the shore. Fish were then removed from the net, measured and then returned to the lake. Small bluegills (*Lepomis macrochirus*), yellow perch (*Perca flavescens*) and pumpkinseeds (*Lepomis gibbosus*) (<50 mm) were counted, but not measured because they were so numerous. That night, an electrofishing boat was used to stun and capture fish using standard procedures at three sites in the lower basin (Green 1989). Fish were measured, recorded and returned to the lake. Hatch Lake collections were made on 22 June 03 using the same protocols. Data were compiled and the total numbers of each fish found were recorded. The Shannon-Weaver Indices of the fish from Lake Moraine and Hatch Lakes were calculated and compared.

RESULTS

Limnological water quality characteristics of Lake Moraine and Hatch Lake are compared in Table 1, as are relevant watershed attributes. The greatest difference is in watershed area. The proportion of watershed area to lake area for Hatch is about twice that for Moraine. Although both are eutrophic, exhibiting complete anoxia throughout the hypolimnion by early summer, phosphorus loading and other characteristics listed indicate that Lake Moraine is somewhat more productive.

Table 2 provides macrophyte species richness (total number of species), standing crop (biomass) and diversity (Shannon-Weaver). *Myriophyllum spicatum* was abundant in the northern basin of Lake Moraine (average biomass 341.9 g/m² dry wt.) but only 30.63 g/m² dry wt. in the main (south) basin. *Elodea canadensis*, common in past years in the main basin (Harman et al. 1998; 1999; 2000; 2001), was absent on 30 July 2003.

Table 3 illustrates zooplankton species in each lake and includes mean numbers of individuals of triplicate slides examined and average lengths in μm . Because known volumes were not filtered, the data are summarized as proportions of cladocera to copepoda to rotifera. The zooplankton ratio by each taxa for Lake Moraine was 2.01:1.00:3.78. The ratio for Hatch Lake was 3.14:1.00:2.00.

Table 4 indicates the numbers of macrobenthic invertebrate taxa collected at the class, family and genus level in both lakes as well as an indication of their respective biomasses. In all cases, Lake Moraine taxa richness at all levels is slightly less than that of Hatch Lake. Of note is that Lake Moraine has only 64% of the littoral molluscan taxa present compared to Hatch Lake and 73% of the arthropod taxa. The paucity of arthropods in Lake Moraine is

more or less evenly distributed among all the orders with the exception of the Coleoptera (beetles) and Hemiptera (true bugs), which are about equally represented in both lakes. A more equitable distribution of biomass between taxa in Lake Moraine adds to the diversity there compared to the uneven distribution of biomass among the taxa in Hatch Lake resulting in similar diversity as expressed by the Shannon-Weaver index despite the presence of a greater richness in Hatch (Lake Moraine = 0.2865; Hatch lake = 0.2351).

Fish species present, their numbers and percent abundance from each lake are presented in Table 5. Of 15 total taxa represented, 14 are present in Lake Moraine, 11 in Hatch Lake. Muskellunge (not collected), large- and smallmouth black bass and chain pickerel are the top predators in Lake Moraine. In Hatch Lake walleye replace muskellunge. The remaining top piscivores are identical with Moraine. Three smaller centrarchids are present in Moraine, 4 in Hatch. There are 5 forage fish species in Lake Moraine, 4 in Hatch Lake. The Shannon-Weaver indices are 0.6172 and 0.6481 respectively.

Taxa	Standing Crop (Ave. g/m ² dry wt.)	
	Moraine	Hatch
<i>Chara vulgaris</i> (Musk grass)	1160.25	0.54
<i>Nitella</i> sp. (Stonewort)		*
<i>Myriophyllum spicatum</i> (Eurasian water-milfoil)	30.63	50.27
<i>Myriophyllum sibiricum</i> (Northern water-milfoil)		2.62
<i>Potamogeton crispus</i> (Curly Pondweed)	8.50	*
<i>Potamogeton pusillus</i> (Slender Pondweed)	0.05	9.93
<i>Potamogeton richardsonii</i> (Clasping-leaved Pondweed)	*	*
<i>Potamogeton illinoensis</i> (Illinois pondweed)		*
<i>Potamogeton zosteriformis</i> (Flat stemmed Pond weed)	12.78	
<i>Potamogeton amplifolius</i> (Big-leaved Pondweed)		19.02
<i>Stuckenia pectinata</i> (White stemmed Pondweed)	0.03	
<i>Zosterella dubia</i> (Water star-grass)	2.63	0.78
<i>Najas guadalupensis</i> (Bushy Pondweed)	*	1.06
<i>Elodea canadensis</i> (Waterweed)	*	12.93
<i>Megalodonta beckii</i> (Water marigold)		2.63
<i>Ranunculus trichophyllus</i> (Water crowfoot)		*
<i>Ceratophyllum demersum</i> (Coontail)	891.73	12.05
<i>Vallisneria americana</i> (Wild celery)	8.44	15.50
* Taxa noted, but not present in biomass samples.		
TOTAL TAXA	18	12
		16

Table 2. The aquatic macrophytes of Lake Moraine and Hatch Lake, their absence or presence and standing crop expressed as average dry weight biomass (g/m²) of four samples of five replicates each (Lake Moraine) or twenty samples (Hatch Lake). In both lakes the total sample areas are equal.

Taxa	Lake Moraine		Hatch Lake	
	% of total	mean length (μm)	% of total	mean length (μm)
<i>Bosmina</i> sp.	17.1	274.54	0.4	400.00
<i>Daphnia pulex</i>	12.8	695.59	50.8	784.68
Total cladocera	29.9	485.06	51.2	724.68
Cyclopoida	2.1	608.33	12.0	566.43
Calanoida	11.7	591.63	4.3	597.32
Total copepoda	13.8	572.88	16.3	574.70
<i>Asplanchna pridontus</i>	-	-	0.8	375.70
<i>Branchionus</i> sp.	-	-	7.0	119.91
<i>Gastropus stylifer</i>	13.8	125.11	2.7	112.14
<i>Kellicotia longispina</i>	-	-	7.0	131.48
<i>Keratella cochlearis</i>	0.5	92.50	1.6	111.25
<i>Keratella quadrata</i>	-	-	1.2	145.00
<i>Polyartha vulgaris</i>	0.3	105.00	-	-
<i>Synchaeta oblongata</i>	41.5	132.20	9.3	118.81
<i>Trichocera multicrotinus</i>	-	-	1.9	41.00
<i>Notomata</i> sp.	-	-	0.8	132.50
<i>Collotheca</i> sp.	0.1	100.00	0.4	95.00
Unknown rotifera A	0.1	100.00	-	-
Unknown rotifera B	0.1	125.00	-	-
Total rotifera	56.2	113.67	32.6	133.06

Table 3. Zooplankton collected from Moraine and Hatch Lakes, listing the relative proportion contributed by each taxon and the mean length for each taxon.

DISCUSSION

The decision to use Hatch Lake as a point of comparison was made because of the similarities in the morphology, climate and local geology of the two lakes. Both lakes are situated near each other in Madison County, NY. Both watersheds have similar soil types and they are both glacial kettle lakes (Ingmire 2003). The land immediately surrounding both lakes is privately owned, except for a small stretch of highway in the case of Lake Moraine. The watersheds of both lakes are largely agricultural and forested land, with traces of other land uses (Ingmire 2003). The main notable difference between Lake Moraine and Hatch Lake is that while Hatch Lake has remained almost entirely herbicide free and otherwise unmanaged, water levels have been consistently manipulated and significant quantities of at least three different herbicides have been used in Lake Moraine to control nuisance aquatic plants over the last several decades (Rima 2003).

Table 1 illustrates many commonalities between Lake Moraine and Hatch Lake that we feel justifies our assumption that they would possess a similar biota if anthropogenic manipulation had not occurred in Lake Moraine over the years. There are obvious differences in watershed size and shore development, lesser differences in conductivity, phosphorus loading and hypolimnetic oxygen deficits during the period of summer stratification that indicate greater productivity in Lake Moraine, attesting to the perceived need for plant management. The differences in productivity between these two lakes,

Phylum	# Classes	# Families	# Genera	# of Genera		Biomass	
				Moraine	Hatch	Moraine	Hatch
Order							
Annelida	2	4	5	3	4	1.96	1.58
Opisthopora		1	1	1	1	1.88	1.46
Lumbriculida		1	1	1	1	*	0.08
Tubificida		1	1	1	1	0.08	0.03
Pharyngobdellida		1	2	1	1	*	*
Rhynchobdellida		1	1	1	1	*	0.01
Mollusca	2	10	18	9	14	80.06	77.83
Unionoida		1	1	1	1	*	*
Veneroida		2	2	1	2	0.02	1.90
Architaenioglossa		1	1	1	1	64.88	75.5
Neotaenioglossa		2	2	2	1	14.98	0.40
Heterostropha		1	1	1	0	0.18	
Bassomatophora		1	2	0	2		0.03
Arthropoda	3	33	44	24	32	1.13	3.41
Acariformes		4	4	1	3	*	*
Isopoda		1	1	0	1		0.90
Copepoda		1	1				
Amphipoda		3	3	2	3	0.04	0.27
Decapoda		1	1	0	1	*	*
Ephemeroptera		5	7	2	6	0.02	0.76
Odonata		4	8	5	6	0.08	0.83
Hemiptera		3	3	2	1	<0.01	*
Lepidoptera		1	1	0	1		0.03
Trichoptera		1	1	1	1	*	0.03
Coleoptera		4	6	6	2	0.05	*
Diptera		5	9	5	6	0.94	0.59
TOTAL		47	67	36	50	83.33	82.82
Shannon-Weaver Index				0.2865	0.2351		

Table 4. Taxonomic overview and dry weights (g/m^2) of macrobenthos collected at Moraine and Hatch Lakes. Asterisk (*) indicates taxa that were not present in quantitative samples but were encountered in qualitative collections.

compared to the typical ranges of production of inland lakes of the northeast, would be expected to have minimal impacts on the character of the communities involved (USEPA 2002).

The simplest index of the quality of a given biotope is richness (the number of taxa at any selected level present). Somewhat more sensitive indices reflect the diversity of a system. They typically consider population sizes (equitability) as well as richness. We assumed that the richness and diversities of selected communities within these two lakes would each be approximately equal if there had been no history of cultural impacts stressing either system.

TAXA	Lake Moraine		Hatch Lake		
	Number	% Catch	Number	% Catch	
Walleye (<i>Sander vitreus</i>)	-	-	2	0.38	
Chain pickerel (<i>Esox niger</i>)	28	1.65	1	0.19	
Largemouth bass (<i>Micropterus salmoides</i>)	86	5.06	27	5.11	
Smallmouth bass (<i>Micropterus dolomieu</i>)	2	0.12	44	8.33	
Rock bass (<i>Ambloplites rupestris</i>)	45	2.65	224	42.42	
Pumpkinseed (<i>Lepomis gibbosus</i>)	289	17.00	129	24.43	
Bluegill (<i>Lepomis macrochirus</i>)	416	24.47	-	-	
Black crappie (<i>Pomoxis nigromaculatus</i>)	145	8.53	-	-	
Yellow perch (<i>Perca flavescens</i>)	576	33.88	79	14.96	
Swamp darter (<i>Etheostoma fusiforme</i>)	2	0.12	1	0.19	
Brown bullhead (<i>Ictalurus nebulosus</i>)	5	0.29	15	2.84	
White sucker (<i>Catostomus commersoni</i>)	4	0.24	3	0.57	
Banded killifish (<i>Fundulus diaphanous</i>)	51	3.00	-	-	
Golden shiner (<i>Notemogonus crysoleucas</i>)	34	2.00	3	0.57	
Golden redhorse (<i>Moxostoma erythrurum</i>)	21	1.24	-	-	
Total taxa = 15	Total numbers =	1700	100	528	100
Shannon-Weaver Index =		0.6172		0.6481	

Figure 5. Taxa of fish collected from Moraine and Hatch Lakes, given as numbers and percent of the total catch.

The Shannon-Weaver Index used to evaluate the diversity of the two lakes yields three values. The first value, H' is calculated by $\sum(p_i \log(p_i))$. This calculates a theoretical value of the amount of diversity in the community. Alone, this value is meaningless. H'_{\max} is calculated to evaluate the maximum amount of diversity possible, given a community with the same number of species and total number of individuals, but where each species is equally represented in the community. H'/H'_{\max} gives the relationship between maximum possible diversity, H'_{\max} , and actual diversity, H' (Cole 1979). The value calculated by this expression is not suitable for statistical tests, but allows for comparisons of diversity between communities.

Taxa richness and the diversity indices applied to the aquatic macrophytes are similar between Lake Moraine and Hatch Lakes. The greatest disparity is the lack of *Myriophyllum spicatum* and *Elodea canadensis* in the south (main) basin of Lake Moraine. The elimination of *M. spicatum* was the intent of the application of fluridone in 2002. The intolerance of *Elodea* to fluridone is similar to *M. spicatum*. It often is the most impacted non-target species when fluridone is applied (Harman et. al. 2003; Lord 2003). That is undoubtedly the reason for its absence in 2003 as it had been common previously. The presence of *M. spicatum* and *E. canadensis* in abundance in the northern basin, where no fluridone was applied, attests to the efficacy of this treatment. Annual monitoring of macrophytes in Lake Moraine since 1997 (Harman et al. 1998; 1999; 2000; 2001) has demonstrated the selectivity of fluridone, with effective *M. spicatum* control lasting up to three growing seasons after the 1996 application. Therefore these results exemplify short-term impacts. We assume the present situation will prevail for a similar period after which the milfoil will fully recover. While *Chara vulgaris* is common in Lake Moraine, there is much less in Hatch Lake, where *Nitella* sp. is the common stonewort. The absence of other anomalies suggest that the large

amounts of herbicides used to control Eurasian water-milfoil have had little long term impact on the aquatic macrophyte community of Lake Moraine.

Zooplankton richness is similar in both lakes (Table 2). Resources dedicated to sampling the community precluded population estimates suitable for the use of the Shannon-Weaver Index. We believe a ratio of the numbers of cladocera to copepoda to rotifera, and an analysis of their average sizes, provides an indication of their functional efficiency and the stresses (such as predation) impacting them. The ratios exhibited are not similar, indicating obvious community differences. These can be explained by differences in foraging efforts of zooplankton predators. Large predator fish make up about 50% of the abundance of fish collected from Hatch Lake and only about 10% in Lake Moraine. The differences in fish populations are, at least in part, a direct result of fisheries management (stocking) and angling pressure. Zooplanktivorous forage fish are therefore in greater abundance in Lake Moraine. Crustacean zooplankton in Moraine are less numerous (relative to rotifers) and mean cladoceran length is less than in Hatch, reflecting higher zooplanktivory.

The diversity indices applied to the macroinvertebrate quantitative samples suggest that the diversity between Moraine and Hatch invertebrates is similar, since the difference in the H'/H'_{\max} ratio is only 0.0514; however, richness at the genus level is quite different. There was a paucity of species collected in Moraine that are intolerant to winter lowering of water levels and the resultant exposure of littoral sediments to freezing during the winter months. Indeed, in some situations these techniques have been utilized for years to manage some of the taxa involved (Barlow 1933; Malek and Cheng 1974; Cheng 1974). Early instars of many aquatic arthropods survive over the winter buried in shallow sediments avoiding stressful conditions (Merritt and Cummins 1996). It must be expected that the majority of individuals in many populations may be eliminated during severe winters when drying, freezing and erosion of exposed substrates during spring recharge periods occur. The mollusks and arthropod taxa most impacted are those with poor abilities to avoid these stresses. Groups such as the Coleoptera and Hemiptera are relatively independent of changes in water level because of high dispersal rates and over wintering strategies. Their presence testifies to their tolerance. Based on research involved in the regulatory processes involved in herbicide labeling in recent years (SePRO 2003a; 2003b) it appears unlikely that the toxicity of the herbicides used would exhibit the observed selectivity between faunal groups correlating with the impacts observed with varying water levels.

Overall, species richness and diversity in Lake Moraine and Hatch Lakes are remarkably similar. Differences documented in the macrophyte communities can be reasonably accounted for by citing the absence of certain species (Eurasian milfoil, waterweed) as a short-term result of the impacts of herbicide treatment. Variation in the zooplankton communities in the two lakes seems attributable to trophic cascading impacts resulting from the balance of forage fish populations to piscivorous fish populations in the two lakes. Changes in the invertebrate macrobenthos appear to be a direct result of management activities; however, anecdotal correlations between the ecology of the invertebrate taxa and potential stressors imply annual winter draw-down as having greater negative effects than long-term herbicide utilization.

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