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Does Long-Term Macrophyte Management in Lakes Affect Biotic Richness and Diversity?

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ABSTRACT

We hypothesize that the richness and diversity of the biota in Lake Moraine (42°50’47”N, 75°31’39”W) in New York have been negatively impacted by 60 years of macrophyte and algae management to control Eurasian watermilfoil (*Myriophyllum spicatum* L.) and associated noxious plants. To test this hypothesis we compare water quality characteristics, richness and selected indicators of plant diversity, zooplankton, benthic macroinvertebrates and fish in Lake Moraine with those in nearby Hatch Lake (42°50’06”N, 75°40’67”W). The latter is of similar size and would be expected to have similar biota, but has not been subjected to management. Measurements of temperature, pH, oxygen, conductivity, Secchi transparency, calcium, total phosphorus and nitrites + nitrates are comparable. Taxa richness and the diversity indices applied to the aquatic macrophytes are similar in both lakes. The greatest disparity is the lack of Eurasian watermilfoil and Canadian waterweed (*Elodea canadensis* Michx.) in the main basin of Lake Moraine. The elimination of the former was the intent of a 2001 application of fluridone (1-methyl-3phenyl-5(3-(trifuromethyl)phenyl)-4(1H)-pyridinone[$C_{19}H_{14}F_3NO$]) and the loss of the latter was a related consequence. Zooplankton richness is similar in both lakes. The diversity of benthic macroinvertebrates is similar; however, richness at the genus level is quite different. There is a paucity of species collected in Lake Moraine that are intolerant to winter lowering of water levels. Fish species richness in both lakes is similar, but there are differences in specific taxa and percent abundance directly related to stocking and the balance between forage fish populations and piscivorous fish populations in the two lakes. That phenomenon also appears responsible for some of the variation in the zooplankton communities in both lakes. Overall, taxonomic richness and diversity in Lake Moraine and Hatch Lake are remarkably similar. Annual winter drawdown of water levels is implicated as having greater effect on the biota than long-term herbicide utilization. The hypothesis is rejected.

Key words: Eurasian watermilfoil, management history, non-target species, fluridone, whole-lake management.

INTRODUCTION

Lake Moraine (42°50’47”N, 75°31’39”W), in Madison County in east-central New York, 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. 1998). 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 watermilfoil (milfoil), has chronically impaired recreational activities (Anon. 1991, Harman et al. 1997).

Milfoil is a non-native aquatic macrophyte that 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 soon forms at the surface of the water.[4] Milfoil may produce flowers in the late growing season and later seeds, but in Lake Moraine, it reproduces primarily 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 New York State Erie Canal system, which 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.[5] Management of

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[4]Lord, P. H. 2004. Personal communication. Dept. Ecology and Evolutionary Biology, Cornell University. Ithaca, NY.
[5]Staley, J. 2004. Personal communication. Lake Moraine Association, Hamilton, NY.

milfoil has been a priority of the Lake Moraine Association, and before it by the American Management Association, both of which have developed long histories of in-lake plant control activities; mechanical, 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 plant growth (Harman 1978). The first chemical methods used to control macrophyte growth were implemented in the late 1940s (Anon. 1991). Initially, copper sulfate ($CuSO_4$) was used as a non-selective herbicide.[6] It has been frequently used since the 1970s for control of planktonic algae. In 1972-73 Diquat (1,1'-ethylene-2,2'-bipyridiylium dibromide salt [$C1_2H_{12}N_2Br_2$]) was used for control of planktonic algae.[6] Simazine (6-chloro-N_2,N_4-diethyl-1,3,5-triazine-2,4-diamine [$C_7H_{12}ClN_5$]) was used in 1974-75 for algae and macrophyte control (Harman 1978). Anecdotal data indicate the use of additional herbicides in the 1980s (Anon., 1991). In 1996, fluridone 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 experiments.

[6]Kastens, K. A. 1974. Lake Moraine: Algae and weeds, the problems and the solutions. Unpublished manuscript, Colgate University, Hamilton, NY.

There are three herbivorous insects in the northeast US that have been considered for milfoil management. The aquatic macrophyte moth, *Acentria ephemerella* (Dennis and Schiffermuller), the milfoil weevil, *Euhrychiopsis leconti* (Dietz) and the milfoil midge, *Cricotopus myriophylli* (Oliver) 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 three sites in the north basin of Lake Moraine (Harman et al. 2004). 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.[4]

We hypothesize 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 milfoil and associated noxious plants. To test this hypothesis we compare classic limnological water quality characteristics, richness and selected indicators of diversity of the above-mentioned communities 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 specific macrophyte control activities. The surface elevation of Hatch Lake is lowered <1 m during winter periods.[4] Table 1 provides data comparing the limnological characteristics of Moraine and Hatch lakes as well as relevant hydrological attributes of their respective watersheds.

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

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]	Epilimnion—11.9 mg/l[2]
	Hypolimnion—0.2 mg/l[1]	Hypolimnion—1.3 mg/l[2]
Total Phosphorus	North basin—25 µg/l[1]	18 µg/l[2]
	South Basin—38 µg/l[1]	
Nitrite + nitrate	North Basin—0.230 mg/l[1]	0.083 mg/l[2]
	South basin—0.740 mg/l[1]	
Calcium	25.7 mg/l[1]	28.1 mg/l[2]
pH	Epilimnion—8.7[1]	Epilimnion—9.0[2]
	Hypolimnion—7.2[1]	Hypolimnion—7.1[2]
Conductivity	Epilimnion—270 *us*/cm[1]	Epilimnion—213 *us*/cm[2]
	Hypolimnion—325 *us*/cm[1]	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

[1]Measured 29 May 03.
[2]Measured 28 May 03.

We feel that if any community in Lake Moraine exhibits taxa richness that significantly deviates from that found in Hatch Lake, particularly less richness, either a documented logical explanation will be needed, or further work will have to be carried out to ascertain the reasons for the differences. We feel that if all communities exhibit 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 may be reasonable to assume that plant management efforts have not imparted any lasting negative impacts. We recognize that the use of selective herbicides can potentially result in an increase of plant diversity if a dominant target species is decimated, but few treatments are capable of the long-term elimination of just one dominant species.

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 $CuSO_4$ 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.

MATERIALS AND METHODS

Measurements of temperature, pH, oxygen and conductivity, were 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 phosphorus 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 intra-site replicate sample locations. Divers equipped with snorkels, masks and 0.32 m diameter nets collected the samples. Nets were lowered so that any macrophytes beneath them were collected, but roots and dead plant parts were discarded. 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, b). 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-Weiner Index was applied as a measure of diversity. The Index, expressed as the ratio H'/H'max (evenness), is obtained by calculating $(p_i\log(p_i))/\Sigma(p_d(\log(p_d))$, 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 differences in the resultant numbers yielded between compared communities the more similar are their diversities. We determined statistical significance between the differences in numbers of taxa, biomass and relevant sizes of organisms making up the communities in each lake using the Kruskal-Wallis One-way Analysis of Variance (ANOVA).

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 for a distance of 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 Smith (2001), and Thorp and Covich (1991). Zooplankton were identified to sub-order (copepoda) 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 in Table 3. Numbers of zooplankton taxa and plankton lengths in each lake were compared using the Kruskal-Wallis ANOVA.

On 17 June 2003 qualitative samples of benthic macroinvertebrates 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 15 × 15 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 µm sieve. A profundal quantitative sample was taken in the middle of the lake with a 23 × 23 cm Ekman dredge. 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-Weiner Index for these values was calculated. Numbers of benthic taxa and biomass in both Lake Moraine and Hatch Lake were subjected to the Kruskal-Wallis ANOVA.

On 1 July 2003 a 61 m (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* Raf., yellow perch, *Perca flavescens* (Mitchell) and pumpkinseeds, *Lepomis gibbosus* (L.), (<50 mm) were counted, but not measured because they were so numerous. That night, an electrofishing boat was used to stun and capture fish at three sites in the lower basin using standard procedures (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-Weiner 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 which proportionally for Hatch is about one half 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-Weiner). Milfoil was abundant in the northern basin of Lake Moraine (average biomass 341.9 g/m^2 dry wt.) but only 30.63 g/m^2 dry wt. in the main (south) basin. Canadian waterweed, common in past years in the main basin (Harman et al. 1998, 1999, 2000, 2001), was absent on 30 July 2003. There is no significant difference in the numbers of plant taxa between the lakes (P = 0.906). However, there are highly significant differences in biomass (P = 0.007). Although Lake Moraine has two species of macrophytes exhibiting large amounts of biomass, Hatch Lake has many species with moderate amounts.

Table 3 illustrates zooplankton species in each lake and includes mean numbers of individuals of triplicate slides examined and average lengths in µm. Because volumes of water filtered during sampling were potentially not equal, the data are summarized as proportions of cladocera to copepoda to rotifera. The zooplankton ratio by each taxon for Lake Moraine was 2.01:1.00:3.78. The ratio for Hatch Lake was 3.14:1.00:2.00. There are no significant differences in numbers of zooplankton taxa between the lakes, or between copepod or rotifer lengths in each lake (P = 0.658; P = 0.513; P = 0.275 respectively). However, total length of cladocera is statistically greater in Hatch Lake (P = 0.050).

Table 4 indicates the numbers of benthic macroinvertebrate 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

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/M^2) OF FOUR SAMPLES OF FIVE REPLICATES EACH (LAKE MORAINE) OR TWENTY SAMPLES (HATCH LAKE). IN BOTH LAKES THE TOTAL SAMPLE AREAS ARE EQUAL.

Taxa	Standing crop (ave. g/m^2 dry wt.) Lake Moraine	Hatch Lake
Chara vulgaris L. (Musk grass)	1160.25	0.54
Nitella sp. (Stonewort)	23.75	
Myriophyllum spicatum L. (Eurasian water-milfoil)	30.63	50.27
Myriophyllum sibiricum Komarov (Northern water-milfoil)		2.62
Potamogeton crispus L. (Curly Pondweed)	8.50	*
Potamogeton pusillus L. (Slender Pondweed)	0.05	9.93
Potamogeton richardsonii (Ar. Benn.) (Clasping-leaved Pondweed)	*	*
Potamogeton illinoensis Morong (Illinois pondweed)		*
Potamogeton zosteriformis Fern. (Flat stemmed Pond weed)	12.78	
Potamogeton amplifolius Tuckerm. (Big-leaved Pondweed)		19.02
Stuckenia pectinata (L.) (White stemmed Pondweed)	0.03	
Zosterella dubia (Jacq.) (Water star-grass)	2.63	0.78
Najas guadalupensis (Spreng) (Bushy Pondweed)	*	1.06
Elodea canadensis Michx. (Waterweed)	*	12.93
Megalodonta beckii (Torr. Ex Spreng) (Water marigold)	2.63	
Ranunuclus trichophyllus Chaix (Water crowfoot)		*
Ceratophyllum demersum L. (Coontail)	891.73	12.05
Vallisneria americana Michx. (Wild celery)	8.44	15.50
Total taxa = 18	12	16
Total biomass	2115.04	151.08
Shannon-Weiner Index	0.2648	0.2613

*Taxa noted, but not present in biomass samples.
ANOVA: # of Taxa P = 0.906 (no significance). Biomass P = 0.007 (significant difference).

TABLE 3. ZOOPLANKTON COLLECTED FROM MORAINE AND HATCH LAKES, LISTING THE RELATIVE PROPORTION CONTRIBUTED BY EACH TAXON AND THE MEAN LENGTH FOR EACH TAXON.

	Lake Moraine		Hatch Lake	
Taxa	% of total	mean length (µm)	% of total	mean length (µm)
Bosmina sp.	17.1	274.54	0.4	400.00
Daphnia pulex Leydig	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
Asplanchna pridontus Goss	—	—	0.8	375.70
Branchionus sp.	—	—	7.0	119.91
Gastropus stylifer Imhof	13.8	125.11	2.7	112.14
Kellicotia longispina Kellicot	—	—	7.0	131.48
Keratella cochlearis Gosse	0.5	92.50	1.6	111.25
Keratella quadrata (Muller)	—	—	1.2	145.00
Polyarthra vulgaris Carlin	0.3	105.00	—	—
Synchaeta oblongata Ehrenberg	41.5	132.20	9.3	118.81
Trichocerca multicrinus (Kellicot)	—	—	1.9	41.00
Notomata sp.	—	—	0.8	132.50
Collotheca 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
CL:CO:R Ratios	2.01:1.00:3.78		3.14:1.00:2.00	

ANOVA: # of Taxa P = 0.658 (no significance). Cladocera length P = 0.050 (significant difference).
Copepoda length P = 0.513 (no significance). Rotifer length P = 0.275 (no significance).

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-Weiner Index despite the presence of a greater richness in Hatch (Lake Moraine = 0.2865; Hatch lake = 0.2351). There is no significant difference in the biomass of benthic macroinvertebrates in both lakes (P = 0.275). However, the numbers of benthic taxa are significantly greater in Hatch Lake (P = 0.043).

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, *Esox masquinongy* Mitchell, (not collected), large- and smallmouth black bass, *Micropropterus* spp., and chain pickerel, *Esox niger* Lesueur, are the top predators in Lake Moraine. In Hatch Lake walleye, *Sander vitreus* (Mitchell), replace muskellunge. The remaining top piscivores are identical with Moraine. Three smaller centrarchids are present in Moraine, four in Hatch. There are five forage fish species in Lake Moraine, four in Hatch Lake. The Shannon-Weaver indices are 0.6172 and 0.6481 for Moraine and Hatch lakes, respectively.

DISCUSSION

The decision to use Hatch Lake as a point of comparison with nearby Lake Moraine was made because of the similarities in the morphology, climate and local geology of the two lakes. Both watersheds have similar soil types and they are both glacial kettle lakes.[7] 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.[7] 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 at least three different herbicides have been used repeatedly in Lake Moraine to control nuisance aquatic plants over the last several decades.[8]

Table 1 illustrates many commonalities between Lake Moraine and Hatch Lake that we feel justifies our assumption that they would possess similar biota if anthropogenic manipulation had not occurred in Lake Moraine over the years.

[7]Ingmire, S. 2003. Personal communication. Madison County Planning Department. Wampsville, NY.

[8]Rima, R. K. 2003. Permit records from 1996-2003. New York State Department of Environmental Conservation Division of Solid and Hazardous Materials.

TABLE 4. TAXONOMIC OVERVIEW AND DRY WEIGHTS (G/M²) OF MACROBENTHOS COLLECTED AT MORAINE AND HATCH LAKES. ASTERISK (*) INDICATES TAXA THAT WERE NOT PRESENT IN QUANTITATIVE SAMPLES BUT WERE ENCOUNTERED IN QUALITATIVE COLLECTIONS. PHYLA AND ORDERS ARE SPELLED OUT AT THE LEFT. THE NUMBERS OF CLASSES, FAMILIES AND GENERA FOLLOW. NUMBERS IN BOLD REPRESENT THE TOTAL NUMBERS OF EACH TAXON IN THE PHYLUM INDICATED.

Phylum				# of Genera		Biomass	
Order	# Classes	# Families	# Genera	Moraine	Hatch	Moraine	Hatch
Annelida	**2**	**5**	**6**	**5**	**5**	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**	**8**	**9**	**4**	**7**	80.06	77.83
Unionoida		1	1	1	1	*	*
Veneroida		2	2	0	2	0.02	1.90
Architaenioglossa		1	1	1	1	64.88	75.50
Neotaenioglossa		2	2	2	1	14.98	0.40
Heterostropha		1	1	0	0	0.18	
Bassommatophora		1	2	0	2		0.03
Arthropoda	**3**	**33**	**46**	**25**	**32**	1.13	3.41
Acariformes		4	4	1	3	*	*
Isopoda		1	1	0	1		0.90
Copepoda		1	1	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	**7**	**46**	**61**	**34**	**44**	83.33	82.82
Shannon-Weiner Index				0.2865		0.2351	

ANOVA # benthic taxa P = 0.043 (Hatch > Moraine).
Biomass P = 0.275 (no significance).

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

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

The Shannon-Weiner Index (H'/H'_{max}) used to evaluate the diversity of the two lakes yields three values. The first value, H' is calculated by $\sum(p_i \log(p_i))$, which provides a theoretical value of the amount of diversity in the community. Alone, this value has no comparative value, as it reflects multiple variables that limit interpretation. However, 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. Thus, 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, or evenness, between communities.

Taxa richness and the diversity indices applied to the aquatic macrophytes are similar between both lakes. The greatest disparity is the lack of milfoil and Canadian waterweed in the south (main) basin of Lake Moraine. The elimination of milfoil was the intent of the application of fluridone in 2001. The intolerance of Canadian waterweed to fluridone is similar to milfoil and it often is the most impacted non-target species when fluridone is applied (Har-

TABLE 5. TAXA OF FISH COLLECTED FROM MORAINE AND HATCH LAKES, GIVEN AS NUMBERS AND PERCENT OF THE TOTAL CATCH.

	Lake Moraine		Hatch Lake	
Taxa	Number	% Catch	Number	% Catch
Walleye (*Sander vitreus*) (Mitchell)	—	—	2	0.38
Chain pickerel (*Esox niger*) Lesueur	28	1.65	1	0.19
Largemouth bass (*Micropterus salmoides*) (Lacepede)	86	5.06	27	5.11
Smallmouth bass (*Micropterus dolomieui*) Lacepede	2	0.12	44	8.33
Rock bass (*Ambloplites rupestris*) Rafinseque	45	2.65	224	42.42
Pumpkinseed (*Lepomis gibbosus*) Linnaeus	289	17.00	129	24.43
Bluegill (*Lepomis macrochirus*) Rafinseque	416	24.47	—	—
Black crappie (*Pomoxis nigromaculatus*) (Lesueur)	145	8.53	—	—
Yellow perch (*Perca flavescens*) (Mitchell)	576	33.88	79	14.96
Tesselated darter (*Etheostoma olmstedi*) Storer	2	0.12	1	0.19
Brown bullhead (*Ictalurus nebulosus*) (Lesueur)	5	0.29	15	2.84
White sucker (*Catostomus commersoni*) (Lacepede)	4	0.24	3	0.57
Banded killifish (*Fundulus diaphanous*) (Lesueur)	51	3.00	—	—
Golden shiner (*Notemogonus crysoleucas*) (Mitchell)	34	2.00	3	0.57
Creek chubsucker (*Erimyzon oblongus*) (Mitchell)	21	1.24	—	—
Total Taxa = 15 Total Numbers	1700	100.00	528	100.00
Shannon-Weiner Index	0.6172		0.6481	

man et al. 2003, Lord 2003). That is undoubtedly the reason for its absence in 2003 as it had been common previously.[9] The presence of milfoil and Canadian waterweed 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 milfoil control lasting up to three growing seasons after the 1996 application. Therefore, these results exemplify short-term impacts. While muskgrass, *Chara vulgaris* L., is common in Lake Moraine, there is much less in Hatch Lake where stonewarts *Nitella* spp. are the common charophytes. The absence of other anomalies suggest that the frequent use of herbicides used to control milfoil have had little long term impact on the aquatic macrophyte community of Lake Moraine.

Zooplankton richness is similar in both lakes (Table 3). Resources dedicated to sampling the community precluded population estimates suitable for Shannon-Weiner Index diversity measurements. 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 (Table 5). The differences in fish populations are, at least in part, a direct result of differences in game fish stocking and angling pressure. Zooplanktivorous forage fish are therefore in greater abundance in Lake Moraine. Crustacean zooplankton in Lake Moraine are less numerous (relative to rotifers) and mean cladoceran length is less than in Hatch, reflecting higher zooplanktivory by fish.

The diversity indices applied to the benthic 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, 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 then 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 (below the eulittoral zone) because of high dispersal rates and overwintering strategies. Their presence testifies to their tolerance. Based on non-target organism toxicology testing required for the herbicide registration process and subsequent labeling for aquatic sites in recent years (SePRO 2003a, b) it appears unlikely that any toxicity of the herbicides used would exhibit the observed selectively 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, in spite of the fact that Lake Moraine has received six decades of active plant management, including the frequent use of herbicides. Dif-

[9]Since this work was completed Canadian waterweed has reappeared in abundance in collections of macrophytes from Lake Moraine.

ferences documented in the macrophyte communities can be reasonably accounted for by citing the absence of certain species (milfoil, Canadian waterweed) as a short-term result of the impacts of herbicide treatment. Variation in the zooplankton communities in the two lakes is probably unrelated to impacts of herbicide treatments but attributable to trophic cascades resulting from the balance of forage fish populations to piscivorous fish populations in the two lakes. Changes in the benthic macroinvertebrate community appear to be a direct result of human activities; however, correlations between the ecology of the invertebrate taxa and potential stressors imply annual winter drawdown for protection of lakeside infrastructure as having greater negative effects than long-term macrophyte management. There is no direct evidence of any lasting, negative effect of plant management activities, most recently fluridone treatment, on richness or diversity metrics of Lake Moraine biota.

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