Biological Control of Eurasian Watermilfoil

Completion Report for 2001-2004

BY

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TO

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Deliverable A-6. Report of results from 2003 and preceding years.

Content: Processing and analysis of 2003 samples will be completed and the results will be summarized in a multi-page progress report that will be submitted to the MnDNR. Results from all data collected will be analyzed and interpreted. In addition, analysis and synthesis of results from research done in the preceding years over five biennia will be presented.

Introduction

Eurasian watermilfoil (*Myriophyllum spicatum* L.) is an exotic aquatic weed that often interferes with recreation (Smith and Barko 1990), inhibits water flow, impedes navigation, (Grace and Wetzel 1978) and will displace other aquatic macrophytes (Madsen et al. 1991). It was first reported in Minnesota in 1987 and occurred in over 150 Minnesota waterbodies by fall 2003 (Exotic Species Program 2004).

Recent work on the biological control of Eurasian watermilfoil has focused on the indigenous weevil *Euhrychiopsis lecontei* (Dietz) (= *Eubrychiopsis lecontei*), although the caterpillar *Acentria nivea* and the midge *Cricotopus myriophylli* are also potential control agents (Newman 2004). This work suggests that *E. lecontei* is the most promising control agent (Creed and Sheldon 1995, Sheldon and Creed 1995, Creed 1998, Newman and Biesboer 2000). The weevil is native to Minnesota and Wisconsin (Newman and Maher 1995, Jester et al. 1997) and is highly specific to watermilfoils (Solarz and Newman 2001). Sheldon and O'Bryan (1996), Newman et al. (1996, 1997), Mazzei et al. (1999) and Newman et al. (2001) describe the life history and development times of the weevil. Newman (2004) provides a comprehensive review of agents and the biological control of Eurasian watermilfoil.

Although declines of milfoil in several lakes have been related to the occurrence of *E. lecontei* (Sheldon and Creed 1995, Lillie 2000, Newman and Biesboer 2000, Creed 1998), it is clear that at many sites in Minnesota, weevil densities do not get high enough to effect control (Newman et al. 1996, Newman et al. 1998, Newman and Biesboer 2000). Fish predation may be one factor limiting populations in some lakes (Sutter and Newman 1997, Newman and Biesboer 2000, Ward 2002, Newman 2004). Identification and amelioration of factors limiting the milfoil weevil is essential for operational biological control of Eurasian watermilfoil (Newman et al. 1998). Getsinger et al. (2002) provide a good overview of the potential use of the weevil for control of milfoil and Newman (2004) provides a review of limiting factors and success across the country.

The aim of this project is to attempt to detect milfoil declines and assess milfoil weevil populations, identify and manipulate factors that may be limiting control agent densities and identify and manipulate factors that may limit the effectiveness of milfoil control agents (plant community response). This report presents our results from 2001-2003 and summarizes our overall results during the past 10 years and provides some final conclusions and recommendations.

Acknowledgements

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Methods

Semi-permanent Transect Sites:

During the summers of 1993 and 1994, we initiated selection of semi-permanent sampling sites, which can be repeatedly sampled at fixed locations (Newman and Ragsdale 1995). The sites were Lake Auburn (Carver Co.; T116N; R24W; S10), Otter Lake (Anoka and Ramsey Co.; T30-31N; R22W; S3-4, S35-36), Cedar Lake (Hennepin Co.; T29N; R24W; S29) and Smith's Bay of Lake Minnetonka (Hennepin Co.; T117N; R23W; S10,11). At each site, 5 transects, 30 m apart, were run from near shore (0.5 m depth) toward the plant limit. At Lake Auburn and Cedar Lake, the transects extended to 50 m from the shoreward starting point, in approximately 2.5 m depth at Auburn and 5 m depth in Cedar. Semipermanent stations were marked along the transect at 10 m intervals with fluorescent floats that were attached to bricks and suspended 0.5-1m beneath the surface. At Otter Lake, the transects were extended 100 m from shore, in approximately 2 m depth. At Smith's Bay, transects were started 100 m from shore (1.5m depth) and run to 4.5 m depth, approximately 0.8 km from shore, with 5 sampling stations along each transect approximately geometrically spaced. Distances from shore determined from GPS data were: 100m, 200m, 370m, 585m and 805m. These stations were marked with floating milfoil buoys.

In summer 1996, we noticed a dense population of weevils at Cenaiko Lake (Anoka Co.; T31N; R24W; S26). We therefore sampled this lake in July and September as a new site to be regularly sampled. We ran 3 or 4 transects, west to east across the north end of the lake, with sampling stations every 30 m. This resulted in 25-32 samples on each date (21-30 with plants; deep stations were deleted from the analysis). At Lake Auburn transects were sampled at 10 m intervals (stations) , resulting in 6 samples per transect, or 30 samples. At Otter Lake samples were taken at each 20m sampling station, resulting in 5-6 samples per transect or 27 samples. At Cedar (30) and Smiths Bay (25), all stations were sampled, however, several stations in Cedar Lake were deeper than the plant limit (>7m) and these are excluded if no plants occurred there during the season. In 1997 sampling occurred twice: in late June to early July and in mid-September. In 1998, three lakes (Auburn, Cenaiko and Smith's Bay) were sampled thrice, in June, late-July or early August and in September. Otter and Cedar were sampled in June and September. Samples were alternately taken 2m from each side of each station on successive sampling dates to minimize sampling disturbance. In 1999, two lakes (Cenaiko, and Smith's Bay) were sampled thrice, in June, late-July or early August and in late August. Auburn and Cedar were sampled in June and late August and Otter was sampled in June and early August. In 2000, four lakes were sampled three times (Auburn, Cenaiko, Otter and Smith's Bay), in June, July and August and Cedar Lake was sampled twice, in June and August. Twenty-four to thirty samples were collected at each lake on each date. In 2001, four lakes (Auburn, Cenaiko, Otter and Smith's Bay) were sampled three times, in June, late July and late August. Cedar was sampled in June and August. In 2002 all 5 lakes were sampled twice, in early (late June or early July) and late (late August or early September) summer. In 2003 4 lakes (Auburn, Cedar, Cenaiko, and Otter) were sampled once, in August or early September. Smith's Bay was not sampled in 2003. Twenty to thirty samples were collected at each lake on each date.

At each sampling station, plant biomass and invertebrate samples were taken from 0.1 m^2 quadrats (all plant material was clipped at sediment interface and immediately placed in a sealable bag underwater). Sediment cores were also collected at shallow, medium and deep stations along 3 transects at each site.

A set of water column parameters was measured in the open water (>5.5m depth and >100 m from the bed) at each site on each sampling date. Secchi depth and surface conductivity were measured and a water sample (combined surface and Secchi depth sample) was collected for pH, alkalinity and chlorophyll a determination. A light (Photosynthetically Active Radiation = PAR, Li-Cor LI-189 with LI-192SA quantum sensor), temperature and oxygen (YSI 50B) profile was taken at 0.5 m depth increments from surface to bottom.

Alkalinity was determined by titration. For chlorophyll, 500 ml of water were filtered through a 1.2 mm glass fiber filter, the filter was placed on dry ice and returned to the laboratory and frozen until analysis. Chlorophyll was extracted with buffered acetone and measured spectrophotometrically (APHA 1989). Sediment cores were stored on ice and returned to the laboratory. Within 48 hr the top 15 cm of sediment was homogenized. A 5 ml sediment subsample was dried at 105 ˚C for 24-48 hrs and then weighed to obtain bulk density (g dry mass ml^{-1}). The dried sediment was then ashed at 550 ˚C for 4 hrs to obtain percent organic matter ([AFDM dry $mass^{-1}$] X 100). Pore water was extracted from the remaining sediment by centrifugation, acidified to < pH 2 and stored in the refrigerator. The remaining spun sediment was either processed immediately or was frozen for later analysis. In 2001-2003 we further extracted the spun sediment with 2M KCl (shaken for 1 hr) to determine exchangeable nitrogen. The extract was filtered and acidified. Within seven days, the NH_3 concentration was determined for both pore water and KCl-extracted fractions by selective electrode (APHA, 1989). These results should allow us to evaluate McComas's (1999) hypothesis that nuisance levels of milfoil should only appear in sediments with high total nitrogen (e.g., > 3 mgN/L), whereas native plants should dominate in lower nitrogen sediments.

Biomass samples were rinsed of invertebrates and invertebrates were picked (endophytic and external on milfoil and from the wash water) from all samples; weevils and Lepidoptera were enumerated. Milfoil stems were counted and the average maximum stem length determined. Plants were separated, identified to species, spun for 15 sec in a salad spinner and wet mass was recorded. These samples were dried (105 ˚C for 48h) and weighed or were frozen for later dry mass determination.

Because the relatively infrequent sampling of these sites (2 or 3 times per summer) does not provide very good resolution of weevil population dynamics, we initiated a biweekly weevil survey in Lake Auburn 1998 and in 1999 added Cenaiko and Smiths Bay to our weevil surveys. In 2000 we added Otter to our survey sites and we conducted bi-weekly surveys at Auburn, Cenaiko, Otter and Smith's Bay each year from 2000-2003. For each survey, 5-8 stems (top 50 cm) of milfoil were collected at each of 15-18 stations every other week (at Cenaiko and Otter after declines we were unable to find milfoil at some stations). At sites with lower densities of weevils we have been collected 7 or 8 stems to increase our power to detect weevils. Weevils and Lepidoptera were removed from the samples, which were scanned at 8X magnification, and enumerated by life stage. Results were expressed as numbers per basal stem. Single weevil surveys were also conducted during 2002 in Bald Eagle (Ramsey Co.), Calhoun, Cedar, Centerville (Anoka Co.), Independence (Hennepin Co.), Peltier (Anoka Co.), Schultz (Dakota Co.) and Vadnais (Ramsey Co.) to correlate weevil density with fish density (see below). These surveys were repeated in 2003 at Calhoun and Cedar.

Survey Sites:

In 2001 and previous years, we conducted broader scale (whole lake or bay) surveys of plants in August at 5 sites: Lake Calhoun Hennepin Co.; T28-29N; R24W; S4,5,32,33), Lake Harriet (Hennepin Co.; T28N; R24W; S8,9,16,17), Lake of the Isles (Hennepin Co.; T29N; R24W; S32,33) and Shady Island (Hennepin Co.; T117N; R23W; S26) and Grays Bay (Hennepin Co.; T117N; R22W; S8) in Lake Minnetonka. In 2002 we sampled Calhoun, Cedar, Harriet and Isles, plus Centerville, Schultz and Vadnais. Weevil surveys were conducted on all of the lakes (except Isles, which had little milfoil by August) in 2002 to relate weevil density to sunfish abundance (see below). At each lake, plant community structure was determined with plant hook surveys along 5-15 transects and water quality was recorded. In 2003 we surveyed Calhoun, Cedar, Harriet and Isles.

To quantitatively determine the extent of milfoil coverage, a set of 5-15 transects, perpendicular to shore, was located around the lake or bay in a stratified random manner (i.e., 1 transect located within each 1/10 of the lake shoreline circumference) in August. Along each transect, observations were made from shore (0.5 m depth) to the plant limit at 5 to 6 stations, at 7.5, 15, 30, 60, or 90m intervals to the depth of the plant limit. At steeper transects the shorter intervals were used, at long and gently sloping transects, the longer intervals were used. Transects were laid with a measuring rope and marked with jugs attached to bricks; the shoreward and offshore positions were recorded with a GPS unit. At each observation point, visible milfoil (% coverage) and other plant occurrence was recorded, plant height determined and plant disk (depth at which a Secchi disk disappears; Crowell et al. 1994) was measured within a $1m^2$ area around the marker jug. Depth was recorded by dropping a plant hook vertically; plant species found on the plant hook or the jug rope and brick were also recorded and milfoil was examined for weevils and given a weevil damage rating (0-5). These data provide an estimate of milfoil and other plant coverage and frequency of occurrence around the lake as well as a relative estimate of weevil damage or occurrence.

Semi-quantitative estimates of plant density and weevil abundance were determined along a stratified subset of 5 of the transects with modification of a grapple hook method of Jessen and Lound (1962). At each sampling point 3 or 4 grapple throws were collected and rated for plant occurrence and density on a scale of 0-5 (Jessen and Lound 1962); these data provide species occurrence and relative density estimates for each species. The milfoil collected on each throw was scanned for the presence of weevils and visually assigned a damage rating (0-5). Thus for these 5 transects, we have both visual estimates of plant occurrence and density as well as the semiquantitative plant hook estimates.

Localized sites at Calhoun, Harriet and Isles were sampled quantitatively for milfoil, invertebrates and site characteristics in 2001-2003. At Calhoun, Lake of the Isles and Harriet, 5 transects with 5 stations on each transect were sampled twice in 2001 (June and August) and once in 2002 and 2003 (August). At each station $0.1m^2$ quadrat samples were taken for plants and invertebrates. Sediment cores were sampled at the intermediate depth station along each transect. Open-water water quality samples were taken and processed in the same manner as the permanent transect sites. Samples were processed as above for plant mass by species, weevil abundance, and sediment characteristics.

Relationship of Weevil and Sunfish Densities:

Because previous research suggested that high sunfish densities were limiting weevil populations, we selected a set of lakes for which recent DNR fish population assessment were conducted and conducted single weevil surveys in late July or August 2002. These lakes were Bald Eagle (Ramsey Co.), Calhoun, Cedar, Centerville (Anoka Co.), Independence (Hennepin Co.), Peltier (Anoka Co.), Schultz (Dakota Co.) and Vadnais (Ramsey Co.). At each lake, 5 transects were established around the lake and 4 stations (from shore to deep edge of the bed) on each transect were sampled for herbivores by collecting 8 milfoil stems (top 50 cm). These plants were processed and herbivores enumerated as done for other weevil surveys. At five of these lakes we also conducted plant community surveys (see above) to see if declines in milfoil were related to weevil or sunfish density.

The DNR fisheries survey results for trapnet catches of all sunfish (bluegill, pumpkinseed, bluegill X pumpkinseed hybrids and green sunfish) were used to estimate relative sunfish density (mean catch per overnight trapnet set). Most fisheries assessments were conducted in 2002, but assessments on Independence and Vadnais were conducted in 2001 and Calhoun and Cedar in 2000. Regression of our single-sample summer weevil density estimates with sunfish abundance was used to determine if there is an among-lake relationship of weevil density with sunfish density. To increase sample size, we also obtained DNR fisheries population assessments for the lakes on which we have been conducting regular bi-weekly weevil surveys. Fisheries assessments were available for Auburn in 2000, Cenaiko in 1998 and 2002 and Otter in 2001 and 2002. For these lakes we used average summer weevil densities for the year in which the fisheries assessment was conducted.

Weevil Introduction/Manipulation:

Previously we conducted small-scale augmentations in caged fish exclosures and enclosures (Ward 2002). To provide a more realistic assessment of the feasibility of stocking or augmenting weevil populations we stocked weevils into two lakes with low weevil populations and different sunfish densities in 2002: Harriet and Hiawatha. Based on prior DNR fisheries assessments, Harriet was considered a high sunfish lake (340/trapnet) and Hiawatha a low sunfish lake (11/trapnet). An herbivore (weevil) stem survey (5 transects, 4 stations) was conducted prior to stocking to determine weevil abundance (no weevils were found in these surveys).

In mid-July, two contiguous plots (approximately 120m along shoreline to the deep edge of milfoil bed, each plot was ≥ 100m apart) were chosen in each lake and plant biomass and herbivore densities were determined with quantitative 0.1 m^2 quadrat samples from 4 stations (shallow to deep) on three transects in each plot (12 samples per plot). Adult weevils and associated meristems (including eggs and larvae) were collected from Otter Lake and 3000 adult weevils were stocked into one randomly selected plot in each lake in mid-July 2002. Meristems (with adults and associated eggs and larvae) were tied to individual plants with biodegradable twine. Biweekly weevil (herbivore) stem surveys (12 stations per plot, 8 stems per station) were conducted to monitor weevil populations and in mid-September 2002, 12 quadrat samples were collected from each plot to determine plant biomass and areal herbivore densities. The lakes were re-sampled for biomass in June of 2003 and biweekly weevil surveys were conducted through summer 2003. In July 2003 an additional 2000 adult weevils were stocked into each lake and biomass was again sampled at the end of the summer.

Effects of plant community:

To test the hypothesis that plant competition may be important in the reestablishment of Eurasian watermilfoil after a decline (or reduction due to weevil damage) we established plots in Otter Lake (good water clarity and healthy native plant community) and in Lake Auburn (poor water clarity with community dominated by Eurasian watermilfoil and coontail) for plant community manipulation experiments. Initial experiments were conducted in 1998-1999.

We established a new set of plant manipulation plots in Otter Lake and Lake Auburn in 2001 and in Cedar (good clarity but low diversity) in 2002. At each lake we established 20 plots marked by 2mx2m pvc quadrats. The plots were sampled in early June for plant biomass (2 0.1-m^2 quadrat samples per plot) prior to manipulation. After initial sampling, the randomly assigned manipulation was applied to the plot by divers using SCUBA who manually removed vegetation within the area delineated by the 2x2 PVC quadrat. Harvested vegetation was not retained but allowed to float away. In five plots no plants were removed, in 5 plots all plants were removed and in the other plots either all native plants or all Eurasian watermilfoil was removed. Several times each summer, visual surveys (means of 16 0.5x0.5 cells) of plant coverage were conducted and in September, two biomass samples were taken from each plot. Otter Lake and Lake Auburn were re-sampled for biomass in June and September 2002 and visual surveys were conducted several times during summer 2002 to further follow community changes. In 2003, the removal plots in Cedar and Otter were resampled for biomass in late June or early July. The duplicate biomass samples within plots were averaged and statistical analyses were conducted on the replicate plots. We collected sediment cores from each plot in Otter Lake in September 2001 and 2002 and June 2003 and from each plot in Cedar and Auburn in September 2002 and Cedar in July 2003.

Relationship of plant community to sediment characteristics:

McComas (1999) proposed that sediment nitrogen may be a good predictor of nuisance levels of Eurasian watermilfoil; high nitrogen sites should support dense growths of milfoil while lower nitrogen sites would be more amenable to native plants that are adapted to lower nitrogen levels. At low nitrogen sites, Eurasian watermilfoil should not reach nuisance levels. Recently, McComas (2003) updated his predictions and predicted that nuisance milfoil should occur in sediments with > 6ppm exchangeable ammonia. This prediction was based on a volume basis (mg/cm^3, McComas, personal communication). In 2001 we started measuring exchangeable (KCl extractable ammonium) N from the sediments because pore water ammonium is rapidly influenced by short-term plant uptake and may not reflect longer-term nitrogen availability. We analyzed all the sediment samples from 2001-2003 for exchangeable N (see above for methods). We report exchangeable N from the KCl extract as well as total exchangeable N (KCl extract plus pore water nitrogen). Although our measures based on dry mass (mg N/g dm sediment) are not directly comparable to McComas's, they should provide some basis for testing his hypothesis and an assessment of possible N limitation of milfoil at our sites.

Results and Discussion

Semi-permanent Transect Sites:

Milfoil and total plant biomass fluctuated over time and differed among lakes (Fig. 1); annual climatic factors do not appear to be the main determinants of milfoil biomass at these sites.

Lake Auburn showed large changes in milfoil biomass over time, increasing to high levels in 1995-1996, followed by a decline from 1998-2000 with a slow increase from 2001-2002 and another decline in 2003 (Table 1). Plants other than milfoil also increased in 1995 and generally remained over 1000 g wet/m^2 through 2001 (Table 2). Non-milfoil biomass dipped in 2002, but returned to near 1000 g/m^2 in 2003. During years of high milfoil biomass, milfoil composed 60-90% of total plant biomass, but during 1998-1999 it composed <40% of total plant biomass (Table 3). Biomass of non-milfoil plants at Auburn was dominated by coontail (Fig. 1) and generally only 2-3 species were found per sample (Table 2). The total number of species found per date ranged from 3 to 12 (Table 3) with 6-9 species being typical. Milfoil biomass was not significantly correlated with coontail or other plants and the plant community varied independently.

Lake Auburn had fertile sediments with an intermediate bulk density (0.4-0.6 g dm/ml) and percent organic matter (10-20%; Table 4). Pore water ammonium tended to be suppressed with high densities of plants. Water clarity was fair to poor at Lake Auburn; late summer Secchi depths were less than 2m in about half the years, but low Secchi depths in 1997 and 2001 did not appear to suppress milfoil growth, so it is unclear if equally poor clarity in 1998 and 1999 was responsible for the low biomass in those years. Changes associated with herbivores are addressed in the following section.

Cedar Lake showed less variation in milfoil and total plant biomass. Biomass was low in 1996, despite fair water clarity (Table 4), and increased to more than 2500 g/m^2 in 1997 and 1998 following alum treatments (and improved clarity) before returning to slightly lower levels between 1500 and 2000 g/m^2. Biomass of non-milfoil plants was typically < 1000 g/m^2 (Table 2) and was dominated by coontail. Cedar consistently had the lowest mean number of species per sample among the lakes, typically < 2 species per sample (milfoil and coontail). It also had the lowest total number of species; occasionally 5 species were found but 2-4 species were more typical (Table 3). As with Auburn, milfoil biomass was not significantly correlated with coontail or other plants. Cedar Lake sediments were similar to Auburn with an intermediate bulk density and percent organics (Table 4). Poor late summer clarity in 1995 may have suppressed milfoil and the improved clarity after alum treatment in 1996 appeared to enhance milfoil biomass in 1997-1999.

Otter Lake had a high biomass of milfoil in 1994 and 1995 (Table 1), when it composed 75-95% of total plant biomass (Table 3). A dramatic decline in milfoil biomass occurred over the winter of 1995-1996; milfoil biomass was extremely low in June 1996 and dropped to zero by the end of the summer. This decline was likely due to a severe winterkill that killed the stems, root crowns and roots of the milfoil plants. Native plants, many which reproduce from seed, increased over the summer and remained dominant through 1999 (Table 3). Milfoil slowly increased and reached a peak of 2600 g/m^2 in June 2000 and then declined with increasing herbivore densities (see below). Milfoil remained at <30% of biomass until 2003 when it increased to 40% (Table 3).

In contrast to Auburn and Cedar, Otter Lake had a higher diversity of native plants; typically 9-15 species were found (3-5 species per sample) and even during years of high milfoil biomass, 9-12 species were found. Milfoil was not significantly correlated with coontail, but it was negatively correlated with other plants ($r = -0.46$, $p<0.05$) and coontail was marginally negatively correlated with other plants ($r = -0.38$. $p<0.1$). When milfoil was suppressed, rooted native plants colonized and coontail did not become dominant. Otter Lake sediments had a lower bulk density and higher organic content than the other lakes (Table 4) and better Secchi depths than Auburn (typically >2m throughout the summer).

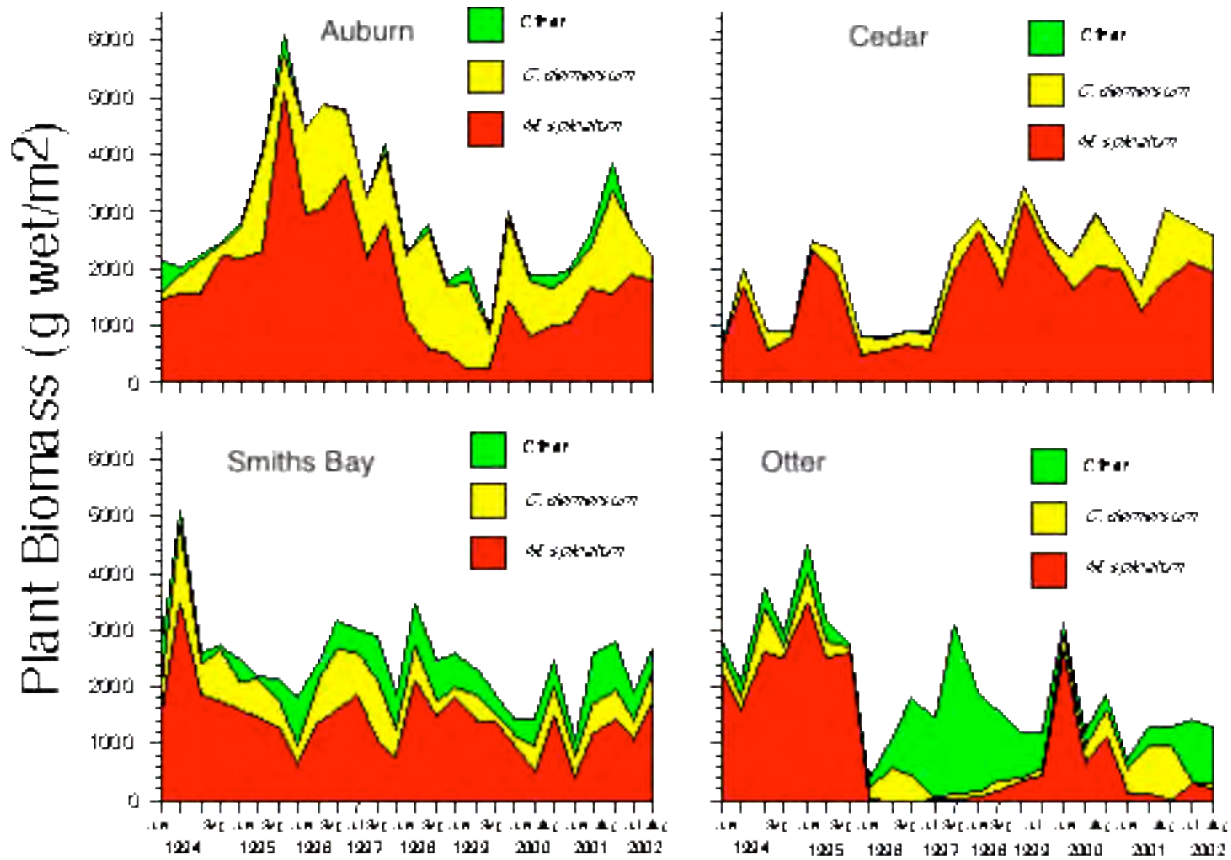

Fig. 1. Total plant biomass (Eurasian watermilfoil, coontail and other non-milfoil biomass; g wet/m^2) at the four permanent transect sites from May 1994 - August 2002.

Smith's Bay generally had the most consistent milfoil density. After a peak biomass of 3500 g/m^2 in 1994, milfoil only exceeded 2000 g/m^2 once (1998) and typically ranged from 800-1500 g/m^2 (Table 1) and composed 40-60% of total plant biomass. Like Otter, the plant community was more diverse and 10-15 species were commonly found with a mean of 3-4 species per sample. Non-milfoil biomass ranged from 600-1800 g/m^2 and coontail typically composed 20-50% of non-milfoil biomass. At Smith's Bay, milfoil and coontail biomass were significantly positively correlated ($r=0.58$. $p<0.01$) but neither milfoil nor coontail were correlated with other plant density. Smith's Bay had the best water clarity of the sites and Secchi depths typically exceeded 2.5m throughout the summer (Table 4). Sediment bulk density was slightly lower than Cedar but percent organics were also lower, generally ranging from 10-15%.

Table 1. Biomass ± 1SE (g wet/m^2) of Eurasian watermilfoil at the four sampling sites in 1994-2003. n = number of samples. Dry biomass (g/m^2 ± 1SE) is presented for 1995-2003.

Sampling Date	Auburn	n	Cedar	n	Otter	n	Smith's Bay	n
5/19-6/3/94	1474 ± 326	10	610 ± 289	18	2208 ± 332	21	1470 ± 320	14
7/1-7/11/94	1570 ± 297	16	1642 ± 523	18	1589 ± 231	27	3478 ± 399	16
8/12-8/19/94	1581 ± 224	15	601 ± 207	15	2626 ± 472	14	1886 ± 328	16
9/14-9/21/94	2205 ± 350	19	824 ± 188	24	2510 ± 557	9	1767 ± 386	14
6/07-6/27/95	1999 ± 324	30	2307 ± 631	23	3444 ± 336	27	1618 ± 289	25
dry	280 ± 43		245 ± 67		312 ± 33		158 ± 28	
7/31-8/15/95	2277 ± 417	19	1821 ± 797	10	2526 ± 385	15	1481 ± 245	25
dry	267 ± 46		172 ± 79		171 ± 29		149 ± 28	
9/18-9/29/95	5044 ± 752	17	479 ± 173	17	2629 ± 323	18	1281 ± 178	25
dry	551 ± 94		37 ± 13		194 ± 23		113 ± 15	
6/12-6/24/96	2959 ± 402	30	568 ± 200	30	21± 8	27	665 ± 144	25
dry	306 ± 40		59 ± 24		2 ± 1		46 ± 10	
7/30-8/9/96	3035 ± 619	27	665 ± 219	30	1± 1	27	1415 ± 256	25
dry	390 ± 82		62 ± 20		0 ± 0		176 ± 36	
9/12-9/19/96	3622 ± 469	30	574 ± 174	30	0± 0	27	1656 ± 393	25
dry	361 ± 49		50 ± 14		0 ± 0		156 ± 40	
6/27-7/17/97	2134 ± 321	30	1906 ± 341	28	24 ± 22	26	1880 ± 327	25
dry	294 ± 46		210 ± 40		3 ± 3		296 ± 55	
9/8-9/18/97	2786 ± 400	30	2646 ± 502	29	4 ± 4	27	1055 ± 170	25
dry	321 ± 49		271 ± 55		0 ± 0		100 ± 18	
6/8-6/18/98	1080 ± 168	30	1690 ± 360	31	79 ± 52	27	815 ± 164	25
dry	130 ± 18	30	213 ± 52	31	7 ± 4	27	105 ± 21	25
7/27-8/3/98	581 ± 133	30					2103 ± 475	25
dry	67 ± 16	30					286 ± 65	25
9/8-9/16/98	530 ± 76	30	3146 ± 514	29	181 ± 44	27	1487 ± 338	25
dry	48 ± 7	30	367 ± 63	29	15 ± 4	27	172 ± 40	25
6/15-6/22/99	202 ± 50	30	2238 ± 393	28	355 ± 113	27	1806 ± 289	25
dry	24 ± 7	30	252 ± 50	28	25± 8	27	155 ± 32	25
7/29-8/3/99					483 ± 101	27	1358 ± 289	25
dry					36 ± 8	27	189 ± 44	25
8/23-8/25/99	253 ± 83	30	1632 ± 237	30			1362 ± 320	25
dry	25 ± 9	30	105 ± 15	30			106 ± 26	25
6/6-6/23/00	1392 ± 263	30	2045 ± 321	29	2652 ± 340	27	981 ± 318	25
dry	208 ± 39	30	219 ± 38	29	331 ± 42	27	109 ± 37	25
7/11-7/19/00	783 ± 200	30			607 ± 82	27	501 ± 150	25
dry	115 ± 32	30			45 ± 7	27	77 ± 22	25
8/23-8/29/00	1007 ± 152	30	1988 ± 305	29	1098 ± 136	27	1474 ± 346	25
dry	91 ± 14	30	175 ± 28	29	90 ± 14	27	162 ± 40	25
6/18-6/25/01	1022 ± 199	30	1213 ± 267	29	116 ± 34	27	408 ± 107	25
dry	109 ± 21	30	111 ± 26	29	9 ± 3	27	31 ± 8	25
7/17/-7/30/01	1641 ± 279	30			138 ± 58	25	1211 ± 290	25
dry	232 ± 45	30			6 ± 3	27	168 ± 43	25
8/23-8/30/01	1549 ± 289	30	1798 ± 398	25	24 ± 11	27	1438 ± 381	25
dry	158 ± 33	30	162 ± 41	25	2 ± 1	27	160 ± 43	25
6/2-7/8/02	1886 ± 339	30	2123 ± 468	21	302 ± 87	30	1067 ± 245	25
dry	254 ± 46	30	231 ± 52	21	28 ± 7	30	137 ± 36	25
8/8-9/6/02	1776 ± 273	30	1910 ± 294	32	205 ± 49	30	1746 ± 346	25
dry	222 ± 37	30	149 ± 23	32	13 ± 3	30	246 ± 47	25
8/8/-9/19/03	346 ± 98	25	1564 ± 338	25	1073 ± 241	18		
dry	22 ± 6	25	132 ± 32	25	74 ± 20	18		

Table 2. Mean number of species per sample (Spp/S) ± 1SE and non-milfoil biomass (B; g wet /m^2) at the 4 sampling sites in 1994-2003. Number of samples is given in Table 1.

Sampling Date	Auburn		Cedar		Otter		Smith's Bay	
	Spp/S	B	Spp/S	B	Spp/S	B	Spp/S	B
5/19-6/3/94	3.80±0.47	670	1.33±0.28	75	4.76±0.19	600	3.29±0.22	1231
7/1-7/11/94	3.63±0.29	444	1.83±0.28	370	4.37±0.29	520	3.75±0.35	1604
8/12-8/19/94	3.00±0.28	647	1.53±0.26	282	5.57±0.39	1126	3.13±0.42	765
9/14-9/21/94	3.11±0.37	268	1.46±0.19	54	4.89±0.61	431	3.50±0.39	975
6/07-6/27/95	2.23±0.22	822	1.43±0.20	214	4.70±0.21	1065	3.64±0.30	877
7/31-8/15/95	3.37±0.26	1789	1.70±0.15	516	4.27±0.30	642	2.68±0.24	703
9/18-9/29/95	2.18±0.18	1058	1.41±0.17	337	2.44±0.34	135	2.80±0.20	856
6/12-6/24/96	2.93±0.24	1450	2.10±0.22	248	5.19±0.25	434	4.32±0.36	1159
7/30-8/9/96	2.78±0.31	1186	1.43±0.18	270	4.19±0.20	1171	3.88±0.41	1017
9/12-9/19/96	2.50±0.20	1166	1.57±0.16	307	3.93±0.28	1798	3.88±0.32	1531
6/27-7/17/97	2.97±0.14	1435	1.82±0.14	460	4.31±0.29	1516	4.16±0.39	1162
9/8-9/18/97	2.63±0.17	1500	1.59±0.09	235	4.81±0.26	3180	3.64±0.27	1863
6/8-6/18/98	2.43±0.18	1158	1.74±0.81	637	5.37±0.24	1835	5.32±0.43	1038
7/27-8/3/98	2.97±0.23	2197					5.00±0.44	1385
9/8-9/16/98	2.40±0.12	1258	1.62±0.12	296	4.74±0.39	1423	4.32±0.38	969
6/15-6/22/99	3.07±0.16	1806	1.86±0.13	326	4.52±0.31	825	4.60±0.37	810
7/29-8/3/99					5.33±0.30	720	3.72± 0.31	973
8/23-8/25/99	1.93±0.13	679	1.37±0.09	570			2.92± 0.33	534
6/6-6/23/00	3.17±0.19	1597	1.62±0.10	919	4.33±0.28	471	3.44±0.39	458
7/11-7/19/00	2.70±0.20	1090			4.59±0.24	595	4.48±0.45	949
8/23-8/29/00	2.30±0.12	852	1.62±0.10	354	4.33±0.21	778	4.00±0.36	979
6/18-6/25/01	2.77±0.21	971	1.52±0.11	495	4.44±0.23	628	4.00±0.35	663
7/17/-7/30/01	2.40±0.11	996			3.04±0.24	1189	3.96±0.32	1387
8/23-8/30/01	2.80±0.16	2314	1.80±0.08	1303	3.81±0.27	1293	3.60±0.28	1342
6/2-7/8/02	2.17±0.11	861	1.67±0.11	738	3.53±0.26	1128	3.28±0.26	858
8/8-9/6/02	2.30±0.14	398	1.53±0.12	709	4.53±0.25	1094	3.12±0.19	928
8/8/-9/19/03	1.92±0.11	993	1.76±0.13	1596	4.67±0.26	1552		

Table 3. Percentages of total plant wet biomass that was Eurasian watermilfoil (±1SE) and total number of species (N) collected at each site. These are the average percentage found in the samples and are thus not equal to total mean milfoil biomass/plant biomass.

Sampling Date	Auburn	N	Cedar	N	Otter	N	Smith's Bay	N
5/19-6/3/94	65% ±10%	9	67% ±11%	4	80% ± 6%	9	64% ±10%	8
7/1-7/11/94	79% ± 6%	9	67% ± 9%	4	75% ± 5%	9	72% ± 6%	11
8/12-8/19/94	74% ± 6%	9	61% ±13%	3	75% ± 6%	11	81% ± 5%	11
9/14-9/21/94	91% ± 6%	9	87% ± 5%	4	83% ± 6%	11	71% ± 8%	9
6/07-6/27/95	72% ± 7%	7	82% ± 7%	3	79% ± 4%	9	61% ± 5%	10
7/31-8/15/95	58% ± 7%	7	58% ± 6%	2	80% ± 7%	9	63% ± 6%	11
9/18-9/29/95	81% ± 7%	5	38% ± 5%	2	95% ± 1%	6	63% ± 7%	10
6/12-6/24/96	70% ± 7%	7	57% ± 7%	5	7% ± 5%	9	33% ± 6%	10
7/30-8/9/96	56% ± 8%	7	59% ± 9%	5	0.1% ± 0.1%	10	56% ± 7%	11
9/12-9/19/96	69% ± 6%	8	73% ± 6%	4	0% ± 0%	9	49% ± 7%	10
6/27-7/17/97	53% ± 13%	10	82% ± 9%	3	1% ± 2%	12	54% ± 14%	12
9/8-9/18/97	60% ± 13%	8	88% ± 9%	2	0.2% ± 0.3%	13	40% ± 14%	11
6/8-6/18/98	42% ± 5%	11	79% ± 5%	4	4% ± 2%	15	37% ± 6%	15
7/27-8/3/98	24% ± 4%	12					49% ± 8%	16
9/8-9/16/98	34% ± 4%	7	82% ± 6%	4	20% ± 5%	13	50% ± 8%	13
6/15-6/22/99	14% ± 4%	7	82% ± 6%	3	30% ± 6%	13	61% ± 7%	12
7/29-8/3/99					40% ± 5%	14	53% ± 8%	13
8/23-8/25/99	36% ± 7%	6	85% ± 6%	2			61% ± 8%	12
6/6-6/23/00	43% ± 6%	9	75% ± 7%	5	81% ± 5%	12	49% ± 9%	13
7/11-7/19/00	37% ± 6%	9			53% ± 4%	15	40% ± 8%	15
8/23-8/29/00	55% ± 6%	6	77% ± 6%	3	63% ± 5%	9	50% ± 8%	13
6/18-6/25/01	52% ± 6%	10	77% ± 6%	2	20% ± 5%	15	35% ± 8%	14
7/17/-7/30/01	56% ± 6%	5			9% ± 4%	11	42% ± 7%	14
8/23-8/30/01	40% ± 6%	5	59% ± 8%	2	5% ± 3%	12	42% ± 8%	12
6/2-7/8/02	65% ± 6%	6	63% ± 9%	2	26% ± 5%	13	44% ± 8%	11
8/8-9/6/02	76% ± 5%	6	73% ± 7%	4	26% ± 5%	16	52% ± 8%	11
8/29/03	32% ± 7%	3	55% ± 9%	4	39% ± 6%	14		

Table 4. Sediment characteristics (bulk density, percent organic matter, sediment pore water ammonium and water column characteristics in 1995-2003 at the four permanent transect sites. Sediment samples were collected from shallow, moderate and deep stations along transects 1, 3 and 5 (n=9). Secchi depth (SD), chlorophyll a (Chl-a; pooled surface and SD sample) and light and temperature profiles were taken in deep water > 100 m from the plant bed. Temperature is at 1m depth and 10% PAR depth is the depth at which light intensity was 10% of surface light (presented as the range which encompassed the 10% value).

Lake/Date	Bulk Dens. (g dm/ml)	NH_4 (mg/L)	% Organic	Chl-a (mg/m^3)	SD (m)	Temp (˚C 1m)	10% PAR Depth (m)	Plant Limit (m)
Auburn								
6/15/95	0.60	3.96	11.34	9.5	2.3	20.7	2.5-3.0	3.0
2se	0.15	0.91	3.73					
8/1/95	0.49	4.00	10.69	13.9	1.4	26.0	1.5-2.0	3.0
2se	0.18	1.24	4.39					
9/26/95	0.45	4.40	12.67	8.0	2.0	14.8	2.5	3.0
2se	0.13	1.96	4.05					
6/13/96	0.41	3.08	16.0	2.9	4.2	25.1	3	3.0
2se	0.11	1.66	8.6					
7/31/96	0.42	5.81	13.6	12.8	2.4	23.3	1-1.5	3.0
2se	0.17	1.52	4.7					
9/12/96	0.38	2.68	13.7	8.8	2.4	21.2	2.5-3.0	3.0
2se	0.14	0.95	4.3					
6/23/97	0.59	1.93	25.6	11.2	1.2	24.5	2.0	3.4
2se	0.22	0.56	16.8					
9/8/97	0.48	4.42	12.3	16.6	1.4	22.4	1.5-2.0	3.4
2se	0.14	1.46	3.3					
6/8/98	0.23	11.82	11.9	14.4	1.9	18.8	1.5-2.0	
2se	0.08	4.07	4.4					
7/28/98	0.45	20.09	9.5	41.2	0.7	25.7	0.5-1.0	
2se	0.27	3.68	4.3					
9/9/98	0.44	37.72	11.9	36.4	1.1	21.9	1.0-1.5	
2se	0.15	12.57	4.6					
6/22/99	0.50	2.79	13.6	9.4	1.8	22.4	2.0	
2SE	0.16	1.06	3.8					
8/23/99	0.44	10.98	11.6	11.0	1.5	23.1	1.0-1.5	
2SE	0.12	1.81	4.2					
6/19/00	0.51	2.36	11.1	5.9	2.1	20.4	2.5-3.0	
2se	0.14	0.51	4.0					
7/17/00	0.57	4.61	10.2	5.3	2.5	25.3	2.5-3.0	
2se	0.22	1.54	3.6					
8/28/00	0.53	7.75	11.8	5.3	2.3	24.3	3.0	
2se	0.14	1.58	3.9					
6/15/01	0.50	0.98	11.2	6.7	2.9	21.5	3	
2se	0.18	0.38	4.2					
7/17/01	0.57	3.72	25.7	7.2	1.8	27.9	2.5	
2se	0.26	1.92	30.5					
8/29/01	0.47	5.46	10.9	0.8	1.7	24.3	2-2.5	
2se	0.18	1.11	3.8					
6/27/02	0.53	6.61	18.8	-	1.6	26.2	2-2.5	
2se	0.12	3.25	6.3					
9/6/02	0.62	5.14	19.7	17.1	2.6	21.0	2.5	
2se	0.22	-	10.4					
8/29/03	0.35	3.71	11.3	.	1.9	25	2.0	
2se	0.10	1.86	3.5					
Cedar								
6/28/95	0.62	3.90	13.73	10.2	4.5	24.0	4.5	4.0
2se	0.36	1.63	6.00					
8/3/95	0.45	7.27	16.41	16.3	1.2	26.7	1.0-1.5	3.1
2se	0.33	1.39	7.40					
9/28/95	0.43	6.06	21.56	27.5	0.8	14.8	1.0-1.5	3.1
2se	0.36	1.98	7.38					

Table 4 Continued

Cedar								
6/18/96	0.57	3.78	13.3	1.1	5.5	24.6	3.5-4.0	6.5
2se	0.38	1.34	6.3					
8/1/96	0.42	3.86	19.0	4.5	1.9	23.8	2.5-3.0	3.1
2se	0.38	1.59	7.5					
9/16/96	0.41	5.12	18.5	5.3	2.8	20.1	2-2.5	3.1
2se	0.37	1.63	6.9					
7/8/97	0.54	3.97	12.89	9.6	2.5	21.0	3.0-4.0	6.0
2se	0.40	2.87	5.97					
9/11/97	0.42	5.69	15.76	0.8	3.7	22.0	3.0-3.5	6.4
2se	0.33	2.26	6.31					
6/18/98	0.31	4.01	18.35	2.1	4.7	22.6	4.5-5.0	
2se	0.30	1.99	5.27					
7/24/98*	N.A.	N.A.	N.A.	1.3	4.7	26.0	4.5-5.0	
9/16/98	0.29	34.77	18.68	6.9	2.6	23.4	2.5-3.0	
2se	0.30	18.72	4.78					
6/23/99	0.51	4.68	16.15	5.3	2.6	25.6	3.5	
2SE	0.36	1.68	8.79					
8/24/99	0.36	12.35	12.14	17.6	1.6	22.9	2.0-2.5	6.1
2SE	0.34	3.87	3.37					
6/23/00	0.32	2.29	18.28	5.1	3.3	23.1	3.0-3.5	
2se	0.25	1.42	4.77					
8/8/00	0.52	4.15	16.89	4.3	1.6	25.9	3.5-4.0	4.6
2se	0.40	3.91	8.43					
6/19/01	0.60	3.83	22.49	15.0	1.9	22.9	3	
2se	0.43	2.14	16.81					
8/30/01	0.45	2.87	14.92	15.8	1.8	24.7	3-3.5	5.0
2se	0.40	0.74	5.99					
7/8/02	0.51	6.11	30.7	-	1.9	28.3	3.5	
2se	0.28	2.51	11.6					
8/30/02	-	-	-	-	2.2	24.6	2.5-3.0	7.8
2se	-	-	-					
8/5/03	0.23	5.08	26.4	.	1.4	25.3	2.5	5.8
2se	0.14	2.62	14.2					
Otter								
6/26/95	0.42	3.27	20.26	5.6	3.0	30.0	3.5-4.0	4.0
2se	0.18	1.43	7.23					
8/10/95	0.39	4.66	24.44	12.5	2.5	24.7	1.5-2.0	4.0
2se	0.26	1.77	9.49					
9/30/95	0.38	2.76	25.07	3.7	1.1	14.5	1.0-1.5	4.0
2se	0.26	1.34	11.34					
6/20/96	0.47	4.86	23.5	8.5	1.9	21.1	1.5-2.0	3.5
2se	0.34	1.67	10.2					
8/6/96	0.27	3.54	27.5	4.8	2	26	2-2.5	4.0
2se	0.16	0.88	8.6					
9/17/96	0.33	3.77	24.9	8.0	1.5	17.9	1.5-2.0	4.0
2se	0.24	1.76	9.5					
7/2/97	0.33	1.89	26.42	9.9	1.3	21.1	2.0-2.5	3.5
2se	0.21	1.09	8.17					
9/15/97	0.29	5.88	27.47	4.8	2.1	21.0	2.0-2.5	3.5
2se	0.16	2.61	9.52					
6/10/98	0.18	10.51	24.24	2.9	2.6	17.8	4.5-5.0	
2se	0.11	3.55	8.54					
9/10/98	0.24	27.47	24.36	1.6	4.0	21.1	3.5-4.0	
2se	0.11	9.40	7.55					
6/21/99	0.24	3.37	27.31	15.5	2.7	24.5	2.5	
2SE	0.07	0.83	8.34					
7/29/99	0.22	9.58	25.37	13.4	2.1	26.4	2.0	
2SE	0.12	3.02	8.61					
7/11/00	0.47	2.69	21.36	6.9	2.5	26.7	1.5-2.0	
2se	0.32	1.63	9.13					
8/29/00	0.25	3.16	29.84	4.5	2.9	23.7	2.0-2.5	
2se	0.13	1.69	9.13					

Table 4 Continued

Otter continued								
6/21/01	0.34	2.55	25.25	3.2	2.9	22.5	2.5	
2se	0.20	1.07	10.83					
7/18/01	0.36	3.64	27.71	3.2	2.1	27.8	2.0-2.5	
2se	0.21	1.38	9.70					
8/28/01	0.35	2.77	23.05	5.1	2	24.9	2.5-3.0	
2se	0.19	1.13	8.12					
6/26/02	0.34	5.86	19.5	-	2.6	24.8	2-2.5	
2se	0.20	4.74	12.1					
9/5/02	0.70	6.92	40.2	6.1	2.3	23.7	2.5-3.0	
2se	0.50	3.31	14.1					
9/18/03	0.15	4.62	32.8		3	20.2	2.5-3.0	
2se	0.06	0.84	6.4					
Smith's								
6/29/95	0.59	5.18	11.81	4.0	3.9	23.7	5.0	5.0
2se	0.25	3.40	4.62					
8/16/95	0.28	4.06	12.86	7.5	2.1	24.9	3.5-4.0	5.0
2se	0.14	0.97	3.71					
9/18/95	0.31	4.25	12.50	10.7	2.1	14.7	2.5	5.0
2se	0.15	0.77	3.98					
6/24/96	0.36	1.13	13.9	3.7	3.7	20.6	3.5-4.0	5.0
2se	0.22	0.32	4.7					
8/8/96	0.37	2.61	17.6	1.3	3.4	24.4	4.5-5.0	5.0
2se	0.21	1.01	5.3					
9/19/96	0.32	2.43	19.1	3.2	3.5	20.1	3.0-3.5	5.0
2se	0.18	0.90	14.3					
7/15/97	0.34	2.44	9.29	1.6	3.5	22.2	4.5-5.0	5.0
2se	0.17	0.80	3.48					
9/18/97	0.31	2.94	14.10	5.3	2.4	20.9	2.5-3.0	5.0
2se	0.17	1.21	4.74					
6/15/98	0.35	3.35	11.50	1.6	3.6	21.0	4.0-4.5	
2se	0.19	1.98	4.22					
8/4/98	0.34	9.32	11.76	4.0	2.9	23.6	3.5-4.0	
2se	0.16	3.27	3.59					
9/15/98	0.30	26.00	13.55	4.3	2.7	22.5	3.0-3.5	
2se	0.14	5.87	3.40					
6/16/99	0.34	2.21	12.71	4.3	3.7	20.8	4.0	
2SE	0.18	0.40	4.08					
8/4/99	0.37	11.54	10.32	4.8	2.6	26.1	4.5-5	
2SE	0.22	8.83	3.84					
8/25/99	0.30	9.71	10.63	7.2	2.9	24.7	4.0	
2SE	0.16	3.24	3.52					
6/20/00	0.39	2.03	11.06	4.3	3.2	19.9	4.0-4.5	
2se	0.16	0.62	3.17					
7/18/00	0.38	4.00	9.91	4.5	1.9	24.3	4.5-5.0	
2se	0.20	1.13	4.71					
8/23/00	0.42	3.02	12.90	4.3	3.2	23.9	4.0	
2se	0.24	0.82	4.69					
6/22/01	0.33	1.93	12.52	2.1	2.9	20.8	4.0-4.5	
2se	0.19	0.81	4.47					
7/24/01	0.38	2.42	13.57	14.4	2.3	26.9	4	
2se	0.24	1.37	5.15					
8/23/01	0.37	3.30	12.93	3.5	3.4	24.7	4.0-4.5	
2se	0.24	1.16	4.29					
7/2/02	0.38	4.41	24.2	-	3.1	26.1	4.5	
2se	0.12	1.73	20.0					
8/8/02	0.62	3.48	17.5	5.1	2.2	23.7	3	
2se	0.24	1.06	10.6					

Changes in milfoil biomass appeared related to herbivores during some periods in 3 lakes: Auburn, Otter and Smith's Bay. No changes associated with herbivores were seen at Cedar Lake. Herbivores were found at a very low density in Cedar Lake (Table 5). Caterpillars were rarely found and milfoil weevil densities rarely exceeded 5/m^2. Adult milfoil weevils were extremely rare and it is possible that some larvae were actually *Phytobius leucogaster* larvae. *Phytobius* adults were found at Cedar and although they and their larvae are restricted to flowering stalks the larvae are indistinguishable from *Euhrychiopsis* and thus some *Phytobius* larvae may have been misidentified as *Euhrychiopsis*. The low density of herbivores and lack of clear declines of Eurasian watermilfoil at Cedar Lake indicates that herbivores are having no effect on the milfoil. Cage experiments reported in previous reports and in Ward (2002) indicate that high densities of sunfish are limiting herbivores at Cedar Lake. DNR Fisheries surveys indicate sunfish densities exceeding 100/trapnet.

Herbivores may have influenced milfoil density at Lake Auburn (Fig. 2). Weevil densities exceeded 100/m^2 in July 1994 (Table 5) and Eurasian watermilfoil was around 1500 g/m^2. Weevil densities were much lower in 1995 (< 10/m^2) when Eurasian watermilfoil increased to over 5000 g/m^2 (Fig. 2). In 1996-1997 weevil densities increased and milfoil declined. Although weevil densities in 1998-1999 were very low, milfoil density remained low until it started to increase in 2000 with low weevil densities. In 2003, milfoil again declined following weevil densities of 20/m^2 (Fig. 2).

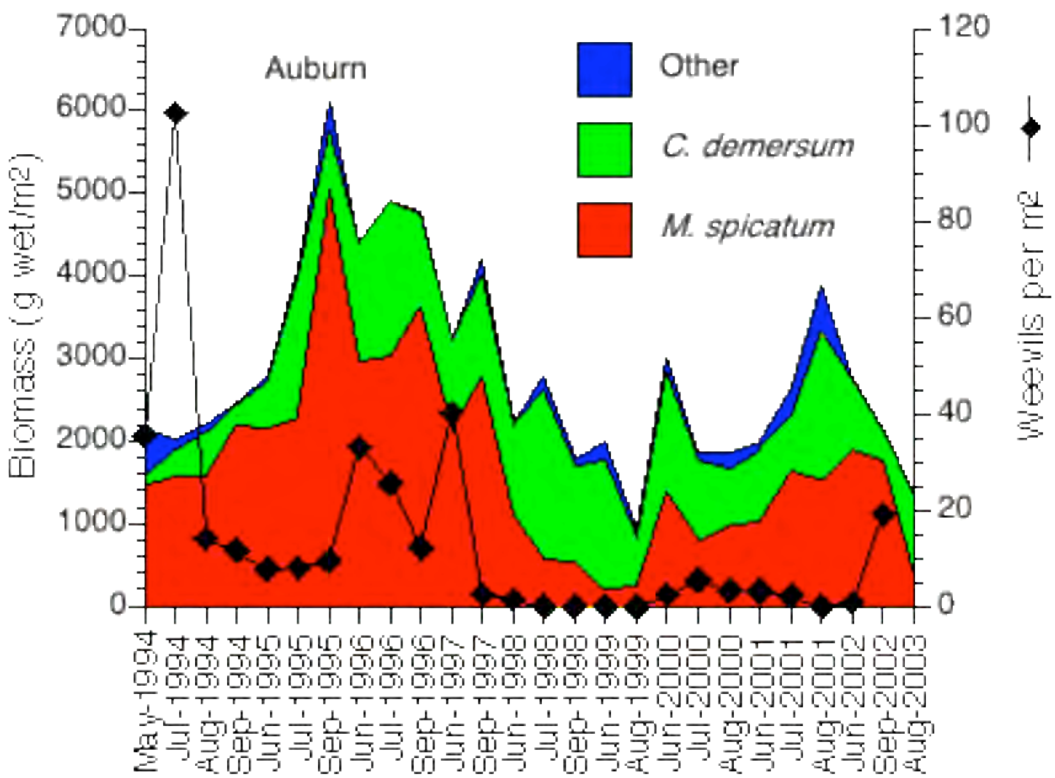

Fig. 2. Milfoil, coontail and other plant biomass (g wet/m^2) and weevil densities (N/m^2) at Lake Auburn as determined from biomass samples.

Densities of caterpillars were always low, generally < 5/m^2 (Table 5). As discussed in the weevil survey section below, weevils disappeared from mid-summer 1998 until spring of 2000. Sunfish densities in Auburn exceeded 110/trapnet in 2000 and 86/trapnet in 1995. Herbivores may have facilitated the decline and suppression of milfoil at Lake Auburn but clearly were unable to have a sustained effect or maintain high densities for several years in a row.

Overall densities of herbivores were lower at Smith's Bay (Table 5), but do appear to have suppressed the plants in the shallow sites. Weevil densities were high in 1994 and Eurasian declined from a peak of over 5000 g/m^2 (Fig 3). Milfoil increased with lower weevil densities but increasing weevil densities were followed by milfoil suppression. The main effects were at the shallowest two sets of stations (100 and 200m from shore at 1.5 and 2m depth respectively) where weevil densities were highest (Fig. 4). Weevils were rarely found at the deepest site (4.5m) and abundances were very low at the 2 intermediate sites. At the shallowest stations, Eurasian watermilfoil was suppressed to <10% of plant biomass after 1996 and northern watermilfoil became common. Thus milfoil weevils appeared to control milfoil at the shallowest two sites in water ≤2m depth but not at deeper sites in Smith's Bay.

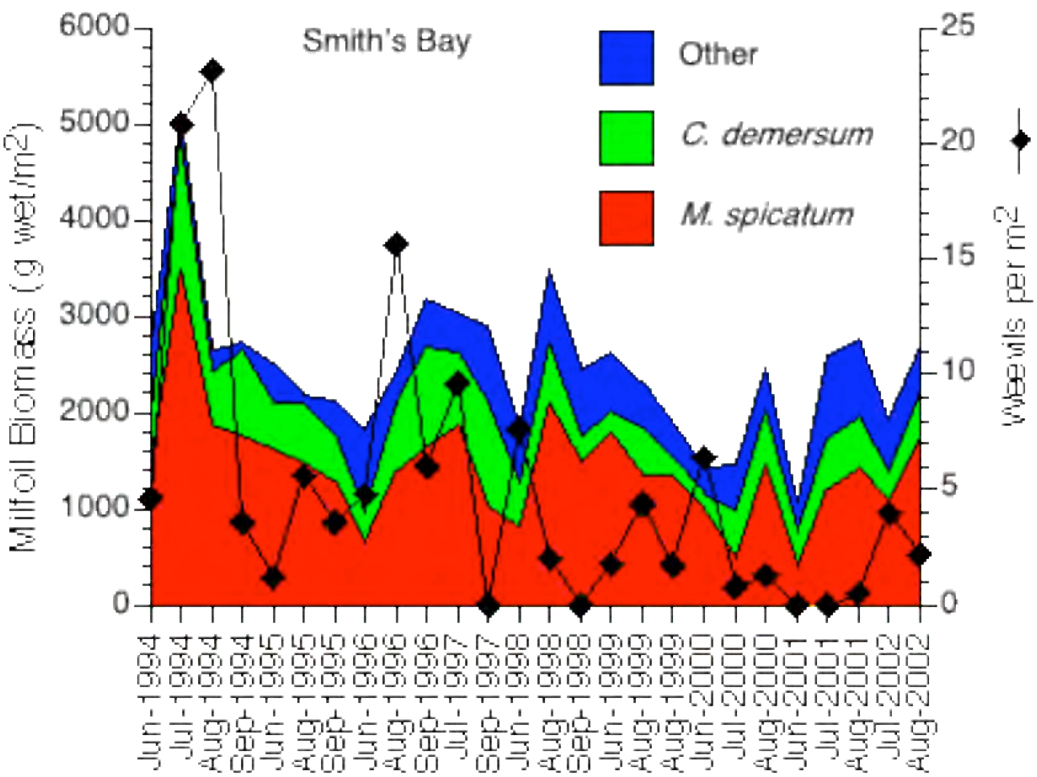

Fig. 3. Milfoil, coontail and other plant biomass (g wet/m^2) and weevil densities (N/m^2) at Smith's Bay as determined from biomass samples.

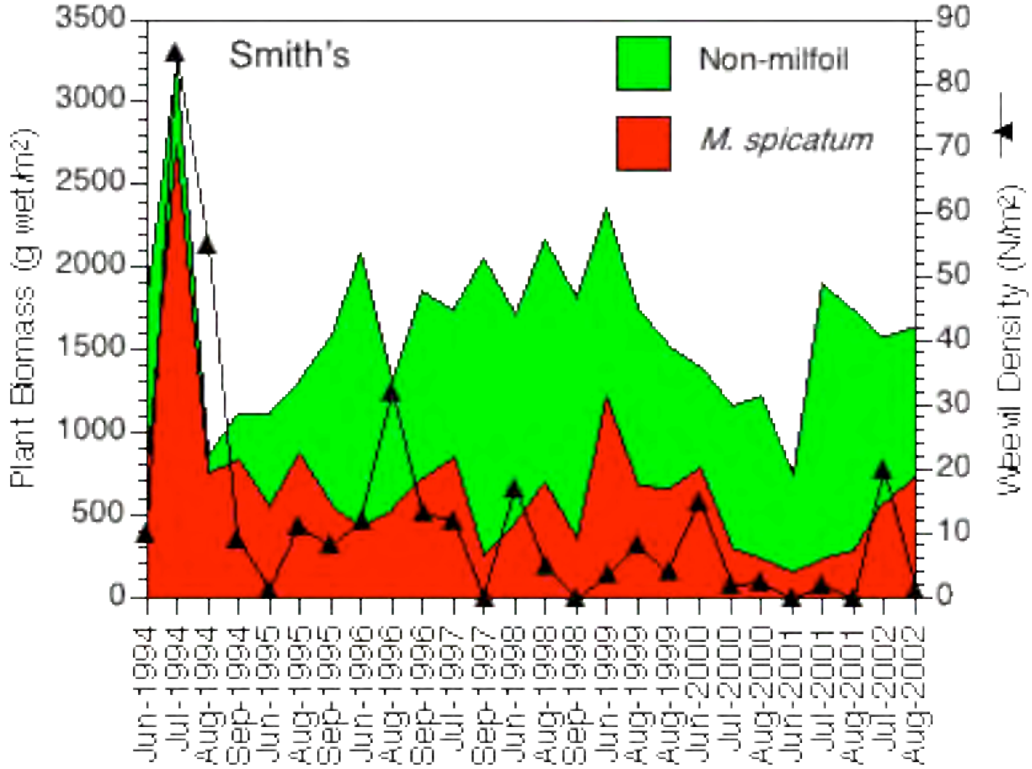

Fig. 4. Milfoil and non-milfoil plant biomass (g wet/m^2) and weevil densities (N/m^2) at the two shallowest stations (1.5 and 2m depth) at Smith's Bay as determined from biomass samples.

The first milfoil decline at Otter Lake, over the winter of 1995-1996, was likely due to winterkill (see above), however, moderate densities of milfoil weevils (12/m^2) may have contributed stress to the plants. Prior to the decline, Lepidoptera densities were quite low. After the milfoil decline in 1996, density of Lepidoptera (primarily *Parapoynx*) increased dramatically (Fig. 5). These herbivores were associated with native *Potamogeton*s and *Zosterella* and weevils were not detected in 1996 due to the lack of milfoil in the lake. As the milfoil slowly recovered, weevils returned and increased to 24/m^2 in June 2000, when milfoil had increased to over 2500 g/m^2 (Table 5). The milfoil subsequently declined that summer and remained suppressed through 2002 (Fig. 5). With the decrease in milfoil and increase in native plants Lepidoptera again became more abundant. Milfoil increased in 2003 with lower densities of milfoil weevils. The milfoil weevil caused extensive damage to milfoil in 2000-2002 and appeared to be the cause of the decline in that period. Aquatic lepidopterans may help suppress the milfoil during times of low density but were most abundant when there was little milfoil but numerous other plants, which they prefer. Sunfish densities in Otter Lake were quite low in 2000-2002 due to winterkills (<2 per trapnet) and were low in previous surveys (3-13/trapnet).

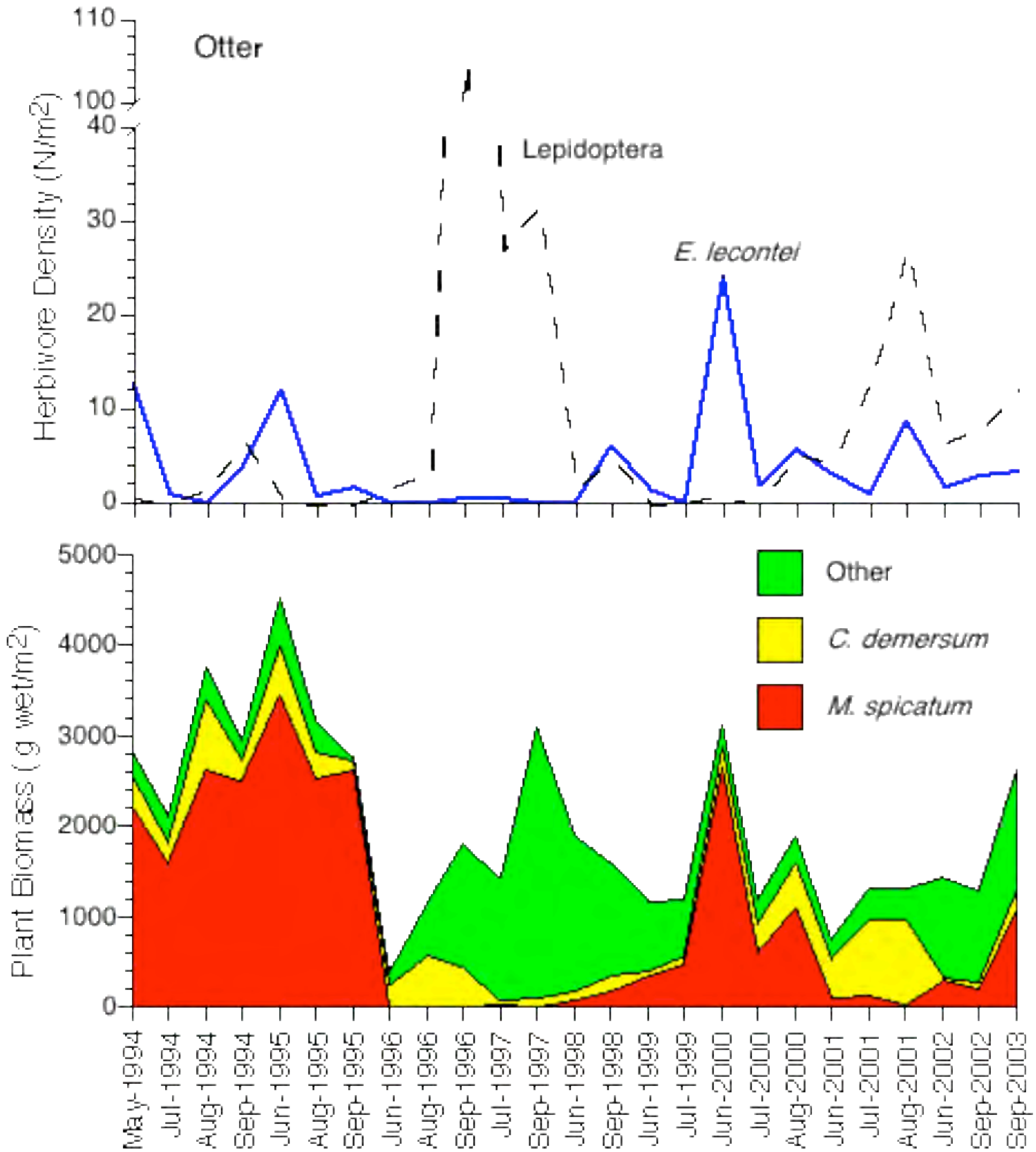

Fig. 5. Milfoil and non-milfoil plant biomass (g wet/m^2) and herbivore (milfoil weevils and Lepidoptera) densities (N/m^2) at Otter Lake as determined from biomass samples.

Table 5. Density (N/m^2 ± 2 SE and N per stem ± 2SE) of *Euhrychiopsis lecontei* larvae, pupae and adults, *Acentria ephemerella* and *Parapoynx* at the four permanent transect sites, 1994-2002. *Parapoynx* were not enumerated before 1996. A stem is a basal milfoil stem emerging from the sediment; estimates per stem do not include samples without milfoil and because caterpillars occurred often without milfoil, per stem estimates are not reported for them.

Cedar Date	Weevil n	Larvae N/m^2	Pupae N/m^2	Adults N/m^2	Total *E.l.* N/m^2	*Acentria* N/m^2	*Parapoynx*
May-94	11	5.5± 10.9	0.0± 0.0	0.9± 1.8	6.4± 10.9	0.0± 0.0	
per stem	0	–	–	–	–		
Jul-94	14	4.3± 8.6	1.4± 2.9	1.4± 2.9	7.1± 14.3	0.0± 0.0	
	0	–	–	–	–		
Aug-94	11	0.0± 0.0	0.0± 0.0	0.0± 0.0	0.0± 0.0	0.0± 0.0	
Sep-94	17	0.0± 0.0	0.0± 0.0	0.0± 0.0	0.0± 0.0	0.0± 0.0	
Jun-95	18	0.0± 0.0	0.0± 0.0	0.0± 0.0	0.0± 0.0	0.0± 0.0	
Aug-95	10	0.0± 0.0	0.0± 0.0	0.0± 0.0	0.0± 0.0	0.0± 0.0	
Sep-95	17	0.0± 0.0	0.0± 0.0	0.0± 0.0	0.0± 0.0	0.0± 0.0	
Jun-96	29	0.3± 0.7	0.0± 0.0	0.0± 0.0	0.3± 0.7	0.0± 0.0	0.0±0.0
per stem	25	0.010±0.020	0.000±0.000	0.000±0.000	0.010±0.020		
Aug-96	21	0.0± 0.0	0.5± 1.0	0.5± 1.0	1.0± 1.9	0.0± 0.0	0.0±0.0
per stem	21	0.000±0.000	0.002±0.004	0.002±0.004	0.004±0.008		
Sep-96	23	0.0± 0.0	0.0± 0.0	0.0± 0.0	0.0± 0.0	0.0± 0.0	0.0±0.0
per stem	24	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Jul-97	28	0.0±0.0	0.0±0.0	0.4±0.7	0.4±0.7	0.4±0.7	0.0±0.0
per stem	28	0.000±0.000	0.000±0.000	0.002±0.003	0.002±0.003		
Sep-97	26	0.8±1.1	0.0±0.0	0.4±0.8	1.2±1.3	0.0±0.0	0.0±0.0
per stem	26	0.012±0.016	0.000±0.000	0.002±0.003	0.013±0.019		
Jun-98	31	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
per stem	30	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Sep-98	28	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.4±0.7	0.0±0.0
per stem	24	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Jun-99	26	1.9±2.5	0.0±0.0	0.38±0.77	2.3±2.6	0.0±0.0	0.0±0.0
per stem	24	0.011±0.013	0.000±0.000	0.003±0.006	0.013±0.013		
Aug-99	27	0.7±1.5	0.0±0.0	0.0±0.0	0.7±1.5	0.0±0.0	0.0±0.0
per stem	26	0.002±0.004	0.000±0.000	0.000±0.000	0.002±0.004		
Jun-00	26	7.7±6.8	0.8±1.5	0.4±0.8	8.8±7.8	0.0±0.0	0.0±0.0
per stem	25	0.035±0.031	0.003±0.005	0.001±0.002	0.039±0.034		
Aug-00	27	3.3±3.2	0.0±0.0	0.0±0.0	3.3±3.2	0.7±1.0	0.0±0.0
per stem	25	0.023±0.023	0.000±0.000	0.000±0.000	0.023±0.023		
Jun-01	28	0.0±0.0	1.1±2.1	2.1±4.3	3.2±6.4	0.0±0.0	0.0±0.0
per stem	20	0.000±0.000	0.017±0.033	0.033±0.067	0.050±0.100		
Aug-01	24	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
per stem	12	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Jul-02	18	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
per stem	16	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Aug-02	29	1.4±1.3	0.0±0.0	0.0±0.0	1.4±1.3	0.0±0.0	0.3±0.7
per stem	23	0.010±0.010	0.000±0.000	0.000±0.000	0.010±0.010		

Table 5. Continued.

Auburn Date	Weevil n	Larvae N/m²	Pupae N/m²	Adults N/m²	Total *E.l.* N/m²	*Acentria* N/m²	*Parapoynx*
May-94	9	27.8 ±27.4	1.1± 2.2	6.7± 8.8	35.6± 36.5	1.1± 2.2	
per stem	9	0.134±0.103	0.002±0.004	0.018±0.020	0.154±0.106		
Jul-94	16	58.8± 21.1	12.5± 9.6	31.3± 14.0	102.5± 36.7	6.3± 7.7	
per stem	16	0.217±0.092	0.034±0.034	0.084±0.036	0.335±0.127		
Aug-94	15	8.7± 7.5	2.0± 2.9	3.3± 3.7	14.0± 9.5	0.7± 1.3	
per stem	15	0.031±0.025	0.003±0.005	0.008±0.008	0.042±0.030		
Sep-94	18	1.7± 3.3	2.2± 2.6	7.8± 7.8	11.7± 11.8	3.9± 3.3	
per stem	18	0.002±0.004	0.006±0.008	0.014±0.012	0.022±0.019		
Jun-95	30	6.0± 4.0	0.7± 0.9	1.0± 1.1	7.7± 2.7	0.3± 0.7	
per stem	21	0.070±0.043	0.003±0.006	0.011±0.015	0.085±0.056		
Jul-95	15	2.0± 2.1	0.7± 1.3	5.3± 5.5	8.0± 3.8	0.0± 0.0	
per stem	14	0.006±0.009	0.000±0.000	0.032±0.039	0.038±0.042		
Sep-95	16	2.5± 2.2	3.1± 3.5	3.8± 4.0	9.4± 3.4	1.3± 1.7	
per stem	11	0.140±0.194	0.049±0.090	0.103±0.180	0.292±0.385		
Jun-96	30	31.0± 17.8	2.0± 2.0	0.0± 0.0	33.0± 19.5	0.3± 0.7	0.0± 0.0
per stem	27	0.729±1.179	0.080±0.148	0.000±0.000	0.809±1.326		
Jul-96	25	9.2± 15.2	3.6± 2.6	12.8± 6.3	25.6± 17.9	1.6±1.5	0.8±1.1
per stem	23	0.029±0.043	0.020±0.021	0.048±0.027	0.096±0.061		
Sep-96	30	6.7± 4.3	2.3± 1.6	3.0± 2.7	12.0± 6.5	0.7±0.9	5.7± 4.4
per stem	29	0.048±0.053	0.007±0.005	0.011±0.010	0.065±0.055		
Jun-97	30	35.7±19.6	0.3±0.7	4.3±5.9	40.3±24.3	0.7±1.3	0.0±0.0
per stem	27	0.201±0.126	0.001±0.003	0.022±0.027	0.224±0.144		
Sep-97	30	0.3±0.7	0.0±0.0	1.7±1.4	2.0±1.5	1.7±2.7	2.3±2.8
per stem	29	0.001±0.001	0.000±0.000	0.007±0.007	0.008±0.008		
Jun-98	27	1.0±1.1	0.0±0.0	0.3±0.7	1.3±1.3	1.0±2.0	0.0±0.0
per stem	27	0.005±0.005	0.000±0.000	0.001±0.003	0.006±0.006		
Jul-98	28	0.0±0.0	0.0±0.0	0.0±0.0	0.±0.0	0.7±1.0	0.0±0.0
per stem	24	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Sep-98	30	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.3±0.7
per stem	28	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Jun-99	27	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.3±0.7	0.0±0.0
per stem	19	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Aug-99	27	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
per stem	19	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Jun-00	26	0.8±1.1	0.0±0.0	1.5±1.4	2.3±2.0	0.0±0.0	0.0±0.0
per stem	23	0.004±0.005	0.000±0.000	0.007±0.007	0.010±0.009		
Jul-00	28	1.6±2.5	0.4±0.8	3.6±3.6	5.4±5.5	0.0±0.0	0.0±0.0
per stem	21	0.009±0.014	0.004±0.008	0.027±0.025	0.039±0.038		
Aug-00	28	1.1±2.1	0.0±0.0	2.1±2.4	3.2±4.4	0.0±0.0	2.1±3.1
per stem	27	0.011±0.022	0.000±0.000	0.024±0.028	0.035±0.047		
Jun-01	29	0.3±0.7	2.4±2.6	0.7±1.0	3.4±2.7	0.0±0.0	0.0±0.0
per stem	24	0.003±0.006	0.023±0.029	0.008±0.012	0.034±0.030		
Jul-01	30	0.7±0.9	0.3±0.7	1.0±1.1	2.0±1.5	0.0±0.0	0.0±0.0
per stem	25	0.011±0.015	0.002±0.003	0.007±0.008	0.019±0.016		
Aug-01	30	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	2.3±4.0	5.0±6.0
per stem	19	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		

Table 5. Continued.

Date	Weevil n	Larvae N/m²	Pupae N/m²	Adults N/m²	Total *E.l.* N/m²	*Acentria* N/m²	*Parapoynx*
Auburn Cont:							
Jun-02	30	0.37±0.7	0.07±0.0	0.37±0.7	0.77±0.9	0.07±0.0	0.07±0.0
per stem	29	0.003±0.006	0.000±0.000	0.001±0.002	0.004±0.006		
Sep-02	27	4.87±3.3	3.07±3.3	11.97±7.6	18.97±11.5	3.07±2.6	0.47±0.0
per stem	27	0.021±0.015	0.009±0.010	0.045±0.028	0.076±0.044		
Otter							
May-94	20	12.5± 10.2	0.0± 0.0	0.0± 0.0	12.5± 10.2	0.5± 1.0	
per stem	20	0.047±0.038	0.000±0.000	0.000±0.000	0.047±0.038		
Jul-94	24	0.4± 0.9	0.0± 0.0	0.4± 0.9	0.8± 1.2	0.0± 0.0	
	24	0.001±0.002	0.000±0.000	0.001±0.003	0.002±0.003		
Aug-94	14	0.0± 0.0	0.0± 0.0	0.0± 0.0	0.0± 0.0	1.4± 2.9	
	14	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Sep-94	8	0.0± 0.0	1.3± 2.5	2.5± 3.3	3.8± 3.7	6.3± 5.3	
	7	0.000±0.000	0.003±0.007	0.013±0.022	0.016±0.021		
Jun-95	27	5.9± 5.1	2.6± 3.3	3.3± 3.4	11.9± 9.0	0.4± 0.7	
	26	0.033±0.030	0.021±0.034	0.022±0.020	0.076±0.071		
Aug-95	15	0.0± 0.0	0.0± 0.0	0.7± 1.3	0.7± 1.3	0.0± 0.0	
	1	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Sep-95	18	0.6± 1.1	0.0± 0.0	1.1± 2.2	1.7± 2.4	0.0± 0.0	
	1	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Jun-96	25	0.0± 0.0	0.0± 0.0	0.0± 0.0	0.0± 0.0	0.8± 1.6	0.8±1.6
	5	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Aug-96	26	0.0± 0.0	0.0± 0.0	0.0± 0.0	0.0± 0.0	0.8± 1.1	2.3± 2.0
	2	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Sep-96	27	0.0± 0.0	0.0± 0.0	0.0± 0.0	0.0± 0.0	4.4± 3.6	100.4±24.5
	0	–	–	–	–		
Jul-97	26	0.4±0.8	0.0±0.0	0.0±0.0	0.4±0.8	6.2± 3.9	20.8±20.5
	3	0.083±0.167	0.000±0.000	0.000±0.000	0.083±0.167		
Sep-97	27	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	1.5±1.8	30.0±13.8
	1	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Jun-98	27	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	1.1±1.6	0.4±0.7
	13	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Sep-98	27	4.1±4.3	0.0±0.0	1.9±3.0	5.9±5.1	0.0±0.0	4.4±5.4
	16	0.206±0.219	0.000±0.000	0.049±0.084	0.255±0.223		
Jun-99	22	1.4±2.0	0.0±0.0	0.0±0.0	1.4±2.0	0.0±0.0	0.0±0.0
	20	0.030±0.050	0.000±0.000	0.000±0.000	0.030±0.050		
Jul-99	26	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
	26	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Jun-00	27	14.4±14.8	4.8±4.3	4.8±3.9	24.1±20.4	0.0±0.0	0.4±0.7
	27	0.092±0.093	0.029±0.037	0.028±0.027	0.150±0.131		
Jul-00	27	1.1±1.6	0.0±0.0	0.7±1.5	1.9±3.0	0.0±0.0	0.0±0.0
	27	0.019±0.030	0.000±0.000	0.015±0.030	0.033±0.059		
Aug-00	27	4.1±4.8	0.0±0.0	1.5±1.4	5.6±5.7	1.9±1.5	3.3±2.4
	27	0.064±0.074	0.000±0.000	0.011±0.012	0.076±0.083		

Table 5. Continued.
Otter Continued:

Date	Weevil n	Larvae N/m^2	Pupae N/m^2	Adults N/m^2	Total *E.l.* N/m^2	*Acentria* N/m^2	*Parapoynx* N/m^2
Jun-01	27	1.1±2.2	0.4±0.7	2.2±3.3	3.7±4.3	4.1±3.6	0.7±1.5
per stem	21	0.024±0.034	0.005±0.010	0.083±0.131	0.111±0.134		
Jul-01	25	0.0±0.0	0.0±0.0	0.8±1.6	0.8±1.6	0.4±0.8	13.2±9.5
per stem	4	0.000±0.000	0.000±0.000	0.250±0.500	0.250±0.500		
Aug-01	23	5.7±6.6	0.0±0.0	0.4±0.9	6.1±7.4	2.6±3.8	27.0±11.6
per stem	0	.-	.-	.-.	.-		
Jun-02	27	1.1±1.2	0.7±1.5	0.7±1.0	1.5±1.8	3.3±2.4	3.0±2.8
per stem	20	0.078±0.109	0.007±0.013	0.006±0.009	0.091±0.109		
Sep-02	26	1.5±1.8	0.4±0.8	0.8±1.1	2.7±2.1	2.7±2.4	5.0±5.0
per stem	26	0.038±0.046	0.005±0.010	0.019±0.027	0.063±0.051		
Smith's Bay							
Jun-94	13	3.8± 5.3	0.0± 0.0	0.8± 1.5	4.6± 6.6	0.0± 0.0	
per stem	12	0.020±0.030	0.000±0.000	0.005±0.010	0.025±0.040		
Jul-94	11	12.3± 13.0	6.9± 8.0	1.5± 2.1	20.8± 20.9	0.8± 1.5	
	13	0.064±0.083	0.038±0.052	0.006±0.009	0.108±0.137		
Aug-94	16	18.0± 15.0	3.1± 4.0	1.9± 2.7	23.1± 20.2	0.6± 1.3	
	15	0.104±0.079	0.019±0.022	0.010±0.015	0.133±0.109		
Sep-94	14	0.0± 0.0	1.4± 2.9	2.1± 2.3	3.6± 4.5	0.0± 0.0	
	14	0.000±0.000	0.003±0.006	0.013±0.020	0.016±0.022		
Jun-95	25	0.4± 0.8	0.0± 0.0	0.8± 1.1	1.2± 1.3	0.0± 0.0	
	14	0.001±0.003	0.000±0.000	0.027±0.048	0.028±0.047		
Aug-95	25	4.0± 4.3	1.2± 1.8	0.4± 0.8	5.6± 5.3	0.0± 0.0	
	9	0.080±0.096	0.000±0.000	0.007±0.015	0.087±0.107		
Sep-95	25	0.8± 1.1	2.0± 3.3	0.8± 1.1	3.6± 5.0	0.0± 0.0	
	15	0.010±0.014	0.025±0.039	0.013±0.019	0.048±0.061		
Jun-96	25	4.8± 5.8	0.0± 0.0	0.0± 0.0	4.8± 5.8	5.2± 8.8	0.0± 0.0
	20	0.037±0.043	0.000±0.000	0.000±0.000	0.037±0.043		
Aug-96	25	12.4± 10.0	1.2± 1.8	2.0± 2.0	15.6± 10.5	0.0± 0.0	1.6± 2.5
	24	0.107±0.084	0.006±0.008	0.015±0.015	0.127±0.087		
Sep-96	25	1.2± 1.8	2.0± 2.0	2.8± 3.4	6.0± 5.3	0.8± 1.1	0.0± 0.0
	24	0.005±0.007	0.009±0.009	0.014±0.015	0.028±0.022		
Jul-97	25	5.2±4.3	0.4±0.8	4.0±3.7	9.6±6.9	0.0± 0.0	0.8±1.6
	21	0.049±0.053	0.003±0.005	0.043±0.049	0.094±0.094		
Sep-97	25	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.4±0.8	0.0± 0.0
	21	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Jun-98	25	7.2±7.2	0.4±0.8	0.0±0.0	7.6±7.6	1.2±1.8	0.0±0.0
	21	0.052±0.054	0.002±0.005	0.000±0.000	0.054±0.055		
Aug-98	25	1.2±1.8	0.0±0.0	0.8±1.1	2.0±2.0	0.0±0.0	0.0±0.0
	20	0.017±0.023	0.000±0.000	0.002±0.005	0.019±0.023		
Sep-98	25	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.4±0.8
	19	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Jun-99	22	0.9±1.3	0.0±0.0	0.9±1.3	1.8±2.1	0.9±1.3	0.0±0.0
	22	0.047±0.091	0.000±0.000	0.047±0.091	0.094±0.182		
Jul-99	25	2.4±4.8	0.8±1.1	1.2±1.3	4.4±4.9	0.0±0.0	1.2±1.5
	21	0.000±0.000	0.002±0.003	0.014±0.024	0.017±0.024		
Aug-99	23	0.9±1.2	0.0±0.0	0.9±1.2	1.7±2.0	0.0±0.0	0.0±0.0
	22	0.005±0.007	0.000±0.000	0.007±0.010	0.012±0.015		

Table 5. Continued.
Smith's Bay Continued:

Date	Weevil n	Larvae N/m^2	Pupae N/m^2	Adults N/m^2	Total *E.l.* N/m^2	*Acentria* N/m^2	*Parapoynx* N/m^2
Jun-00	22	3.6±4.1	0.9±1.8	1.8±1.7	6.4±5.5	1.4±2.0	0.0±0.0
	20	0.027±0.035	0.007±0.014	0.008±0.009	0.042±0.042		
Jul-00	24	0.0±0.0	0.0±0.0	0.8±1.7	0.8±1.7	0.0±0.0	0.0±0.0
	19	0.000±0.000	0.000±0.000	0.009±0.018	0.009±0.018		
Aug-00	23	1.3±1.4	0.0±0.0	0.0±0.0	1.3±1.4	0.0±0.0	1.7±2.4
	21	0.009±0.010	0.000±0.000	0.000±0.000	0.009±0.010		
Jun-01	25	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.4±0.8	0.0±0.0
per stem	13	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Jul-01	24	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
per stem	17	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
Aug-01	20	0.0±0.0	0.0±0.0	0.5±1.0	0.5±1.0	0.0±0.0	0.0±0.0
per stem	14	0.000±0.000	0.000±0.000	0.002±0.005	0.002±0.005		
Jul-02	25	5.6±4.8	0.8±1.1	1.6±2.2	4.0±5.0	0.0±0.0	0.0±0.0
per stem	19	0.117±0.210	0.001±0.002	0.113±0.210	0.231±0.420		
Aug-02	24	1.4±2.5	0.1±0.0	0.9±1.2	2.2±2.7	0.5±0.8	0.1±0.0
per stem	19	0.004±0.009	0.000±0.000	0.009±0.012	0.013±0.014		

Cenaiko Lake:

Cenaiko Lake provides a clear example of a weevil induced decline and also illustrates the role of sunfish in herbivore densities and milfoil control. Milfoil biomass declined significantly in 1996 with high densities of weevils (Newman and Biesboer 2001). Milfoil increased in summer 1998 but was again controlled by weevils and remained suppressed (<10% of total biomass) through 2001 (Fig 6). Milfoil increased to nearly 70 g/m^2 and more than 30% of total biomass in 2002 (Table 6). Milfoil biomass continued to increase at Cenaiko Lake in 2003 to 170 g/m^2, exceeding the previous peak biomass (123 g dry/m^2) found in 1996 at the start of the decline (Fig 6). Milfoil became the dominant plant, composing almost 70% of total plant biomass in late July 2003, the highest percentage since the decline in 1996. Herbivore densities were very low in 2001-2002 (Table 7). Native plant biomass remained relatively high and similar to 2000-2001 at 120g dry/m^2, and the mean and total number of species remained similar to previous years. Good water clarity in 2003 (Secchi of 4.8m in late July) probably helped maintain some native plants while enhancing milfoil growth, in contrast to 2002 when poor water clarity associated with summer rains may have suppressed the plant community (Table 8). However, low densities of herbivores since 2002 (only 2 weevil eggs detected in 2003; see below) are failing to control the milfoil.

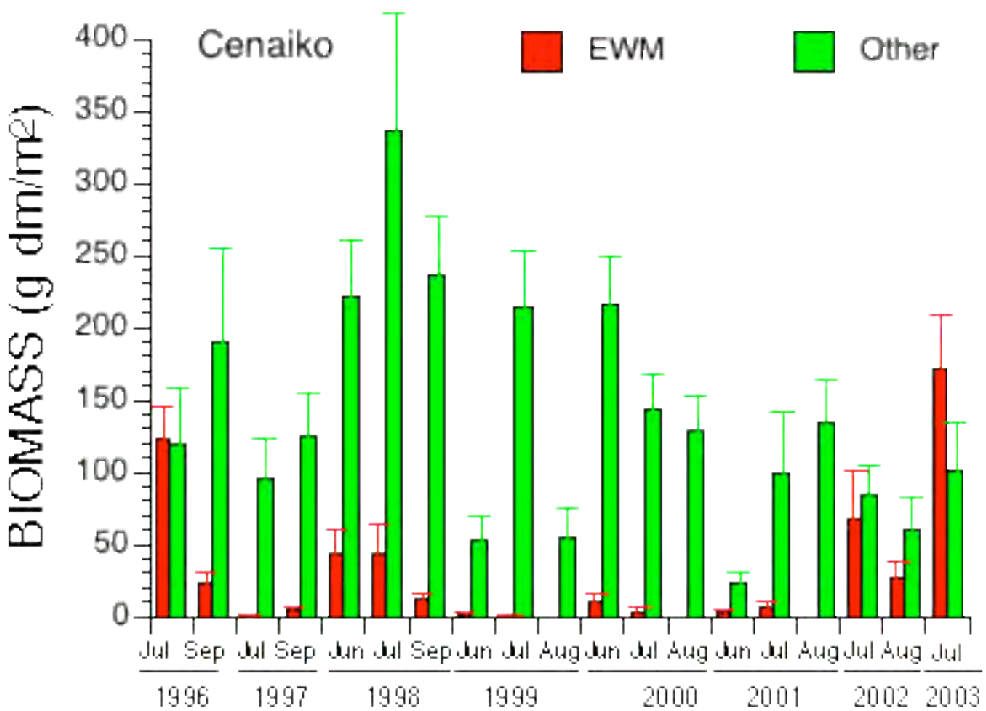

Fig. 6. Biomass (g dm/m^2 +1SE) of Eurasian watermilfoil and all other plants at Cenaiko Lake 1996-2003.

Table 6. Biomass (g dry/m^2) of all plants (Total), Eurasian watermilfoil (MSP), the dominant plants (coontail (CRT), *Zosterella* (= *Heteranthera*) *dubia* (ZOS), *Potamogeton zosteriformis* (PZS), *Chara* (CHA) and *Potamogeton amplifolius* (PAM)), non-milfoil biomass (NAT), total (TN) and mean number of species (N Sp) and mean percentage of biomass that was Eurasian watermilfoil in Cenaiko Lake 1999-2003. N=17-27 samples per date. In July and August 2001, *Potamogeton nodosus* was present at densities of 36 and 19 g dry/m^2 and in August 2002 at 50 g/m^2. In 2002 *P. pectinatus* was present at 2-3 g/m^2. In 2003, *P. pectinatus* was present at 2g/m^2.

Date	Total	MSP	CRT	PZS	ZOS	CHA	PAM	TN	N Sp.	NAT	%MSP
6/24/99	53.7	1.3	32.2	0.2	3.0	0.5	12.3	11	1.9	52.4	7.9%
1 S.E.	17.0	0.9	12.0	0.2	2.5	0.4	10.7		0.2	17.1	5.2%
8/2/99	214.6	1.1	124.5	0.0	26.7	0.0	34.1	10	2.6	213.5	1.0%
1 S.E.	40.1	0.8	37.5	0.0	9.7	0.0	23.6		0.2	40.2	0.7%
8/26/99	55.0	0.0	30.2	0.1	5.0	0.0	6.7	5	1.5	55.0	0.0%
1 S.E.	20.1	0.0	20.1	0.1	3.4	0.0	4.4		0.1	20.1	0.0%
6/29/00	225.9	10.0	123.9	0.0	16.3	46.0	19.8	9	2.1	215.9	3.1%
1 SE	34.1	5.2	31.2	0.0	8.2	21.1	14.3		0.2	33.1	1.7%
7/20/00	146.8	3.7	86.4	0.0	19.5	14.5	18.3	8	2.4	143.2	8.4%
1 SE	23.6	2.2	22.5	0.0	10.1	9.4	11.8		0.3	24.1	5.1%
8/30/00	134.5	0.1	89.4	34.5	0.0	8.0	1.7	8	1.8	129.4	0.1%
1 SE	22.0	0.1	23.5	14.9	0.0	7.3	1.5		0.2	22.8	0.1%
6/26/01	25.5	2.8	17.2	0.6	0.0	0.0	0.6	7	1.4	22.7	3.5%
1 SE	8.5	2.8	7.9	0.3	0.0	0.0	0.6		0.4	8.0	3.3%
7/30/01	105.4	6.8	59.5	0.0	0.0	0.0	0.0	7	1.1	98.6	7.1%
1 SE	43.1	4.0	26.1	0.0	0.0	0.0	0.0		0.3	42.6	4.4%
8/27/01	133.6	0.0	98.8	1.0	0.0	0.0	8.8	6	1.0	133.6	4.0%
1 SE	29.6	0.0	27.3	0.5	0.0	0.0	6.4		0.1	29.6	4.0%
7/1/02	152.4	67.7	74.6	4.0	0.0	0.0	0.0	5	2.2	84.8	19.4%
1 SE	44.5	34.3	21.8	3.2	0.0	0.0	0.0		0.2	20.7	8.7%
8/27/02	87.8	26.9	51.3	0.1	0.0	0.0	0.0	6	1.8	60.9	36.8%
1 SE	21.1	11.3	22.5	0.1	0.0	0.0	0.0		0.2	22.0	11.3%
7/28/03	271.2	170.7	69.9	9.6	0.0	4.4	15.1	6	2.6	100.4	70.4%
1 SE	53.2	37.1	22.3	9.3	0.0	3.3	15.1		0.1	34.2	7.1%

Fish surveys (DNR Lake Survey) in 1992, prior to the decline in 1996, indicated a high density of sunfish (95/trapnet set). In 1998, just after the decline and during a period of high weevil densities, sunfish density had dropped to 5/trapnet. Fish surveys in 2002 indicated a density of sunfish of 25/trapnet, 5 times higher than in 1998. As noted below sunfish appear to be limiting weevil and herbivore densities in many of our lakes. Although preliminary analysis of fish survey data from 2003 indicated only 15 sunfish/trapnet, the higher sunfish density in 2002 may have effectively eliminated the milfoil weevil from Cenaiko during 2003 (see below). It is not known how long natural recolonization would take to reestablish a viable weevil population if sunfish density would further decline.

Table 7. Density (N/m^2 ± 2 SE and N per stem) of *Euhrychiopsis lecontei* (*E.l.*) larvae, pupae and adults, and *Acentria ephemerella* and *Parapoynx* sp. at Cenaiko Lake in 1996-2002. Densities per stem were only calculated for samples with Eurasian watermilfoil and because the caterpillars often occurred in samples with no milfoil their densities per stem were not calculated. A stem is a basal milfoil stem emerging from the sediment. Samples with no plants were not included in herbivore density estimates.

Date	Weevil n	Larvae N/m^2	Pupae N/m^2	Adults N/m^2	Total *E.l.* N/m^2	*Acentria* N/m^2	*Parapoynx* N/m^2
7/22/96	29	48.6± 25.2	22.8± 10.8	31.7± 13.6	103.1± 41.9	18.3± 7.7	1.0± 1.5
per stem	26	0.923±1.292	0.337±0.458	0.381±0.280	1.640±1.972		
9/5/96	21	2.9± 2.4	1.0± 1.3	4.3± 4.3	8.1± 5.6	31.9± 20.2	0.0± 0.0
per stem	8	0.229±0.259	0.008±0.017	0.417±0.516	0.654±0.721		
7/16/97	26	1.5±1.8	0.0±0.0	0.0±0.0	1.5±1.8	8.8±5.8	0.0±0.0
per stem	3	0.389±0.401	0.000±0.000	0.000±0.000	0.389±0.401		
9/17/97	24	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	32.1±19.6	1.7±2.0
per stem	6	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
6/16/98	25	0.4±0.8	0.0±0.0	0.0±0.0	0.4±0.8	17.6±9.1	0.4±0.8
per stem	15	0.004±0.009	0.000±0.000	0.000±0.000	0.004±0.009		
7/29/98	25	0.0±0.0	0.0±0.0	0.8±1.6	0.8±1.6	1.6±1.5	0.4±0.8
per stem	12	0.000±0.000	0.000±0.000	0.019±0.037	0.019±0.037		
9/14/98	25	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	6.4±4.5	21.6±19.8
per stem	3	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
6/24/99	26	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	16.9±10.3	0.0±0.0
per stem	3	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
8/2/99	24	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	2.0±1.1	0.0±0.1
per stem	3	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
8/26/99	23	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	6.5±5.4	0.0±0.0
per stem	0	-	-	-	-		
06/29/00	22	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	69.1±43.2	0.0±0.0
per stem	6	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
07/20/00	22	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	32.0±16.1	3.0±5.0
per stem	7	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
08/30/00	21	0.5±1.0	0.0±0.0	0.0±0.0	0.5±1.0	12.9±9.4	4.3±8.6
per stem	7	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
6/26/01	20	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	3.5±4.9	0.0±0.0
per stem	1	0.000±.	0.000±.	0.000±.	0.000±.		
7/30/01	21	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	4.8±4.3	0.0±0.0
per stem	3	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
8/27/01	19	0.5±1.1	0.0±0.0	0.0±0.0	0.5±1.1	0.0±0.0	0.0±0.0
per stem	0	-	-	-	-		
7/1/02	15	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	5.3±5.1	0.0±0.0
per stem	7	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
8/27/02	16	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	1.3±1.7	0.6±1.2
per stem	8	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		

Table 8. Sediment characteristics (bulk density, percent organic matter, sediment pore water ammonium and water column characteristics in 1996-2003 at Cenaiko Lake. Sediment samples were collected from shallow, moderate and deep stations along transects 1, 2 and 3 (n=9).

Date	Bulk Dens. (g dm/ml)	NH_4 (mg/L)	% Organic	Chl-a (mg/m^3)	SD (m)	Temp (˚C 1m)	10% PAR Depth (m)	Plant Limit (m)
7/22/96	1.23	0.60	1.5%	1.34	5.0	25.4	4.5-5.0	3.4
2se	0.22	0.54	0.5%					
9/5/96	1.22	0.67	2.4%	5.61	4.0	25.7	5.0	3.4
2se	0.23	0.40	1.1%					
7/16/97	1.10	1.63	2.5%	4.54	2.3	27.6	3.5	3.0
2se	0.20	0.67	0.6%					
9/17/97	0.96	2.87	2.5%	1.60	2.3	21.3	2.0-2.5	3.0
2se	0.18	1.65	0.5%					
6/16/98	0.98	2.37	2.2%	2.41	3.8	23.7	5.5-6.0	3.4
2se	0.18	0.66	0.5%					
7/29/98	0.97	4.98	2.3%	2.41	4.4	25.9	4.5-5.0	3.4
2se	0.16	2.31	0.7%					
9/14/98	1.12	6.08	1.7%	3.21	3.0	23.8	3.5-4.0	3.2
2se	0.12	4.90	0.5%					
6/24/99	1.12	1.12	1.76%	1.3	2.7	24.3	3.5-4.0	
2SE	0.24	0.24	0.82%					
8/2/99	1.14	2.09	1.29%	3.5	2.7	27.4	3.0-3.5	
2SE	0.17	0.78	0.40%					
8/26/99	1.22	4.20	1.30%	2.1	3.1	24.3	3.0-3.5.0	
2SE	0.14	1.27	0.45%					
6/29/00	1.08	1.11	2.31%	2.14	2.3	23.5	3.5	
2se	0.27	0.73	0.41%					
7/20/00	1.13	4.09	3.01%	3.47	1.6	23.2	2.0-2.5	
2se	0.35	.	1.57%					
8/30/00	1.25	3.27	2.43%	2.94	1.4	23.1	4.5-5.0	
2se	0.26	2.41	0.70%					
6/26/01	1.05	1.45	3.69%	4.3	1.3	25.2	2.5	
2se	0.28	0.75	3.66					
7/30/01	1.27	2.07	1.80%	4.5	0.9	26.9	1.5	
2se	0.23	0.65	0.59					
8/27/01	1.26	3.92	1.70%	17.6	2.3	25.6	4.5	
2se	0.21	2.08	0.60					
7/1/02	1.42	2.39	5.3	-	1.2	29.0	1.5-2.0	
2se	0.63	1.63	4.2					
8/27/02	1.51	2.57	7.8	4.0	3.8	24.6	4	
2se	0.24	1.41	2.2					
7/28/03	1.14	3.54	2.3	.	4.8	26.2	5.0	
2se	0.39	1.72	1.1					

Weevil surveys:

The biomass samples provide an estimate of herbivore densities, however, the samples are infrequent, some herbivores may be overlooked in the large plant samples and when milfoil density is low, relatively few milfoil stems may be sampled. We therefore conducted biweekly weevil surveys, which provide a better assessment of weevil populations and are less likely to miss weevils due to peaks and troughs in abundance through the life cycle. Weevil eggs are also enumerated. Biweekly weevil surveys were conducted in Lake Auburn, Cenaiko Lake, and Smiths Bay from 1999-2003 and Otter from 2000-2003. Results of 1998 and 1999 surveys in Auburn were presented in our previous report and are summarized here.

Weevil densities were highest at Cenaiko Lake in 1999, with a summer mean of 0.7/stem and almost 0.1 adults per stem (Table 9). Weevil densities at Cenaiko slowly declined over the next four years. In 2000, summer average weevil densities exceeded 0.3 per stem but this dropped below 0.1 per stem in 2002; only 2 weevil eggs were found in 2003 and no other life stages were detected (Table 9). *Acentria* and *Parapoynx* densities were also decreased in 2002 and 2003. As noted above, sunfish appear to be limiting weevil and herbivore densities in many of our lakes and Cenaiko Lake appears a prime example. Milfoil started to increase when mean summer density fell below 0.1 per stem (2002).

Lake Auburn illustrates that summer factors are limiting weevil densities. In May 1998 over 1 weevil per stem was found in Auburn but by mid-July no weevils were found in our surveys. No weevils were found the rest of 1998 and in all of 1999. However, weevils were found again in May 2000 (Table 9). Since then summer densities have averaged between 0.04 and 0.07 per stem, however, there were several months each year when no weevils were detected. Fish predation is likely limiting weevil populations and their reappearance in spring 2000 suggests recolonization from elsewhere. The large increase in adults in September 2002 suggests fall movement from elsewhere also. Although densities were not high in our samples in 2003, elsewhere in the lake adult densities were very high. Adult densities were so high that we collected weevils for stocking in Harriet and Hiawatha from Lake Auburn in 2003. *Acentria* and *Parapoynx* were rarely detected at Lake Auburn. High sunfish densities (110/trapnet in 2000) are likely suppressing herbivore densities at Auburn.

Biweekly surveys in Otter Lake show an increase from a summer long average of 0.16/stem in 2000 to 0.42/stem in 2001 (Table 9). There was too little milfoil in biomass samples in 2001-2003 to get good weevil estimates and the stem surveys are likely a better indication of density. Weevil densities during the main decline in June 2000 exceeded 0.4/stem. Weevils remained fairly abundant through 2003 but adult densities were lower in 2003 and the population appeared to be decreasing. *Acentria* and *Parapoynx* densities also decreased in 2002-2003 and neither were very abundant on the milfoil plants (densities <0.3 per stem). As noted above, the high herbivore densities were controlling the milfoil and low sunfish densities (2/trapnet in 2001 and 6/trapnet in 2002) permitted development of high herbivore populations at least through 2002.

Weevil densities in Smith's Bay were fairly high in 1999 and 2000 with summer means of 0.33 and 0.25/stem respectively. These surveys are conducted in the three shallowest stations (1.5-2.5m depth) where the milfoil has been controlled by herbivory. Weevil densities were low in 2001 (mean of 0.09) but increased in to > 0.1/stem 2002 and 2003. A few *Acentria* have been found at Smith's but *Parapoynx* were not detected. As noted above, the moderate and persistent densities of weevils at Smith Bay appear to be controlling milfoil at the shallowest two stations but not at deeper stations.

Table 9. Density of weevil life stages (per stem), total weevils per stem and density of the caterpillars *Acentria* (Acent) and *Parapoynx* (Parap) from the bi-weekly weevil surveys. Caterpillars were not enumerated in the 1999 samples.

Lake	Date	Eggs	Larvae	Pupae	Adults	Total	Acent	Parap
Cenaiko								
	6/10/99	1.0000	0.2500	0.0000	0.3500	1.6000	-	-
	6/24/99	0.1333	0.0556	0.0000	0.0208	0.2097	-	-
	7/9/99	0.2000	0.8500	0.2500	0.0000	1.3000	-	-
	7/22/99	0.2909	0.2909	0.0909	0.0909	0.7636	-	-
	8/2/99	0.1333	0.0000	0.0000	0.0533	0.1867	-	-
	8/18/99	0.4854	0.3760	0.0417	0.1427	1.0458	-	-
	9/2/99	0.0000	0.3472	0.0000	0.0519	0.3991	-	-
	9/15/99	0.0000	0.0000	0.0000	0.0375	0.0375	-	-
	Mean	0.2804	0.2712	0.0478	0.0934	0.6928		
	5/16/00	0.1952	0.0229	0.0000	0.0000	0.2181	0.2762	0.0000
	5/30/00	0.0397	0.0159	0.0069	0.0000	0.0625	0.1905	0.0000
	6/13/00	0.1190	0.0883	0.0488	0.0756	0.3318	0.1584	0.0000
	6/29/00	0.2476	0.0556	0.0397	0.0238	0.3667	0.0508	0.0000
	7/11/00	0.3214	0.0347	0.0208	0.1141	0.4911	0.1141	0.0000
	7/24/00	0.7393	0.0208	0.0069	0.1181	0.8851	0.0417	0.0000
	8/10/00	0.5417	0.0917	0.0000	0.0167	0.5667	0.0083	0.0000
	8/24/00	0.0822	0.0519	0.0065	0.0652	0.2058	0.0465	0.0000
	9/7/00	0.0278	0.0324	0.0379	0.0866	0.1847	0.1554	0.0000
	9/20/00	0.0000	0.0694	0.0000	0.0478	0.1173	0.0556	0.0000
	10/3/00	0.0000	0.0368	0.0000	0.0083	0.0451	0.0000	0.0000
	Mean	0.2104	0.0473	0.0152	0.0506	0.3159	0.0998	0.0000
	5/21/01	0.0833	0.0000	0.0000	0.0000	0.0833	0.8068	0.0000
	6/6/01	0.6893	0.0000	0.0000	0.1857	0.8750	0.1250	0.0000
	6/18/01	0.0500	0.0000	0.0000	0.0000	0.0500	0.0000	0.0000
	7/3/01	0.0343	0.0000	0.0000	0.0000	0.0343	0.0100	0.0000
	7/19/01	0.0000	0.1268	0.0000	0.0000	0.1268	0.0250	0.0000
	7/30/01	0.0000	0.0000	0.0000	0.0125	0.0125	0.0250	0.0000
	8/15/01	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	8/27/01	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	9/5/01	0.0104	0.0000	0.0000	0.0000	0.0104	0.0625	0.0000
	9/18/01	0.0000	0.0000	0.0000	0.0000	0.0000	0.1472	0.0000
	Mean	0.0867	0.0127	0.0000	0.0198	0.1192	0.1202	0.0000
	5/24/02	0.0000	0.0000	0.0000	0.0000	0.0000	0.0625	0.0000
	6/3/02	0.0208	0.0000	0.0000	0.0000	0.0208	0.0046	0.0139
	6/17/02	0.0000	0.0196	0.0000	0.0000	0.0196	0.0000	0.0000
	7/1/02	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	7/16/02	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	7/29/02	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	8/13/02	0.0000	0.0069	0.0000	0.0069	0.0139	0.0228	0.0000
	8/26/02	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	9/10/02	0.0000	0.0069	0.0000	0.0139	0.0208	0.0000	0.0000
	Mean	0.0023	0.0037	0.0000	0.0023	0.0083	0.0100	0.0015
	5/28/03	0.0000	0.0000	0.0000	0.0000	0.0000	0.0208	0.0000
	6/11/03	0.0158	0.0000	0.0000	0.0000	0.0158	0.0000	0.0000
	6/22/03	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	7/7/03	0.0000	0.0000	0.0000	0.0000	0.0000	0.0069	0.0000
	7/24/03	0.0000	0.0000	0.0000	0.0000	0.0000	0.0139	0.0000
	8/4/03	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	8/20/03	0.0000	0.0000	0.0000	0.0000	0.0000	0.0139	0.0000
	Mean	0.0023	0.0000	0.0000	0.0000	0.0023	0.0079	0.0000

Table 9. Continued.

Lake	Date	Eggs	Larvae	Pupae	Adults	Total	Acent	Parap
Auburn								
	5/19/00	0.0267	0.0267	0.0000	0.0000	0.0533	0.0000	0.0000
	6/1/00	0.0000	0.0218	0.0000	0.0079	0.0298	0.0000	0.0000
	6/15/00	0.0139	0.0278	0.0000	0.0000	0.0417	0.0000	0.0000
	6/27/00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	7/10/00	0.0000	0.0000	0.0069	0.0347	0.0417	0.0000	0.0000
	7/25/00	0.1528	0.0000	0.0069	0.0556	0.2153	0.0000	0.0000
	8/9/00	0.0368	0.0515	0.0515	0.0294	0.1691	0.0000	0.0000
	8/28/00	0.0000	0.0000	0.0000	0.0074	0.0074	0.0000	0.0000
	9/12/00	0.0000	0.0208	0.0062	0.0123	0.0394	0.0000	0.0149
	9/28/00	0.0000	0.0000	0.0000	0.0139	0.0139	0.0000	0.0000
	Mean	0.0230	0.0149	0.0072	0.0161	0.0612	0.0000	0.0015
	5/10/01	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	5/24/01	0.2562	0.0139	0.0000	0.0309	0.3009	0.0000	0.0000
	5/30/01	0.1847	0.0000	0.0000	0.0000	0.1847	0.0000	0.0000
	6/13/01	0.0069	0.0139	0.0139	0.0308	0.0655	0.0000	0.0000
	6/28/01	0.0278	0.0139	0.0000	0.0000	0.0417	0.0000	0.0000
	7/9/01	0.0278	0.1389	0.0139	0.0139	0.1944	0.0000	0.0000
	7/23/01	0.0000	0.0123	0.0270	0.0139	0.0532	0.0000	0.0000
	8/8/01	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	8/20/01	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	9/11/01	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	9/27/01	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Mean	0.0458	0.0175	0.0050	0.0081	0.0764	0.0000	0.0000
	5/22/02	0.0185	0.0000	0.0000	0.0000	0.0185	0.0000	0.0000
	6/13/02	0.0074	0.0000	0.0000	0.0000	0.0074	0.0000	0.0000
	6/26/02	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	7/11/02	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	7/22/02	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	8/7/02	0.0000	0.0000	0.0000	0.0208	0.0208	0.0000	0.0000
	8/21/02	0.0185	0.0417	0.0024	0.0062	0.0688	0.0000	0.0000
	9/4/02	0.0000	0.0000	0.0000	0.0417	0.0417	0.0000	0.0000
	9/20/02	0.0000	0.0208	0.0417	0.2708	0.3333	0.0000	0.0069
	Mean	0.0049	0.0069	0.0049	0.0377	0.0545	0.0000	0.0008
	5/16/03	0.0820	0.0000	0.0000	0.0093	0.0913	0.0069	0.0000
	5/27/03	0.0324	0.0000	0.0000	0.0069	0.0394	0.0069	0.0000
	6/9/03	0.0079	0.0139	0.0079	0.0000	0.0298	0.0000	0.0000
	6/24/03	0.0000	0.0000	0.0074	0.0221	0.0294	0.0000	0.0000
	7/8/03	0.0000	0.0262	0.0083	0.0179	0.0524	0.0000	0.0000
	7/21/03	0.0780	0.0188	0.0000	0.0000	0.0968	0.0000	0.0000
	8/5/03	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	8/20/03	0.0347	0.0069	0.0000	0.0139	0.0556	0.0000	0.0000
	9/22/03	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Mean	0.0261	0.0073	0.0026	0.0078	0.0439	0.0015	0.0000
Otter								
	6/5/00	0.1940	0.1321	0.0500	0.0821	0.4583	0.0250	0.0000
	6/22/00	0.1395	0.2027	0.0580	0.0804	0.4806	0.0268	0.0089
	7/5/00	0.0000	0.0403	0.0079	0.0079	0.0575	0.0000	0.0000
	7/18/00	0.0000	0.0074	0.0074	0.0000	0.0147	0.0000	0.0000
	8/2/00	0.0218	0.0000	0.0069	0.0218	0.0506	0.0069	0.0000
	8/16/00	0.0074	0.0147	0.0000	0.0000	0.0221	0.0000	0.0000
	8/29/00	0.0000	0.0441	0.0074	0.0515	0.1029	0.0000	0.0000
	9/13/00	0.0000	0.0394	0.0278	0.0231	0.0903	0.0000	0.0000
	9/26/00	0.0000	0.0069	0.0764	0.1042	0.1875	0.0000	0.0000
	Mean	0.0403	0.0542	0.0269	0.0412	0.1627	0.0065	0.0010

Table 9. Continued.

Lake	Date	Eggs	Larvae	Pupae	Adults	Total	Acent	Parap
Otter								
	5/21/01	0.3268	0.0000	0.0000	0.1250	0.4518	0.0000	0.0000
	6/4/01	0.2225	0.0000	0.0000	0.1789	0.4015	0.0417	0.0147
	6/21/01	0.5345	0.0407	0.0000	0.0663	0.6415	0.0074	0.0000
	7/5/01	0.4117	0.1354	0.0851	0.1634	0.7955	0.0202	0.0000
	7/16/01	0.1119	0.0000	0.0000	0.2608	0.3727	0.0000	0.0000
	8/1/01	0.1027	0.0469	0.0000	0.1007	0.2502	0.0000	0.0000
	8/13/01	0.1507	0.0306	0.0000	0.0512	0.2324	0.0000	0.0000
	8/28/01	0.0515	0.1922	0.0000	0.0221	0.2658	0.0074	0.0000
	9/5/01	0.1128	0.1553	0.0131	0.1063	0.3875	0.0378	0.0069
	9/17/01	0.0278	0.2750	0.0486	0.2935	0.6449	0.0069	0.1918
	10/2/01	0.0193	0.0432	0.0288	0.1211	0.2124	0.0455	0.0481
	Mean	0.1884	0.0836	0.0160	0.1354	0.4233	0.0152	0.0238
	5/21/02	0.0179	0.0000	0.0000	0.0625	0.0804	0.0238	0.0000
	6/2/02	0.5218	0.1862	0.0147	0.1183	0.8646	0.0000	0.0715
	6/17/02	0.0981	0.2302	0.0591	0.0757	0.4631	0.0083	0.0000
	7/3/02	0.1759	0.2037	0.0208	0.1319	0.5324	0.0000	0.0069
	7/16/02	0.1911	0.0000	0.0000	0.2444	0.4355	0.0000	0.0069
	7/29/02	0.0294	0.0296	0.0000	0.0795	0.1459	0.0000	0.0131
	8/13/02	0.0964	0.0182	0.0000	0.0339	0.1484	0.0000	0.0000
	8/26/02	0.0672	0.0389	0.0000	0.0546	0.1607	0.0000	0.0000
	9/9/02	0.0208	0.0069	0.0000	0.0208	0.0486	0.0000	0.0000
	Mean	0.1354	0.0793	0.0105	0.0913	0.3200	0.0036	0.0109
	5/21/03	0.2944	0.0062	0.0000	0.0340	0.3345	0.0062	0.0000
	6/5/03	0.2167	0.1379	0.0634	0.0368	0.4622	0.0000	0.0074
	6/18/03	0.0915	0.1612	0.0697	0.0526	0.3253	0.0000	0.0062
	7/3/03	0.1538	0.2083	0.0347	0.0506	0.4474	0.0000	0.0000
	7/15/03	0.0238	0.0300	0.0000	0.0265	0.0406	0.0000	0.0000
	7/29/03	0.0610	0.0866	0.0069	0.0208	0.1754	0.0000	0.0000
	8/14/03	0.0347	0.2083	0.0000	0.0000	0.2431	0.0000	0.0000
	9/19/03	0.0278	0.0208	0.0139	0.0208	0.0833	0.0069	0.0000
	Mean	0.1130	0.1074	0.0236	0.0303	0.2640	0.0016	0.0017
Smith's								
	5/21/99	0.5200	0.0000	0.0000	0.0933	0.6133	-	-
	6/3/99	0.1600	0.0933	0.0000	0.0133	0.2667	-	-
	6/16/99	0.0533	0.1200	0.0000	0.0000	0.1733	-	-
	6/30/99	0.0400	0.0533	0.0000	0.0000	0.0933	-	-
	7/15/99	0.0267	0.1333	0.0000	0.0267	0.1867	-	-
	7/27/99	0.0000	0.1067	0.0133	0.0267	0.1467	-	-
	8/11/99	0.0933	0.3600	0.0000	0.0267	0.4800	-	-
	8/25/99	0.0800	0.5067	0.0133	0.0000	0.6000	-	-
	9/10/99	0.0133	0.2289	0.1333	0.0000	0.3756	-	-
	Mean	0.1096	0.1780	0.0178	0.0207	0.3262		
	5/25/00	0.2867	0.0267	0.0000	0.0000	0.3133	0.0000	0.0000
	6/8/00	0.2095	0.1429	0.0095	0.0000	0.3619	0.0000	0.0000
	6/21/00	0.2519	0.0824	0.0429	0.0167	0.3938	0.0583	0.0000
	7/3/00	0.0810	0.0369	0.0000	0.0000	0.1179	0.0000	0.0000
	7/19/00	0.0167	0.0250	0.0111	0.0417	0.0944	0.0000	0.0000
	8/4/00	0.2604	0.0702	0.1339	0.0274	0.4919	0.0000	0.0000
	8/15/00	0.0472	0.0750	0.0074	0.0389	0.1685	0.0000	0.0000
	8/23/00	0.0919	0.1100	0.0726	0.0871	0.3361	0.0085	0.0000
	9/6/00	0.0250	0.0880	0.0000	0.0591	0.1721	0.0000	0.0000
	9/19/00	0.0000	0.0167	0.0000	0.0167	0.0333	0.0000	0.0000
	Mean	0.1270	0.0674	0.0277	0.0288	0.2483	0.0067	0.0000

Table 9. Continued.

Lake	Date	Eggs	Larvae	Pupae	Adults	Total	Acent	Parap
Smith's								
	5/15/01	0.0000	0.0000	0.0000	0.0083	0.0083	0.0000	0.0000
	5/31/01	0.0241	0.0000	0.0000	0.0333	0.0574	0.0000	0.0000
	6/11/01	0.2287	0.0083	0.0000	0.0095	0.2466	0.0000	0.0000
	6/25/01	0.0222	0.0000	0.0000	0.0274	0.0496	0.0000	0.0000
	7/10/01	0.0000	0.0482	0.0240	0.0000	0.0722	0.0000	0.0000
	7/23/01	0.0000	0.0639	0.0307	0.0000	0.0946	0.0000	0.0000
	8/8/01	0.0250	0.1480	0.0194	0.0083	0.2008	0.0000	0.0000
	8/24/01	0.0148	0.0917	0.0083	0.0000	0.1148	0.0000	0.0000
	9/13/01	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Mean	0.0350	0.0400	0.0092	0.0096	0.0938	0.0000	0.0000
	6/5/02	0.1790	0.0000	0.0000	0.0079	0.1870	0.0102	0.0000
	6/18/02	0.2113	0.1247	0.0000	0.0000	0.3360	0.0000	0.0000
	7/2/02	0.0676	0.0475	0.0079	0.0119	0.1349	0.0000	0.0000
	7/19/02	0.0111	0.0000	0.0083	0.0194	0.0389	0.0000	0.0000
	8/1/02	0.0167	0.0400	0.0000	0.0328	0.0894	0.0000	0.0000
	8/12/02	0.0000	0.0398	0.0000	0.0083	0.0481	0.0000	0.0000
	8/28/02	0.0083	0.0824	0.0000	0.0324	0.1231	0.0000	0.0000
	9/10/02	0.0000	0.0000	0.0000	0.0102	0.0102	0.0000	0.0000
	Mean	0.0618	0.0418	0.0020	0.0154	0.1210	0.0013	0.0000
	6/3/03	0.0687	0.0077	0.0000	0.0000	0.0764	0.0000	0.0000
	6/18/03	0.1000	0.6446	0.0000	0.0909	0.8355	0.0000	0.0000
	7/1/03	0.0165	0.0165	0.0000	0.0000	0.0330	0.0000	0.0000
	7/16/03	0.0089	0.0170	0.0000	0.0000	0.0259	0.0000	0.0000
	7/31/03	0.0381	0.0116	0.0000	0.0042	0.0539	0.0000	0.0000
	8/12/03	0.0171	0.0313	0.0000	0.0000	0.0484	0.0000	0.0000
	Mean	0.0416	0.1215	0.0000	0.0159	0.1789	0.0000	0.0000

Single surveys (5 transects each) in Cedar and Calhoun during in 2002 and 2003 failed to detect any herbivorous insects in Calhoun and only 0.005 weevils per stem in 2002 (none in 2003) at Cedar. Both lakes have high sunfish densities (>100/trapnet). There was too little milfoil to conduct weevil surveys at Lake of the Isles.

Minneapolis survey lakes:

Milfoil biomass in the four Minneapolis lakes varied among lakes and years (Table 10 and Table 1). Milfoil and total plant biomass was generally low at Lake-of-the-Isles although milfoil biomass exceeded 150 g dry/m^2 in 1996 and 2000. Most of the non-milfoil biomass was coontail. The low densities in most years are likely due to poor water clarity (Table 11); total biomass showed similar patterns, when milfoil was not dominant coontail was the main plant present, and late summer Secchi depths were typically <1.5m. One sample per year does not capture the dynamics of the plants at Isles. For example, just prior to sampling in 2002, milfoil was much more dense (Ward, personal observation), but it declined with a rapid decrease in clarity. Sediment pore water ammonium was moderate (Table 11) and exchangeable N levels were well above those expected for nuisance milfoil (> 0.01 mg N/g sediment).

Table 10. Total plant and milfoil biomass (g dry/m^2) and mean percent of plant biomass that was Eurasian watermilfoil at Minneapolis Chain of Lakes lakes in summer 1999-2003. N ≥ 20 samples at all sites. See Tables 1-3 for Cedar results.

Lake	Date	Total Plant Biomass (g/m^2)	Milfoil Biomass (g/m^2)	% Milfoil (of biomass)	Secchi Depth (m)
Lake of the Isles	9/14/95	62.5	58.3	90.1%	0.5
	SE	20.6	22.6	5.0%	
	8/30/96	199.7	169.2	74.6%	1.1
	SE	74.0	74.1	10.1%	
	8/14/97	31.9	9.9	22.4%	1.4
	SE	10.4	5.3	8.6%	
	8/31/98	28.2	14.0	36.9%	0.3
	1 SE	4.7	6.1	12.2%	
	8/16/99	51.8	49.3	88.3%	0.5
	1SE	14.8	14.5	4.4%	
	6/28/00	265.4	252.9	88.9%	2.3
	1 SE	45.6	46.9	3.7%	
	8/16/00	195.4	192.7	97.7%	2.2
	1 SE	17.6	17.8	1.1%	
	6/27/01	22.0	4.5	30.0%	1.6
	1 SE	7.1	1.8	8.2%	
	9/7/01	16.0	3.0	18.6%	0.8
	1 SE	8.9	2.2	7.9%	
	7/9/02	37.7	24.9	32.4%	1.1
	1 SE	9.4	9.0	9.1%	
	8/22/03	27.3	26.1	79.4%	0.4
	1 SE	18.9	18.5	10.0%	
Calhoun	9/16/99	41.6	8.1	10.8%	1.6
	1 SE	10.7	3.9	5.5%	
	6/26/00	22.7	10.8	38.3%	3.1
	1 SE	11.3	5.6	13.5%	
	8/18/00	12.5	10.9	56.5%	1.8
	1 SE	4.0	4.1	10.0%	
	6/28/01	99.8	98.1	81.0%	3.2
	1 SE	24.9	25.0	7.1%	
	9/6/01	142.1	121.9	73.3%	2.3
	1 SE	30.5	31.3	8.4%	
	7/26/02	181.4	179.5	94.1%	2.8
	1 SE	26.4	26.6	4.3%	
	8/26/03	155.2	154.9	95.9%	2.6
	1 SE	27.1	27.1	3.5%	
Harriet	9/23/99	180.2	168.3	87.9%	2.6
	1 SE	27.6	26.8	5.2%	
	6/30/00	332.1	215.0	61.5%	1.6
	1 SE	53.2	37.8	5.7%	
	8/22/00	106.0	90.7	78.0%	2.3
	1 SE	18.9	19.5	5.9%	
	7/2/01	311.1	259.4	74.1%	2.5
	1 SE	46.4	45.9	6.9%	
	9/12/01	170.5	149.6	83.7%	3.0
	1 SE	25.7	23.6	5.3%	
	7/11/02	252.9	237.3	86.1%	2.2
	1 SE	42.3	44.0	5.0%	
	9/14/02	354.8	337.3	95.5%	2.9
	1 SE	43.6	42.0	1.8%	
	6/16/03	281.9	267.9	91.6%	2.3
	1 SE	46.9	44.3	4.1%	
	8/25/03	252.2	225.0	85.1%	3.3
	1 SE	41.5	40.1	5.3%	

Table 11. Sediment characteristics (bulk density, percent organic matter, sediment pore water ammonium concentrations) and water column characteristics at Minneapolis Chain of Lakes lakes in summer 1999-2002. Nine sediment samples from the shallow, intermediate and deep stations were collected at each lake.

Lake/Date	Bulk Dens. (g dm/ml)	NH_4 (mg/L)	% Organic	Chl-a (mg/m^3)	SD (m)	Temp (˚C 1m)	10% PAR Depth (m)	Plant Limit (m)
Calhoun								
9/24/97				7.2	3.1	18.9	2.5-3.0	4.7
9/4/98				3.7	3.0	23.7	3.5-4.0	4.1
9/21/99				17.1	1.6	18.5	2.0	3.8
6/26/00	0.75	2.00	6.17	4.3	3.1	21.4	3.5-4	
2se	0.32	1.08	2.60					
8/18/00	0.65	1.15	0.17	8.6	1.8	24.3	3.5-4	2.4
2se	0.38	0.33	0.03					
6/28/01	0.68	1.31	6.0	19.8	3.2	26.1	3.5	
2se	0.31	1.02	2.4					
9/6/01	0.68	2.96	7.6	3.5	2.3	22.9	5	4.8
2se	0.40	1.58	3.2					
7/26/02	0.74	6.62	15.3	.	2.8	25.2	3.5	
2se	0.37	4.33	14.3					
8/23/02	.	.	.	11.2	2.2	22.1	3-3.5	5.1
2se	.	.	.					
8/5/03	0.61	2.69	6.1	.	2.6	25.5	4	4.5
2se	0.27	1.37	2.4					
Lake of the Isles								
9/14/95	1.45	5.21	1.8	57.4	0.5	20.3	0.5-1.0	0.5
2se	0.36	4.36	1.1					
8/30/96	0.28	9.30	10.0	6.9	1.1	24.6	1.5-2.0	2.0
2se	0.08	5.32	6.7					
8/13/97	0.71	8.48	16.2	26.2	1.4	22.5	1.0-1.5	3.7
2se	0.58	0.88	20.0					
8/31/98	0.25	29.33	23.9	54.3	0.3	24.3	0.5-1.0	3.3
2se	0.28	19.07	19.0					
8/16/99	0.15	0.54	24.2	83.7	0.5	22.5	0.5-1.0	3.0
2se	0.05	0.56	12.5					
6/28/00	0.72	0.57	41.1	8.8	2.3	22.9	1.5-2.0	
2se	0.87	0.23	13.3					
8/16/00	0.51	1.13	26.1	15.8	2.2	25.7	2.5-3.0	4.0
2se	0.39	1.09	12.8					
6/29/01	0.95	2.55	16.8	49.5	1.6	26.3	2.0-2.5	
2se	0.49	1.96	14.1					
9/7/01	0.53	3.42	27.6	42.8	0.8	23.5	1.0-1.5	2.6
2se	0.44	1.38	15.8					
7/9/02	0.60	2.66	42.1	.	1.1	28.4	1.0-1.5	
2se	0.66	2.03	55.7					
8/22/02				82.3	0.7	22.7	1	3.9
8/5/03	0.69	3.74	22.7	.	0.4	25.5	0.5-1.0	3.7
2se	0.44	1.46	16.0					

Table 11. continued

Lake/Date	Bulk Dens. (g dm/ml)	NH_4 (mg/L)	% Organic	Chl-a (mg/m^3)	SD (m)	Temp (˚C 1m)	10% PAR Depth (m)	Plant Limit (m)
Harriet								
10/9/97				4.5	> 5.4	17.3	3.0-3.5	5.2
9/23/98				3.7	2.6	20.3	4.0-4.5	5.0
9/24/99				7.5	2.6	17.5	3.5	4.0
6/30/00	0.74	3.74	7.69	6.1	1.6	22.8	2.5-3	
2se	0.42	1.43	3.87					
8/22/00	0.76	6.72	.	8.3	2.3	23.1	3.5-4	4.2
2se	0.48	1.59	.					
7/2/01	0.94	3.59	7.0	9.1	2.5	23.4	2.5-3.0	
2se	0.44	2.31	3.6					
9/12/01	0.78	2.13	7.3	4.0	3.6	21.5	4.5-5.0	4.3
2se	0.44	1.21	3.7					
7/11/02	1.23	3.28	6.1	7.4	2.2	25.4	3.5	
2se	0.44	1.64	1.1					
9/14/02	.	.	.	.	2.9	23.1	4.0	4.2
8/25/03	0.44	3.62	10.8	.	2.3	26.4	4	4.9
2se	0.32	1.07	3.7					
9/4/03				.	3.3	22.9	4	
2se								

Milfoil biomass increased at Lake Calhoun from very low levels in 1999-2000 (Table 10) to 150-180 g/m^2 in 2002 and 2003 when it composed > 94% of total plant biomass. It is unclear why biomass was low in 1999-2000, but biomass of all plants was low both years. Sediment characteristics and clarity were not notably different from the more recent years with higher density (Table 11). Exchangeable N was well above levels for nuisance milfoil in June 2001 and almost as high in 2002. Unfortunately detailed sediment data are not available 1999 and exchangeable N was not measured in 2000. Milfoil biomass was quite high at the connected Lake-of-the-Isle in 2000 so the low biomass in 2000 must be related to Calhoun specific conditions.

Milfoil biomass has been consistently high at Lake Harriet ranging from 170 g/m^2 in 1999 to over 325 g/m^2 in 2002 (Table 10). Milfoil typically composed 85-95% of total plant biomass at Harriet. Water clarity was similar to Calhoun as were sediment characteristics (Table 11), however milfoil and total plants were much more abundant at Harriet in 1999 and 2000 than they were at Calhoun and in subsequent years, plants were twice as dense at Harriet than at Calhoun. Harriet biomass was more similar to Cedar Lake (Table 1) with milfoil dominating, followed by coontail.

Plant coverage and occurrence (Table 12) showed trends similar to biomass. At Cedar Lake, milfoil occurred at 80-90% of sample locations and was visible at 66-80% of stations. Density was lowest (2.8) in 2001 when biomass was lowest. Coontail was generally the second most frequent and dense plant, occurring at 25-50% of stations. More species are found in the whole lake surveys than in biomass samples, but rarely more than 6 species were found at Cedar Lake. Weevil damage was extremely rare.

Whole lake estimates at Lake Calhoun reflect the low biomass found in 1999-2000 and indicate a decline from levels in 1998, with an increase from 2001-2003. Milfoil density dropped from 3.7 in 1998 to 1.8 and 1.6 in 1999 and 2000 respectively before increasing to 3.7 in 2003. Coontail was the second most common plant at Calhoun but the number of species was higher than Cedar and Isles. Typically 6-12 species were found at Calhoun, although with the exception of coontail, they were infrequent and had density ratings <0.5. The number of species found decreased in 2002 and 2003 as milfoil returned to dominance. Very little weevil damage was noted.

Milfoil coverage and occurrence was consistently high at Lake Harriet. Milfoil occurred at 75 to 85% of station and density ranged from 3.4 to 4.4. Coontail was also more frequent and dense than at the other lakes generally occurring at more than half the sites with a density rating of 2 to 3. Typically 5-7 species were found but the total number of species collected declined in 2002-2003 (Table 12). Species other than milfoil and coontail were infrequent and at low density. Weevil damage was also low at Harriet.

Lake-of-the-Isles showed the greatest variation in coverage and density. In several years coontail was more frequent or denser than milfoil. Density and coverage were highest in 2000 when biomass was high and density generally followed biomass trends but did not fluctuate as much as biomass. Coverage and density were much lower in 2001-2003 than in 2000, probably due to poorer clarity (Table 11). Typically 4-6 species were found in Lake of the Isles and the low number of species appears to be as much related to water clarity as it is to milfoil density. Weevil damage was also rare at Lake of the Isles.

It should be noted that we expected that alum treatments in the Minneapolis Chain-of-Lakes would eventually enhance native plant communities. Although we predicted that Eurasian watermilfoil would initially be enhanced by better water clarity, we expected that better water clarity would favor the native plants after several years, reducing the competitive advantage Eurasian watermilfoil appears to have in lower light environments. To date we have no indication that alum treatments have enhanced the native plant communities. Eurasian watermilfoil remained dominant in Cedar Lake, 7 years after treatment in 1996. The number of plant species remains low and the better clarity appears to have reduced seasonal fluctuations in milfoil biomass. Eurasian watermilfoil increased and also remains dominant in Harriet and Calhoun, although the alum treatments are likely too recent to have resulted in a longer-term shift in plant community composition. However, it should also be noted that there are few milfoil weevils in any of these lakes and a shift to native communities may not occur without some additional factor, such as herbivory, limiting Eurasian watermilfoil.

Coverage and density of milfoil was generally lower at the three additional lakes surveyed in 2002, Centerville, Schultz and Vadnais (Table 12), but relative densities were moderate (2.5-3.25). Coontail was the dominant native plant in these lakes. Poor clarity and high chlorophyll (Table 13) probably limited coverage and plant growth in these lakes, although weevils (see below) may also be a factor.

Table 12. Estimates of plant coverage and occurrence for the whole-lake surveys (Calhoun, Cedar, Harriet, Isles, Centerville, Schultz and Vadnais). Estimates of visual milfoil cover (% Vis MSP Cov), percent visual occurrence, occurrence on the drop hook and mean weevil damage rating (0-5) for the whole lake estimates were based on n = 66-82 stations at each of the Minneapolis lakes and 25-30 stations at Centerville, Schultz and Vadnais. Jessen and Lound (1962) relative density ratings (0-5) were determined from a subset of 5-6 transects (n=24-29 stations). Relative density is the mean for all stations sampled. Species abbreviations are given in Appendix I.

Cedar Lake		% Vis MSP Cov	% Occurrence (Visual)		% Occurrence (Drop Hook)		Density Rating	n = 26
Date	n	Mean ± 1S.E.	Spp.	% Occ. ± 1S.D.	Spp.	% Occ. ± 1S.D.	Spp.	Density ± 2S.E.
9/27/99	75	50.1 ± 4.2%	MSP	78.7 ± 4.7%	MSP	90.7 ± 3.4%	MSP	3.96 ± 0.46
			NMP	13.3 ± 3.9%	CRT	25.3 ± 5.0%	CRT	1.50 ± 0.60
					NMP	6.7 ± 2.9%	NMP	0.12 ± 0.23
							PRI	0.04 ± 0.08
							DRC	0.04 ± 0.08

Cedar Lake		% Vis MSP Cov	% Occurrence (Visual)		% Occurrence (Drop Hook)		Density Rating	n = 24
Date	n	Mean ± 1S.E.	Spp.	% Occ. ± 1S.D.	Spp.	% Occ. ± 1S.D.	Spp.	Density ± 2S.E.
8/9/00	72	44.3 ±4.7%	MSP	68.1 ± 5.5%	MSP	87.5 ± 3.9%	MSP	3.58 ± 0.61
			CRT	9.7 ± 3.5%	CRT	23.6 ± 5.0%	CRT	1.29 ± 0.53
Eurasian Watermilfoil			NMP	15.3 ± 4.2%	NAJ	1.4 ± 1.4%	NMP	0.38 ± 0.38
Total Area: 17.7 ha.			PAM	1.4 ± 1.4%	NMP	6.9 ± 3.0%	NAJ	0.08 ± 0.17
% of Litt. Zone: 69.4%			PEC	1.4 ± 1.4%	PAM	1.4 ± 1.4%	CHA	0.04 ± 0.08
% of Lake Area: 26.7%					PCR	1.4 ± 1.4%		
					CHA	1.4 ± 1.4%		

Cedar Lake		% Vis MSP Cov	% Occurrence (Visual)		% Occurrence (Drop Hook)		Density Rating	n = 24
Date	n	Mean 1S.E.	Spp.	% Occ. 1S.D.	Spp.	% Occ. 1S.D.	Spp.	Density 2S.E.
8/21/01	75	36.3 ± 4.2%	MSP	66.7 ± 5.4%	MSP	81.3 ± 4.5%	MSP	2.83 ± 0.71
			NMP	16.0 ± 4.2%	CRT	34.7 ± 5.5%	CRT	0.71 ± 0.52
			CRT	9.3 ± 3.4%	NMP	5.3 ± 2.6%	NMP	0.08 ± 0.17
			PEC	1.3 ± 1.3%	CHA	1.3 ± 1.3%		
			PRI	1.3 ± 1.3%	PEC	1.3 ± 1.3%		
			PZS	1.3 ± 1.3%	PRI	1.3 ± 1.3%		
Weevil Damage Rating:		0.24						

Cedar		% Vis MSP Cov	% Occurrence (Visual)		% Occurrence (Drop Hook)		Density Rating	n =18
Date	n	Mean ± 1SE	Spp.	% Occ. ± 1 SD	Spp.	% Occ. ± 1 SD	Spp.	Density ± 2SE
8/26/02	68	56.6% ±4.6%	MSP	77.9 ± 0.1	MSP	83.6 ± 0.0	MSP	4.44 ± 0.29
			CRT	19.1 ± 0.0	CRT	47.1 ± 0.1	CRT	2.00 ± 0.76
Eurasian Watermilfoil			PAM	5.9 ± 0.0	PAM	4.4 ± 0.0	PAM	0.28 ± 0.56
Total Area:		21.6 ha.	NMP	4.4 ± 0.0	PPR	4.4 ± 0.0		
% of Litt. Zone:		84.6%	PPR	4.4 ± 0.0	NMP	2.9 ± 0.0		
% of Lake Area:		32.5%	PCR	1.5 ± 0.0				
Weevil Damage Rating:		0.31						

Cedar		% Vis MSP Cov	% Occurrence (Visual)		% Occurrence (Drop Hook)		Density Rating	n =26
Date	n	Mean ± 1SE	Spp.	% Occ. ± 1 SD	Spp.	% Occ. ± 1 SD	Spp.	Density ± 2SE
8/18/03	74	34.7% ±4.4%	MSP	66.2 ± 0.1	MSP	83.8 ± 0.0	MSP	3.2 ± 0.7
			CRT	21.6 ± 0.0	CRT	47.3 ± 0.1	CRT	1.8 ± 0.6
			NMP	17.6 ± 0.0	NMP	8.1 ± 0.0	NMP	0.2 ± 0.3
			PGR	2.7 ± 0.0	PGR	2.7 ± 0.0	PRI	0.1 ± 0.2
Weevil Damage Rating:		0.25			PRI	1.4 ± 0.0	PGR	0.2 ± 0.3

Table 12 Continued

Lake Calhoun		% Vis MSP Cov	% Occurrence (Visual)		% Occurrence (Drop Hook)		Density Rating	n = 27
Date	n	Mean ± 1SE	Spp.	% Occ. ± 1 SD	Spp.	% Occ. ± 1 SD	Spp.	Density ± 2SE
9/4/98	63	30.7 ± 4.4%	MSP	87.3 ± 4.2%	MSP	76.2 ± 5.4%	MSP	3.67 ± 0.49
			PEC	17.5 ± 4.8%	CRT	50.8 ± 6.3%	CRT	3.07 ± 0.53
Eurasian Watermilfoil			PRI	14.3 ± 4.4%	PEC	12.7 ± 4.2%	PCR	0.48 ± 0.38
Total Area: 27.9 ha.			CRT	11.1 ± 4.0%	PRI	3.2 ± 2.2%	PEC	0.48 ± 0.43
% of Litt. Zone: 56%			PCR	7.9 ± 3.1%	PZS	1.6 ± 1.6%	PRI	0.41 ± 0.36
% of Lake Area: 16.7%			NAJ	6.3 ± 3.1%			NAJ	0.33 ± 0.34
			ELD	1.6 ± 1.6%			ELD	0.04 ± 0.07
Weevil Damage Rating: 0.698±0.133			HET	1.6 ± 1.6%			HET	0.04 ± 0.07

Lake Calhoun		% Vis MSP Cov	% Occurrence (Visual)		% Occurrence (Drop Hook)		Density Rating	n = 25
Date	n	Mean ± 1SE	Spp.	% Occ. ± 1 SD	Spp.	% Occ. ± 1 SD	Spp.	Density ± 2SE.
9/16/99	74	45.0± 4.5%	MSP	87.3 ± 3.9%	MSP	76.2 ± 5.0%	MSP	1.84 ± 0.75
			PEC	17.5 ± 4.4%	CRT	50.8 ± 5.8%	CRT	3.32 ± 0.47
Eurasian Watermilfoil			PRI	14.3 ± 4.1%	PEC	12.7 ± 3.9%	PRI	0.20 ± 0.23
Total Area:			CRT	11.1 ± 3.7%	PRI	3.2 ± 2.0%		
% of Litt. Zone:			PCR	7.9 ± 3.1%	PZS	1.6 ± 1.5%		
% of Lake Area:			NAJ	6.3 ± 2.8%				
			ELD	1.6 ± 1.5%				
Weevil Damage Rating:			HET	1.6 ± 1.5%				

Lake Calhoun		% Vis MSP Cov	% Occurrence (Visual)		% Occurrence (Drop Hook		Density Rating	n = 26
Date	n	Mean ±1S.E.	Spp.	% Occ. ±1S.D.	Spp.	% Occ. ±1S.D.	Spp.	Density ±2S.E.
8/17/00	73	6.8±2.0%	MSP	26.0 ± 5.1%	MSP	24.7 ± 5.0%	MSP	1.62 ± 0.70
			PEC	1.4 ± 1.4%	CRT	11.0 ± 3.7%	PEC	0.04 ± 0.08
Eurasian Watermilfoil			PRI	2.7 ± 1.9%	NAJ	2.7 ± 1.9%	PZS	0.12 ± 0.17
Total Area: 10.4 ha.			NAJ	1.4 ± 1.4%	PRI	2.7 ± 1.9%	CRT	2.00 ± 0.63
% of Litt. Zone: 20.9%			CHA	1.4 ± 1.4%	PZS	1.4 ± 1.4%	ELD	0.04 ± 0.08
% of Lake Area: 6.2%							PCR	0.38 ± 0.35
							NAJ	0.31 ± 0.29
							PRI	0.12 ± 0.17
							HET	0.08 ± 0.15
							CHA	0.42 ± 0.32
							VAL	0.04 ± 0.08
							ZPA	0.15 ± 0.31

Lake Calhoun		% Vis MSP Cov	% Occurrence (Visual)		% Occurrence (Drop Hook		Density Rating	n = 26
Date	n	Mean ±1S.E.	Spp.	% Occ. ±1S.D.	Spp.	% Occ. ±1S.D.	Spp.	Density ±2S.E.
8/17/01	66	31.3 ± 4.9%	MSP	39.4 ± 6.0%	MSP	56.1 ± 6.1%	MSP	2.62 ± 0.62
			PEC	7.6 ± 3.3%	CRT	15.2 ± 4.4%	NAJ	0.54 ± 0.40
Eurasian Watermilfoil			CRT	3.0 ± 2.1%	PEC	7.6 ± 3.3%	CRT	0.46 ± 0.28
Total Area: 31.5 ha.			PCR	3.0 ± 2.1%	PRI	6.1 ± 2.9%	PRI	0.27 ± 0.38
% of Litt. Zone: 63.2%			NAJ	1.5 ± 1.5%	NAJ	3.0 ± 2.1%	PCR	0.19 ± 0.19
% of Lake Area:18.8%			PZS	1.5 ± 1.5%	PZS	3.0 ± 2.1%	PEC	0.15 ± 0.24
					PCR	1.5 ± 1.5%	PZS	0.15 ± 0.24
Weevil Damage Rating:		0.2			PFO	1.5 ± 1.5%	PPR	0.12 ± 0.23
							CHA	0.08 ± 0.11
							HET	0.04 ± 0.08
							PFO	0.04 ± 0.08

Calhoun		% Vis MSP Cov	% Occurrence (Visual)		% Occurrence (Drop Hook)		Density Rating	n =25
Date	n	Mean ±1S.E.	Spp.	% Occ. ±1S.D.	Spp.	% Occ. ±1S.D.	Spp.	Density ±2S.E.
8/20/02	68	52.2 ± 4.0%	MSP	80.9 ± 0.0	MSP	71.4 ± 0.1	MSP	3.16 ± 0.71
			CRT	7.5 ± 0.0	CRT	19.0 ± 0.0	CRT	0.16 ± 0.19
			PRI	6.9 ± 0.0	PRI	4.8 ± 0.0	NAJ	0.04 ± 0.08
			VAL	2.9 ± 0.0	NAJ	1.6 ± 0.0	PRI	0.28 ± 0.29
			PEC	1.5 ± 0.0			VAL	0.04 ± 0.08
Weevil Damage Rating:		0.15	PIL	1.5 ± 0.0				

Table 12 Continued

Calhoun		% Vis MSP Cov	% Occurrence (Visual)		% Occurrence (Drop Hook)		Density Rating	n =27
Date	n	Mean ±1S.E.	Spp.	% Occ. ±1S.D.	Spp.	% Occ. ±1S.D.	Spp.	Density ±2S.E.
8/13/03	74	34.8% ±4.0%	MSP	63.5 ± 0.1	MSP	85.1 ± 0.0	MSP	3.7 ± 0.4
			CRT	2.7 ± 0.0	CRT	5.4 ± 0.0	CRT	0.4 ± 0.3
			PEC	2.7 ± 0.0	PEC	1.4 ± 0.0	PEC	0.1 ± 0.1
			NAJ	1.4 ± 0.0	PRI	1.4 ± 0.0	NAJ	0.2 ± 0.3
							PRI	0.0 ± 0.1
Weevil Damage Rating: 0.61							CHC	0.2 ± 0.3

Lake Harriet		% Vis MSP Cov	% Occurrence (Visual)		% Occurrence (Drop Hook)		Density Rating	n = 29
Date	n	Mean ± 1 S.E.	Spp.	% Occ. ± 1 S.D.	Spp.	% Occ. ± 1 S.D.	Spp.	Density ± 2S.E.
10/9/97	72	52.2 ± 3.8%	MSP	87.5 ± 3.9%	MSP	86.1 ± 4.1%	MSP	4.41 ± 0.36
Eurasian Watermilfoil:			CRT	8.3 ± 3.3%	CRT	40.3 ± 5.8%	CRT	2.21 ± 0.49
Total Area:		31.4 ha.	HET	1.4 ± 1.4%	PRI	1.4 ± 1.4%	PRI	0.17 ± 0.14
% of Litt. Zone:		91.2%	PRI	1.4 ± 1.4%	PZS	1.4 ± 1.4%	ELD	0.03 ± 0.07
% of Lake Area:		22.7%					NAJ	0.03 ± 0.07
							PEC	0.03 0.07

Weevil Damage rating 0.507±0.072

Lake Harriet		% Vis MSP Cov	% Occurrence (Visual)		% Occurrence (Drop Hook)		Density Rating	n = 27
Date	n	Mean ± 1SE	Spp.	% Occ. ± 1 SD	Spp.	% Occ. ± 1 SD	Spp.	Density ± 2SE
9/23/98	73	59.2 ± 4.2%	MSP	84.9 ± 4.2%	MSP	82. ± 4.5%	MSP	3.81 ± 0.68
			CRT	8.2 ± 3.2%	CRT	39.7 ± 5.7%	CRT	2.07 ± 0.55
Eurasian Watermilfoil:			PRI	6.8 ± 3.0%	PRI	6.8 ± 3.0%	PRI	0.26 ± 0.31
Total Area:		25.9 ha.	NAJ	1.4 ± 1.4%	NAJ	5.7 ± 2.7%	PZS	0.19 ± 0.26
% of Litt. Zone:		75.3%	PZS	1.4 ± 1.4%	PEC	1.4 ± 1.4%	NAJ	0.15 ± 0.18
% of Lake Area:		18.7%			PZS	1.4 ± 1.4%	PEC	0.07 ± 0.10
							HET	0.04 ± 0.07

Weevil Damage Rating: 0.493±0.088

Lake Harriet		% Vis MSP Cov	% Occurrence (Visual)		% Occurrence (Drop Hook)		Density Rating	n = 29
Date	n	Mean ±1S.E.	Spp.	% Occ. ± 1S.D.	Spp. ±	% Occ. ±S.D.	Spp.	Density ±2S.E.
9/24/99	71	71.9 ±2.8%	MSP	79.2 ± 4.8%	MSP	93.1 ± 3.0%	MSP	3.86 ± 0.44
			CRT	11.1 ± 3.7%	CRT	59.7 ± 5.8%	PZS	0.03 ± 0.07
							CRT	3.14 ± 0.46

Lake Harriet		% Vis MSP Cov	% Occurrence (Visual)		% Occurrence (Drop Hook)		Density Rating	n = 25
Date	n	Mean ±1S.E.	Spp.	% Occ. ±1S.D.	Spp.	% Occ. ±1S.D.	Spp.	Density ±2S.E.
8/21/00	66	36.8 ±4.2%	MSP	71.2 ± 5.6%	MSP	74.2 ± 5.4%	MSP	3.56 ± 0.54
			CRT	24.2 ± 5.3%	CRT	62.1 ± 6.0%	PEC	0.12 ± 0.13
Eurasian Watermilfoil:			NAJ	1.5 ± 1.5%	NAJ	1.5 ± 1.5%	PZS	0.08 ± 0.16
Total Area:		21.1 ha.	PZS	3.0 ± 2.1%	PZS	1.5 ± 1.5%	CRT	3.20 ± 0.60
% of Litt. Zone:		61.3%	PEC	3.0 ± 2.1%			NAJ	0.12 ± 0.24
% of Lake Area:		15.3%					PRI	0.04 ± 0.08
							CHA	0.04 ± 0.08

Lake Harriet		% Vis MSP Cov	% Occurrence (Visual)		% Occurrence (Drop Hook)		Density Rating	n = 20
Date	n	Mean ± 1SE	Spp.	% Occ. ± 1 SD	Spp.	% Occ. ± 1 SD	Spp.	Density ± 2SE
8/14/01	71	46.4 ±4.7%	MSP	54.9 ± 5.9%	MSP	81.7 ± 4.6%	MSP	3.65 ± 0.55
			CRT	14.1 ± 4.1%	CRT	60.6 ± 5.8%	CRT	3.05 ± 0.59
			HET	1.4 ± 1.4%	PRI	1.4 ± 1.4%	HET	0.10 ± 0.14
			PEC	1.4 ± 1.4%			NAJ	0.05 ± 0.10
							PRI	0.05 ± 0.10
Weevil Damage Rating: 0.01							PZS	0.05 ± 0.10

Table 12 Continued

Lake Harriet		% Vis MSP Cov	% Occurrence (Visual)	% Occurrence (Drop Hook)	Density Rating n = 20
Date	n	Mean ± 1SE	Spp. % Occ. ± 1 SD	Spp. % Occ. ± 1 SD	Spp. Density ± 2SE
8/19/02	n=66	62.1 ±4.6%	MSP 83.3 ± 0.0	MSP 75.8 ± 0.1	MSP 3.40 ± 0.70
			CRT 10.6 ± 0.0	CRT 34.8 ± 0.1	CRT 2.15 ± 0.71
Weevil Damage Rating: 0.36					PRI 0.05 ± 0.10

Lake Harriet		% Vis MSP Cov	% Occurrence (Visual)	% Occurrence (Drop Hook)	Density Rating n = 27
Date	n	Mean ± 1SE	Spp. % Occ. ± 1 SD	Spp. % Occ. ± 1 SD	Spp. Density ± 2SE
9/4/03	n=74	48.9 ± 4.5%	MSP 77.0 ± 0.0	MSP 85.1 ± 0.0	MSP 3.6 ± 0.5
			CRT 5.4 ± 0.0	CRT 59.5 ± 0.1	CRT 2.9 ± 0.5
			PEC 2.7 ± 0.0	PCR 1.4 ± 0.0	PEC 0.2 ± 0.2
Weevil Damage Rating: 0.54				PEC 1.4 ± 0.0	

Lake of the Isles		% Vis MSP Cov	% Occurrence (Visual)	% Occurrence (Drop Hook)	Density Rating n = 25
Date	n	Mean ± 1 S.E.	Spp. % Occ. ± 1 S.D.	Spp. % Occ. ± 1 S.D.	Spp. Density ± 2S.E.
8/13/97	72	15.4 ± 3.5%	MSP 31.9 ± 5.5%	MSP 59.7 ± 5.8%	CRT 2.48 ± 0.37
Eurasian Watermilfoil:			CRT 26.4 ± 5.2%	CRT 62.5 ± 5.7%	MSP 1.84 ± 0.53
Total Area:		13.9 ha.	PZS 1.4 ± 1.4%	NAJ 2.8 ± 1.9%	PZS 0.04 ± 0.08
% of Litt. Zone:		38.5%		PZS 2.8 ± 1.9%	
% of Lake Area:		31.8%			

Lake of the Isles		% Vis MSP Cov	% Occurrence (Visual)	% Occurrence (Drop Hook)	Density Rating n = 26
Date	n	Mean ± 1SE	Spp. % Occ. ± 1 SD	Spp. % Occ. ± 1 SD	Spp. Density ± 2SE
8/31/98	73	8.5 ± 2.0%	MSP 28.8 ± 5.3%	MSP 56.2 ± 5.8%	CRT 2.85 ± 0.60
Eurasian Watermilfoil			CRT 15.1 ± 4.2%	CRT 39.7 ± 5.7%	MSP 2.81 ± 0.69
Total Area:		36.0 ha.		CHC 2.7 ± 1.9%	NAJ 0.08 ± 0.15
% of Litt. Zone:		100.0%		NAJ 2.7 ± 1.9%	CHC 0.04 ± 0.08
% of Lake Area:		49.6%		PEC 1.4 ± 1.4%	PCR 0.04 ± 0.08
Weevil Damage Rating: 1.411±0.320					PEC 0.04 ± 0.08

Lake of the Isles		% Vis MSP Cov	% Occurrence (Visual)	% Occurrence (Drop Hook)	Density Rating n = 26
Date	n	Mean ±1S.E.	Spp.% Occ. ± 1S.D.	Spp.% Occ. ± 1S.D.	Spp.Density ± 2S.E.
8/17/99	72	21.2 ± 2.8%	MSP 22.2 ± 4.9%	MSP 72.2 ± 5.3%	MSP 3.69 ± 0.57
			CRT 1.4 ± 1.4%	CRT 40.3 ± 5.8%	PEC 0.04 ± 0.08
					CRT 2.88 ± 0.52
					NAJ 0.04 ± 0.08
					CHA 0.04 ± 0.08

Lake of the Isles		% Vis MSP Cov	% Occurrence (Visual)	% Occurrence (Drop Hook)	Density Rating n = 26
Date	n	Mean ±1S.E.	Spp.% Occ. ± 1S.D.	Spp.% Occ. ± 1S.D.	Spp.Density ± 2S.E.
8/14/00	82	50.7 ± 4.4%	MSP 82.2 ±14.2%	MSP 87.7 ±13.6%	MSP 3.73 ± 0.49
Eurasian Watermilfoil				CRT 24.7 ±14.8%	CRT 1.58 ± 0.58
Total Area:					PCR 0.23 ± 0.26
% of Litt. Zone:					NAJ 0.04 ± 0.08
% of Lake Area:					PRI 0.04 ± 0.08

Lake of the Isles		% Vis MSP Cov	% Occurrence (Visual)	% Occurrence (Drop Hook)	Density Rating n = 26
Date	n	Mean ±1S.E.	Spp.% Occ. ± 1S.D.	Spp.% Occ. ± 1S.D.	Spp.Density ± 2S.E.
8/15/01	82	3.9 ± 1.4%	MSP 7.3 ± 2.9%	MSP 25.6 ± 4.8%	CRT 2.88 ± 0.56
			CRT 7.3 ± 2.9%	CRT 36.6 ± 5.3%	MSP 1.65 ± 0.68
Eurasian Watermilfoil				NAJ 1.2 ± 1.2%	NAJ 0.08 ± 0.15
Total Area:		5.4 ha.		PCR 1.2 ± 1.2%	PCR 0.08 ± 0.15
% of Litt. Zone:		15.1%			PFO 0.04 ± 0.08
% of Lake Area:		12.5%			PRI 0.04 ± 0.08
Weevil Damage Rating:		0.15			

Table 12 Continued

Lake of the Isles		% Vis MSP Cov	% Occurrence (Visual)	% Occurrence (Drop Hook)	Density Rating n = 21
Date	n	Mean ±1S.E.	Spp.% Occ. ± 1S.D.	Spp.% Occ. ± 1S.D.	Spp.Density ± 2S.E.
8/22/02	70	17.3 ± 3.6%	MSP 39.0 ± 0.1	MSP 55.7 ± 0.1	MSP 2.90 ± 0.79
Eurasian Watermilfoil			CRT 19.5 ± 0.0	CRT 40.0 ± 0.1	CRT 1.67 ± 0.68
Total Area:		12.7 ha.	BRA 1.2 ± 0.0	CHA 1.4 ± 0.0	CHA 0.05 ± 0.10
% of Litt. Zone:		35.3%	PEC 1.2 ± 0.0		
% of Lake Area:		29.1%			
Weevil Damage Rating: 0.06					

Lake of the Isles		% Vis MSP Cov	% Occurrence (Visual)	% Occurrence (Drop Hook)	Density Rating n = 27
Date	n	Mean ±1S.E.	Spp.% Occ. ± 1S.D.	Spp.% Occ. ± 1S.D.	Spp.Density ± 2S.E.
8/6/03	74	4.2% ±.3%	MSP ± 18.9 0.0	MSP 48.6 ± 0.1	MSP 1.5 ± 0.6
			CRT ± 12.2 0.0	CRT 23.0 ± 0.0	CRT 1.2 ± 0.6
Weevil Damage Rating: 0.28					PRI 0.0 ± 0.1

Centerville		% Vis MSP Cov	% Occurrence (Visual)	% Occurrence (Drop Hook)	Density Rating n = 20
Date	n	Mean 1S.E.	Spp.% Occ. ± 1S.D.	Spp.% Occ ±. 1S.D.	Spp.Density ± 2S.E.
8/14/02	35	0.3 ±0.2%	MSP 8.6 ± 0.0	MSP 71.4 ± 0.1	MSP 3.25 ± 0.66
			CRT 2.9 ± 0.0	CRT 71.4 ± 0.1	CRT 1.65 ± 0.57
			LTR 2.9 ± 0.0	CHA 22.9 ± 0.1	PCR 0.05 ± 0.10
			PEC 2.9 ± 0.0	PCR 2.9 ± 0.0	CHA 0.80 ± 0.64
Weevil Damage Rating:		0.79		PEC 2.9 ± 0.0	

Schultz		% Vis MSP Cov	% Occurrence (Visual)	% Occurrence (Drop Hook)	Density Rating n =24
Date	n	Mean 1S.E.	Spp.% Occ. ± 1S.D.	Spp.% Occ. ± 1S.D.	Spp.Density ± 2S.E.
9/3/02	25	16.6 ±4.4%	MSP 80.8 ± 0.1	MSP 84.6 ± 0.1	MSP 2.46 ± 0.58
			CRT 69.2 ± 0.1	CRT 100.0 ± 0.0	PEC 0.04 ± 0.08
			PEC 30.8 ± 0.1	PAM 30.8 ± 0.1	CRT 3.38 ± 0.66
			PAM 23.1 ± 0.1	PEC 19.2 ± 0.1	PAM 0.83 ± 0.62
			NAJ 3.8 ± 0.0	NAJ 7.7 ± 0.1	
				PCR 7.7 ± 0.1	

Vadnais		% Vis MSP Cov	% Occurrence (Visual)	% Occurrence (Drop Hook)	Density Rating n =31
Date	n	Mean 1S.E.	Spp.% Occ. ± 1S.D.	Spp.% Occ. ± 1S.D.	Spp.Density ± 2S.E.
8/16/02	34	22.4 ±3.8%	MSP 55.9 ± 0.1	MSP 82.4 ± 0.1	MSP 2.65 ± 0.48
			CRT 38.2 ± 0.1	CRT 82.4 ± 0.1	PEC 0.58 ± 0.40
			PEC 26.5 ± 0.1	PEC 38.2 ± 0.1	PZS 0.90 ± 0.40
			VAL 23.5 ± 0.1	VAL 35.3 ± 0.1	CRT 2.97 ± 0.51
			PRI 11.8 ± 0.1	PZS 23.5 ± 0.1	NMP 0.03 ± 0.06
			PZS 8.8 ± 0.0	PPR 20.6 ± 0.1	NAJ 0.10 ± 0.19
			PPR 5.9 ± 0.0	PRI 5.9 ± 0.0	PRI 0.10 ± 0.14
			NAJ 2.9 ± 0.0	NAJ 2.9 ± 0.0	PPR 0.29 ± 0.19
Weevil Damage Rating: 0.49			NMP 2.9 ± 0.0	NMP 2.9 ± 0.0	VAL 0.87 ± 0.55

Table 13. Water column characteristics at additional survey lakes in summer 2002 and sediment characteristics (bulk density, percent organic matter, sediment pore water ammonium concentrations) at a subset of these lakes.

Lake/Date	Bulk Dens. (g dm/ml)	NH_4 (mg/L)	% Organic	Chl-a (mg/m^3)	SD (m)	Temp (˚C 1m)	10% PAR Depth (m)
Bald Eagle							
8/5/02				53.4	0.8	24.7	0.5-1.0
Centerville							
8/14/02	1.00	10.20	13.5	39.0	1.1	25.9	1.5
2se	0.61	.	7.4				
Independence							
7/31/02				38.2	1.0	26.5	1.0-1.5
Peltier							
7/30/02				85.3	0.8	25.1	1.0
Schultz							
9/3/02				20.0	2.0	24.4	2.0
Vadnais							
8/7/02	1.40	1.24	7.5	15.2	1.7	23.5	2
2se	0.23	.	5.8				

Surveys of weevils and fish

To attempt to detect additional declines and to determine if agent and perhaps milfoil density may be related to fish density, we also conducted weevil surveys on 6 new lakes along with Cedar Lake and Calhoun in August 2002. These lakes had DNR fish surveys conducted in 2000, 2001 or 2002 (Table 14). A range of weevil densities was found; generally lakes with high fish densities had low weevil densities and lakes with high weevil densities had low sunfish densities (Table 14). There was a significant ($p = 0.05$) regression of adult weevil density on ln(sunfish/trapnet):

$$\text{Adults/stem} = 0.16 - 0.034 \ln(\text{sunfish/trapnet}),\ r^2 = 0.49$$

Abundance of sunfish that results in zero weevils can be predicted from the converse regression, which gave an intercept of 4.36, or 78 sunfish per trapnet. The regression of sunfish on total weevil abundance was marginally significant ($p=0.1$).

To increase sample size we included lakes for which fisheries surveys were available and for which we had weevil surveys during the same year. For Cenaiko Lake in 1998 we had one weevil survey from September, one week prior to the fisheries survey. For Lake Auburn in 2000, Cenaiko in 2002 and Otter Lake in 2001 and 2002 we averaged our bi-weekly weevil surveys to provide an average summer density. We then used the combined data set to determine the relationship between weevil density and sunfish relative abundance (Fig. 7). Cenaiko Lake in 1998 was determined to be an outlier (weevil density was much higher than all other sites, Table 14) and was dropped from the regressions (Fig. 7). Because the relationship with total weevil density appeared bimodal, we used a logistic regression for total weevil density, using a threshold of <0.2 weevils/stem (low) or >0.2 weevils/stem (high). The regressions of total weevil density and adult weevil density on ln(sunfish/trapnet) were highly significant (p=0.003 and p=0.001, respectively).

For adult weevils (Fig 7):
Adult weevils per stem = 0.146 - 0.071 $\log_{10}$[sunfish/trapnet], $r^2 = 0.71$

Thus sunfish catch rates explain 70% of the variation in adult weevil abundance across the lakes. Because sunfish prey directly on adult weevils (Sutter and Newman 1997) a direct relationship with adult density makes sense.

With total weevil density (sum of eggs, larvae, pupae and adults), the relationship is clearly bimodal with high and low weevil densities. Because sunfish do not prey on eggs and pupae and larvae are relatively immune to predation the indirect effects of predation on adults might be expected to result in a threshold with low predation allowing high densities and higher predation inhibiting development of significant weevil populations.

The logistic regression of qualitative (high vs. low) total weevil density on sunfish catch rate was highly significant (G^2=8.77, P=0.003) and explained 57% of the variation in qualitative total weevil density. The logistic model suggests a threshold catch rate of 30 sunfish per trap net, above which weevil populations will be at low density (<0.1/stem, Fig. 7).

These regressions suggest that sunfish density explains 60 and 70% of the variation in total weevil and adult weevil density, respectively, among lakes and support our experimental observations that sunfish predation is an important factor limiting weevil density (and thus milfoil control) in Minnesota lakes. The stronger relationship between sunfish and adult densities is intuitively appealing as sunfish prey primarily on adults (Sutter and Newman 1997) and thus indirectly limit total weevil densities. The high density of weevils in Cenaiko in 1998 is consistent with the other results and suggests that at some low fish density, fish are not limiting weevil populations; modeling suggests that with low adult mortality, fall densities can be very high (Ward 2002). The regressions suggest that weevil populations would be below detection with about 80 sunfish per trapnet. A density of more than 25-30 sunfish per trapnet would result in weevil densities less than 0.1/stem and likely be limiting to milfoil control.

There was no clear relationship between weevil density and milfoil relative density at the survey lakes (Tables 12 and 14), however, without several years of data it is difficult to tell if weevil densities had recently increased or if milfoil density was increasing or decreasing.

Table. 14. Results of mid-summer 2002 weevil surveys (number per stem) at lakes with a range of fish densities. Fish densities are the mean number of sunfish (bluegill, pumpkinseed, hybrid and green sunfish) per trapnet set based on MN DNR fisheries surveys (2000-2002; Date provided). Below these results are results of historical fish surveys that correspond to weevil surveys from the same year in our regularly sampled lakes (summer-long average of bi-weekly weevil surveys, except Cenaiko when only one weevil survey was conducted in September 1998, one week prior to the fish survey).

Lake/Date	Date	Fish Density	Eggs	Larvae	Pupae	Adults	Total
Calhoun	7/24/00	241	0	0	0	0	0
Cedar	7/17/00	101	0	0.005	0	0	0.005
Bald Eagle	7/8/02	64	0	0	0	0.008	0.008
Peltier	8/5/02	60	0.042	0	0	0	0.042
Schultz	8/1/02	55	0	0	0	0.013	0.013
Centerville	7/29/02	35	0.218	0.066	0.019	0.042	0.346
Independence	7/23/01	28	0	0	0	0.014	0.014
Vadnais	7/16/01	20	0.169	0.013	0.025	0.113	0.319
Historical surveys							
Auburn	6/19/00	113	0.023	0.015	0.007	0.016	0.061
Cenaiko	9/9/98	5	0.856	1.978	0.156	0.611	3.600
Cenaiko	9/4/02	25	0.002	0.004	0.000	0.002	0.008
Otter	7/30/01	2	0.205	0.088	0.015	0.137	0.444
Otter	6/10/02	6	0.135	0.079	0.011	0.091	0.320

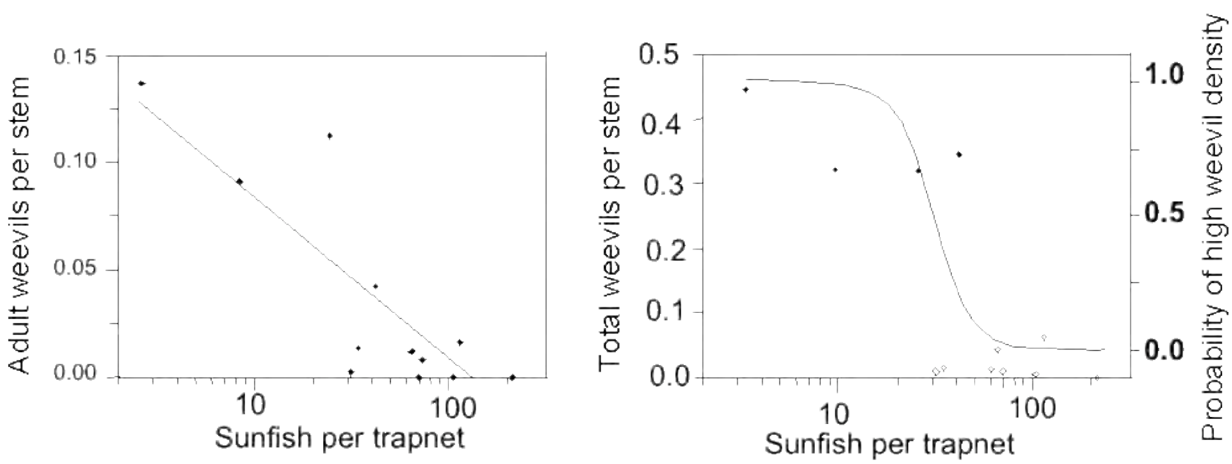

Fig. 7. Regression of adult weevil density on sunfish trapnet catch and logistic regression with total weevil density. Cenaiko Lake 1998 weevil densities were very high (Table 14) and were outliers and were dropped from the analysis.

Weevil Introduction/Manipulation:

To determine if we could stock weevils to enhance populations and get control of Eurasian watermilfoil, we stocked weevils into two Minneapolis lakes: Harriet (high sunfish density) and Hiawatha (low sunfish density). No weevils were found in stem surveys prior to stocking and no weevils were found in biomass samples taken immediately prior to stocking at either lake (Table 15). Weevils were found at both lakes after stocking (Table 15 and 17).

At Harriet, there was a significant increase in weevil abundance (per m^2 and per stem) after stocking in 2002 (Table 15; $p < 0.004$) but no difference between stocked and not-stocked plots. Stocking enhanced abundance, but weevils quickly moved beyond the stocked plots. Weevil densities increased through early September to 0.1 per stem in Harriet (Table 17). However, even though the plots were > 100m apart, weevils moved and colonized the not-stocked plots. Although a few weevil juveniles have been found in previous years in Lake Harriet, all adults since 2000 have been *Phytobius*, suggesting that milfoil weevil populations were very low in Lake Harriet prior to stocking in 2002. *Acentria* and *Parapoynx* were not found at Harriet.

In 2003, weevils were found in May and June prior to additional stocking, but the population did not increase even with stocking (Table 17). Only one weevil was found in the biomass samples, a pupa in the June 2003 not-stocked plot. Thus although Harriet attained a higher density of weevils after stocking in summer 2002 than Hiawatha, the population failed to increase in 2003, even with additional stocking. Stocking did appear to establish a low density of weevils at Harriet (Table 17) although it is not clear if the population will persist.

At Hiawatha, *Acentria* was present at low densities prior to stocking in 2002 but no milfoil weevils were found (Table 15). Weevils appeared after stocking in 2002 but densities were lower than Harriet and it was mid-September before weevils were common (Table 17). There was a significant increase in weevil abundance (per m^2 and per stem) after stocking (Table 15; $p < 0.1$), but no difference in weevil abundance between stocked and not stocked plots ($p>0.8$). These results suggest substantial within-lake movement of weevils within a summer and indicate that control and treatment plots should be placed very far apart (opposite sides of the lake).

In 2003, weevils were found at low densities in both the biomass and biweekly surveys; densities were similar between stocked and not-stocked plots (Tables 15 and 17). Densities were typically <0.2 per stem. There was no evidence of an additional increase in weevil density due to stocking in 2003 and it is likely a low-density population was established in both stocked and not-stocked plots. *Acentria* was much more abundant in 2003, particularly in the stocked plots (20-40/m^2). *Acentria* was rare in the biweekly surveys and its high occurrence in the biomass samples was likely because it was on non-milfoil plants. The overall higher density of weevils and caterpillars in Hiawatha compared to Harriet is consistent with lower sunfish predation and the lower density of sunfish found in Hiawatha (11/trapnet vs 340/trapnet at Harriet, MN DNR Lake Surveys). More study is required to determine if herbivore densities will persist or increase at Hiawatha.

Milfoil and total plant biomass was lower in Hiawatha than Harriet (perhaps due to clarity) and milfoil was more dominant in Harriet (Table 16). Significant declines of milfoil were not noted in either lake, but in 2002, milfoil increased significantly more in the not-stocked plots compared to stocked plots at Harriet (ANOVA of differences; $p < 0.04$) while no significant change in non-milfoil biomass was detected ($p>0.8$). Overall, milfoil increased over the summer at Harriet and there was a significant ($p < 0.07$) stocking by session interaction with the increase in milfoil at the not-stocked plots. The potential differences in milfoil among stocked and not-stocked plots did not carry over into 2003. Repeated measures ANOVA with the post stocking data found no significant difference in milfoil or non-milfoil biomass and not significant session by treatment interactions (all $p>0.5$). No significant differences in weevil densities were found either.

At Hiawatha, there was no effect of treatment on milfoil biomass and no change in milfoil biomass with treatment or date (all $p > 0.1$) in 2002 although milfoil biomass decreased in stocked plots and increased in unstocked plots. There was a significant decrease in non-watermilfoil biomass from June to September 2002 ($p<0.001$) and a significant decrease in number of species, both likely due to decreases in water clarity. A repeated measures ANOVA with the post stocking samples (September 2002, June and August 2003) indicated a significant site (treatment) effect ($p < 0.05$) on milfoil biomass, however, milfoil biomass was higher in the stocked plots. No significant time or time by plot interaction was found and no significant effects were found for total biomass. Native plants did increase over the study ($p < 0.1$) and the percentage of milfoil was lower in not-stocked plots. Thus no significant reduction in milfoil biomass was evident, however, weevils were distributed across stocked and not-stocked plots and may have prevented an increase in milfoil at Hiawatha (compare to Harriet) and may have contributed to the significant decrease in the control plots. Weevil densities in biweekly surveys were 50% higher in the not-stocked plots (0.15/stem) than the stocked plots (0.09/stem; Table 17), although the biomass samples showed less of a difference and a higher density per area in the stocked plots. An ANCOVA with weevil density (number per sample) as the covariate showed that weevil density was a significant covariate ($p<0.01$), although it is unclear how weevils were affecting the noted treatment effect.

It was somewhat surprising that adult weevil densities were similar in both lakes after stocking in 2002 and total weevil densities were higher in Harriet than in Hiawatha because Harriet has a much high density of sunfish (over 320/trapnet set in 2000) than Hiawatha (11/trapnet set in 2001). However, poor water quality and clarity in Hiawatha may have limited weevil success there during 2002. In 2003, weevil densities were similar in both lakes before restocking but adults became more common in Hiawatha as the summer progressed (Tables 15 and 17). The 2003 summer mean total weevil density was 0.12 per stem. The very low density in Harriet after early July 2003 and the absence of herbivores from the biomass samples in August suggests that herbivores will likely not persist in Harriet as long as the high sunfish density remains.

In summary, stocking did result in establishment of detectible weevils populations in both lakes that carried over to the next summer. Weevils may remain established at Hiawatha but it is less clear if they will persist at Harriet. The summer average weevil density in 2003 was 3 times higher in Hiawatha (0.12/stem) than Harriet (0.04/stem). Weevils dispersed into not-stocked areas and densities were not adequate to control the plants, although the fair population at Hiawatha in 2003 may have prevented the milfoil from increasing to higher density. Overall, however, there were no significant reductions of milfoil associated with weevil stocking in either lake. More time may be required to develop an adequate density of herbivores at Hiawatha. Predation by sunfish likely limited weevils at Harriet and future surveys should be conducted to determine if populations will persist in either lake.

Table 15. Abundance of weevil stages (N/m^2 and number per milfoil stem ± 2SE) and *Acentria* and *Parapoynx* before stocking (June and July) and after stocking (August and September) from biomass samples from stocked and not-stocked plots at Lakes Harriet and Hiawatha in 2002 and 2003. N = 12 samples from each plot and date.

Harriet Date	Weevil	Larvae N/m^2	Pupae N/m^2	Adults N/m^2	Total *E.l.* N/m^2	*Acentria* N/m^2	*Parapoynx* N/m^2
7/11/02	Stocked	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
	per stem	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
	Not Stocked	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
	per stem	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
9/14/02	Stocked	5.8±8.3	1.7±2.2	4.2±4.6	11.7±13.2	0.0±0.0	0.0±0.0
	per stem	0.014±0.016	0.006±0.009	0.018±0.023	0.038±0.031		
	Not Stocked	5.0±6.7	2.5±3.6	5.8±5.8	13.3±9.0	0.0±0.0	0.0±0.0
	per stem	0.012±0.016	0.013±0.022	0.023±0.022	0.047±0.037		
6/16/03	Stocked	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
	per stem	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
	Not Stocked	0.0±0.0	0.8±1.7	0.0±0.0	0.8±1.7	0.0±0.0	0.0±0.0
	per stem	0.000±0.000	0.006±0.012	0.000±0.000	0.006±0.012		
8/25/03	Stocked	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
	per stem	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
	Not Stocked	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
	per stem	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		

Hiawatha Date	Weevil	Larvae N/m^2	Pupae N/m^2	Adults N/m^2	Total *E.l.* N/m^2	*Acentria* N/m^2	*Parapoynx* N/m^2
7/18/02	Stocked	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	3.3±2.8	0.0±0.0
	per stem	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
	Not Stocked	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	2.7±2.8	0.0±0.0
	per stem	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000		
9/12/02	Stocked	0.0±0.0	0.0±0.0	5.0±8.0	5.0±8.0	2.0±4.0	0.0±0.0
	per stem	0.000±0.000	0.000±0.000	0.050±0.083	0.050±0.083		
	Not Stocked	1.0±2.0	0.0±0.0	3.0±4.3	4.0±6.1	0.0±0.0	0.0±0.0
	per stem	0.009±0.019	0.000±0.000	0.056±0.079	0.065±0.087		
6/27/03	Stocked	0.0±0.0	0.0±0.0	1.7±2.2	1.7±2.2	20.0±16.7	0.0±0.0
	per stem	0.000±0.000	0.000±0.000	0.019±0.028	0.019±0.028		
	Not Stocked	0.0±0.0	0.0±0.0	1.7±2.2	1.7±2.2	2.5±3.6	0.0±0.0
	per stem	0.000±0.000	0.000±.000	0.080±0.141	0.080±0.141		
8/28/03	Stocked	0.0±0.0	0.0±0.0	2.5±3.6	2.5±3.6	39.2±19.5	1.7±3.3
	per stem	0.000±0.000	0.000±0.000	0.034±0.049	0.034±0.049		
	Not Stocked	0.0±0.0	0.0±0.0	1.8±2.4	1.8±2.4	2.7±3.9	0.0±0.0
	per stem	0.000±0.000	0.000±0.000	0.047±0.066	0.047±0.066		

Table 17. Results of weevil surveys in stocked lakes Hiawatha and Harriet. Numbers are densities of weevil life stages (per stem), total weevils per stem and density (per stem) of the caterpillars *Acentria* (Acent) and *Parapoynx* (Parap). In 2003 additional weevils were stocked in mid-July.

Date	Treatment	Eggs	Larvae	Pupae	Adults	Total	*Acent*	*Parap*
Hiawatha								
7/30/02	stocked	0.000	0.000	0.000	0.013	0.013	0.009	0.000
7/30/02	notstocked	0.013	0.000	0.000	0.000	0.013	0.000	0.000
8/12/02	stocked	0.000	0.000	0.000	0.000	0.000	0.008	0.000
8/12/02	notstocked	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8/26/02	stocked	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8/26/02	notstocked	0.023	0.034	0.000	0.000	0.057	0.000	0.000
9/12/02	stocked	0.000	0.000	0.000	0.073	0.073	0.000	0.000
9/12/02	notstocked	0.000	0.000	0.000	0.072	0.072	0.000	0.000
2002	mean	0.005	0.004	0.000	0.020	0.029	0.002	0.000
5/23/03	stocked	0.021	0.000	0.000	0.000	0.021	0.000	0.000
5/23/03	notstocked	0.278	0.000	0.000	0.000	0.278	0.000	0.000
6/4/03	stocked	0.025	0.000	0.000	0.000	0.025	0.000	0.000
6/4/03	notstocked	0.029	0.057	0.000	0.000	0.086	0.000	0.000
6/17/03	stocked	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6/17/03	notstocked	0.000	0.089	0.000	0.056	0.144	0.000	0.000
7/2/03	stocked	0.056	0.000	0.000	0.000	0.056	0.000	0.000
7/2/03	notstocked	0.098	0.000	0.000	0.000	0.098	0.000	0.000
7/14/03	stocked	0.045	0.023	0.000	0.011	0.080	0.000	0.000
7/14/03	notstocked	0.167	0.000	0.000	0.028	0.194	0.000	0.000
7/31/03	stocked	0.162	0.083	0.000	0.021	0.266	0.021	0.000
7/31/03	notstocked	0.014	0.022	0.014	0.014	0.064	0.000	0.000
8/12/03	stocked	0.068	0.114	0.000	0.011	0.193	0.057	0.000
8/12/03	notstocked	0.064	0.076	0.000	0.030	0.170	0.021	0.000
2003	mean	0.073	0.033	0.001	0.012	0.120	0.007	0.000
Harriet								
7/24/02	stocked	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7/24/02	notstocked	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8/6/02	stocked	0.000	0.000	0.000	0.010	0.010	0.000	0.000
8/6/02	notstocked	0.104	0.000	0.000	0.000	0.104	0.000	0.000
8/19/02	stocked	0.031	0.000	0.021	0.014	0.066	0.000	0.000
8/19/02	notstocked	0.010	0.104	0.021	0.010	0.146	0.000	0.000
9/6/02	stocked	0.000	0.021	0.010	0.052	0.083	0.000	0.000
9/6/02	notstocked	0.063	0.000	0.000	0.045	0.107	0.000	0.000
9/17/02	stocked	0.000	0.021	0.000	0.021	0.042	0.000	0.000
9/17/02	notstocked	0.000	0.031	0.031	0.031	0.094	0.000	0.000
2002	mean	0.021	0.018	0.008	0.018	0.065	0.000	0.000
5/23/03	stocked	0.088	0.000	0.000	0.000	0.088	0.000	0.000
5/23/03	notstocked	0.227	0.000	0.000	0.023	0.250	0.000	0.000
6/4/03	stocked	0.057	0.000	0.000	0.000	0.057	0.000	0.000
6/4/03	notstocked	0.021	0.010	0.000	0.021	0.052	0.000	0.000
6/17/03	stocked	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6/17/03	notstocked	0.000	0.056	0.000	0.000	0.056	0.000	0.000
7/2/03	stocked	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7/2/03	notstocked	0.000	0.000	0.009	0.009	0.019	0.000	0.000
7/15/03	stocked	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7/15/03	notstocked	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7/30/03	stocked	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7/30/03	notstocked	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8/11/03	stocked	0.000	0.000	0.073	0.000	0.073	0.033	0.000
8/11/03	notstocked	0.000	0.010	0.000	0.010	0.021	0.000	0.000
2003	mean	0.028	0.005	0.006	0.005	0.044	0.002	0.000

Table 16. Total plant biomass (g dm/m^2, ±SE), milfoil biomass (MSP), non-milfoil biomass and percent milfoil before (July) and 7 weeks after stocking weevils in stocked and not-stocked plots at Hiawatha and Harriet.

Session	Date	Trt	Total Biomass	MSP	NonMSP	%MSP
Hiawatha	7/18/02	Stocked	77±23	38±21	39±18	42.7± 19.9%
	7/18/02	Not Stocked	99±40	18±16	81±40	19.0± 16.2%
	9/12/02	Stocked	39±24	29±24	10±11	52.6± 25.9%
	9/12/02	Not Stocked	37±15	22±14	15±8	55.0± 20.0%
	6/27/03	Stocked	135±103	103±93	32±28	66.5± 20.9%
	6/27/03	Not Stocked	86±85	51±86	33±22	22.6± 17.7%
	8/28/03	Stocked	92±47	55±24	36±29	66.8± 19.9%
	8/28/03	Not Stocked	62±35	18±17	43±28	28.8± 17.8%
Harriet	7/11/02	Stocked	336±133	319±143	16±19	84.2± 17.4%
	7/11/02	Not Stocked	170± 84	155± 85	14±10	88.0± 11.0%
	9/14/02	Stocked	339±123	308±114	31±26	92.3± 6.5%
	9/14/02	Not Stocked	371±128	367±126	4±3	98.7± 1.2%
	6/16/03	Stocked	275±138	264±135	11±15	95.4± 4.8%
	6/16/03	Not Stocked	289±133	272±121	18±35	87.8± 15.5%
	8/25/03	Stocked	271±114	253±110	18±22	89.8± 10.6%
	8/25/03	Not Stocked	130±251	211±126	39±40	79.1± 19.5%

Effects of plant community:

Plant manipulation plots were established in Otter Lake and Lake Auburn in 2001 and were resampled in 2002. A set of plots was established in Cedar Lake in 2002. Each manipulation consisted of twenty plots; five replicates each of 4 treatments (remove no plants (Control), remove all plants, remove milfoil, or remove native plants). Treatments were assigned to plots in a randomized block (by location) manner. In 2003, the removal plots in Cedar and Otter were resampled for biomass in late June or early July.

At Lake Auburn, the community was dominated by coontail (>90% of native biomass) and Eurasian watermilfoil (MSP) (Table 18). There were no significant differences in biomass or number of species prior to the manipulation (ANOVA, all $p > 0.2$).

Table 18. Mean biomass ± 2SE (g dry/m^2) of all plants (Total), Eurasian watermilfoil (MSP), all other plants (NAT) and the most common plants (coontail (CRT), flatstem pondweed (PZS), sago pondweed (PEC; now *Stuckenia pectinata*) and *Nymphaea* (NMP)) by treatment for the plant community manipulation at Lake Auburn 2001-2002. The percent of total plant biomass composed by MSP and percent of native plant mass composed of CRT along with the mean number of non-MSP species per sample (NSpec) are also given. Treatments were: No removal (Contr), Remove all plants (Remall), remove Eurasian watermilfoil (RemMSP) and remove all plants except MSP (RemNat). Plant manipulations occurred just after the initial sampling in June 2001. n = 5 plots per treatment.

Treat	Total	MSP	CRT	PZS	PEC	NMP	NAT	%MSP	%CRT	NSpec
6/13/01										
Contr	178.9	102.3	67.2	0.0	0.0	9.4	68.8	49.5%	95.9%	1.0
	55.3	75.7	50.4	0.0	0.0	18.8	57.7	25.8%	8.3%	0.3
Remall	239.4	118.0	101.0	0.1	0.0	20.3	121.4	45.6%	91.1%	1.3
	53.8	83.5	45.8	0.2	0.0	32.4	72.2	26.4%	9.6%	0.2
RemMSP	198.3	88.0	109.7	0.6	0.0	0.0	110.3	43.3%	99.8%	1.1
	38.8	38.2	67.0	1.3	0.0	0.0	68.1	23.5%	0.4%	0.2
RemNat	253.8	145.9	94.2	0.0	0.0	13.7	107.9	47.1%	86.2%	1.3
	84.2	94.9	65.4	0.0	0.0	12.4	60.4	23.5%	13.1%	0.2
9/21/01										
Contr	291.8	196.5	82.2	0.0	3.2	9.9	95.3	59.6%	77.6%	1.6
	126.6	150.3	63.8	0.0	4.2	13.1	55.3	24.6%	19.9%	0.4
Remall	104.8	5.7	91.0	0.3	0.0	7.8	99.1	11.3%	93.2%	1.3
	34.0	8.0	40.4	0.6	0.0	13.5	40.7	19.9%	8.2%	0.2
RemMSP	200.1	17.5	179.3	1.2	0.2	1.9	182.6	11.5%	97.7%	1.4
	74.6	15.8	72.3	2.4	0.4	3.8	71.3	10.6%	3.5%	0.6
RemNat	293.0	194.2	75.7	0.0	0.3	22.8	98.8	60.6%	72.4%	1.4
	106.8	157.1	91.0	0.0	0.4	27.5	83.7	34.0%	22.8%	0.5
6/13/02										
Contr	145.0	66.4	71.1	0.0	0.0	7.5	78.6	45.2%	96.1%	1.2
	53.9	62.4	64.8	0.0	0.0	15.0	77.5	38.0%	7.8%	0.4
Remall	154.6	64.9	88.1	0.2	0.0	0.0	89.8	51.4%	95.5%	1.3
	72.7	39.6	80.4	0.3	0.0	0.0	79.1	28.2%	9.0%	0.4
RemMSP	230.7	94.5	136.0	0.1	0.0	0.0	136.2	40.4%	98.3%	1.4
	124.7	76.9	106.0	0.3	0.0	0.0	105.8	14.9%	3.3%	0.2
RemNat	133.3	86.6	46.7	0.1	0.0	0.0	46.7	50.0%	99.4%	1.1
	77.6	58.1	27.2	0.1	0.0	0.0	27.2	23.1%	1.2%	0.4
9/20/02										
Contr	428.8	348.4	80.4	0.0	0.0	0.0	80.4	70.6%	100.0%	0.9
	176.6	189.1	83.0	0.0	0.0	0.0	83.0	33.2%	0.0%	0.2
Remall	231.8	82.6	137.7	0.0	0.0	11.4	149.2	42.9%	78.8%	1.3
	90.5	73.5	103.1	0.0	0.0	14.5	98.5	35.6%	23.2%	0.2
RemMSP	219.1	123.0	96.1	0.0	0.0	0.0	96.1	46.7%	100.0%	0.9
	123.5	129.5	61.0	0.0	0.0	0.0	61.0	35.5%	0.0%	0.2
RemNat	167.6	101.6	64.4	0.0	0.0	1.6	66.0	49.2%	97.5%	1.1
	124.2	111.2	46.4	0.0	0.0	3.2	46.3	23.8%	5.0%	0.5

Visual estimates of plant coverage confirm that the manipulations altered the community (Table 19; in July 2001 %MSP was lower in the Remove All and Remove-MSP treatments (Tukey's HSD, $p<0.01$) and % Natives was lower in Remove-All and Remove-Natives compared to the Remove-MSP treatment (Tukey's HSD, $p<0.05$). Repeated measures ANOVA with all sample dates indicated significant treatment effects for %MSP, %CRT, and %Native species (all $p < 0.01$), but not for other individual species or the mean number of species per plot. Significant session effects were found for MSP, %Natives and mean number of species (all $p<0.05$), but a significant session by treatment interaction was found only for %MSP ($p<0.05$). Milfoil increased, but remained reduced in the Remove-All and Remove-MSP treatments compared to the Remove-Natives treatment through 2001 (sessions 2 and 3), and continued to increase but did not differ by treatment in 2002 (sessions 4 and 5). Conversely, %CRT and %Natives were higher in the Remove-MSP treatment than the other treatments in session 2 and were higher in Remove-MSP than the Control and Remove-Natives in session 3 (Tukey's HSD, all $p<0.1$). In sessions 3 and 4, abundance of Natives remained higher in the Remove-All plots compared to Remove-Native plots (Tukey's HSD, all $p<0.1$). Native plants, predominantly CRT, quickly colonized the Remove-All plots and reduced the recovery of MSP until the fall of 2002. Removal of MSP allowed expansion of the natives in 2001, but by September of the second year milfoil recovered and was not dominated by the natives. Removal of natives favored Eurasian watermilfoil over natives, which remained suppressed through September 2002. As noted above, no changes in number of species were associated with the treatments.

The plant removals were also successful at manipulating the plant community biomass during the first summer; total plant biomass was reduced in the Remove-All treatment and milfoil biomass was reduced in the Remove-MSP treatment (Table 18). Overall, treatments resulted in significant changes in total dry biomass, MSP biomass, the percentage of MSP and coontail, and mean number of species (ANOVA, all $p<0.1$), but no significant changes in non-MSP biomass, coontail biomass or the mean number of non-watermilfoil species were detected in 2001. Coontail biomass increased (but not significantly) with removal of MSP and MSP increased substantially in both the Control and Remove-native treatments. In September, total biomass was lower in Remove-All than in the Control and Remove-Native treatments (Tukey's HSD, $p< 0.05$; the same was seen for MSP except $p=0.1$) and the percentage of MSP was lower in the Remove-All and Remove-MSP treatments than the Control and Remove-Native treatments (Tukey's HSD, $p< 0.05$). These results, consistent with visual estimates, suggest that coontail was able to quickly colonize and take advantage of removal of MSP and that proportional representation of MSP was reduced through the summer in the plots from which it was removed, however, MSP continued to dominate in the Control plots and the Remove-Natives plots. In the lower diversity and poorer water clarity system of Lake Auburn, Eurasian watermilfoil retained dominance in the Control or when natives were removed, but coontail was able to become dominant where Eurasian watermilfoil was removed, even in the Remove-All treatment.

Table 19. Visual estimates (2SE) of plant coverage of Eurasian watermilfoil (%MSP), all other plants (%NAT), the most common plants (coontail (%CRT), flatstem pondweed (%PZS), sago pondweed (%PEC; now *Stuckenia pectinata*) and *Nymphaea* (%NMP)) and the mean number of species by treatment for the plant community manipulation at Lake Auburn 2001-2002. Treatments were: No removal (Contr), remove all plants (RemAll), remove Eurasian watermilfoil (RemMSP) and remove all plants except MSP (RemNat). Plant manipulations occurred three weeks prior to the first visual estimate in June 2001. n = 5 plots per treatment.

Date	Treat	% MSP	% CRT	% PZS	% PEC	% NMP	%Nat	NSpp
7/9/01	Contr	43.9	37.0	0.1	2.5	4.0	43.6	3.0
		15.4	21.3	0.3	4.5	7.1	22.0	0.6
7/9/01	RemAll	5.6	25.6	0.6	0.0	0.9	27.1	2.8
		3.4	20.0	0.6	0.0	1.6	19.8	0.7
7/9/01	RemMSP	13.0	60.0	0.5	0.7	0.6	61.9	3.4
		7.9	14.9	0.5	1.4	0.8	15.6	1.0
7/9/01	RemNat	43.8	21.1	0.0	0.1	1.9	23.1	3.0
		12.4	6.3	0.0	0.2	2.1	6.3	0.6
8/2/01	Contr	43.7	40.0	0.1	2.6	3.7	46.4	3.6
		17.8	19.4	0.1	3.3	5.9	19.6	0.8
8/2/01	RemAll	18.5	43.4	0.4	0.4	2.0	46.3	3.2
		11.9	11.4	0.6	0.6	2.6	11.3	0.4
8/2/01	RemMSP	17.1	71.1	0.5	1.4	0.8	73.8	3.2
		10.8	13.2	0.6	2.2	1.3	14.5	1.2
8/2/01	RemNat	49.0	31.8	0.7	0.3	5.5	38.3	3.6
		16.0	13.5	1.0	0.3	5.5	13.8	1.0
9/21/01	Contr	44.0	34.3	0.0	4.5	10.4	49.1	3.0
		11.1	5.3	0.0	7.0	11.5	9.6	0.0
9/21/01	RemAll	20.1	54.8	0.3	0.8	6.6	62.4	2.8
		16.8	16.1	0.5	1.5	8.6	12.7	0.4
9/21/01	RemMSP	20.0	65.5	0.8	1.6	7.5	75.4	3.2
		6.6	18.6	1.5	2.4	11.2	15.5	1.2
9/21/01	RemNat	63.4	31.1	0.0	0.0	4.6	35.8	2.6
		14.4	15.6	0.0	0.0	3.9	14.4	0.5
7/22/02	Contr	11.6	24.6	0.0	0.0	0.4	25.0	2.2
		5.6	16.8	0.0	0.0	0.8	17.1	0.4
7/22/02	RemAll	17.3	56.2	0.0	0.0	3.0	59.2	2.6
		10.3	22.1	0.0	0.0	5.4	22.0	0.5
7/22/02	RemMSP	16.1	44.2	0.0	0.0	1.1	45.4	2.4
		6.4	24.7	0.0	0.0	1.7	25.0	0.5
7/22/02	RemNat	14.9	15.2	0.0	0.0	5.4	20.6	2.4
		9.1	10.7	0.0	0.0	6.7	12.0	0.5
9/4/02	Contr	38.5	36.6	0.3	0.0	0.5	37.4	2.6
		22.8	20.1	0.5	0.0	0.6	20.7	0.8
9/4/02	RemAll	20.6	49.8	0.0	0.0	1.9	51.6	2.2
		5.9	28.3	0.0	0.0	3.8	28.5	0.4
9/4/02	RemMSP	33.5	43.5	0.1	0.0	2.5	46.1	2.6
		17.4	17.4	0.3	0.0	3.3	18.1	0.8
9/4/02	RemNat	42.4	16.5	0.5	0.0	2.0	19.0	2.8
		31.9	22.0	1.0	0.0	2.6	25.3	0.7

In June 2002 biomass was lower at all plots than in June 2001, probably due to weather. However, MSP had recovered in the Remove-All and Remove-MSP plots (Table 18). To examine the longer-term effects of the manipulation, repeated measures ANOVA (treatments with repeated samples over time) was used to analyze the post manipulation (Sep 2001, June 2002, Sep 2002) data. Univariate results are only reported if the overall response was significant in the repeated measures analysis. Total biomass and MSP biomass both varied significantly by treatment ($p<0.01$), date ($p<0.1$) and the treatment by date interaction ($p<0.1$), however, no significant effects were found for coontail, non-MSP biomass, percentage milfoil or number of species. No significant treatment effects were found for any response variable in June 2002 but in September, MSP remained low in the Remove-All plots (Tukey's HSD, $p <0.05$). Although the mean number of non-MSP species declined throughout the experiment ($p<0.05$) there was no treatment effect or treatment by time interaction for number of species. Eurasian watermilfoil maintained its dominance in the Control and recovered in the Remove-MSP plots. Surprisingly, it did not increase its dominance in the Remove-Native and Remove-All plots; milfoil biomass was significantly lower than the Control at these plots in September 2002 (Tukey's HSD, both $p < 0.1$).

In September 2002 total biomass and MSP biomass were significantly related to pore water NH_4 (lower due to use), but there were no significant differences in exchangeable N with treatment and neither pore water or exchangeable N were significant covariates.

In this low clarity system, dominated by Eurasian watermilfoil and coontail, milfoil recovered from removal within a year and plants other than coontail failed to increase where Eurasian watermilfoil was reduced. This was not entirely due to a total lack of propagules, as *Stuckenia pectinata*, *Potamogeton zosteriformis* and *Nymphaea* were found at low levels in many plots, but clearly, environmental conditions, Eurasian watermilfoil and coontail prevented them from establishing significant populations after removal of some or all plants.

Otter Lake had a much more diverse plant community (Table 20) with 3 to 6 species (2-4 nonMSP species) per sample commonly collected. Coontail, although common, was typically < 15% of total plant biomass. Analysis of the pre-manipulation biomass indicated no differences associated with treatment plots (all $p> 0.1$). Date was a more significant factor in Otter Lake; total plant biomass declined significantly from June to September 2001 ($p < 0.001$) and this was primarily due to a significant decline in Eurasian watermilfoil from over 36 g/m^2 to less than 1 g/m^2 in September 2001. Non-Eurasian watermilfoil biomass also decreased significantly after our removal treatments, however, no significant differences in plant biomass due to treatment were found in 2001 with the exception of a significant increase in *Potamogeton richardsonii* in the Remove-MSP plots (Tukey's HSD, $p < 0.05$). The decline in milfoil was likely due to herbivore damage. In June 2001, weevil densities averaged $0.5/m^2$ and *Acentria* and *Parapoynx* averaged 1.5 and $1.25/m^2$ respectively, but by September *Acentria* and *Parapoynx* increased to 2.75 and $33/m^2$, It should be noted that the removal plots were distant from our regular transect sites and illustrate the lake-wide decline of Eurasian watermilfoil associated with herbivore damage. The percent contribution of Eurasian watermilfoil decreased and the percent coontail increased from June to September and the mean number of species also decreased over time (all $p < 0.05$), but no significant treatment effects were found for these variables. No significant differences among treatments in sediment nitrogen (pore water or exchangeable N), bulk density or percent organic matter were found for the September 2001 sediment cores.

Table 20. Mean biomass ± 2SE (g dry/m^2) of all plants (Total), Eurasian watermilfoil (MSP), all other plants (NAT) and the most common plants (coontail (CRT), *Elodea* (ELD), *Najas* (NAJ), flatstem pondweed (PZS), sago pondweed (PEC), *Potamogeton richardsonii* and *praelongus* (PRI) and *Chara* (CHA)) by treatment for the plant community manipulation at Otter Lake 2001-2003. The percent of total plant biomass composed by MSP and CRT along with the mean number of non-MSP species per sample (Spec) are also given. Treatments were: No removal (Contr), Remove all plants (Remall), remove Eurasian watermilfoil (RemMSP) and remove all plants except MSP (RemNat). Plant manipulations occurred just after the initial sampling in June 2001. n = 5 plots per treatment.

Treat	Total	MSP	CRT	ELD	PZS	NAJ	PEC	PRI	CHA	NAT	%Spic	%CRT	Spec
6/7/01													
Contr	144.2	43.2	24.5	34.2	14.3	2.2	0.0	5.3	20.5	97.5	36.9%	13.3%	4.8
	60.6	39.9	31.8	30.0	14.8	3.2	0.0	3.4	25.6	90.5	32.3%	10.3%	0.2
Remall	114.7	37.3	10.1	18.3	11.2	35.9	0.0	1.9	0.1	77.4	41.7%	8.1%	3.8
	74.1	22.5	8.4	25.7	11.8	55.2	0.0	2.4	0.1	71.8	29.1%	4.2%	1.1
RemMSP	114.2	36.4	18.8	32.7	21.7	3.1	0.0	0.0	1.5	77.8	40.8%	14.2%	3.8
	55.4	32.0	15.7	42.9	14.2	5.7	0.0	0.0	2.5	71.7	32.1%	7.8%	0.7
RemNat	192.7	130.2	13.6	19.6	15.4	1.1	0.0	0.0	12.7	62.5	68.2%	7.9%	4.1
	128.0	120.2	18.4	33.4	19.0	1.1	0.0	0.0	25.1	65.9	25.0%	8.2%	0.2
9/20/01													
Contr	60.4	0.3	12.0	16.2	2.2	13.1	0.7	1.1	11.7	60.1	0.4%	28.0%	3.7
	37.5	0.6	11.3	22.1	2.2	13.5	1.4	2.2	23.4	37.5	0.7%	17.2%	0.7
Remall	15.7	0.3	5.5	5.2	1.7	1.6	0.0	0.4	0.0	15.4	2.0%	25.5%	3.0
	11.9	0.6	6.4	6.4	2.2	2.0	0.0	0.8	0.0	12.0	4.1%	21.0%	0.7
RemMSP	53.6	0.1	14.1	15.0	4.0	13.1	3.5	3.0	0.1	53.5	0.1%	26.8%	3.5
	43.4	0.1	10.2	8.1	2.5	16.1	7.0	5.5	0.2	43.3	0.1%	14.5%	1.6
RemNat	41.3	0.2	2.6	9.9	2.5	14.2	4.3	1.2	3.8	41.1	0.5%	11.5%	3.6
	28.1	0.4	1.7	9.4	3.8	15.7	7.9	1.0	7.6	28.1	1.0%	13.0%	0.9
6/11/02													
Contr	73.9	12.4	3.2	56.3	0.0	0.4	0.0	0.3	1.3	61.5	16.5%	11.7%	1.9
	39.3	17.7	3.3	36.1	0.1	0.8	0.0	0.6	1.7	34.6	19.1%	19.3%	0.8
Remall	121.0	9.6	9.2	45.5	0.0	14.4	0.0	0.0	37.5	111.4	9.8%	5.4%	2.0
	50.9	18.7	18.4	38.0	0.0	28.8	0.0	0.0	20.1	58.5	18.4%	10.7%	0.8
RemMSP	70.1	0.4	17.8	29.6	1.9	18.6	0.0	0.0	1.5	69.7	0.7%	10.7%	2.2
	25.7	0.8	34.1	23.8	3.5	22.8	0.0	0.0	2.3	26.2	1.3%	19.3%	1.0
RemNat	88.7	2.4	2.7	61.5	0.7	9.5	0.0	0.5	9.2	86.3	3.6%	1.7%	2.4
	33.6	2.1	3.3	41.2	0.9	16.6	0.0	1.0	18.4	34.2	3.9%	1.7%	1.0
9/13/02													
Contr	97.9	0.1	4.2	64.4	5.7	4.9	8.1	4.1	6.1	97.8	0.2%	5.5%	4.1
	71.4	0.1	4.3	71.6	8.0	4.3	16.2	7.4	7.5	71.4	0.3%	7.0%	1.0
Remall	68.5	0.1	5.7	27.0	0.3	15.8	0.0	6.8	6.4	68.4	2.3%	12.2%	2.8
	57.3	0.1	7.0	35.3	0.3	31.1	0.0	8.9	11.4	57.3	4.5%	19.4%	0.7
RemMSP	113.9	0.1	8.9	75.4	0.2	24.9	0.2	0.0	0.0	113.8	0.0%	7.3%	3.6
	68.0	0.1	6.8	40.7	0.3	41.3	0.4	0.0	0.0	68.0	0.1%	5.5%	1.2
RemNat	145.1	0.5	0.6	105.3	1.0	18.4	0.0	0.6	14.7	144.6	1.0%	0.3%	4.2
	68.7	1.0	0.5	74.7	2.0	33.6	0.0	1.2	28.7	68.8	2.1%	0.3%	1.1

Table 20 Continued

Treat	Total	MSP	CRT	ELD	PZS	NAJ	PEC	PRI	CHA	NAT	%Spic	%CRT	Spec
6/18/03													
Contr	52.4	9.7	0.0	38.1	0.7	0.0	0.0	0.0	0.2	42.6	18.3%	0.4%	2.6
	44.2	14.2	0.1	49.6	0.8	0.0	0.1	0.0	0.3	48.4	25.0%	0.7%	0.4
Remall	74.1	0.2	0.2	58.5	0.4	0.0	0.0	0.0	13.0	73.0	0.3%	0.5%	2.5
	73.7	0.2	0.4	78.9	0.5	0.0	0.0	0.0	26.0	74.2	0.5%	0.7%	1.3
RemMSP	101.4	0.6	28.9	68.9	2.4	0.0	0.0	0.0	0.6	100.8	0.4%	15.1%	2.7
	77.6	1.0	51.2	31.0	1.2	0.0	0.0	0.0	1.2	76.7	0.5%	19.5%	0.6
RemNat	201.2	0.6	0.4	127.1	0.4	0.0	0.0	0.0	39.1	200.4	0.4%	0.3%	2.1
	103.5	1.0	0.5	110.2	0.4	0.0	0.1	0.0	78.2	103.8	0.6%	0.5%	0.4

Visual estimates of coverage three weeks after manipulations show that milfoil was reduced in the Remove-MSP and Remove-All plots (<2% coverage) and was highest Control and Remove-Native treatments (Table 21; Tukey's HSD, all $p < 0.07$). Native species coverage was highest in the Remove-MSP and Control plots and significantly reduced in the Remove-All treatment (Tukey's HSD, all $p < 0.01$). Repeated measures ANOVA indicated significant treatment effects for Eurasian watermilfoil and significant treatment by date interactions for Eurasian watermilfoil and total native plants (all $p < 0.05$), but not for other taxa or the mean number of species per plot. Most taxa showed significant changes over time. When the last session was dropped (due to loss of 3 replicates), repeated measures ANOVA indicated significant treatment effects for Eurasian watermilfoil, sago pondweed, broad-leafed *Potamogeton*, and total native plants ($p \leq 0.1$) and significant treatment by date interactions for Eurasian watermilfoil and native plants ($p<0.05$). Broad leafed *Potamogetons* (*P. amplifolius, richardsonii, robbinsii, gramineus* and *praelongus*) remained highest in Control plots (Tukey's HSD, all $p < 0.05$), but sago pondweed was more abundant in the Remove-Native plots than Remove-MSP plots (Tukey's HSD), suggesting that it had been suppressed by other native plants. Eurasian watermilfoil coverage was highest in the remove native plots and native plant coverage was lower in Remove-All compared to the Controls and Remove-MSP treatments (Tukey's HSD, all $p < 0.05$). Eurasian watermilfoil remained suppressed in the Remove-All and Remove-MSP plots over time and decreased after early July in the Control and Remove-Native plots (Fig. 8); the suppression was due to herbivore damage. Native plants remained relatively constant in the Control and Remove-MSP plots, but increased in the Remove-All and Remove-Native plots, recovering to premanipulation levels by late 2001 or early 2003. Because Eurasian watermilfoil was already at low density and suppressed by herbivores, no significant increase in native plants was noted in the Remove-MSP treatment relative to the Control. The recovery of native plants in the Remove-All and Remove-Native plots was not due to any single species. *Elodea* and coontail were initially dominant, followed by *Najas*, which became dominant in September 2001 (Table 21). While *Elodea* continued to increase in 2002, coontail and *Najas* decreased. The mean number of species and native species declined over time ($p< 0.001$) in all plots (from 7 in July 2001 to <4 in September 2002), but no significant treatment or treatment by time interactions were found.

As reflected in the visual surveys, Eurasian watermilfoil biomass remained suppressed in all treatments in 2002, again due to suppression by herbivores. Milfoil was apparently too rare to support detectible weevil populations, but low densities of *Acentria* (0.3 ± 0.5 /m^2) and *Parapoynx* (4.3 ± 2.9 /m^2) were found in June, probably associated with native plants. Perhaps because of the low Eurasian density, few significant treatment effects were noted for biomass after the manipulation. Other than a significant decline of Eurasian watermilfoil and percent milfoil between June and September 2002 and a significant increase in total and non-watermilfoil biomass during the same time, the only treatment effect was for *Chara*, due mainly to its abundance in Remove-All plots in June 2002. Repeated measures analyses of all post removal samples (Sep 2001, June 2002, Sep 2002 and June 2003) revealed few significant treatment effects. Coontail was affected by treatment ($p<0.05$); it was higher in Remove-MSP plots. Total biomass, non-MSP biomass and *Chara* showed date by time interactions. Most other measures showed no effects or a significant date effect (MSP, %MSP, *Elodea*, number of species). For example, *Elodea* increased and %CRT decreased throughout the study and the number of native species was higher in September than June samples. Conversely, Eurasian watermilfoil was more abundant in June than in September (perhaps due to summer suppression by herbivores). Native plant biomass had apparently reached an equilibrium prior to the removals and the suppression of Eurasian watermilfoil by milfoil weevils eliminated it as a competitive factor after June 2001.

Analysis of sediment in September 2001 and 2002 showed no overall effects of treatment on sediment (bulk density, %organic, exchangeable N and pore water ammonium), but pore water ammonium was significantly lower in 2002. Analysis of treatment effects on total and native plant biomass in September 2001 and 2002 with sediment nitrogen as a covariate resulted in some significant treatment effects that were not otherwise evident. Pore water ammonium and exchangeable nitrogen were significant covariates (they were significantly correlated, $r=0.64$) and inclusion of either as a covariate resulted in significant treatment effects with total and native plant biomass; with single species, these covariates were not significant and did not result in significant treatment effects for any single species, however. Total and native plant biomass increased with nitrogen and given the nutrient levels, Remove-MSP had higher native biomass and Remove-All had lower biomass given nitrogen levels.

Table 21. Visual estimates (2SE) of plant coverage of Eurasian watermilfoil (MSP), all other plants (NAT) and the most common plants (coontail (CRT), *Elodea* (ELD), *Najas* (NAJ), *Zosterella dubia* (HET), flatstem pondweed (PZS), sago pondweed (PEC; now *Stuckenia pectinata*), Broad leaf Potamogetons (*P. amplifolius*, *richardsonii*, *robbinsii*, *gramineus* and *praelongus* (BroadP)) and *Chara* (CHA)) by treatment for the plant community manipulation at Otter Lake 2001-2002. The mean number of species (NoSpp) and non-MSP species per plot (NatSp) are also given. Treatments were: No removal (Contr), Remove all plants (RemAll), remove Eurasian watermilfoil (RemMSP) and remove all plants except MSP (RemNat). n = 5 plots per treatment.

Treat	MSP	CRT	ELD	PZS	NAJ	HET	PEC	BroadP	CHA	NAT	Nospp	NatSp
7/6/01												
Contr	13.9	16.0	24.3	4.6	8.9	4.1	2.4	6.2	0.0	66.6	8.2	7.2
	9.3	7.0	15.9	2.1	9.5	2.6	2.3	3.1	0.0	17.6	1.7	1.7
RemAll	1.3	3.8	2.4	0.9	2.2	4.8	0.4	0.4	0.0	15.0	6.8	6.2
	2.0	3.3	1.8	0.8	3.3	1.3	0.8	0.2	0.0	5.3	1.2	0.7
RemMSP	1.6	20.4	22.4	7.0	15.8	7.7	0.3	3.3	0.3	77.9	8.0	7.0
	0.8	17.8	14.0	4.2	15.7	6.2	0.5	3.0	0.3	22.5	1.1	1.1
RemNat	23.5	8.7	7.8	4.3	5.6	7.8	0.3	1.4	4.4	41.1	8.4	7.4
	8.4	6.7	7.9	0.4	5.2	3.3	0.5	1.2	5.9	9.7	0.8	0.8
7/25/01												
Contr	2.8	12.1	24.5	9.0	7.6	2.4	1.0	5.9	2.5	65.4	8.6	7.6
	1.2	7.7	19.6	6.9	8.9	1.8	1.7	2.3	3.1	26.1	0.5	0.5
RemAll	1.1	12.3	6.3	4.1	7.4	4.1	1.1	0.8	4.6	41.5	7.6	6.8
	1.5	9.8	5.9	3.1	7.9	3.5	1.2	1.3	8.6	22.0	1.4	1.3
RemMSP	0.4	24.8	17.4	9.1	13.8	2.6	0.5	1.3	2.1	72.2	7.8	7.2
	0.5	23.5	11.3	7.8	15.8	3.8	0.6	1.0	2.5	31.6	1.7	1.3
RemNat	6.7	15.6	11.9	4.2	7.6	5.9	2.2	1.2	7.4	58.8	8.8	7.8
	3.6	13.0	12.9	2.6	5.6	6.3	2.8	1.0	11.6	20.9	2.0	2.0
8/14/01												
Contr	1.8	21.4	13.8	7.4	16.1	0.8	2.3	3.6	0.1	65.9	7.0	6.2
	1.8	14.7	10.8	7.3	18.2	0.8	2.5	2.6	0.3	22.9	2.1	2.0
RemAll	0.5	11.8	7.6	2.3	10.8	2.4	0.8	0.5	0.0	36.5	5.2	4.8
	0.7	10.2	6.6	2.6	13.6	2.9	0.7	0.7	0.0	30.1	2.8	2.6
RemMSP	1.6	21.8	18.4	4.6	18.6	4.2	0.8	0.9	0.0	70.1	7.6	7.0
	1.9	13.3	11.2	5.0	19.7	5.3	0.8	0.6	0.0	21.8	1.6	1.4
RemNat	4.1	19.6	10.3	3.1	17.8	2.2	3.2	0.6	0.0	56.9	6.6	5.6
	2.4	11.7	12.7	3.4	11.1	1.8	1.3	1.1	0.0	14.9	1.0	1.0
9/19/01												
Contr	2.6	18.4	20.8	7.5	25.9	1.8	1.3	4.8	0.0	80.8	7.8	7.0
	2.8	15.8	10.6	5.8	24.3	1.4	1.6	3.5	0.0	23.7	1.9	2.1
RemAll	3.4	5.9	8.9	1.4	34.4	5.9	1.1	2.4	0.0	60.5	6.2	5.4
	3.3	7.5	12.5	1.3	21.5	3.7	1.2	3.0	0.0	29.4	2.1	1.7
RemMSP	0.8	13.8	23.1	8.6	29.3	7.6	0.6	1.0	0.0	84.6	7.0	6.2
	0.6	10.0	14.4	4.9	12.2	13.1	1.3	0.6	0.0	20.3	0.6	0.7
RemNat	9.3	8.0	17.0	3.0	28.5	7.0	5.3	1.3	5.3	77.0	7.6	6.6
	7.0	4.8	14.4	2.3	21.1	2.8	5.6	1.6	10.5	15.8	1.0	1.0
7/23/02												
Contr	3.3	10.3	34.0	3.4	0.0	1.5	5.1	3.7	1.8	65.7	5.6	5.2
	5.9	10.9	17.7	5.3	0.0	3.0	4.4	4.8	3.5	16.6	1.0	1.2
RemAll	2.1	3.1	38.5	3.4	1.0	0.0	5.3	1.4	13.5	70.4	4.8	4.4
	3.9	3.2	35.2	4.1	2.0	0.0	8.2	2.1	17.0	24.0	0.7	1.2
RemMSP	0.8	7.4	45.8	4.0	1.9	0.3	2.0	5.0	4.6	73.8	5.6	5.2
	1.2	8.1	14.3	4.5	3.8	0.5	1.6	9.4	4.8	17.5	0.8	0.4
RemNat	4.0	5.0	51.1	2.8	6.3	2.0	7.9	0.4	0.8	78.0	5.2	4.8
	6.8	8.3	21.1	4.3	12.5	4.0	5.4	0.5	1.0	21.5	1.2	1.2

Table 21. continued

Treat	MSP	CRT	ELD	PZS	NAJ	HET	PEC	BroadP	CHA	NAT	Nospp	NatSp
9/9/02												
Contr	3.3	6.9	35.4	4.4	0.0	0.0	0.2	3.0	16.4	71.5	4.8	4.0
	2.5	7.4	25.8	3.4	0.0	0.0	0.4	4.8	16.8	18.4	0.7	0.9
RemAll	1.0	5.1	24.1	1.3	0.0	0.0	0.0	1.3	26.8	74.8	4.0	3.4
	0.9	3.5	34.6	1.1	0.0	0.0	0.0	1.9	32.3	34.0	0.9	1.0
RemMSP	0.3	6.1	49.6	4.4	0.0	0.1	0.0	1.0	14.8	77.1	4.4	4.2
	0.5	4.8	18.0	4.4	0.0	0.2	0.0	1.7	28.3	22.6	1.9	1.6
RemNat	0.0	2.5	63.8	4.4	0.0	0.0	0.3	1.3	0.6	74.0	1.8	1.8
	0.0	0.0	47.5	8.8	0.0	0.0	0.5	2.5	1.3	52.0	2.2	2.2

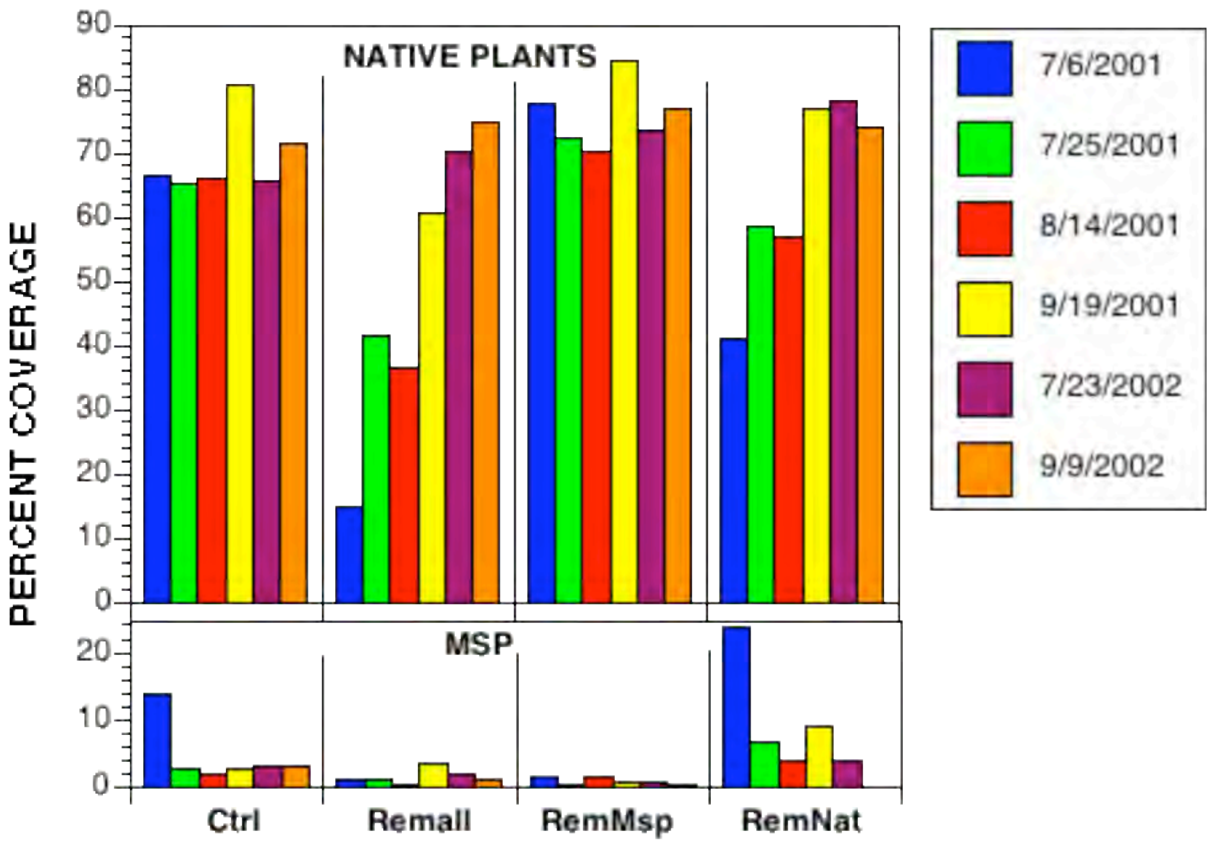

Fig. 8. Visual estimates of coverage of native plants and Eurasian watermilfoil (MSP) in the Otter Lake removal plots.

At Cedar Lake, removal manipulations were initiated in June 2002. Eurasian watermilfoil and coontail were the dominant taxa followed by some *Nymphaea* (Table 22). No differences in response variables were found among treatment plots prior to removal. Removals were successful and reducing total biomass and number of milfoil stems (both $p<0.1$) and milfoil biomass ($p<0.05$) in remove-all and remove-MSP plots (ANOVA of differences) but no reductions in natives were seen in September in the Remove-Native plots. This is probably due to rapid colonization by the unrooted coontail and by new shoots of *Nymphaea* from tubers (plants were pulled with roots but tubers were not removed from the plots). No treatment effects were found for native plant biomass, percentage of milfoil or coontail or number of species. Visual estimates of coverage also showed a reduction of plant coverage with removals (Table 23). Repeated measures ANOVA indicated significant treatment effects on milfoil coverage ($p<0.01$) but no seasonal effect or treatment by date interaction. Interestingly, milfoil coverage was significant lower in Remove-All plots compared to the Control and Remove-Native plots (Tukey's HSD, all $p<0.05$). No significant differences in coontail or number of species due to treatment or session were found.

Repeated measures ANOVAs on biomass confirmed these results; significant treatment effects were found for total biomass and milfoil biomass ($p<0.05$), but no treatment effects were found for native plant biomass, percentage of milfoil or coontail or number of species. Repeated measures analysis with the post-removal data indicated the same response; there were significant treatment effects on milfoil and total biomass but not on the other variables. The number of species did significantly increase from fall 2002. Eurasian watermilfoil was reduced in the Remove-All treatments relative to the Control and Remove-Native treatments however this effect did not continue in 2003; analysis of the July 2003 data revealed no significant treatment effects for milfoil or total biomass (Tukey's HSD, all $p > 0.1$). In Cedar Lake, removal of all plants and milfoil resulted in reductions in milfoil during the first year but by the second year, milfoil had recovered, although less so in the Remove-All plots. Although Eurasian watermilfoil became more abundant in the Remove-Native plots the increase was not significant. It is unclear why coontail and milfoil failed to return to pre-removal levels in the Remove-All plots, however, shading by *Nymphaea* may have been a factor. No differences in sediment (organics, bulk density, pore water ammonium or exchangeable N) among treatments were found but pore water ammonium was about 50% higher in the Remove-All and Remove-Native plots, likely due to less uptake by the fewer plants.

Overall, the manipulations did not reveal dramatic shifts or competitive interactions. Coontail tended to move into the remove milfoil plots but within a year milfoil recovered (in Otter Lake, other native plants such as *Elodea* replaced the coontail). Coontail also rapidly colonized the Remove-All plots, but within a year milfoil again became dominant, with the exception of Otter Lake, where it was controlled by herbivores. Except in Otter Lake, rooted native plants did not show a strong response to milfoil removal. Somewhat surprisingly, milfoil did not respond rapidly in the Remove-All plots; apparently due to its need to develop an extensive root system, milfoil is slow to recover from removal however the lack of a response by rooted natives enabled it to again become dominant a year or more after removal. It is possible that the longer suppression in Remove-All plots compared to Remove-MSP plots was due to a more complete removal of all plants in Remove-All compared to the Remove-MSP plots where we tried not to disturb other plants and may have left more milfoil roots.

Table 22. Mean biomass ± 2SE (g dryt/m^2) of all plants (Total), Eurasian watermilfoil (MSP), all other plants (NAT) and the most common plants (coontail (CRT), and *Nymphaea* (NMP)) by treatment for the plant community manipulation at Cedar Lake 2002-2003. The percent of total plant biomass composed by MSP and CRT along with the mean number of species (Spec) and non-MSP species per sample (NSpec) are also given. Treatments were: No removal (Contr), Remove all plants (Remall), Remove Eurasian watermilfoil (RemMSP) and Remove all plants except MSP (RemNat). Plant manipulations occurred just after the initial sampling in June 2002. n = 5 plots per treatment.

Treat	Total	MSP	CRT	NMP	NAT	%MSP	%CRT	Stems	Spec	NSpec
6/10/02										
Contr	187.1	109.9	70.0	5.3	77.2	58.2%	35.4%	182.0	2.3	1.3
	106.9	78.5	70.4	10.6	67.5	32.7%	25.9%	97.5	0.7	0.7
Remall	201.6	181.5	14.5	5.5	20.2	80.9%	16.2%	207.0	2.1	1.0
	120.0	121.9	17.2	11.0	22.2	17.7%	17.0%	111.4	0.6	0.7
RemMSP	167.9	124.8	37.3	5.8	43.1	78.7%	19.3%	204.0	1.7	0.7
	37.7	55.6	59.3	11.6	56.8	31.7%	32.7%	112.0	0.4	0.4
RemNat	139.0	127.7	11.3	0.0	11.3	93.4%	6.6%	171.0	1.4	0.4
	62.1	50.8	19.7	0.0	19.7	8.5%	8.5%	60.8	0.5	0.5
9/5/02										
Contr	319.9	222.4	97.5	0.0	97.5	76.0%	24.0%	189.0	1.8	0.8
	155.0	86.9	121.6	0.0	121.6	24.2%	24.2%	54.3	0.2	0.2
Remall	95.3	28.8	44.5	22.0	66.5	59.2%	31.4%	44.0	1.7	0.7
	103.1	40.4	65.6	44.0	68.3	33.7%	29.0%	36.2	0.6	0.6
RemMSP	87.7	45.7	38.3	3.7	42.0	73.5%	20.9%	84.0	1.5	0.5
	57.6	29.4	73.6	7.4	72.3	37.0%	37.6%	37.9	0.4	0.4
RemNat	219.2	170.5	30.3	18.4	48.7	82.4%	14.2%	137.0	1.4	0.4
	99.4	114.1	60.6	36.8	97.4	35.2%	28.4%	81.7	0.6	0.6
7/9/03										
Contr	266.2	223.9	35.1	5.4	42.0	64.3%	26.3%	156.3	2.0	1.0
	168.8	201.5	54.2	10.8	52.3	41.5%	37.9%	130.9	0.6	0.6
Remall	140.3	96.2	6.2	37.0	44.2	52.5%	19.7%	81.7	2.2	1.3
	166.5	185.8	8.0	74.0	67.7	40.5%	18.8%	133.5	0.9	0.7
RemMSP	278.0	205.4	54.8	16.8	72.6	68.7%	27.4%	78.0	2.0	1.0
	168.4	200.1	88.1	33.6	84.9	34.0%	36.1%	48.6	0.3	0.3
RemNat	309.4	277.6	31.7	0.0	31.8	81.9%	18.1%	152.0	1.8	0.8
	141.6	171.6	40.1	0.0	40.1	28.2%	28.3%	86.6	0.5	0.5

Table 23. Visual estimates (2SE) of plant coverage (%) of Eurasian watermilfoil (MSP), and the most common plants (coontail (CRT), *Potamogeton crispus* (PCR), sago pondweed (PEC; now *Stuckenia pectinata*),and *Nymphaea* (NMP)) by treatment for the plant community manipulation at Cedar Lake 2002. The mean number of species per plot (NoSp) is also given. Treatments were: No removal (Contr), Remove all plants (RemAll), remove Eurasian watermilfoil (RemMSP) and remove all plants except MSP (RemNat). n = 5 plots per treatment.

Date	Treatment	MSP	CRT	PCR	PEC	NMP	NoSp
6/28/02	Contr	47.3	5.6	0.4	0.0	5.5	2.2
		27.6	10.6	0.8	0.0	8.2	1.0
6/28/02	RemAll	16.3	2.9	0.5	0.0	0.3	1.6
		26.4	4.6	1.0	0.0	0.5	1.0
6/28/02	RemMSP	26.5	1.9	0.6	0.0	1.3	2.2
		22.6	1.7	1.3	0.0	2.5	0.4
6/28/02	RemNat	43.0	0.4	0.6	0.0	0.4	1.8
		28.0	0.8	1.3	0.0	0.7	1.2
7/29/02	Contr	39.9	11.9	0.0	1.0	4.5	2.0
		31.6	22.8	0.0	2.0	5.5	0.6
7/29/02	RemAll	6.7	1.3	0.0	0.0	0.6	1.8
		2.7	1.4	0.0	0.0	1.1	0.7
7/29/02	RemMSP	15.2	19.3	0.0	0.0	0.8	1.6
		19.7	36.0	0.0	0.0	1.6	1.0
7/29/02	RemNat	58.3	12.5	0.0	0.0	2.0	1.4
		34.5	25.0	0.0	0.0	4.0	0.8
8/9/02	Contr	58.8	12.9	0.0	0.0	6.9	2.2
		26.8	10.5	0.0	0.0	13.8	1.0
8/9/02	RemAll	4.6	1.6	0.0	0.0	1.3	2.0
		2.6	1.5	0.0	0.0	2.5	0.6
8/9/02	RemMSP	32.4	13.3	0.0	0.0	0.8	2.2
		20.4	15.2	0.0	0.0	1.5	0.4
8/9/02	RemNat	67.4	0.1	0.0	0.0	0.0	1.2
		30.9	0.3	0.0	0.0	0.0	0.4

Relationship of plant community to sediment characteristics:

McComas (1999) proposed that sediment nitrogen may be a good predictor of nuisance levels of Eurasian watermilfoil; high nitrogen sites should support dense growths of milfoil while lower nitrogen sites would be more amenable to native plants that are adapted to lower nitrogen levels. At low nitrogen sites, Eurasian watermilfoil should not reach nuisance levels. Recently, McComas (2003) updated his predictions and predicted that nuisance milfoil should occur in sediments with > 6ppm exchangeable ammonia. This prediction was based on a volume basis (mg/cm^3, McComas, personal communication). In 2001 we started measuring exchangeable (KCL extractable ammonium) N from the sediments because pore water ammonium is rapidly influenced by short-term plant uptake and may not reflect longer-term nitrogen availability. We analyzed all the sediment samples from 2001-2003 for exchangeable N and present analyses at three scales. Although our measures based on dry mass (mg N/g dm sediment) are not directly comparable to McComas's, they should provide some basis for testing his hypothesis and an assessment of possible N limitation of milfoil at our sites.

Mean total exchangeable N (mg N/g dry sediment) ranged from ≤ 0.005 (occasions at Cenaiko, Hiawatha and Vadnais) to > 0.1 mg/g (occasions at Otter and Cedar) (Table 24). Almost all individual sample values (95% of 378) were above the threshold of approximately 0.001 mg/g, which is not surprising as all sites have supported nuisance growths of Eurasian watermilfoil. Pore water ammonium typically contributed a small percentage of the total exchangeable N (compare KCL N in mg/kg to total exchangeable N in mg/g). As addressed below, pore water ammonium is more likely affected directly by plant density and uptake and exchangeable N might better reflect longer-term nutrient availability.

Among the lakes Cedar and Otter had high exchangeable N (ca. 0.08 mg/g), Auburn, Isles and Smiths had intermediate levels (ca. 0.05 mg/g) and Calhoun, Cenaiko, Harriet and Hiawatha had low exchangeable N (≤0.02 mg/g). This might explain the relatively low biomass at Hiawatha, however, lakes with low or intermediate levels of exchangeable N (e.g., Harriet, Auburn and Smith’s Bay) often had equal or higher densities of milfoil than Cedar and Otter. Furthermore, the two lakes with clear milfoil declines, Otter and Cenaiko, represent opposite ends of sediment fertility, suggesting that herbivore induced declines are not limited to poor or highly fertile sites.

Table 24. Sediment bulk density (g/mL), % organic matter, pore water NH_4+ (mgN/L), KCL extracted N (ppm, less pore water)) and total exchangeable N (mg N/ g dry sediment) Values are means (2SEs) of typically 9 samples, three shallow, three intermediate and three deep at each site.

Lake	Date	Density	% Organic	NH_4	KCL ext N	Total Exch N
Auburn	6/15/01	0.50	11.23	0.98	72.85	0.0745
		0.18	4.23	0.38	20.81	0.0215
	7/17/01	0.57	25.69	3.72	38.67	0.0448
		0.26	30.49	1.92	17.55	0.0212
	8/29/01	0.47	10.90	5.46	42.99	0.0551
		0.18	3.77	1.11	15.47	0.0227
	6/27/02	0.53	18.83	6.61	47.34	0.0585
		0.12	6.27	3.25	25.97	0.0391
	9/6/02	0.62	19.70	5.14	32.77	0.0332
		0.22	10.41	.	12.67	0.0126
	8/29/03	0.35	11.29	3.71	48.78	0.0570
		0.10	3.49	1.86	16.56	0.0209
Calhoun	6/28/01	0.68	6.02	1.31	24.57	0.0263
		0.31	2.37	1.02	12.67	0.0132
	9/6/01	0.68	7.57	2.96	4.82	0.0121
		0.40	3.22	1.58	2.12	0.0095
	7/26/02	0.74	15.31	6.62	18.30	0.0204
		0.37	14.30	4.33	16.07	0.0155
	8/26/03	0.61	6.15	2.69	9.89	0.0149
		0.27	2.45	1.37	5.74	0.0103
Cenaiko	6/26/01	1.05	3.69	1.45	18.22	0.0206
		0.28	3.66	0.75	19.22	0.0233
	7/30/01	1.27	1.80	2.07	11.83	0.0124
		0.23	0.59	0.65	6.31	0.0068
	8/27/01	1.26	1.70	3.92	4.83	0.0058
		0.21	0.60	2.08	0.89	0.0014
	7/1/02	1.42	5.32	2.39	10.85	0.0115
		0.63	4.23	1.63	7.57	0.0080
	8/27/02	1.51	7.83	2.57	4.76	0.0049
		0.24	2.23	1.41	3.80	0.0038
	7/29/03	1.14	2.35	3.54	12.37	0.0135
		0.39	1.06	1.72	8.07	0.0088
Centerville	8/14/02	1.00	13.49	10.20	8.56	0.0142
		0.61	7.42	.	9.67	.

Table 24 Continued

Lake	Date	Density	% Organic	NH_4	KCL ext N	Total Exch N
Cedar	6/19/01	0.60	22.49	3.83	96.36	0.1188
		0.43	16.81	2.14	88.26	0.1178
	8/30/01	0.45	14.92	2.87	23.79	0.0376
		0.40	5.99	0.74	12.57	0.0189
	7/8/02	0.51	30.67	6.11	49.40	0.0611
		0.28	11.62	2.51	28.67	0.0333
	8/8/03	0.23	26.45	5.08	64.62	0.1008
		0.14	14.17	2.62	29.14	0.0504
Gray's Bay	8/6/01	0.11	26.26	5.97	54.43	0.1015
		0.01	4.60	2.22	9.31	0.0243
Harriet	7/2/01	0.94	7.01	3.59	11.65	0.0154
		0.44	3.56	2.31	6.96	0.0094
	9/12/01	0.78	7.29	2.13	12.89	0.0177
		0.44	3.65	1.21	9.06	0.0109
	7/18/02	1.23	6.08	3.28	11.77	0.0136
		0.44	1.08	1.64	16.44	0.0184
	6/16/03	0.49	7.99	4.51	16.51	0.0247
		0.25	3.80	1.87	11.48	0.0164
	8/25/03	0.44	10.78	3.62	21.46	0.0333
		0.32	3.66	1.07	13.84	0.0164
Hiawatha	7/18/02	1.57	3.44	3.55	4.43	0.0046
		0.07	1.87	1.80	2.27	0.0024
	9/12/02	1.55	3.10	.	3.92	0.0052
		0.10	1.19	.	2.76	0.0013
	6/27/03	1.37	1.92	1.63	2.87	0.0029
		0.14	1.05	.	0.62	0.0006
	8/28/03	1.45	1.06	.	3.37	0.0034
		0.05	0.57	.	1.00	0.0010
Isles	6/29/01	0.95	16.78	2.55	32.09	0.0377
		0.49	14.10	1.96	24.87	0.0313
	9/7/01	0.53	27.60	3.42	49.24	0.0793
		0.44	15.76	1.38	33.55	0.0516
	7/9/02	0.60	42.14	2.66	15.58	0.0164
		0.66	55.71	2.03	21.12	0.0221
	8/22/03	0.69	22.65	3.74	51.33	0.0718
		0.44	16.03	1.46	46.01	0.0664

Table 24 Continued

Lake	Date	Density	% Organic	NH_4	KCL ext N	Total Exch N
Otter	6/21/01	0.34	25.25	2.55	177.64	0.1928
		0.20	10.83	1.07	100.28	0.1089
Otter	7/18/01	0.36	27.71	3.64	41.15	0.0546
		0.21	9.70	1.38	20.02	0.0236
Otter	8/28/01	0.35	23.05	2.77	63.58	0.0774
		0.19	8.12	1.13	33.27	0.0439
Otter	6/26/02	0.34	19.50	5.86	60.68	0.0674
		0.20	12.14	4.74	33.36	0.0358
Otter	9/5/02	0.70	40.18	6.92	28.00	0.0319
		0.50	14.08	3.31	23.13	0.0225
Otter	9/18/03	0.15	32.79	4.62	37.70	0.0754
		0.06	6.41	0.84	19.29	0.0365
Shady	8/6/01	0.17	20.21	2.05	26.26	0.0377
		0.04	3.98	1.05	13.84	0.0211
Smith's Bay	6/22/01	0.33	12.52	1.93	24.11	0.0336
		0.19	4.47	0.81	12.52	0.0158
	7/24/01	0.38	13.57	2.42	84.26	0.0973
		0.24	5.15	1.37	62.66	0.0679
	8/23/01	0.37	12.93	3.30	16.02	0.0302
		0.24	4.29	1.16	6.67	0.0136
	7/2/02	0.38	29.00	4.41	39.76	0.0521
		0.12	21.49	1.73	18.54	0.0242
	8/8/02	0.62	17.46	3.48	11.15	0.0155
		0.24	10.55	1.06	5.46	0.0073
Vandalis	8/16/02	1.40	7.54	1.24	2.72	0.0028
		0.23	5.81	.	1.35	.

Analysis across lakes suggests that exchangeable N is not explaining differences in seasonal or yearly average milfoil or total plant biomass. Correlations with mean sample date values (plant biomass and sediment characteristics) for the 10 lakes for which we had sediment exchangeable N and biomass (2001-2003) showed no significant correlation of milfoil average biomass with any sediment parameter (pore water ammonium, bulk density, percent organic, or exchangeable N; all $p > 0.1$ except pore water ammonium). Pore water ammonium was positively correlated with milfoil biomass ($r=0.258$, $p=0.099$) and exchangeable nitrogen was negative correlated, which is contrary to predictions. Mean sediment characters were significantly correlated: bulk density was negatively related to percent organic and total exchangeable N (both $r>0.55$) and ammonium and total exchangeable N were positively related to percent organic. Similar results were found with annual averages except there was no relationship of milfoil and pore water ammonium.

Seasonal and annual average milfoil biomass across the lakes we sampled appears not to be driven by differences in sediment. These results could indicate that our sites, which were all selected for the presence of milfoil varied too little in mean sediment or that other factors such as clarity or herbivores were more important in determining average milfoil biomass during 2001-2003.

We therefore compared plant and sediment characteristics at the sample level (generally 9 samples per lake on each date), first within lakes and then among lakes. Correlations were conducted for plant and sediment variables in each lake for all samples on all dates combined. Relationships among the sediment variables were most consistent. Across all lake analyses, KCL extractable N (does not include pore water) was highly correlated (r typically > 0.95) with total exchangeable N (includes pore water), but pore water ammonium was rarely significantly related to exchangeable N and relationships were positive and negative. Furthermore, exchangeable N was consistently negatively related to bulk density (r typically –0.4 to –0.6) and positively related to organic content (0.3 to 0.5). Thus about 10-40% of variation in exchangeable N can be explained by these variables (which are negatively related). However, bulk density and organics and thus exchangeable N are related to depth and distance from shore, due in part to wave action, scouring and deposition.

Thus several consistent relationships emerged, which inform and constrain interpretation of the influence of sediment: 1) exchangeable N is highly positively correlated with sediment organic matter, and negatively correlated with bulk density, 2) there is no consistent relationship with pore water ammonium (which is more immediately affected by plant density), 3) bulk density decreases with depth (or distance from shore) and organic content increases with depth and 4), exchangeable N is typically lower at the shallowest stations (which also have higher bulk density and lower percent organics) compared to deeper stations.

These relationships can be illustrated more formally with an analysis of sample data from Auburn, Cedar, Otter and Smith's Bay 2001-2003; for these lakes and dates we have complete sediment information (including exchangeable N), depths and plant biomass for 9 sampling sites at each lake on each sampling date. Exchangeable N (mg N/g dry sediment) decreases exponentially with increasing bulk density (Fig. 9; ln ExchN = -4.52 – 1.11 lnDensity(mg/ml); $p < 0.001$, $r^2 = 0.599$) and bulk density explains about 60% of the variation in exchangeable N. Bulk density decreases with distance from shore and depth (Fig. 10: lnDensity = -0.67 – 0.74 lnDepth; $p < 0.001$, $r^2 = 0.233$) and thus exchangeable nitrogen increases with depth (ln ExchN = -3.71 + 0.72lnDepth, $p < 0.001$, $r^2 = 0.106$). Although depth only explains about 10% of the variation in exchangeable N, it is a significant factor that should be considered because it will likely also affect species composition and biomass independent of nitrogen.

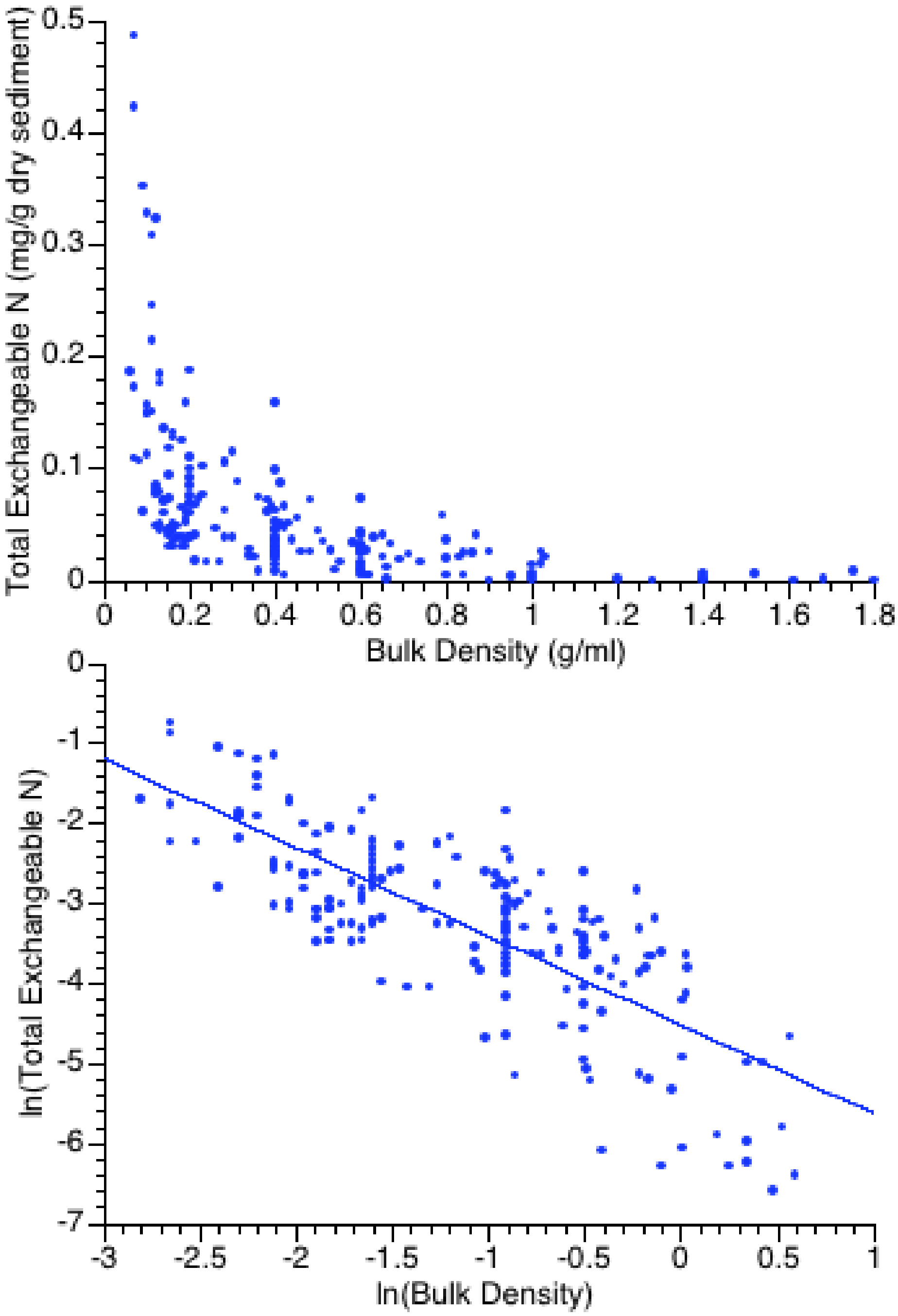

Fig. 9. Relationship of exchangeable N and bulk density from four study lakes. ln ExchN = -4.52 – 1.11 lnDensity(mg/ml); $p < 0.001$, $r^2 = 0.599$

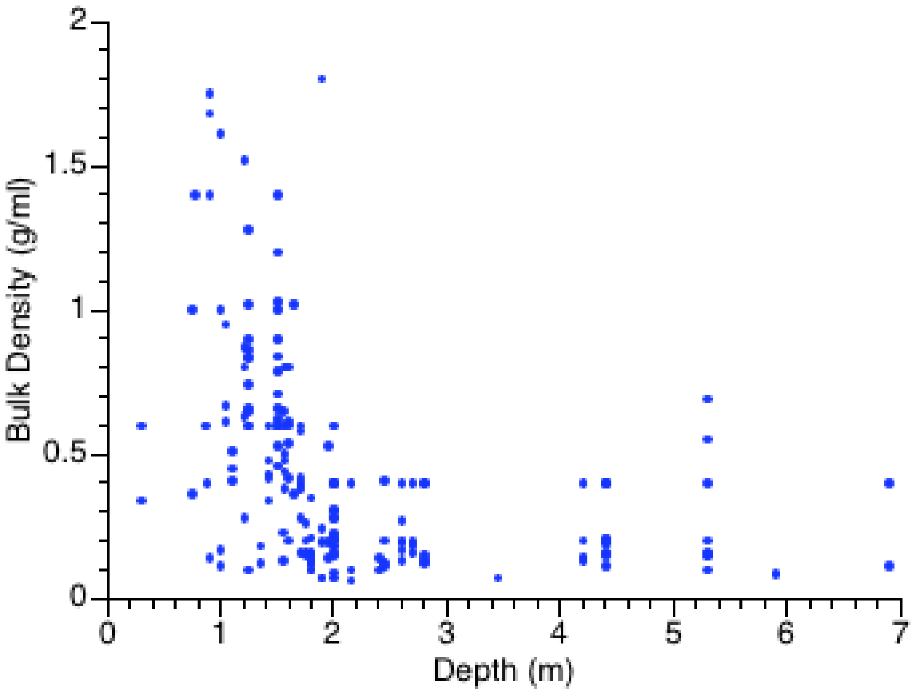

Fig. 10. Bulk density decreases with depth or distance from shore.

Analyses of plant biomass samples collected at the same location as the sediment cores were used to assess the relationship of sediment characteristics to milfoil and native plant biomass. Correlations with the individual samples across the four lakes with depth data (Auburn, Cedar, Otter and Smiths) indicated that milfoil biomass was weakly negatively correlated with bulk density and positively correlated with lnExch N ($p<0.1$) and positively correlated with ln Depth. Milfoil was also negatively correlated with other plants and number of species per sample ($r=-.0237$ and -0.236 respectively, both $p<0.001$). Coontail was also negatively correlated with bulk density, other plants and number of species and positively correlated with depth and total exchangeable nitrogen. Biomass of other plants generally showed the opposite significant relationships (positive correlation with number of species and negative with nitrogen). Pore water ammonium was not correlated with any plant’s biomass.

Correlations with the full data set (9 lakes, 370 samples), confirmed some of the above relationships (significance at $p<0.05$). Milfoil biomass was negatively related to bulk density ($r=-0.194$) and positively related to ln ExchN ($r=0.174$) and was negatively correlated with other plant density ($r=-0.148$). Coontail was positively correlated with ln ExchN ($r=0.104$). However, the correlations were generally weaker indicating much variation among lakes.

Correlations were also performed for each lake. Because there were fewer sampling points for each lake (typically 40-50) few correlations with plant variables were significant (although the general relationships among sediment variables were usually significant). Harriet and Auburn showed significant negative correlation of milfoil biomass and bulk density and a positive correlation with exchangeable nitrogen. Calhoun, in contrast, showed a significant positive correlation of milfoil biomass and bulk density and a non-significant negative relationship with total exchangeable N. It is unclear why the plant-sediment relationship in Calhoun was opposite of most other lakes. One possibility is a steeper depth gradient; the shallow sites that supported high biomass of milfoil may have a higher bulk density and the deeper sites with low biomass (due to depth and light limitation) had a low bulk density.

To determine if high milfoil sites within a lake were associated with high exchangeable N or low bulk density we compared means for sites with milfoil biomass > and < 200 g/m^2, High milfoil sites generally had higher exchangeable N and lower bulk density, but the differences were not significant. At Calhoun and Smiths, bulk density and nitrogen were lower at the high milfoil sites, albeit not significantly. We also compared plant biomass at high and low nitrogen sites (> or < 0.01 mgN/g sediment). These comparisons typically showed greater differences, with higher milfoil biomass in the high nitrogen sites. At four lakes, milfoil biomass in high N sites was double that of low N sites, however, the differences were significant only at Smith’s Bay and Harriet. Calhoun was again the anomaly with higher (but not significant) milfoil biomass in the low nitrogen sites.

If sediment characters are good predictors of high milfoil biomass, then they should distinguish high and low density milfoil in a discriminant function analysis (DFA). A DFA (Systat 5; Wilkinson 1991) was conducted using the above mentioned individual sample values from the four lakes for depth, bulk density, organic content, pore water ammonium and total exchangeable N to distinguish high (>200 g/m^2) from low (<200 g/m^2) density milfoil sites. None of these variables were significant (multivariate p> 0.5, all p > 0.2). Further subdividing milfoil biomass into low (<100 g/m^2) medium (100-200) and high (>200 g/m^2) did not result in a significant model. Thus, sediment values alone are not good predictors of high milfoil biomass. If factors such as herbivore damage or water clarity are affecting milfoil density, it may be low at sediment sites where it has the potential to be high. We therefore decided that it might be best to ask if milfoil and other plant community members can discriminate high and low nitrogen sediment sites. A DFA was conducted using milfoil, coontail and other (all other plants) biomass and number of species per sample to discriminate high nitrogen (>0.01 mgN/g sediment exchangeable N) from low nitrogen (<0.01) sites. Milfoil (p=0.01), coontail (p<0.01) and other plants (p<0.05) were all significant as was the overall model (p =0.001). Milfoil and coontail showed positive relationships with high nitrogen while other plants were negatively related. Furthermore, the model classified 86% of the 29 low nitrogen sites correctly. It fared more poorly predicting high nitrogen sites; 40% of the high nitrogen sites were classified as low nitrogen sites. However, this misclassification makes sense as these sites likely have high sediment potential but other factors such as herbivores or water clarity reduced milfoil density.

These results suggest that sediment nutrient availability, as reflected in exchangeable N or bulk density do influence milfoil biomass, but at least at the range of values considered in our study lakes, the ability to predict high and low biomass is not strong. Calhoun is a particularly interesting exception, where milfoil biomass on low N sediment (mean of 0.005mg/g) was higher than high N sediment and much higher than milfoil biomass at high N sites in Smith’s Bay.

Overall, we found weak support for McComas’s hypothesis that exchangeable N can distinguish low milfoil potential sites for high milfoil potential sites. Several confounding factors need to be considered in further analyses. First, if weevils are controlling milfoil then the nuisance milfoil may not exist where it otherwise would. For example, McComas (pers.

com.) determined that nuisance milfoil should occur in most of Otter Lake but did not in 2002, likely due to weevil impacts. Second, shallower sites generally have lower exchangeable N, related to less organics and higher bulk density at these higher energy sites. These shallow sites also tend to have more species and greater abundance of native plants. It is unclear how much of this difference is due to depth vs sediment. Bulk density may be an easier to measure predictor but it also is confounded with depth. Comparisons across similar depths would be most appropriate.

Synthesis:

Four declines of Eurasian watermilfoil in Minnesota appear related to herbivory by biological control agents. Two declines were lake-wide and persisted for 3 or more years. The decline in Cenaiko Lake followed high densities of the milfoil weevil and Eurasian watermilfoil was suppressed for 7 years (<20% of total plant biomass). Native plants became abundant after the decline and a fairly diverse community persisted. Densities of herbivores decreased at Cenaiko after 2001 and by 2003 Eurasian watermilfoil exceeded pre-decline levels and composed 70% of total plant biomass. A decline in Otter Lake was also associated with high densities of the milfoil weevil; milfoil declined from over 350 g dm/m^2 or 80% of total plant biomass in June 2000 to < 10% of plant biomass in 2001 and 26% of plant biomass in 2002. Milfoil increased to 40% of plant biomass in 2003 and it is unclear if the decline will persist. At both lakes, summer average weevil densities exceeded 0.1/stem during and after the decline and often exceeded 0.25/stem.

Milfoil weevils may have suppressed Eurasian watermilfoil at Lake Auburn during several declines. The declines did not persist and macrophytes other than coontail did not become abundant. Milfoil weevils did suppress Eurasian watermilfoil at the shallowest stations in Smith's Bay of Lake Minnetonka; at the shallowest station Eurasian watermilfoil was reduced to <10% of biomass for 8 years and typically <30% of plant biomass at the shallowest two stations (≤ 2.1 m) during this time. Weevil densities at these stations generally exceeded 0.1 per stem and averaged 0.2 per stem over the 8 years. Weevil densities were much lower at deeper stations and did not influence milfoil density.

No declines associated with herbivores were noted at the other lakes we studied. Milfoil remained very dense during the entire 10 yr study period at Cedar Lake and the 5-year study period at Lake Harriet. Weevil and caterpillar densities were quite low at these lakes and although weevils were stocked into both lakes on several occasions, herbivore densities never increased.

Experiments in aquaria, tanks and field mesocosms indicate that milfoil weevils can effectively control Eurasian watermilfoil under controlled conditions; furthermore, numerous field declines of Eurasian watermilfoil have been associated with high densities of milfoil weevils (reviewed by Newman 2004). Our observations and work from elsewhere indicates that milfoil weevils can control Eurasian watermilfoil when adequate weevil densities are reached and sustained. However, in many lakes, weevils do not reach adequate densities or their densities do not persist through the summer over several years to sustain control.

A variety of factors could limit milfoil weevil populations. Work in Minnesota with relatively undeveloped lakes suggests that overwinter conditions are not a major limiting factor (Newman et al. 2001). Low densities of weevils and disappearance of weevils during the summer indicates that in-lake factors are more important at our study sites. Shoreline overwinter habitat may be limiting at some sites and more assessment of shoreline habitat is needed. Jester et al. (2000) and Tamayo (2003) found that weevil densities were higher in lakes and areas with less undisturbed shoreline and high levels of development or winter shoreline flooding may limit overwinter habitat and survival. Parasites and pathogens also do not appear to be important (Newman et al. 2001), although more investigation is warranted.

Predation by fish, particularly sunfish, does appear to be an important limiting factor. Sutter and Newman (1997) showed that sunfish prey on milfoil weevils (primarily adults) and a high density of sunfish could theoretically limit weevil populations. Ward (2002) showed that adult (female) longevity is critical to developing high weevil populations. Because the milfoil weevil is iteroparous (and can live for several months), laying several eggs per day, female egg laying longevity is very important; doubling female egg laying longevity from 3 to 6 days can result in an 8-fold increase in late summer weevil populations. Fish predation on adults would reduce female longevity and can therefore have a large effect on end of summer population density.

Stocking and cage experiments at Cedar and Otter Lake indicate that sunfish can reduce herbivore establishment and density (Newman et al. 2002, Ward 2002). Our surveys of weevil density compared to sunfish density further indicate that sunfish are limiting weevil densities in many of our lakes. Over 70% of variation in adult weevil density was explained by sunfish trapnet catch and total weevil density appears to respond to a threshold of sunfish density. At sunfish densities < 30/trapnet weevil densities have a high probability of exceeding 0.3/stem (adequate to control milfoil) but at greater sunfish densities, weevil densities are <0.1 per stem. Sunfish > 6cm (age II or older) can prey on adult weevils (Ward 2002) and it is likely that abundant small sunfish that use vegetation are the major source of mortality. Both sustained declines in Minnesota occurred with low sunfish populations and the decline of weevils and loss of milfoil control at Cenaiko when sunfish increased to 25/trapnet further indicates that low sunfish densities may be required for successful control.

Work from elsewhere is also indicating that fish predation may be an important limiting factor. In New York, Lord and Johnson (see Lord 2003) have shown that sunfish may be limiting *Acentria* and weevil populations. Parsons et al. (2003 and J. Parsons, personal communication) also have evidence that sunfish are limiting weevil populations and ability to control milfoil in Washington state. Furthermore, the oft-cited weevil induced decline at McCullom Lake, IL (see Creed 1998) occurred the summer following a rotenone treatment that eliminated all fish (R.L. Kirchner, personal communication). Brownington Pond, the site of one of the best-documented declines caused by the milfoil weevil (Creed and Sheldon 1995, Sheldon and Creed 1995), lacks sunfish, and perch, which are present, do not appear to consume milfoil weevils. Thus an increasing body of evidence suggests that high sunfish populations will limit control agents including the milfoil weevil.

The distribution of milfoil weevils within lakes also suggests that fish predation may be important. Weevils appear to do better in large shallow expanses of milfoil rather than steeper areas that may provide better access by fish (Newman 2004). Tamayo et al. (2000) and Jester et al. (2000) found higher densities of weevils in shallow sites and Lillie (2000) found highest densities of weevils in shallow and moderate depths and much lower densities at the deep edges. In Minnesota we also find the highest densities of weevils at shallow to moderate depths (<3m; see above and Newman et al. 2002). Johnson et al. (2000) found weevil densities negatively correlated with lake depth and suggested weevils do better in shallow lakes. These relationships do not appear to be related to distance from shore (Jester et al. 2000, Newman 2004) but are more likely related to depth. Deeper plants likely allow more ready access to predation by fish and wave action might also limit weevils by disrupting adults or breaking plant parts inhabited by larvae or pupae.

There may, however, be a negative feedback of high plant density in shallow sites. High plant density may favor development of large populations of small sunfish (e.g., Olson et al. 1998), which could then limit milfoil herbivore populations, promoting denser plants, and more abundant small sunfish. Once an abundant population of small sunfish develops, it may be difficult to shift the sunfish population and develop significant herbivore populations.

Stocking or augmenting weevils will likely be ineffective in lakes with high sunfish densities. Previous open augmentations in Cedar and Isles in 1996 proved to be ineffective (Newman et al. 1997b) and did not establish weevil populations. Stocking into cages at Cedar Lake did establish populations within sunfish exclusion cages, but despite the stocking of several thousand weevils into open and closed cages at Cedar each year from 1998-2001, a viable weevil population has not developed at Cedar Lake. Stocking of higher densities of weevils in open plots at Lake Harriet in 2002 and 2003 may have resulted in establishment of a weevil population, however, by end of summer the densities were very low and the population was too low (0.04/stem summer average in 2003) to have any effect on milfoil. All of these lakes have high sunfish densities (>100/trapnet).

Weevil stocking may have been more successful in Hiawatha, a low sunfish (11/trapnet) lake, however, weevil densities were not adequate to cause an obvious milfoil decline at Hiawatha. Weevils did overwinter at Hiawatha and in 2003 the summer mean density was 0.12/stem. Additional monitoring should be done to determine if weevil populations will increase at Hiawatha. It is possible that several years may be required to develop populations adequate for control, however, population modeling suggests that populations should develop quickly if female survival is high (Ward 2002).

Biocontrol of milfoil will likely be effective only in lakes with low sunfish density and because milfoil weevils and other herbivores (*Acentria* and *Parapoynx*) appear widespread, natural populations may develop in these lakes, obviating the need for stocking. Sunfish populations do appear variable (e.g., Cenaiko Lake, Shroyer et al. 2003) and stocking or augmentation might be viable in situations where sunfish have been controlled or are not present.

Reducing overabundant sunfish populations should be explored as one approach to enhance control; in addition to enhancing milfoil biocontrol, better size structured (i.e., low density of large fish) sunfish populations are desired by fisheries manager (e.g., Cross et al. 1992, Olson et al. 1998, Jacobson *in press*). Reducing overabundant sunfish is not trivial and enhancing predators (e.g. Shroyer et al. 2003) or manipulating macrophytes (e.g., Cross et al. 1992, Olson et al. 1998) alone is likely to not be successful and angling restrictions on sunfish may also be required (e.g., Jacobson *in press*). Experimental management to reduce overabundant sunfish populations to enhance herbivores and biological control should be considered. It is likely that a combination of sunfish regulations (reduced creel limits for larger fish), enhancement of predator populations and vegetation manipulation (e.g., strip cutting) might be required to shift sunfish populations to a less abundant and more balanced size structures. It is interesting to note that the milfoil decline in Fish Lake, WI (Lillie 2000) occurred during an assessment of strip cutting to enhance sunfish and bass populations (Olson et al. 1998, Unmuth et al. 1999), however, it appears that the decline occurred prior to and during the manipulation and that weevil densities declined the year after the strip cutting. The increased edge may have simply increased sunfish access to milfoil weevils and the effects of plant manipulations will need to be carefully considered to achieve the desired results.

A positive native plant response is important to the sustained biological control of invasive weeds (Newman et al. 1998). In the two lakes where declines persisted (Cenaiko and Otter), an array of rooted native plants responded positively and developed substantial biomass. Similarly, at the shallow stations in Smiths Bay, rooted native plants replaced the Eurasian watermilfoil. Conversely, at Lake Auburn, rooted plants did not appreciably increase and coontail remained the dominant native plant. It should be noted that during the last two years of the decline at Cenaiko, rooted plants became less common and coontail was the dominant native plant. Because coontail is not rooted, it may be less able to displace milfoil, however, it may also be better adapted to coexist with milfoil. In many of the lakes with high milfoil biomass, coontail is the second most abundant plant. The general lack of negative correlations between coontail and milfoil, despite their being the dominant plants in most of the study lakes, suggests they are readily able to coexist and there may be some yet undetermined facilitation between these plants.

Our removal experiments shed some light on these interactions but suggest that a positive rooted plant response may not be expected in milfoil-coontail dominated systems. In the lower water clarity, milfoil-coontail community at Lake Auburn, coontail quickly filled in when milfoil was removed but was eventually replaced by milfoil. Milfoil maintained dominance in the controls or when native plants were removed but rooted native plants did not respond positively when milfoil or all plants were removed. A similar response was seen in the higher clarity milfoil-coontail community at Cedar Lake. Coontail was able to colonize removal plots within the first season, but by the second year milfoil returned to pre-removal levels and rooted natives did not respond. It does not appear that clarity alone was inhibiting the colonization by rooted plants, although the response to removals at different times of the year may be different. In contrast, at Otter Lake, where herbivory was important during the manipulations, Eurasian watermilfoil was suppressed by herbivores and did not respond to the manipulations. Coontail was able to initially respond to removals but as the summer progressed rooted plants had responded positively and by the second year were dominant. With herbivore pressure and a positive rooted plant response a more desirable community was maintained. Unfortunately in all three experiments, the communities returned relatively quickly to the control situation – either milfoil-coontail or more diverse rooted plants. It is not clear if the failure of rooted plants to respond at Cedar and Auburn was due to lack of propagules or some direct suppression by milfoil or coontail.

Attempts to increase water clarity via alum treatments also did not enhance native plant communities. In the three Minneapolis lakes with successful alum treatments, Eurasian water milfoil maintained or increased its dominance after alum treatments. It is possible that the improvements in clarity were not sufficiently large or sustained for a long enough time to benefit native plants. Alternatively, a milfoil stressor, such as herbivory, may be needed to reduce milfoil's competitive advantage and dominance. The Minneapolis lakes have very high sunfish densities and very low herbivore populations.

It is likely that recovery of rooted native vegetation will be important for successful chemical control as well as biological control. More work to enhance positive native plant response after milfoil control would be very useful.

McComas (1999, 2003) proposed that sediment nitrogen may be a good predictor of nuisance levels of Eurasian watermilfoil; high nitrogen sites (> 6ppm exchangeable N expressed per volume) should support dense growths of milfoil while lower nitrogen sites would not support nuisance levels of milfoil and would be more amenable to native plants that are adapted to lower nitrogen levels. At low nitrogen sites, Eurasian watermilfoil should not reach nuisance levels. We found weak support for McComas’s hypothesis and the confounding effects of depth, bulk density and exchangeable nitrogen should be considered in any analysis. Bulk density decreases with depth and exchangeable N is negatively correlated with bulk density; thus shallow sites tend to have lower exchangeable N.

Milfoil biomass across lakes was positively correlated with exchangeable N, however the relationship was weak (explains < 4% of variation in milfoil biomass). Sediment characters were not able to discriminate high and low density milfoil sites, likely because other factor such as herbivory and water clarity were more important determinants of low milfoil biomass. Plant biomass was however able to discriminate high (>0.01 mgN/g sediment exchangeable N) from low nitrogen (<0.01 mgN/g) sites and 86% of low nitrogen sites were correctly classified (but many high nitrogen sites were incorrectly classified as low nitrogen). Furthermore, the classification indicated that milfoil and coontail were positively associated with high nitrogen and other plants negatively loaded with high nitrogen, as McComas predicted. Most of our sites have higher nitrogen than the level that might limit milfoil growth and it is unclear if calculating nitrogen on a volume basis rather than a dry mass basis (standard aquatic protocol) would affect the results. Thus sites with low exchangeable N (<0.01 or 0.001 mg N/g) might on average be expected to support lower biomass of milfoil but the predictions are not precise. Biomass at Calhoun on sediments with <0.005 mgN/g occasionally exceeded 200 and in several cases 400 g dm/m^2.

Initially we speculated that poor sediment conditions at Cenaiko Lake may have facilitated the milfoil decline and that higher weevil densities might be required to facilitate declines on more fertile sediments (Newman and Biesboer 2000). The decline at Otter suggests this is not the case as the decline there occurred with lower weevil densities and much “better” sediment (higher organics, lower bulk density and higher exchangeable N). Thus the two lakes with clear milfoil declines, Otter and Cenaiko, represent opposite ends of sediment fertility, suggesting that herbivore induced declines are not limited to poor or highly fertile sites.

In summary, the milfoil weevil can cause sustained declines of Eurasian watermilfoil if sufficient densities are maintained throughout the summer each year. Sunfish appear to be limiting herbivore densities in many lakes and lakes with high densities of sunfish will likely not support adequate weevil populations to achieve milfoil control. A positive rooted native plant response is also likely required for sustained control and more research into methods to reduce sunfish predation and to enhance native plant response is needed.

<u>Conclusions</u>

- Sustained milfoil declines associated with the milfoil weevil occurred in two lakes. The decline at Cenaiko Lake persisted for 7 years and at Otter Lake for three years. Milfoil was also suppressed for more than 7 years at the shallowest (≤2m) sites at Smith’s Bay of Lake Minnetonka, but not at deeper sites. Limited and variable control was seen at Lake Auburn.

- Adequate weevil densities that persist throughout the summer are required for sustained milfoil declines. Lakes with low densities of weevils (<0.1 per stem) showed no evidence of herbivore induced declines during the 5-10 years of study (Cedar, Isles, Calhoun, Harriet).

- Weevil densities appear limited by sunfish predation. Lakes with persistent declines had low densities of sunfish and when sunfish densities increased at Cenaiko Lake to 25/trapnet, the weevil population was greatly reduced.

- Comparison of milfoil weevil densities in 11 lakes with sunfish densities determined by DNR Fisheries assessments shows that weevil density declines significantly with increasing sunfish density. Sunfish densities greater than 25-30 per trapnet may severely limit weevil populations and their ability to control Eurasian watermilfoil. These results confirm that fish predation is an important limiting factor in Minnesota lakes.

- Augmentation or stocking of weevils into high sunfish density Lake Harriet resulted in establishment of a weevil population but the densities were low and may not persist. Densities of herbivores were too low to have a significant effect on milfoil biomass. Stocking weevils into a low fish density lake (Hiawatha) resulted in establishment of weevils and the population appeared to be increasing after the second year of stocking. Weevil populations, however, did not build to high densities predicted by modeling. A significant decline of milfoil due to herbivores was not found, but herbivores may have limited the expansion of milfoil at Hiawatha. Future stocking or augmentation should not be conducted in high sunfish density lakes.

- Plant community manipulation experiments in high and low clarity milfoil-coontail lakes showed that coontail can colonize quickly when all plants or milfoil are removed but within a year milfoil will return to dominance. Rooted plants did not become abundant and milfoil and coontail remain dominant where not controlled by the milfoil weevil. At sites where milfoil is controlled by herbivores, coontail can initially be successful but rooted plants can dominate over the summer and in following years. More work on reestablishing rooted plants communities after control of Eurasian watermilfoil is needed.

- There is some support for McComas’s hypothesis that native plants will do better on low nitrogen sites and milfoil biomass will not reach nuisance levels on low nitrogen sites but milfoil will reach nuisance levels on high nitrogen sites. If milfoil is controlled by factors other than sediment, such as herbivory or water clarity, it will not reach nuisance levels. High levels of milfoil biomass appear less common on low nitrogen sediments and low and high nitrogen sediments can be discriminated by milfoil and native plant biomass but exceptions were found.

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Appendix I. Key to plant abbreviations used in this report.

CHA	*Chara* spp. (muskgrass)
CRT	*Ceratophyllum demersum* (coontail)
ELD	*Elodea canadensis* (Canada waterweed)
HET	*Heteranthera dubia* (mud plantain) = *Zosterella dubia* (ZOS)
LMR	*Lemna minor* (lesser duckweed)
LTR	*Lemna trisulca* (star duckweed)
MGD	*Megalodonta beckii* (water marigold)
MSI	*Myriophyllum sibiricum* (northern watermilfoil)
MSP	*Myriophyllum spicatum* (Eurasian watermilfoil)
NAJ	*Najas* spp.
NMP	*Nymphaea* spp.
NUP	*Nuphar* spp.
PAM	*Potamogeton amplifolius* (largeleaf pondweed)
PBE	*Potamogeton berchtoldi* (Berchtolds' pondweed)
PCR	*Potamogeton crispus* (curled pondweed)
PDI	*Potamogeton diversifolius*
PEC	*Potamogeton pectinatus* (sage pondweed) (now *Stuckenia pectinata*)
PFO	*Potamogeton foliosus* (leafy pondweed)
PGR	*Potamogeton gramineus* (variable pondweed)
PIL	*Potamogeton illinoensis* (Illinois pondweed)
PNA	*Potamogeton natans*(floating leaf pondweed)
PNO	*Potamogeton nodosus* (river pondweed)
PRI	*Potamogeton richardsonii* (claspingleaf pondweed)
PRO	*Potamogeton robbinsii* (Robins' pondweed)
PSP	*Potamogeton spirillus* (snailedseed pondweed)
PZS	*Potamogeton zosteriformis* (flatstem pondweed)
RAN	*Ranunculus* spp. (white water buttercup)
SPO	*Spirodela polyrhiza* (greater duckweed)
VAL	*Vallisneria americana* (wild celery)
UTV	*Utricularia vulgaris* (bladderwort)