

Factors Influencing the Control of Eurasian Watermilfoil With Native Or Naturalized Insects

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BY

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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 now occurs in 90 lakes and six streams in Minnesota (Exotics Species Programs 1999).

Recently, interest has increased in potential of native and naturalized invertebrates as biological controls of Eurasian watermilfoil. Declines of the plant have been associated the occurrence of populations of three herbivores: the moth *Acentria ephemerella* (Denis & Schiffermüller) (= *Acentria nivea* (Olivier)) a naturalized Pyralidae, the indigenous midge *Cricotopus myriophylli* Oliver and the indigenous weevil *Euhrychiopsis lecontei* (Dietz) (= *Eubrychiopsis lecontei*). Although all three taxa may have some potential to control milfoil, recent work (Creed and Sheldon 1994a, 1995, Sheldon and Creed 1995, Newman et al. 1996, Sheldon 1997, Creed 1998) suggests that *E. lecontei* is the most promising control agent; it occurs more broadly and in greater abundance than the other taxa in Minnesota and Wisconsin (Newman and Maher 1995, Jester et al. 1997) and is highly specific to watermilfoils (Solarz and Newman 1996). Sheldon and O'Bryan (1996) and Newman et al. (1996, 1997a) describe the life history and development times of the weevil.

Declines of milfoil in several lakes have been correlated with the occurrence of *E. lecontei* (Sheldon and Creed 1995, Lillie 1996, Newman and Biesboer *in press*, Creed 1998). Reductions in individual milfoil plant growth and mass due to *E. lecontei* adults (Creed and Sheldon 1993) and larvae (Creed and Sheldon 1994b) and reductions in plant buoyancy due to weevil feeding (Creed et al. 1992) have been demonstrated in laboratory experiments. In pond enclosures, significant reductions in milfoil growth and biomass due to weevil adults and larvae have been shown (Creed and Sheldon 1995, Sheldon and Creed 1995). Creed et al. (1992) suggested larval stem mining may reduce plant vigor by reducing plant buoyancy and light capture. Stem damage may also inhibit translocation of gases and nutrients, and reductions in carbohydrate translocation to roots in the summer would lower over winter carbohydrate reserves resulting in overwinter declines or reduced growth in the spring (Creed and Sheldon 1995). Increasing weevil abundance resulted in significant reductions of milfoil shoot and root biomass and carbohydrate stocks in experimental tanks (Newman et al. 1996), suggesting that weevil damage may affect plant health and overwinter ability. However, Newman et al. (1996) also suggested that densities of 200-300 weevils per m² may be needed to effect control, levels that have not yet been documented in Minnesota lakes. Fish predation may be one factor limiting populations (Sutter and Newman 1997).

The aim of this project is to monitor a set of milfoil populations for potential declines, determine factors that may be limiting control agent densities and their effectiveness in the field, determine the effects of fish on weevil augmentations and determine if chronic effects such as disruption of milfoil nutrient stores or competition with native plants is responsible for declines of milfoil associated with herbivores. This report summarizes our methods and results during 1997-1998, integrates these results with pertinent prior information, and makes predictions for when and where successful control might be expected and identifies factors that appear to limit control.

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Content:: Field analyses will be completed and included in a report summarizing the results of all objectives. The field results will be integrated with the lab and experimental results, and if feasible, compared to simulation predictions. These results will be presented in a synthetic report which will also attempt to predict when and where successful control might be expected and what circumstances are needed for control. This will be the final report.

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 were 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 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.

At each sampling station, plant biomass and invertebrate samples were taken from 0.1 m² quadrats (all plant material was clipped at sediment interface and immediately placed in a sealable bag underwater). Sediment cores, water samples (for chlorophyll a) and samples of milfoil (for carbohydrate analysis) were also collected at shallow, medium and deep stations along 3 transects (transects 1, 3 and 5 at all but Cenaiko, where 1-3 were sampled) at each site.

A set of water column parameters were 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 in the field. 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 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 ($[\text{AFDM dry mass}^{-1}] \times 100$). Pore water was extracted from the remaining sediment by centrifugation, acidified to < pH 2 and stored in the refrigerator. Within seven days, the NH₄ concentration was determined by selective electrode (APHA, 1989).

The milfoil plants collected for carbohydrate analysis were placed on ice and frozen as soon as they were returned to the laboratory. For analysis, the plants were rapidly thawed to room temperature, separated into roots and into stems with attached leaves, and dried at 100 °C for 90 min followed by several hrs of drying at 70 °C (Raguse and Smith 1965). The plant organs from each sample were pooled into roots, stems and leaves, weighed, and ground in a Wiley mill to pass through a 0.5 mm screen. The ground tissues were collected and dried for one hour at 70 °C to remove any remaining moisture, placed into petri dishes sealed with parafilm, and stored in the freezer until analysis.

Both total nonstructural carbohydrates and total sugars were determined for the root, stem and leaf samples using the methods of Smith (1969) with the following modifications: amyloglucosidase (EC 3.2.1.3 - Sigma Chemical Co., St. Louis, MO) was used to digest starch present in the samples and the 3,5 dinitrosalicylic acid method was used to detect reducing sugars. All analyses were performed in triplicate. Enzyme solution was prepared daily. Sugars were extracted in 80% ethanol. Glucose was used as the standard reducing sugar. Percent starch in samples was calculated by subtraction of percent total sugars from percent total nonstructural carbohydrates.

At least 20 quadrat biomass samples from each site and date in 1997-1998 were processed for invertebrates and plant biomass. 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 then frozen for later dry mass determination. Frozen plants were thawed, dried at 105 °C for 48h and weighed. Plant damage was not recorded in 1998 due to the effort required to obtain a marginally useful response.

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, starting on 8 May 1998. For the first survey, we sampled two transects (2 and 4) and for the remaining surveys we sampled three transects (1, 3 and 5). Along each transect samples were collected from six stations, 10m apart starting at 10m from shore. At each station, five milfoil stems (upper 50 cm of basal stems) were collected and placed in sealable plastic bags. The samples were returned to the lab and within a day were examined under 8X magnification; all weevil life stages (eggs, larvae, pupae and adults) were enumerated. Results were expressed as numbers per stem. We conducted one similar survey in Cenaiko Lake on 9 September 1998. Six samples were collected from each of three transects which ran coincident to our regular transects in Cenaiko Lake. The weevil surveys were conducted by Erik Heinen.

Survey Sites:

To give a broader coverage of sites and to detect possible declines we expanded our sampling to additional waterbodies in 1997 and 1998. These surveys included broader scale (whole lake) surveys at all sites and a combination of whole lake and site specific surveys at 3 sites for which we had prior data from localized areas for previous years. We hope to be able to assess our large scale sampling and the degree to which small scale intensive sampling is

reflective of broader scale effects by comparing the results from the localized sites to the whole lake results for the 3 sites where we have both sets of data.

Three localized sites previously sampled in 1992, 1993, 1995 and 1996 were resampled in 1997 and 1998 for milfoil, invertebrates and site characteristics in mid to late August. The three sites chosen were in 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. Fish Lake (Dane Co., Wisconsin; T9N; R7E; S3), was not sampled due to logistical constraints. At each of these sites, 3 transects were run perpendicular to shore and 3 stations, based on depth (e.g., 2, 3 and 4 m), were sampled along each transect. At each station 0.1m² quadrat samples were taken for plants and invertebrates. Sediment cores and milfoil roots and shoots (for carbohydrate analyses) 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, sediment characteristics and plant carbohydrates.

At these three waterbodies and an additional 6 waterbodies, we conducted whole lake or bay surveys. The six additional waterbodies were: Calhoun (Hennepin Co.; T28-29N; R24W; S4,5,32,33), Harriet (Hennepin Co.; T28N; R24W; S8,9,16,17), Long (Hennepin Co.; T118N; R23W; S26,27,34,35), Minnewashta (Carver Co.; T116N; R23W; S4,5,8,9), Pierson (Carver Co.; T116N; R24W; S21,22,27,28) and St. Alban's Bay (Hennepin Co.; T117N; R23W; S26,35) of Lake Minnetonka. Each lake or bay was sampled once in September-October 1997. In 1998, we sampled 4 of these sites in September; Minnewashta and Long Lake were not sampled. Secchi depth, light, temperature and oxygen profiles, chlorophyll and conductivity were measured in the middle of the waterbody. The extent of surfaced (matted) or visible milfoil was mapped by navigating along the edge of the matted milfoil (contiguous milfoil that reaches the surface and blocks ability to see beneath the surface) around the lake or bay while continuously recording our position with a GPS unit (Trimble Pathfinder Basic Plus). If very little milfoil was matted, this was noted and the extent of visible (seen beneath the surface) milfoil was mapped. At most lakes we mapped visible milfoil because surface matting was not extensive around the entire lake. The extent of matted or visible milfoil coverage (and thus area of nuisance level) was determined by subtracting the area encompassed by the differentially corrected GPS coordinates (calculated by Pathfinder program) from the lake and littoral (DNR 15 ft contour) surface areas.

To quantitatively determine the extent of milfoil coverage, a set of 10-15 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). 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 1m² 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; see Newman et al. 1994 for discussion of this approach). At each sampling point 3 or 4 grapple throws were collected and rated for plant occurrence (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.

Weevil Introduction/Manipulation:

Our aim was to determine the effects of artificial introduction of weevils, *Euhrychiopsis lecontei*, on the density and condition of Eurasian watermilfoil and other macrophytes during a single growing season by introductions of weevils at replicated sites in fish exclosures and open areas. This should allow us to determine if fish predation may be limiting the success of prior introductions to open areas (see Newman et al. 1997b). To exclude fish, 3m X 3m cages were constructed with PVC pipe and fitted with 1/2" bar nylon mesh netting. The netting was attached to 1m high cross supports and was connected to cylinder floats that allowed the netting to extend to the surface from 1m to 2.25m maximum depth; the tops and bottoms of the cages were open. Ten cages were fitted with mesh on all four sides (complete enclosures) and 10 cages were fitted with two mesh panels that each covered 1.5 sides (i.e., a total of 3m or 1/4 of the cage was open); the open cages served as controls by permitting fish entry.

In July 1998 20 sites were located in milfoil beds in the NE bay of Cedar Lake in water 2.2m deep and marked with floats. Two plant biomass samples (0.1m² quadrat) were collected 3m from each float (on opposite sides). These samples were designed to be 1-2 m outside of the cage area to minimize the effects of sampling on the plants in the caged area. One week later, the cages were placed over each float such that the float was in the center of each cage; the frames dropped straight to the bottom and the cylinder floats keep the mesh taut to the surface). Cage bottoms were pushed into the sediment and weighted with bricks. Cages were then electrofished to remove fish trapped within the cages. Cages (open or closed) and treatment (stocked or not stocked with weevils) were assigned to the sites in a stratified random block design. Eighty adult weevils (adults and the apical tips they were collected from, which contained some larvae and eggs), collected from Cenaiko Lake, were stocked into each cage designated to receive weevils (5 closed and 5 open cages). Care was taken to ensure that adults moved onto the live milfoil and the meristems were attached to milfoil plants to ensure that associated larvae and eggs also had access to the live plants.

At approximately biweekly intervals, cages were examined and counts of visible weevils (eggs, larvae, pupae and adults) were made by examining 100 to 150 stems during a 15 min period. Larval occurrence was estimated based on recent stem damage. Any fish observed in the closed cages were enumerated. Additional electrofishing was conducted to remove fish, however we became concerned about the disruption to the plants so angling was used to remove fish. We were not entirely successful at removing fish from some cages and this may have influenced the results.

Three weeks after the initial stocking we added another 50 adults (plus associated meristems) to each stocked cage to further supplement the populations. This resulted in a total stocking of 130 adults per cage or 14 adults per m².

In mid-September, 8 weeks after the initial stocking, three plant biomass samples were taken from each cage, ca 0.75m from the center float in three directions. These samples were processed for plant species, picked of invertebrates, weighed and frozen for later dry mass determination. The samples within each cage (for pre and post stocking samples) were averaged and statistical analyses were performed treating each cage as a true replicate.

Competitive interactions between northern and Eurasian watermilfoil:

We completed an experiment to assess the competitive interactions between Eurasian and northern watermilfoil in 1997. The results of that experiment were published in the Journal of Aquatic Plant Management (Valley and Newman 1998) and will not be reported here.

Influence of milfoil genotype and rearing sediment on weevil performance:

Because previous work indicated that weevils perform better on different milfoil species (Newman et al. 1997a), other studies have shown that plant genotype and nutritional status can affect biocontrol agent performance (Newman et al. 1998), and because we have seen

substantial variation in weevil densities amongst lakes, we conducted an experiment to determine the effects of milfoil genotype (lake source) and milfoil rearing sediment on weevil performance. This experiment was conducted by Ramona Johnson.

The experiment was set up as a 2 sediment by 2 genotype factorial. Milfoil plants and lake sediment were collected from two Minnesota lakes which have contrasting weevil populations; Auburn Lake, Carver Co. and Otter Lake, Ramsey Co. Fifteen cm long cuttings were placed in stock tanks containing either Auburn or Otter sediment, resulting in the two plant genotypes being reared on both lake sediments. The plants were allowed to root and grow for 2 1/2 weeks until they reached ~35 cm. One of eight female weevils, collected from Lake Auburn, was introduced to the meristem of a plant and allowed to oviposit. The egg and plant were then transplanted to a 45 cm tall clear plastic tube containing 5 cm of the original growing sediment. The tubes were placed in a 27 °C environmental chamber (16h daylength, 120 $\mu\text{moles}/\text{m}^2/\text{s}$ at tube tops) and observed daily for weevil development. Development to each stage was recorded based on criteria of Newman et al. (1997a). Newly eclosed weevils were removed and weighed.

Plants and sediment were also analyzed for nutrient content. Individual plants were sectioned into top 20 cm, bottom stem, leaves, and roots and then frozen with liquid nitrogen. The plants were then sent to Dr. David Spencer the Exotic & Invasive Weed Research Unit at UC Davis for analysis of carbon, nitrogen and phenolics. The sediment was analyzed for NH_4^+ , organic content and bulk density with previously described methods.

Effects of plant community on recolonization:

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 16 plots in Otter Lake (good water clarity and healthy native plant community) and 16 plots in Lake Auburn (poor water clarity with community dominated by Eurasian watermilfoil and coontail). Plots were marked with a center float and spaced at least 10 m apart. Biomass was determined in each plot (two 0.1m² samples) and each plot was assigned to one of four treatments: no manipulation, removal of all Eurasian watermilfoil, removal of all native plants or removal of all plants. After initial sampling, the randomly assigned manipulation was applied to the plot by divers using SCUBA who manually removed vegetation with the area delineated by a 2x2 PVC quadrat. Harvested vegetation was not retained but allowed to float away. The plots were resampled for biomass (two 0.1m² samples per plot) five weeks later, at the end of the summer.

Overwinter assessments:

Shoreline surveys: Periodic samples have been taken on several lakes in Minnesota. Spring and fall shoreline soil litter (overwinter) samples were collected at Smith's Bay and Lake Auburn from 1993 - 1999. In fall 1996, Cenaiko Lake was added to our shoreline collection sites, however, it was not sampled in Fall 1997 due to high water; we subsequently have dropped this site due to the low density of weevils and logistical constraints associated with high water. Shoreline soil samples consist of the top 2.5-7.6 cm of soil and leaf litter in a 0.2 m² area area. Samples were returned to the laboratory, dried if needed, sifted through a series of gradually decreasing sieves and examined for the presence of weevil adults. Litter sampling was used to estimate weevil population density, timing when insects move into the terrestrial habitat and when they emerge in the spring to recolonize the aquatic habitat.

In spring 1998 we initiated an experiment to determine when soil emerging weevils that enter the water start to develop and lay eggs.

Weevil development with temperature and initial modelling:

To determine the relationship between weevil development time and temperature, weevils were reared from egg to adult in growth chambers at 8 temperatures: 15, 19, 21, 23, 25, 27, 29 and 31 °C. Development at 5 temperatures was assessed in 1996 and 3 additional

temperatures was assessed in 1997 along with length of stem damaged. Eurasian watermilfoil plants were started in outdoor tanks and allowed to root and grow to a length of ca 35 cm. A female weevil was allowed to oviposit on a plant and the plant was then transferred to an individual acrylic tube (7.5 cm diameter, 45 cm tall) and rooted in lake sediment. The tube was filled with 20 °C well water. The tube was then randomly assigned to a temperature (environmental chamber). Sixteen such tubes were assigned to each chamber in a stratified procedure, to ensure that each female had one egg per temperature and that eggs were started in each chamber at about the same time. Plants were examined within the tubes daily and developmental stage was noted. Hatch was determined when the egg disappeared, followed by subsequent typical stem damage; larvae burrow through the stem as they continue development. Pupation was noted upon formation of a characteristic puparium and adults were captured and weighed as soon as they emerged from the puparium. Damage was determined by measuring the length of stem damaged each day during larval development. Development times were determined for each stage and development rate (1/d) was calculated along with the threshold temperature for development.

Degree days above 10 °C were determined for two lakes (Auburn and Smith's Bay) that were monitored with temperature data loggers (Optic StowAway, Onset Computer, Pocasset, MA) from April or May through October 1996 and 1998. Temperatures were recorded every 0.5 hr at 0.75m depth and the surface. These results were used to estimate number of generations and potential population growth at the field sites. Data logger failure and loss in 1997 resulted in no data prior to June (Auburn) or July (Smith's Bay).

Results and Discussion

Semi-permanent transect sites:

Milfoil biomass in Cedar Lake was similar in 1998 to 1997, but continued to increase, reaching the second highest density we have seen there in September 1998 (Table 1; Fig. 1). The persistent high density was likely due to good summer-long water clarity which likely was associated with Alum treatments and wetland rehabilitation in 1996. Milfoil biomass declined significantly at Lake Auburn, to the lowest values we have seen since 1993 (530 g wet/m² in September). Part of this decline may have been due to poor water clarity, however native plant biomass was as high as previous years (Table 2), weevil damage appeared high in spring and the decline started over the winter of 1997-1998; June milfoil biomass was the lowest recorded at Lake Auburn since 1993.

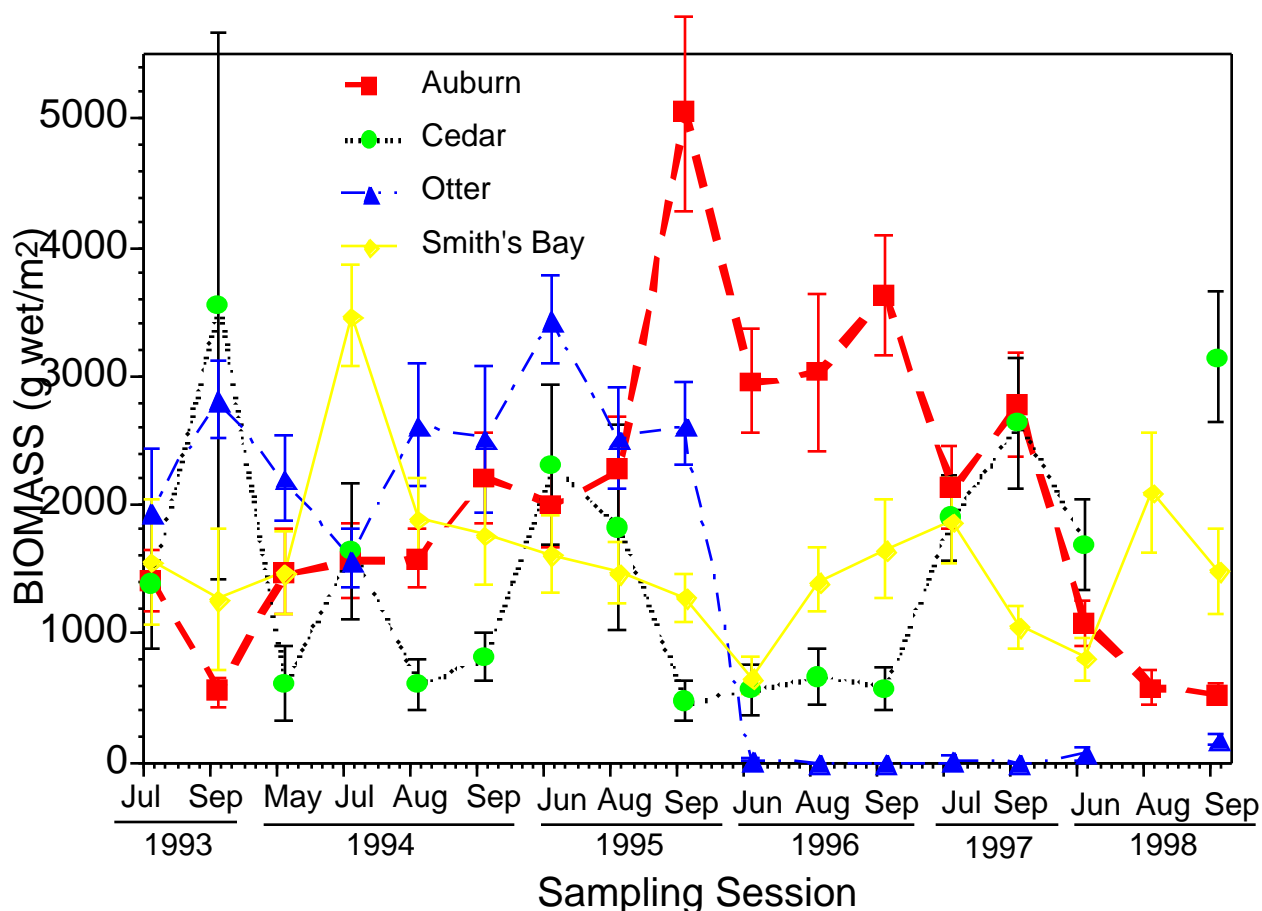


Fig. 1. Milfoil biomass ($\text{g wet/m}^2 \pm 1 \text{ SE}$) from the four field sites from July 1993 through September 1998.

Milfoil in Smith's Bay was low in early summer 1998 but increased to the highest density in several years before completing the summer at $<1500 \text{ g wet/m}^2$ in September, similar to previous years. The high milfoil density was mainly due to a very high density at the deepest two station (3834 g wet/m^2); density at the three shallower stations remained $< 950 \text{ g wet/m}^2$ during the summer. Milfoil increased at Otter Lake in 1998, from 80 g wet/m^2 in June to 181 g wet/m^2 in September. These are the highest densities we have seen since the catastrophic decline in 1996, but Eurasian watermilfoil still remained 20% of total plant biomass (Table 3), well below pre-decline densities. Changes in milfoil biomass at our sites (Fig. 1) are not due to regional changes; there was little concordance among the sites. The only significant correlation for milfoil biomass among sites was a negative relationship between Cedar and Auburn milfoil biomass ($r=-0.59$). Similarly, changes in milfoil biomass were not always in the same direction as other plant species; milfoil biomass was positively correlated with other plant biomass in Cedar Lake ($r=0.52$), but negatively related to other plant biomass in Otter Lake ($r=-0.58$) and no relationship was found for Auburn and Smith's Bay.

Table 1. Biomass \pm 1SE (g wet/m²) of Eurasian watermilfoil at the four sampling sites in 1994-1997. n = number of samples. Dry biomass (g/m² \pm 1SE) is presented for 1995-1998.

Sampling Date	Auburn	n	Cedar	n	Otter	n	Smith's Bay	n
5/19-6/3/94	1474 \pm 326	10	610 \pm 289	18	2208 \pm 332	21	1470 \pm 320	14
7/1-7/11/94	1570 \pm 297	16	1642 \pm 523	18	1589 \pm 231	27	3478 \pm 399	16
8/12-8/19/94	1581 \pm 224	15	601 \pm 207	15	2626 \pm 472	14	1886 \pm 328	16
9/14-9/21/94	2205 \pm 350	19	824 \pm 188	24	2510 \pm 557	9	1767 \pm 386	14
6/07-6/27/95	1999 \pm 324	30	2307 \pm 631	23	3444 \pm 336	27	1618 \pm 289	25
dry	280 \pm 43		245 \pm 67		312 \pm 33		158 \pm 28	
7/31-8/15/95	2277 \pm 417	19	1821 \pm 797	10	2526 \pm 385	15	1481 \pm 245	25
dry	267 \pm 46		172 \pm 79		171 \pm 29		149 \pm 28	
9/18-9/29/95	5044 \pm 752	17	479 \pm 173	17	2629 \pm 323	18	1281 \pm 178	25
dry	551 \pm 94		37 \pm 13		194 \pm 23		113 \pm 15	
6/12-6/24/96	2959 \pm 402	30	568 \pm 200	30	21 \pm 8	27	665 \pm 144	25
dry	306 \pm 40		59 \pm 24		2 \pm 1		46 \pm 10	
7/30-8/9/96	3035 \pm 619	27	665 \pm 219	30	1 \pm 1	27	1415 \pm 256	25
dry	390 \pm 82		62 \pm 20		0 \pm 0		176 \pm 36	
9/12-9/19/96	3622 \pm 469	30	574 \pm 174	30	0 \pm 0	27	1656 \pm 393	25
dry	361 \pm 49		50 \pm 14		0 \pm 0		156 \pm 40	
6/27-7/17/97	2134 \pm 321	30	1906 \pm 341	28	24 \pm 22	26	1880 \pm 327	25
dry	294 \pm 46		210 \pm 40		3 \pm 3		296 \pm 55	
9/8-9/18/97	2786 \pm 400	30	2646 \pm 502	29	4 \pm 4	27	1055 \pm 170	25
dry	321 \pm 49		271 \pm 55		0 \pm 0		100 \pm 18	
6/8-6/18/98	1080 \pm 168	30	1690 \pm 360	31	79 \pm 52	27	815 \pm 164	25
dry	130 \pm 18	30	213 \pm 52	31	7 \pm 4	27	105 \pm 21	25
7/27-8/3/98	581 \pm 133	30					2103 \pm 475	25
dry	67 \pm 16	30					286 \pm 65	25
9/8-9/16/98	530 \pm 76	30	3146 \pm 514	29	181 \pm 44	27	1487 \pm 338	25
dry	48 \pm 7	30	367 \pm 63	29	15 \pm 4	27	172 \pm 40	25

The contribution of the non-milfoil plant community remained high at all sites except Cedar Lake; Eurasian watermilfoil contributed 50% of the biomass at Auburn, Otter and Smith's Bay. During 1998, the total number of species increased at these three sites to the highest numbers we have seen, with 12 species noted at Auburn and 16 at Smith's Bay in July (Table 3). At Lake Auburn and Smith's Bay, native plants increased particularly in the shallower water sites and northern watermilfoil persisted in these samples. Non-milfoil biomass reached the highest proportion we have seen at Lake Auburn and remained 50% of plant biomass at Smith's Bay. In contrast, Eurasian watermilfoil biomass remained high at Cedar Lake and contributed about 80% of the plant biomass there.

Both Lake Auburn and Cedar Lake had lower numbers of species per sample than Otter and Smith's Bay (Table 2); furthermore, the non-milfoil biomass in Auburn and Cedar was

dominated by coontail (Fig 2); coontail composed >90% of the non-milfoil biomass in these two lakes. In Smith's Bay and Otter Lake, coontail was less dominant and composed < 50% of the non-milfoil biomass. These observations suggest that other species may not recover if milfoil decreases are replaced by coontail. The combination of coontail and Eurasian watermilfoil may suppress other plants, or more likely, these two species are more tolerant of lower mid-summer light conditions and thus have an advantage over the other plants. At Lake Auburn coontail increased while milfoil declined during 1998, however, the milfoil decline may not persist if water clarity remains low and rooted plants do not increase.

Since 1994, the total number of species was negatively related to milfoil biomass in Auburn and Otter and positively related to non-milfoil biomass at Otter Lake. At Smith's Bay, mean number of species per sample was positively correlated with non-milfoil biomass. Total number of species and mean number of species per sample were significantly correlated at Smith's Bay and Otter Lake but not at Auburn and Cedar. Total number of species reflects bed-wide conditions and at the low diversity lakes such as Auburn and Cedar, water clarity and milfoil seem to limit diversity. After the decline of milfoil at Otter Lake, total number of species increased and local (per sample) diversity increased with increasing non-milfoil biomass.

Table 2. Mean number of species per sample (Spp/S) \pm 1SE and non-milfoil biomass (B; g wet /m²) at the 4 sampling sites in 1994-1998. Number of samples is given in Table 1. Dry biomass for all plants is given in Appendix I.

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 \pm 0.47	670	1.33 \pm 0.28	75	4.76 \pm 0.19	600	3.29 \pm 0.22	1231
7/1-7/11/94	3.63 \pm 0.29	444	1.83 \pm 0.28	370	4.37 \pm 0.29	520	3.75 \pm 0.35	1604
8/12-8/19/94	3.00 \pm 0.28	647	1.53 \pm 0.26	282	5.57 \pm 0.39	1126	3.13 \pm 0.42	765
9/14-9/21/94	3.11 \pm 0.37	268	1.46 \pm 0.19	54	4.89 \pm 0.61	431	3.50 \pm 0.39	975
6/07-6/27/95	2.23 \pm 0.22	822	1.43 \pm 0.20	214	4.70 \pm 0.21	1065	3.64 \pm 0.30	877
7/31-8/15/95	3.37 \pm 0.26	1789	1.70 \pm 0.15	516	4.27 \pm 0.30	642	2.68 \pm 0.24	703
9/18-9/29/95	2.18 \pm 0.18	1058	1.41 \pm 0.17	337	2.44 \pm 0.34	135	2.80 \pm 0.20	856
6/12-6/24/96	2.93 \pm 0.24	1450	2.10 \pm 0.22	248	5.19 \pm 0.25	434	4.32 \pm 0.36	1159
7/30-8/9/96	2.78 \pm 0.31	1186	1.43 \pm 0.18	270	4.19 \pm 0.20	1171	3.88 \pm 0.41	1017
9/12-9/19/96	2.50 \pm 0.20	1166	1.57 \pm 0.16	307	3.93 \pm 0.28	1798	3.88 \pm 0.32	1531
6/27-7/17/97	2.97 \pm 0.14	1435	1.82 \pm 0.14	460	4.31 \pm 0.29	1516	4.16 \pm 0.39	1162
9/8-9/18/97	2.63 \pm 0.17	1500	1.59 \pm 0.09	235	4.81 \pm 0.26	3180	3.64 \pm 0.27	1863
6/8-6/18/98	2.43 \pm 0.18	1158	1.74 \pm 0.81	637	5.37 \pm 0.24	1835	5.32 \pm 0.43	1038
7/27-8/3/98	2.97 \pm 0.23	2197					5.00 \pm 0.44	1385
9/8-9/16/98	2.40 \pm 0.12	1258	1.62 \pm 0.12	296	4.74 \pm 0.39	1423	4.32 \pm 0.38	969

Sediment bulk density and organic content at each of the lakes in 1997-1998 were similar to previous years (Table 4). Sediment ammonium was generally higher in 1998, particularly in late summer; we are not sure why the values are so much higher, and no obvious errors in previous or in current readings were apparent. Water clarity trends varied among lakes, with Smith's Bay showing good summer-long clarity as in previous years. Lake Auburn had poor water clarity throughout the summer in 1997 and 1998, with values lower than previous years, except for June. The poor water clarity at Lake Auburn may have suppressed growth of native plants other than coontail. Water clarity during 1998 was higher in Cedar and Otter Lakes than in previous years, especially in late summer. Cedar Lake maintained Secchi depths >4m until September when the Secchi declined to 2.6m. The summer-long high water clarity at Cedar Lake was likely due to an alum treatment in Fall 1996 and subsequent wetland restoration.

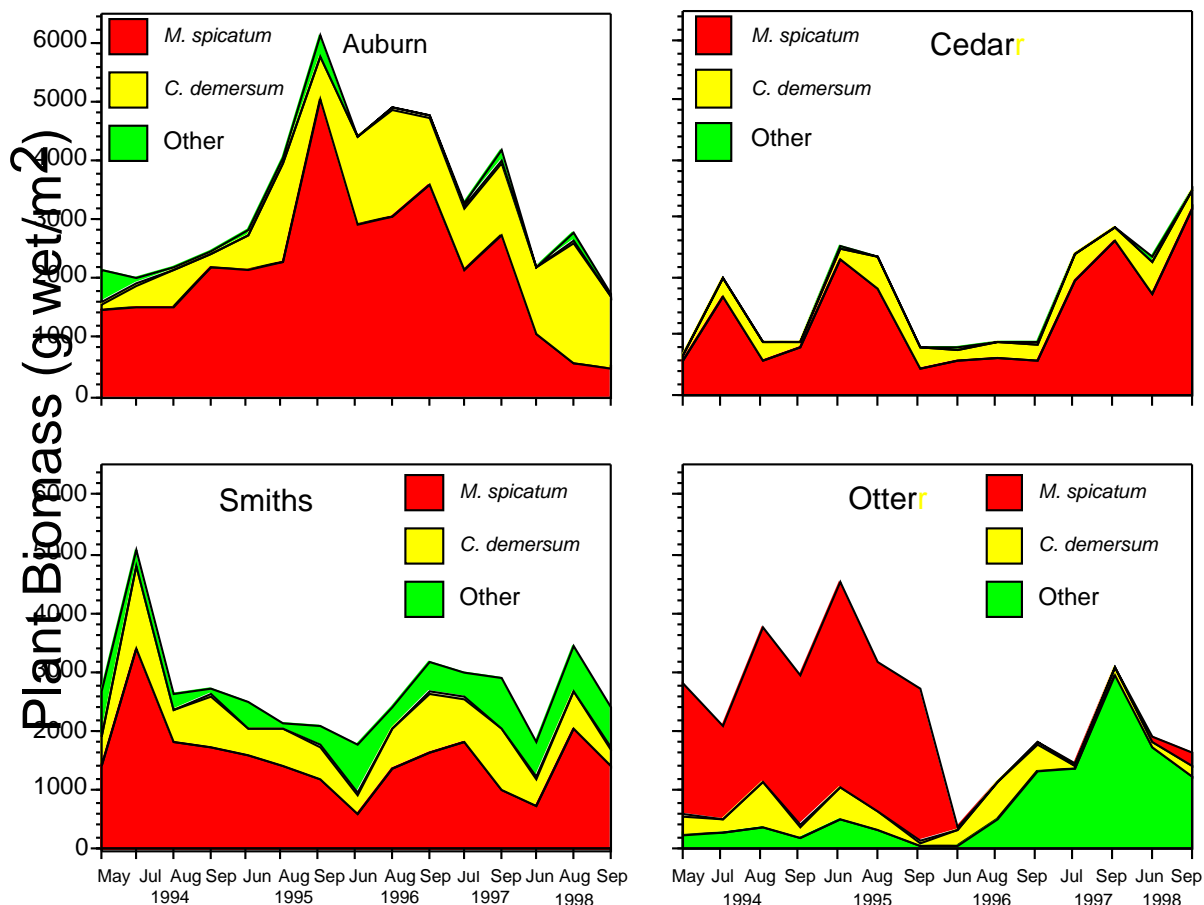


Fig. 2. Total plant biomass (Eurasian watermilfoil, coontail and other non-milfoil biomass; g wet/m²) at the four permanent transect sites from May 1994 - September 1998.

Table 3. Percentages of total plant wet biomass that was Eurasian watermilfoil ($\pm 1SE$) and 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. Dry mass percentages were similar (Appendix I).

Sampling Date	Auburn	N	Cedar	N	Otter	N	Smith's Bay	N
5/19-6/3/94	65% \pm 10%	9	67% \pm 11%	4	80% \pm 6%	9	64% \pm 10%	8
7/1-7/11/94	79% \pm 6%	9	67% \pm 9%	4	75% \pm 5%	9	72% \pm 6%	11
8/12-8/19/94	74% \pm 6%	9	61% \pm 13%	3	75% \pm 6%	11	81% \pm 5%	11
9/14-9/21/94	91% \pm 6%	9	87% \pm 5%	4	83% \pm 6%	11	71% \pm 8%	9
6/07-6/27/95	72% \pm 7%	7	82% \pm 7%	3	79% \pm 4%	9	61% \pm 5%	10
7/31-8/15/95	58% \pm 7%	7	58% \pm 6%	2	80% \pm 7%	9	63% \pm 6%	11
9/18-9/29/95	81% \pm 7%	5	38% \pm 5%	2	95% \pm 1%	6	63% \pm 7%	10
6/12-6/24/96	70% \pm 7%	7	57% \pm 7%	5	7% \pm 5%	9	33% \pm 6%	10
7/30-8/9/96	56% \pm 8%	7	59% \pm 9%	5	0.1% \pm 0.1%	10	56% \pm 7%	11
9/12-9/19/96	69% \pm 6%	8	73% \pm 6%	4	0% \pm 0%	9	49% \pm 7%	10
6/27-7/17/97	53% \pm 13%	10	82% \pm 9%	3	1.2% \pm 2.3%	12	54% \pm 14%	12
9/8-9/18/97	60% \pm 13%	8	88% \pm 9%	2	0.2% \pm 0.3%	13	40% \pm 14%	11
6/8-6/18/98	42% \pm 5%	11	79% \pm 5%	4	4% \pm 2%	15	37% \pm 6%	15
7/27-8/3/98	24% \pm 4%	12					49% \pm 8%	16
9/8-9/16/98	34% \pm 4%	7	82% \pm 6%	4	20% \pm 5%	13	50% \pm 8%	13

Table 4. Sediment characteristics (bulk density, percent organic matter, sediment pore water ammonium and water column characteristics in 1995-1998 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). *Water quality data for Cedar in late July 1998 was collected for the weevil introductions and sediment was not analyzed.

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	25.64	11.2	1.2	24.5	2.0	3.4
2se	0.22	0.56	16.79					
9/8/97	0.48	4.42	12.30	16.6	1.4	22.4	1.5-2.0	3.4
2se	0.14	1.46	3.27					
6/8/98	0.23	11.82	11.91	14.4	1.9	18.8	1.5-2.0	
2se	0.08	4.07	4.43					
7/28/98	0.45	20.09	9.52	41.2	0.7	25.7	0.5-1.0	
2se	0.27	3.68	4.25					
9/9/98	0.44	37.72	11.86	36.4	1.1	21.9	1.0-1.5	
2se	0.15	12.57	4.59					
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					
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					

Table 4 Continued

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					
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					

Carbohydrates levels in milfoil at Cedar and Otter Lakes recovered from low values in 1995-1996 (Table 5). These increases are probably associated with the recovery of milfoil in Otter Lake and improved water clarity at Cedar Lake. By fall 1998, root and stem carbohydrate levels for these plants were comparable to, or higher than, the values from plants in the other lakes. Lake Auburn had generally lower stem and root levels of TNC than in previous years, and although root carbohydrates were high in fall 1998, the stem levels were the lower than previous fall values. Smith's Bay carbohydrate levels were variable in roots, but remained high in stems during both years. Milfoil carbohydrate levels suggest that plants in Cedar, Otter and Smith's Bay were in good condition; plants in Lake Auburn may have been under stress compared to previous years, but the carbohydrate levels remain high compared to the low levels seen in stressed plants in Otter and Cedar during 1996.

Table 5. Percent (of dry mass) sugar (TS), starch (Starch) and total nonstructural carbohydrates (TNC) \pm 1SE for roots, stems and leaves at the four permanent transect sites in 1995-1998. Samples were collected from shallow, moderate and deep stations along transects 1, 3 and 5 (n= 5-9 at each site and date).

Response	Date	Auburn	Cedar	Otter	Smiths	
ROOTS						
%TNC	6/95	9.97 \pm 1.01%	6.37 \pm 1.33%	6.18 \pm 1.02%	12.73 \pm 1.69%	
	8/95	16.42 \pm 2.10%	7.14 \pm 1.19%	9.14 \pm 0.85%	8.67 \pm 0.67%	
	9/95	13.88 \pm 1.39%	1.89 \pm 0.33%	4.18 \pm 0.88%	9.24 \pm 0.51%	
	6/96	11.02 \pm 0.82%	2.49 \pm 0.50%	2.40 \pm 0.45%	6.71 \pm 1.11%	
	8/96	10.95 \pm 0.87%	8.78 \pm 1.38%	.	10.44 \pm 1.03%	
	9/96	14.30 \pm 0.93%	6.71 \pm 1.26%	2.74 \pm 0.46%	10.83 \pm 0.52%	
	7/97	8.61 \pm 0.84%	10.66 \pm 1.10%	10.54 \pm 0.67%	9.20 \pm 0.82%	
	9/97	11.23 \pm 1.04%	8.62 \pm 0.94%	4.87 \pm 0.91%	8.00 \pm 0.54%	
	6/98	8.28 \pm 0.82%	13.90 \pm 2.41%	7.89 \pm 1.17%	12.75 \pm 1.30%	
	8/98	11.91 \pm 1.00%	.	.	9.57 \pm 1.31%	
	9/98	16.05 \pm 2.42%	15.85 \pm 1.54%	10.19 \pm 1.81%	14.88 \pm 1.19%	
	% TS	6/95	3.43 \pm 0.50%	2.52 \pm 0.82%	1.96 \pm 0.32%	4.03 \pm 1.41%
		8/95	9.99 \pm 0.73%	2.90 \pm 0.63%	3.97 \pm 1.04%	4.29 \pm 0.48%
9/95		7.99 \pm 1.14%	0.55 \pm 0.12%	1.37 \pm 0.33%	3.82 \pm 0.28%	
6/96		5.02 \pm 0.60%	1.88 \pm 0.98%	1.54 \pm 0.36%	1.99 \pm 0.29%	
8/96		5.50 \pm 0.92%	2.27 \pm 0.38%	2.75 \pm .	3.30 \pm 0.33%	
9/96		4.11 \pm 0.90%	1.48 \pm 0.32%	0.55 \pm 0.10%	2.30 \pm 0.26%	
7/97		4.62 \pm 0.45%	3.07 \pm 0.24%	3.30 \pm 0.66%	2.59 \pm 0.34%	
9/97		4.32 \pm 0.71%	2.94 \pm 0.22%	2.67 \pm 0.40%	1.83 \pm 0.23%	
6/98		0.99 \pm 0.19%	3.76 \pm 0.70%	5.00 \pm 0.98%	5.66 \pm 1.35%	
8/98		9.59 \pm 1.25%	.	.	4.73 \pm 1.13%	
9/98		4.31 \pm 0.39%	5.76 \pm 2.30%	4.08 \pm 0.83%	2.35 \pm 0.11%	
% Starch		6/95	6.39 \pm 0.70%	3.53 \pm 1.08%	4.96 \pm 0.92%	8.96 \pm 2.60%
		8/95	8.01 \pm 1.19%	4.78 \pm 1.20%	5.17 \pm 0.89%	4.38 \pm 0.60%
	9/95	5.89 \pm 1.03%	1.48 \pm 0.36%	2.96 \pm 0.60%	5.42 \pm 0.44%	
	6/96	6.00 \pm 0.67%	.	0.78 \pm 0.10%	4.72 \pm 0.88%	
	8/96	4.88 \pm 0.78%	6.51 \pm 1.10%	.	7.14 \pm 0.79%	
	9/96	10.19 \pm 0.46%	5.14 \pm 0.86%	2.18 \pm 0.31%	8.54 \pm 0.35%	
	7/97	3.99 \pm 0.86%	7.51 \pm 0.78%	7.24 \pm 0.25%	6.60 \pm 0.52%	
	9/97	6.90 \pm 0.70%	5.68 \pm 0.85%	2.24 \pm 0.55%	6.04 \pm 0.52%	
	6/98	7.29 \pm 0.82%	11.10 \pm 4.92%	2.63 \pm 1.92%	4.00 \pm 3.38%	
	8/98	2.13 \pm 0.60%	.	.	3.29 \pm 2.40%	
	9/98	11.74 \pm 2.46%	15.38 \pm 1.58%	5.18 \pm 2.39%	14.07 \pm 0.85%	
	STEMS					
	%TNC	6/95	19.30 \pm 1.52%	12.26 \pm 1.72%	16.86 \pm 2.17%	24.37 \pm 1.73%
8/95		21.86 \pm 2.06%	11.87 \pm 1.52%	18.43 \pm 2.32%	19.32 \pm 2.24%	
9/95		25.87 \pm 1.57%	2.56 \pm 0.28%	7.96 \pm 0.52%	20.20 \pm 1.53%	
6/96		16.27 \pm 1.06%	2.45 \pm 0.81%	7.13 \pm 1.64%	14.73 \pm 1.01%	
8/96		18.27 \pm 0.87%	14.63 \pm 2.05%	4.66 \pm .	25.13 \pm 2.83%	
9/96		22.96 \pm 1.77%	13.25 \pm 2.73%	2.97 \pm 0.63%	17.22 \pm 1.24%	
7/97		13.93 \pm 1.18%	16.27 \pm 1.89%	18.66 \pm 2.31%	23.52 \pm 2.09%	
9/97		19.77 \pm 0.87%	21.24 \pm 1.65%	11.69 \pm 2.03%	22.00 \pm 2.07%	
6/98		17.02 \pm 1.49%	20.85 \pm 2.62%	17.24 \pm 2.13%	23.12 \pm 1.23%	
8/98		16.12 \pm 1.97%	.	.	22.09 \pm 1.99%	
9/98		13.70 \pm 1.13%	24.40 \pm 1.75%	22.77 \pm 1.70%	18.60 \pm 1.46%	

Table 5 Continued

% TS	6/95	1.50 ± 0.29%	0.68 ± 0.19%	0.93 ± 0.26%	2.80 ± 0.54%
	8/95	4.37 ± 1.10%	2.91 ± 0.69%	2.22 ± 0.44%	1.73 ± 0.24%
	9/95	4.47 ± 0.48%	0.47 ± 0.06%	1.51 ± 0.19%	3.14 ± 0.35%
	6/96	3.35 ± 0.31%	2.20 ± 1.81%	2.65 ± 0.35%	1.33 ± 0.18%
	8/96	3.31 ± 0.30%	0.77 ± 0.04%	0.72 ± 0.00%	3.22 ± 0.37%
	9/96	2.08 ± 0.22%	0.53 ± 0.10%	0.39 ± 0.00%	0.91 ± 0.19%
	7/97	3.06 ± 0.32%	1.57 ± 0.21%	2.71 ± 0.21%	1.36 ± 0.09%
	9/97	2.79 ± 0.25%	1.86 ± 0.39%	3.53 ± 0.82%	1.97 ± 0.22%
	6/98	4.45 ± 0.39%	15.31 ± 2.45%	12.20 ± 2.54%	20.74 ± 0.87%
	8/98	9.99 ± 1.37%	.	.	16.87 ± 1.08%
9/98	3.11 ± 0.23%	17.28 ± 1.75%	13.20 ± 2.36%	15.98 ± 1.36%	
% Starch	6/95	16.74 ± 1.07%	11.62 ± 1.96%	15.93 ± 1.95%	21.57 ± 2.27%
	8/95	17.49 ± 2.96%	8.96 ± 1.86%	16.21 ± 1.94%	17.60 ± 2.36%
	9/95	21.39 ± 1.65%	2.09 ± 0.33%	6.46 ± 0.34%	17.06 ± 1.58%
	6/96	12.92 ± 1.24%	.	5.36 ± 1.30%	13.40 ± 0.99%
	8/96	14.96 ± 0.84%	13.86 ± 2.04%	3.94 ± .	21.90 ± 2.70%
	9/96	20.88 ± 1.67%	12.70 ± 2.66%	2.58 ± 0.63%	16.31 ± 1.15%
	7/97	10.87 ± 1.24%	14.70 ± 1.77%	15.96 ± 2.28%	22.17 ± 2.05%
	9/97	16.98 ± 1.00%	19.38 ± 1.47%	8.16 ± 1.26%	19.06 ± 2.70%
	6/98	12.57 ± 1.78%	5.54 ± 1.99%	5.30 ± 1.40%	3.40 ± 1.11%
	8/98	5.82 ± 2.00%	.	.	7.17 ± 1.52%
9/98	12.73 ± 1.08%	8.13 ± 1.88%	10.96 ± 2.84%	3.99 ± 0.95%	
LEAVES %TNC	6/95	5.28 ± 0.72%	2.76 ± 0.32%	7.73 ± 0.58%	7.33 ± 1.13%
	8/95	9.20 ± 0.90%	5.56 ± 0.33%	6.57 ± 0.71%	8.72 ± 0.86%
	9/95	7.40 ± 0.25%	1.91 ± 0.29%	2.01 ± 0.11%	7.94 ± 0.55%
	6/96	3.56 ± 0.19%	1.12 ± 0.05%	2.52 ± 0.36%	4.77 ± 1.85%
	8/96	4.55 ± 0.71%	6.90 ± 1.47%	2.31 ± .	10.58 ± 0.97%
	9/96	6.57 ± 0.68%	6.23 ± 1.31%	2.12 ± 0.16%	6.00 ± 1.02%
	7/97	3.15 ± 0.15%	6.97 ± 0.29%	7.89 ± 0.68%	10.31 ± 0.45%
	9/97	9.69 ± 0.74%	5.52 ± 1.28%	2.33 ± 0.27%	10.90 ± 0.84%
	6/98	4.68 ± 0.53%	4.09 ± 0.15%	4.57 ± 0.31%	9.48 ± 1.01%
	8/98	4.04 ± 0.42%	.	.	6.03 ± 0.52%
9/98	3.66 ± 0.61%	6.02 ± 0.51%	5.59 ± 0.20%	6.34 ± 0.25%	
% TS	6/95	0.63 ± 0.06%	0.78 ± 0.30%	0.54 ± 0.01%	0.63 ± 0.13%
	8/95	0.82 ± 0.15%	0.46 ± 0.04%	0.49 ± 0.07%	0.39 ± 0.01%
	9/95	0.71 ± 0.09%	0.43 ± 0.08%	0.40 ± 0.01%	0.54 ± 0.07%
	6/96	0.53 ± 0.05%	0.39 ± .	0.39 ± 0.00%	0.43 ± 0.04%
	8/96	0.52 ± 0.06%	0.39 ± 0.00%	0.39 ± 0.00%	0.71 ± 0.07%
	9/96	0.63 ± 0.08%	0.39 ± 0.00%	0.39 ± 0.00%	0.39 ± 0.00%
	7/97	0.49 ± 0.05%	0.39 ± 0.00%	0.52 ± 0.13%	0.39 ± 0.00%
	9/97	1.06 ± 0.15%	0.55 ± 0.09%	0.82 ± 0.10%	0.42 ± 0.05%
	6/98	0.15 ± 0.03%	0.33 ± 0.07%	0.34 ± 0.06%	1.18 ± 0.26%
	8/98	0.22 ± 0.02%	.	.	0.76 ± 0.15%
9/98	1.06 ± 0.19%	0.54 ± 0.17%	1.81 ± 0.26%	0.68 ± 0.11%	
% Starch	6/95	5.69 ± 0.64%	2.54 ± 0.60%	6.44 ± 1.57%	5.69 ± 1.74%
	8/95	8.38 ± 0.97%	5.10 ± 0.34%	6.23 ± 0.78%	8.33 ± 0.86%
	9/95	6.70 ± 0.29%	1.48 ± 0.33%	1.79 ± 0.11%	7.41 ± 0.60%
	6/96	3.03 ± 0.22%	.	2.51 ± 0.97%	4.35 ± 1.82%
	8/96	4.03 ± 0.72%	6.51 ± 1.47%	1.92 ± .	9.88 ± 0.94%
	9/96	5.94 ± 0.67%	5.84 ± 1.31%	1.73 ± 0.16%	5.61 ± 1.02%
	7/97	2.66 ± 0.18%	6.58 ± 0.29%	7.38 ± 0.81%	9.92 ± 0.45%
	9/97	8.64 ± 0.77%	4.97 ± 1.25%	1.50 ± 0.25%	10.21 ± 1.06%
	6/98	4.53 ± 0.51%	3.75 ± 0.14%	4.23 ± 0.35%	8.30 ± 0.90%
	8/98	3.82 ± 0.42%	.	.	5.33 ± 0.47%
9/98	2.60 ± 0.50%	5.48 ± 0.41%	3.78 ± 0.37%	5.66 ± 0.28%	

Weevil densities at Lakes Auburn and Cedar were higher in 1997 than in 1998 (Table 6). No *Euhrychiopsis* were collected at the transect sites on Cedar Lake in 1998 and weevils were

rare in 1997 as they have been in most previous years. In Lake Auburn, densities were high in June 1997 ($40/m^2$), continuing an increase in 1996 from low densities in 1995. However, weevil density declined in September 1997 and the decline continued through 1998, with a June density of $1.3/m^2$ and no weevils being found in July and September biomass samples. The caterpillars *Acentria* and *Parapoynx* remained at very low densities in both lakes. A biweekly survey of weevil densities at Lake Auburn during 1998 was instructive. Weevil densities were highest in our earliest samples, averaging 1.3 per stem (all stages; 0.28 adults per stem) on May 8, but by early June only 0.14 weevils were found per stem (0.01 adults) and after 10 July no weevils were found (Table 7). No weevils were found in these surveys (90 stems per survey) through the rest of the summer.

Table 6. Density ($N/m^2 \pm 2$ SE and N per stem ± 2 SE) of *Euhrychiopsis lecontei* larvae, pupae and adults, *Acentria ephemerella* and *Parapoynx* at the four permanent transect sites, 1994-1998. *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.

Lake	Date	Weevil n	Larvae N/m ²	Pupae N/m ²	Adults N/m ²	Total <i>E.l.</i> N/m ²	<i>Acentria</i> N/m ²	<i>Parapoynx</i>
Auburn	May-94	9	27.8 \pm 27.4	1.1 \pm 2.2	6.7 \pm 8.8	35.6 \pm 36.5	1.1 \pm 2.2	
	per stem	9	0.134 \pm 0.103	0.002 \pm 0.004	0.018 \pm 0.020	0.154 \pm 0.106		
	Jul-94	16	58.8 \pm 21.1	12.5 \pm 9.6	31.3 \pm 14.0	102.5 \pm 36.7	6.3 \pm 7.7	
	per stem	16	0.217 \pm 0.092	0.034 \pm 0.034	0.084 \pm 0.036	0.335 \pm 0.127		
	Aug-94	15	8.7 \pm 7.5	2.0 \pm 2.9	3.3 \pm 3.7	14.0 \pm 9.5	0.7 \pm 1.3	
		15	0.031 \pm 0.025	0.003 \pm 0.005	0.008 \pm 0.008	0.042 \pm 0.030		
	Sep-94	18	1.7 \pm 3.3	2.2 \pm 2.6	7.8 \pm 7.8	11.7 \pm 11.8	3.9 \pm 3.3	
		18	0.002 \pm 0.004	0.006 \pm 0.008	0.014 \pm 0.012	0.022 \pm 0.019		
	Jun-95	30	6.0 \pm 4.0	0.7 \pm 0.9	1.0 \pm 1.1	7.7 \pm 2.7	0.3 \pm 0.7	
		21	0.070 \pm 0.043	0.003 \pm 0.006	0.011 \pm 0.015	0.085 \pm 0.056		
	Jul-95	15	2.0 \pm 2.1	0.7 \pm 1.3	5.3 \pm 5.5	8.0 \pm 3.8	0.0 \pm 0.0	
		14	0.006 \pm 0.009	0.000 \pm 0.000	0.032 \pm 0.039	0.038 \pm 0.042		
	Sep-95	16	2.5 \pm 2.2	3.1 \pm 3.5	3.8 \pm 4.0	9.4 \pm 3.4	1.3 \pm 1.7	
		11	0.140 \pm 0.194	0.049 \pm 0.090	0.103 \pm 0.180	0.292 \pm 0.385		
	Jun-96	30	31.0 \pm 17.8	2.0 \pm 2.0	0.0 \pm 0.0	33.0 \pm 19.5	0.3 \pm 0.7	0.0 \pm 0.0
		27	0.729 \pm 1.179	0.080 \pm 0.148	0.000 \pm 0.000	0.809 \pm 1.326		
	Jul-96	25	9.2 \pm 15.2	3.6 \pm 2.6	12.8 \pm 6.3	25.6 \pm 17.9	1.6 \pm 1.5	0.8 \pm 1.1
		23	0.029 \pm 0.043	0.020 \pm 0.021	0.048 \pm 0.027	0.096 \pm 0.061		
	Sep-96	30	6.7 \pm 4.3	2.3 \pm 1.6	3.0 \pm 2.7	12.0 \pm 6.5	0.7 \pm 0.9	5.7 \pm 4.4
		29	0.048 \pm 0.053	0.007 \pm 0.005	0.011 \pm 0.010	0.065 \pm 0.055		
Jun-97	30	35.7 \pm 19.6	0.3 \pm 0.7	4.3 \pm 5.9	40.3 \pm 24.3	0.7 \pm 1.3	0.0 \pm 0.0	
	27	0.201 \pm 0.126	0.001 \pm 0.003	0.022 \pm 0.027	0.224 \pm 0.144			
Sep-97	30	0.3 \pm 0.7	0.0 \pm 0.0	1.7 \pm 1.4	2.0 \pm 1.5	1.7 \pm 2.7	2.3 \pm 2.8	
	29	0.001 \pm 0.001	0.000 \pm 0.000	0.007 \pm 0.007	0.008 \pm 0.008			
Jun-98	27	1.0 \pm 1.1	0.0 \pm 0.0	0.3 \pm 0.7	1.3 \pm 1.3	1.0 \pm 2.0	0.0 \pm 0.0	
	27	0.005 \pm 0.005	0.000 \pm 0.000	0.001 \pm 0.003	0.006 \pm 0.006			
Jul-98	28	0.0 \pm 0.0	0.0 \pm 0.0	0.0 \pm 0.0	0.0 \pm 0.0	0.7 \pm 1.0	0.0 \pm 0.0	
	24	0.000 \pm 0.000	0.000 \pm 0.000	0.000 \pm 0.000	0.000 \pm 0.000			
Sep-98	30	0.0 \pm 0.0	0.0 \pm 0.0	0.0 \pm 0.0	0.0 \pm 0.0	0.0 \pm 0.0	0.3 \pm 0.7	
	28	0.000 \pm 0.000	0.000 \pm 0.000	0.000 \pm 0.000	0.000 \pm 0.000			

Table 6. Continued.

Cedar		Weevil	Larvae	Pupae	Adults	Total <i>E.l.</i>	<i>Acentria</i>	<i>Parapoynx</i>
Date	n	N/m ²	N/m ²	N/m ²	N/m ²	N/m ²	N/m ²	
May-94	11	5.5± 10.9	0.0± 0.0	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	
	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	
	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	
	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	
	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	
	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	
	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	
	24	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000			

Table 6. Continued.

Otter

	Weevil Date	n	Larvae N/m ²	Pupae N/m ²	Adults N/m ²	Total <i>E.l.</i> N/m ²	<i>Acentria</i> N/m ²	<i>Parapoynx</i>
May-94 per stem	20		12.5± 10.2	0.0± 0.0	0.0± 0.0	12.5± 10.2	0.5± 1.0	
	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		

Table 6. Continued.

Smith's Bay		Weevil	Larvae	Pupae	Adults	Total <i>E.l.</i>	<i>Acentria</i>	<i>Parapoynx</i>
Date	n	N/m ²	N/m ²	N/m ²	N/m ²	N/m ²	N/m ²	
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			

Weevil densities at Smith's Bay were in the middle of the range of previous years. However, in both 1997 and 1998 densities declined over the summer and no weevils were found in September. This is in contrast to previous years when peak densities in Smith's Bay were in August and weevils remained at moderate densities in September. *Acentria* and *Parapoynx* were occasionally present at very low densities. Weevils were found in Otter Lake biomass samples in September 1998, at the highest densities (5.9/m²) we have seen since June 1995. This increase may be associated with the increased availability of Eurasian watermilfoil, however, number of weevils per stem (0.26 per stem) was the highest we have ever seen in Otter Lake. This observation suggests that weevil stem mining may have assisted in inhibiting the recovery of Eurasian watermilfoil since the winter kill of 1995-1996, however, the strong response by the native plant community is surely also important. *Parapoynx* sp. densities were high in Otter Lake in 1997, but less than the peak in fall of 1996; densities of *Acentria ephemereilla* and *Parapoynx* sp. were low at all sites, including Otter Lake, in 1998. As in

previous years, these caterpillars appear to be associated with *P. zosteriformis*, *Heteranthera dubia* (= *Zosterella dubia*) and coontail, along with Eurasian watermilfoil, and do not appear to be the direct cause of any declines. The high densities at Otter in September 1996 and all of 1997 occurred after the decline of milfoil and during the resurgence of native plants.

Table 7. Density (N per stem \pm 2SE) of *E. lecontei* eggs, larvae, pupae and adults collected from the top 50 cm of milfoil stems in Lake Auburn (5 stems per sample, 18 samples per date).

Date	Eggs	Larvae	Pupae	Adults	Total
5/8/98	1.00	0.03	0.00	0.28	1.32
2 S.E.	0.32	0.07	0.00	0.23	0.56
5/15/98	0.47	0.08	0.00	0.00	0.54
2 S.E.	0.19	0.06	0.00	0.00	0.23
6/12/98	0.01	0.09	0.03	0.01	0.14
2 S.E.	0.02	0.07	0.04	0.02	0.08
6/24/98	0.00	0.06	0.02	0.00	0.08
2 S.E.	0.00	0.04	0.04	0.00	0.07
7/10/98	0.00	0.02	0.00	0.00	0.02
2 S.E.	0.00	0.03	0.00	0.00	0.03
7/23/98	0.00	0.00	0.00	0.00	0.00
2 S.E.	0.00	0.00	0.00	0.00	0.00
8/5/98	0.00	0.00	0.00	0.00	0.00
2 S.E.	0.00	0.00	0.00	0.00	0.00
8/17/98	0.00	0.00	0.00	0.00	0.00
2 S.E.	0.00	0.00	0.00	0.00	0.00
9/3/98	0.00	0.00	0.00	0.00	0.00
2 S.E.	0.00	0.00	0.00	0.00	0.00
9/30/98	0.00	0.00	0.00	0.00	0.00
2 S.E.	0.00	0.00	0.00	0.00	0.00

Milfoil and Weevil Distributions

In June 1997, weevils were found throughout the bed at Lake Auburn, with the highest density at 40m from shore (Table 8). In fall 1997 and in 1998, weevils were found in the deeper stations at Lake Auburn, but were absent from the shallowest stations, possibly due lower milfoil densities near shore (Fig. 3), or greater damage to the shallower milfoil. Weevils disappeared from our samples after June 1998. In Smith's Bay, weevils were present at the four stations closest to shore in 1997 and the three stations closest to shore in 1998, but were absent from the deepest and farthest station in both years (4.5m depth, 805 m from shore). Weevils do not appear to be able to develop populations at the deepest site, either because it is too far from shore, or because the milfoil rarely gets to within 1m of the water surface at this station. When densities were stratified by station or distance from shore, maximum densities at Lake Auburn declined from around 100/m² (30-40m from shore) in June 1997, to 4/m² in June 1998 and none thereafter. Maximum densities at Smith's Bay were at 200-370 m from shore and were also higher in early summer.

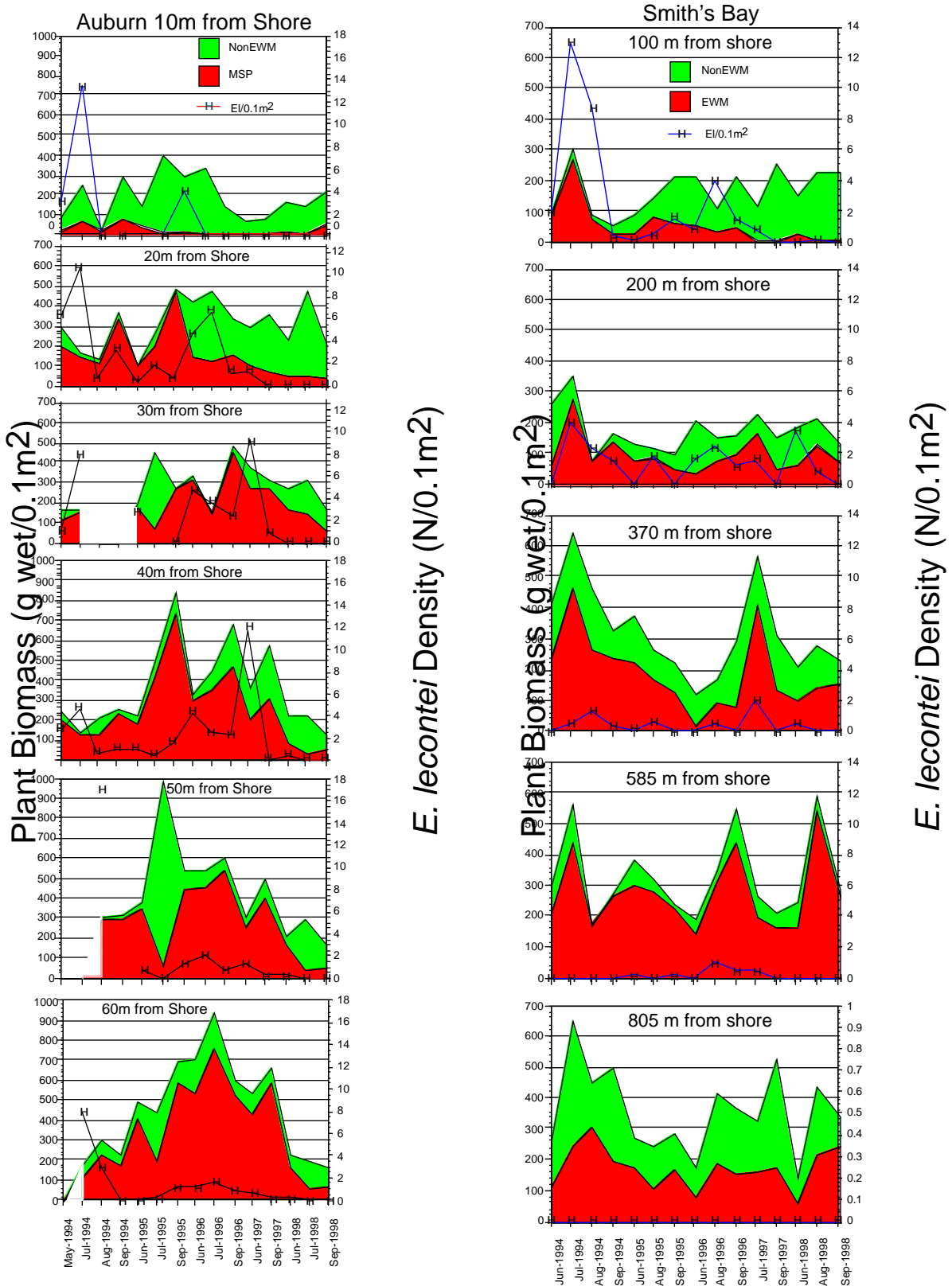


Fig. 3. Distribution of Eurasian watermilfoil, other plants and *E. lecontei* at Lake Auburn and Smith's Bay 1994-1998. Densities are per 0.1m². Gaps represent missing values.

Table 8. Distribution of *E. lecontei* (mean N/m² and N/Stem at each station) along sample transects for Lake Auburn and Smith's Bay, Lake Minnetonka. Distances are from shore and represent sampling stations and the mean distance is an estimate of the weighted distance from shore. It was estimated by $[(N_D * D)]/N_T$ where D = distance, N=N/m² or N/stem and T=total. There were too few weevils at Cedar and Otter Lakes to provide a useful comparison.

Auburn Date	Dist (m)	10	20	30	40	50	60	Mean N	Mean Dist (m)
5/24/94	N/m ²	30.0	63.3	10.0	26.7	0.0	0.0	35.6	22.6
	N/stem	0.43	0.18	0.04	0.11	.	.	0.15	17.7
7/8/94	N/m ²	135.0	106.7	80.0	46.7	170.0	80.0	102.5	34.0
	N/stem	0.60	0.37	0.18	0.20	0.37	0.33	0.33	31.8
8/18/94	N/m ²	.	6.0	.	6.0	.	30.0	14.0	51.4
	N/stem	.	0.02	.	0.04	.	0.08	0.04	49.6
9/20/94	N/m ²	0.0	32.0	.	10.0	.	0.0	11.7	24.8
	N/stem	0.00	0.06	.	0.02	.	0.00	0.02	24.8
6/7/95	N/m ²	0.0	4.0	26.0	10.0	6.0	0.0	7.7	33.9
	N/stem	0.00	0.08	0.30	0.09	0.00	0.00	0.08	30.3
7/31/95	N/m ²	.	18.0	.	4.0	.	2.0	8.0	26.7
	N/stem	.	0.10	.	0.02	.	0.00	0.04	24.6
9/26/95	N/m ²	0.0	6.0	0.0	15.0	.	12.0	9.4	43.6
	N/stem	.	0.26	0.00	0.69	.	0.04	0.29	35.7
6/13/96	N/m ²	40.0	46.0	46.0	42.0	12.0	12.0	33.0	28.8
	N/stem	6.33	0.29	0.12	0.10	0.04	0.04	0.81	11.8
7/31/96	N/m ²	0.0	67.5	36.7	27.1	20.0	16.0	25.6	32.8
	N/stem	0.00	0.19	0.29	0.12	0.07	0.03	0.10	32.0
9/12/96	N/m ²	0.0	12.0	24.0	22.0	6.0	8.0	12.0	36.4
	N/stem	0.00	0.15	0.14	0.06	0.01	0.02	0.07	29.9
6/27/97	N/m ²	0.0	14.0	92.0	118.0	12.0	6.0	40.3	36.0
	N/stem	0.00	0.05	0.68	0.44	0.04	0.02	0.22	34.3
9/8/97	N/m ²	0.0	0.0	8.0	0.0	2.0	2.0	2.0	38.3
	N/stem	0.00	0.00	0.04	0.00	0.00	0.00	0.01	33.6
6/8/98	N/m ²	0.0	0.0	0.0	4.0	2.0	2.0	1.3	47.5
	N/stem	0.00	0.00	0.00	0.02	0.01	0.01	0.01	48.0
7/27/98	N/m ²	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.
	N/stem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.
9/8/98	N/m ²	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.
	N/stem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.

Table 8 continued

Smith's Bay

Date	Dist (m)	100	200	370	585	805	Mean N	Mean Dist (m)
6/3/94	N/m ²	20.0	0.0	0.0	0.0	0.0	4.6	100
	N/stem	0.15	0.00	0.00	0.00	0.00	0.02	100
7/11/94	N/m ²	130.0	40.0	5.0	0.0	0.0	20.8	131
	N/stem	0.87	0.17	0.01	0.00	0.00	0.11	118
8/19/94	N/m ²	86.7	23.3	13.3	0.0	0.0	8.5	148
	N/stem	0.44	0.13	0.09	0.00	0.00	0.13	158
9/21/94	N/m ²	3.3	15.0	3.3	0.0	0.0	3.6	214
	N/stem	0.05	0.03	0.01	0.00	0.00	0.02	158
6/27/95	N/m ²	2.0	0.0	2.0	2.0	0.0	1.2	352
	N/stem	0.07	0.00	0.01	0.02	0.00	0.03	226
8/15/95	N/m ²	4.0	18.0	6.0	0.0	0.0	5.6	222
	N/stem	0.08	0.23	0.00	0.00	0.00	0.09	173
9/18/95	N/m ²	16.0	0.0	0.0	2.0	0.0	3.6	154
	N/stem	0.20	0.00	.	0.03	0.00	0.05	166
6/24/96	N/m ²	8.0	16.0	0.0	0.0	0.0	4.8	167
	N/stem	0.06	0.11	0.00	0.00	0.00	0.04	164
8/9/96	N/m ²	40.0	24.0	4.0	10.0	0.0	15.6	207
	N/stem	0.41	0.15	0.03	0.03	0.00	0.13	158
9/19/96	N/m ²	14.0	12.0	0.0	4.0	0.0	6.0	205
	N/stem	0.07	0.07	0.00	0.01	0.00	0.03	189
7/14/97	N/m ²	8.0	16.0	20.0	4.0	0.0	9.6	286
	N/stem	0.50	0.08	0.10	0.02	0.00	0.09	164
9/18/97	N/m ²	0.0	0.0	0.0	0.0	0.0	0.0	.
	N/stem	0.00	0.00	0.00	0.00	0.00	0.00	.
6/15/98	N/m ²	0.0	34.0	4.0	0.0	0.0	7.6	218
	N/stem	0.00	0.21	0.02	0.00	0.00	0.05	214
8/3/98	N/m ²	2.0	8.0	0.0	0.0	0.0	2.0	180
	N/stem	0.00	0.08	0.00	0.00	0.00	0.02	200
9/15/98	N/m ²	0.0	0.0	0.0	0.0	0.0	0.0	.
	N/stem	0.00	0.00	0.00	0.00	0.00	0.00	.

Over the past five years, peak densities at stations in Lake Auburn ranged between 25 and 170/m² (0.2-0.7 per stem) and peak densities at Smith's Bay ranged from 16-130/m² (0.2-0.9 per stem). Thus, although overall densities appear too low to effect control, densities at stations may be adequate to exert control. At both Lake Auburn and Smith's Bay, milfoil biomass has declined or remained suppressed at the shallowest (closest to shore) stations (Fig. 3). Weevil densities appear to respond to changes in milfoil density, which appears to decline with increases in weevil density. At both lakes, weevil densities appear to have decreased over time at the shallowest sites and mean distance from shore has increased. This is likely due to the decreases in milfoil density at the shallowest sites (Fig. 3). In Smith's Bay, weevils collected from the shallowest station in 1998 were likely from northern watermilfoil, which has largely replaced Eurasian watermilfoil at this station. At both lakes weevil populations appear to be limited at the sites furthest from shore (50 m from shore at Auburn and 585m from shore at Smith's Bay); weevil densities are low and do not appear to influence milfoil density. At Smith's Bay this may simply be a distance or depth problem, however, fish predation, exposure to wave action and plant depth may also limit weevil densities at the edge of the beds. At the shallower stations, native plant densities have increased with decreased milfoil density, whereas deeper stations are dominated by milfoil or milfoil and coontail. These observations suggest that weevils are suppressing milfoil at the sites closer to shore where weevil densities are higher and where native plants can compete with Eurasian watermilfoil.

Cenaiko Lake

The results at Cenaiko Lake are outlined in more detail in Newman and Biesboer (*in press*). The decline in milfoil biomass at Cenaiko Lake continued in 1997 (to <5g/m²) and persisted through 1998 (Fig 4). Eurasian watermilfoil biomass increased relative to 1997 in June and July 1998 with milfoil densities of 44 g dry/m² on both dates (15% of plant biomass), but milfoil biomass declined to <12 g/m² in September (7% of total plant biomass). Native plant biomass increased and was >200 g/m² throughout the summer of 1998. Water clarity was higher in 1998 than 1997, and was more similar to that in 1996 (3-4m Secchi depths; Table 9). Sediment ammonium levels increased after the milfoil decline and even though native plant biomass exceeded total plant biomass in 1996, ammonium levels were higher in 1998 than they were in 1996. Stem carbohydrate levels were relatively high in July 1996 (Table 10) but quickly declined to <2% in September and did not recover in 1997. Root carbohydrates were moderate in July 1996 but roots nearly disappeared from sediments and were impossible to recover in adequate quantity to analyze on subsequent sampling dates. Carbohydrate levels increased in 1998 but remained below the pre-decline levels and did not increase in fall as would be expected.

Weevil densities declined in 1997 with the decline in Eurasian watermilfoil. Densities estimated from the biomass samples in 1998 remained relatively low, less than 1/m² in June and late July and none were found in mid-September (Table 11). The milfoil was low density and patchily distributed and we may have missed patches with higher weevil densities. An early September weevil count based on stem collections (18 sites) indicated very high weevil densities: 3.6 weevils (all stages) per stem and more than one adult for every two stems (Table 11). These numbers are higher than our densities during the initial decline in 1996 and indicate that weevil densities get high in Cenaiko Lake. By the time of this survey, many of the meristems were damaged, yet the high weevil population persisted through the decline in 1998. The further decrease in milfoil during 1998 was clearly due to weevil damage, and it appears that a relatively stable herbivore-plant relationship has developed. Increasing milfoil was met with increasing weevils and milfoil suppression.

Acentria densities were lower in 1998 than in 1996 and 1997 and over half the *Acentria* were found in samples with no milfoil; similarly, most of the *Parapoynx* were found in samples with no milfoil. These herbivores may help suppress the milfoil but they do not appear to be the main cause of the decline, however, further monitoring of their populations is warranted.

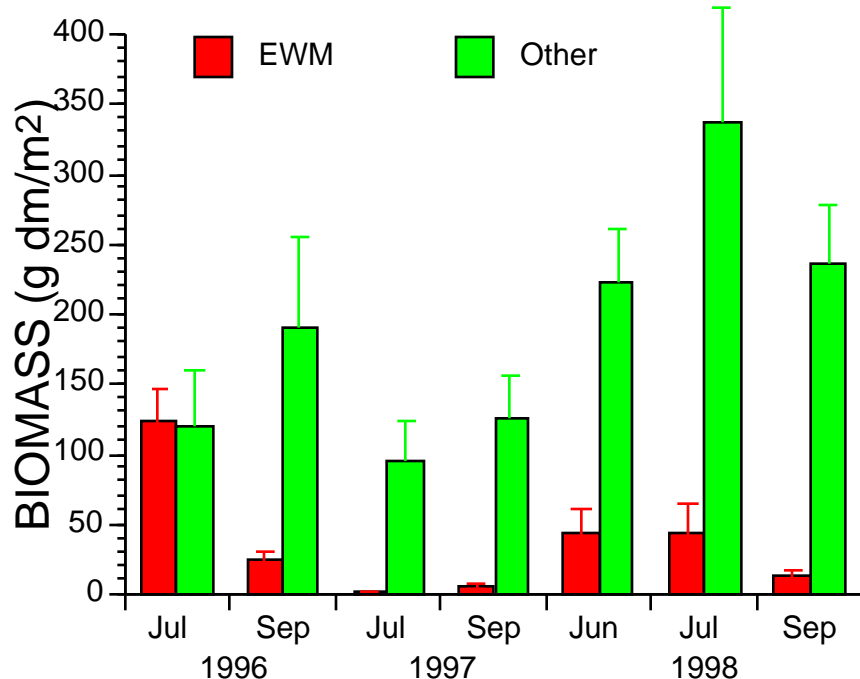


Fig. 4. Dry biomass of milfoil (EWM) and non-milfoil plants at Cenaiko Lake, 1996-1998. There was a significant decline of milfoil between July and September 1996 and July 1997 and a significant increase in native plants. $N > 20$ samples on each date.

Table 9. Sediment characteristics (bulk density, percent organic matter, sediment pore water ammonium and water column characteristics in 1996-1998 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%					

Table 10. Percent (of dry mass) sugar (TS), starch (Starch) and total nonstructural carbohydrates (TNC) \pm 1SE for roots, stems and leaves at Cenaiko Lake in 1996-1998. n= 6-9 in July 1996 and all of 1998. In September 1996, only 3 samples with usable material were collected and few roots were obtained. In 1997 no plants were collected in July and 5 samples were collected in September, however the root mass of the collected plants was too low for good TNC determination. Values with no SE's had only one estimate.

Tissue	Date	%TNC	%TS	%Starch
Roots	Jul-96	8.2% \pm 1.2%	0.9% \pm 0.2%	7.4% \pm 1.1%
	Sep-96	-	0.4% \pm .	-
	Sep-97	-	0.8% \pm .	-
	Jun-98	6.4% \pm 0.7%	4.3% \pm 1.3%	2.5% \pm 0.5%
	Jul-98	6.1% \pm 0.8%	3.0% \pm 0.9%	3.3% \pm 0.3%
	Sep-98	5.0% \pm 0.5%	2.0% \pm 0.4%	3.4% \pm 0.5%
	Stems	Jul-96	24.2% \pm 3.9%	0.8% \pm 0.1%
Sep-96		1.6% \pm .	0.4% \pm 0.0%	1.2% \pm .
Sep-97		3.8% \pm 0.19%	0.8% \pm 0.1%	3.0% \pm 0.2%
Jun-98		13.2% \pm 1.4%	8.8% \pm 1.4%	4.4% \pm 1.4%
Jul-98		12.6% \pm 1.7%	8.2% \pm 1.4%	5.6% \pm 1.6%
Sep-98		9.8% \pm 1.0%	7.7% \pm 1.5%	2.1% \pm 1.1%
Leaves		Jul-96	6.5% \pm 1.3%	0.4% \pm 0.00%
	Sep-96	3.9% \pm .	0.4% \pm 0.00%	3.5% \pm .
	Sep-97	2.7% \pm 0.3%	0.4% \pm 0.00%	2.3% \pm 0.3%
	Jun-98	3.4% \pm 0.3%	0.4% \pm 0.1%	3.0% \pm 0.3%
	Jul-98	3.8% \pm 0.4%	0.5% \pm 0.1%	3.3% \pm 0.4%
	Sep-98	4.7% \pm 0.4%	0.9% \pm 0.2%	3.8% \pm 0.3%

Table 11. Density ($N/m^2 \pm 2$ SE and N per stem) of *Euhrychiopsis lecontei* (*E.l.*) larvae, pupae and adults, and *Acentria ephemerella* and *Parapoynx* sp. at Cenaiko Lake in 1996-1998. Densities per stem were only calculated for samples with Eurasian watermilfoil. A stem is a basal milfoil stem emerging from the sediment. In early September, a separate stem survey was conducted at 6 sites along three transects, providing estimates of weevils per stem (total for this survey includes eggs).

Date	Weevil n	Larvae N/m ²	Pupae N/m ²	Adults N/m ²	Total <i>E.l.</i> N/m ²	<i>Acentria</i> N/m ²	<i>Parapoynx</i> 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		
9/2/98 Stem survey							
per stem	18	1.98±0.66	0.16±0.11	0.61±0.20	3.60±0.84		

Survey sites:

Eurasian watermilfoil biomass at the 3 intensively sampled survey sites ranged from 10 g dry/m² at Lake of the Isle, to 294 g/m² at Grays Bay (Table 12). Biomass decreased from 1997 to 1998 at Shady Island, but increased slightly at Lake of the Isles and substantially at Grays Bay. Non-milfoil biomass decreased at Grays Bay but remained at densities similar to 1997 at the other two sites. Water clarity was poorer in 1998 at all three sites (Table 13) and sediment ammonium was substantially higher. Weevils were only found at the Gray's Bay site in 1998 (1.1/m²) and no weevils were found in biomass samples at any of the three sites in 1997.

Table 12. Total plant and milfoil biomass (g dry/m²) and mean percent of plant biomass that was Eurasian watermilfoil at the three survey sites in summer 1995-1998. N= 9 samples at all sites.

Lake	Date	Total Plant Biomass (g/m ²)	Milfoil Biomass (g/m ²)	% Milfoil (of biomass)	Secchi Depth (m)
Gray's Bay	8/30/95	209.4	194.0	94.0%	2.0
	SE	55.3	53.2	3.8%	
	9/4/96	309.0	49.5	30.9%	1.9
	SE	132.1	21.1	12.7%	
	8/15/97	323.7	99.7	37.3%	3.5
	SE	43.0	29.6	10.6%	
	8/25/98	420.0	294.3	58.5%	2.3
1 SE	61.8	40.8	6.9%		
Shady Island	9/12/95	259.8	215.1	83.6%	1.8
	SE	42.8	37.3	4.8%	
	9/4/96	262.2	158.6	70.5%	2.3
	SE	45.5	30.6	10.8%	
	8/28/97	432.9	175.6	47.4%	2.4
	SE	45.8	47.5	12.5%	
	8/27/98	339.6	139.2	42.6%	1.9
1 SE	59.4	57.7	15.2%		
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%		

The other survey sites had a wide range of water clarities (Table 14) and milfoil occurrence (Table 15). Percent visible milfoil coverage ranged from 4% at Piersons to 59% at Lake Harriet. Coverage and percent occurrence were not directly related, but percent coverage at the 3 intensively surveyed lakes (Grays, Isles, and Shady Island) generally agreed with biomass differences. Lakes with relatively higher occurrence and lower coverage had more evenly spread but less dense milfoil, whereas sites with high coverage generally tended to also have relatively high occurrence.

Milfoil occurrence and relative density increased (from 1997) at Gray's Bay and Shady Island and decreased some at Calhoun and Harriet (Table 15). A larger decline was noted at Piersons, where visual coverage dropped from 21% (1997) to 4% (1998), occurrence dropped to half the frequency in 1997 and relative density decreased from 3.2 to 1.9. The weevil damage rating increased at Piersons (0.4; all life stage of weevils were found), however, other sites (e.g., Lake-of-the-Isles and Shady Island) had higher damage ratings (Table 15). Milfoil was generally in shallower water than in 1997 (Table 16), probably due to the lower water clarity in 1998.

Table 13. Sediment characteristics (bulk density, percent organic matter, sediment pore water ammonium concentrations) and water column characteristics in 1995-1997 at the three survey sites. Three sediment samples from the intermediate depth were collected at each site.

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)
Grays Bay								
8/30/95	0.10	6.75	34.1	6.1	2.0	25.2	3.0-3.5	3.5
2se	0.04	3.39	4.3					
9/4/96	0.12	3.29	21.3	2.1	1.9	26.2	3.0-3.5	3.5
2se	0.04	1.82	1.0					
8/15/97	0.10	4.90	35.4	3.5	3.5	22.6	4.0-4.5	4.1
2se	0.05	3.19	4.9					
8/25/98	0.10	29.13	33.7	3.5	2.3	25.1	3.0-3.5	3.3
2se	0.02	7.08	6.7					
Shady Island								
9/12/95	0.14	3.74	23.9	8.8	1.8	21.0	2.0-2.5	4.5
2se	0.05	3.12	2.8					
9/4/96	0.42	1.44	10.1	7.5	2.3	25.1	3.0-3.5	3.5
2se	0.41	0.48	9.0					
8/28/97	0.09	4.49	27.2	2.4	2.4	23.9	3.0-3.5	4.7
2se	0.77	1.87	16.8					
8/27/98	0.69	10.93	10.8	5.9	1.9	24.6	3.0-3.5	4.4
2se	0.93	8.71	10.7					
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					

Table 14. Water column characteristics of the 6 new survey sites. Long Lake, Minnewashta and St. Alban's Bay were not sampled in 1998.

Lake/Date	Chl-a (mg/m ³)	SD (m)	Temp (°C 1m)	10% PAR Depth (m)	Milfoil Limit (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
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
Long	9/30/97	17.9	1.5	16.9	1.0-2.0	3.2
Minnewashta	9/23/97	6.1	2.7	18.8	2.5-3.0	4.2
Pierson	10/7/97	16.6	2.1	17.2	1.5-2.5	3.2
	9/3/98	12.6	1.7	23.2	2.0-2.5	2.9
St. Alban's	10/6/97	4.8	3.3	17.5	5.0-5.5	5.0

Table 15. Estimates of plant coverage and occurrence at the survey lakes. 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=50-97 stations at each lake. Jessen and Lound (1962) relative density ratings (0-5) were determined from a subset of 5-6 transects (n=15-37 station). Total Eurasian watermilfoil coverage, % of littoral zone and % of lake area with milfoil were determined by GPS mapping based on the criteria indicated.

Lake Calhoun	% Vis MSP Cov	% Occurrence (Visual)	% Occurrence (Drop Hook)	Density Rating	n = 29
Date	n	Mean \pm 1 S.E.	Spp. % Occ. \pm 1 S.D.	Spp. % Occ. \pm 1 S.D.	Spp. Density \pm 2S.E.
9/24/97	69	29.9 \pm 3.3%	MSP 87.0 \pm 4.1%	MSP 94.2 \pm 2.8%	MSP 4.28 \pm 0.43
			CRT 2.9 \pm 2.0%	CRT 52.2 \pm 6.0%	CRT 1.86 \pm 0.58
Eurasian Watermilfoil:		NAJ 1.4 \pm 1.4%	PRI 7.2 \pm 3.1%	PRI 0.31 \pm 0.33	
Total Area:	71.9 ha.		PEC 3.0 \pm 2.0%	NAJ 0.28 \pm 0.28	
% of Litt. Zone:	144.4 %			PEC 0.10 \pm 0.12	
% of Lake Area:	44.3 %			PCR 0.07 \pm 0.10	
Survey Criteria: Visible milfoil				CHA 0.03 \pm 0.07	
Weevil Damage rating	0.493 \pm 0.085			PZS 0.03 \pm 0.07	

Date	n	Mean \pm 1SE	Spp. % Occ. \pm 1 SD	Spp. % Occ. \pm 1 SD	Spp. Density \pm 2SE
9/4/98	63	30.7 \pm 4.4%	MSP 87.3 \pm 4.2%	MSP 76.2 \pm 5.4%	MSP 3.67 \pm 0.49
			PEC 17.5 \pm 4.8%	CRT 50.8 \pm 6.3%	CRT 3.07 \pm 0.53
Eurasian Watermilfoil			PRI 14.3 \pm 4.4%	PEC 12.7 \pm 4.2%	PCR 0.48 \pm 0.38
Total Area: 22.3 ha.			CRT 11.1 \pm 4.0%	PRI 3.2 \pm 2.2%	PEC 0.48 \pm 0.43
% of Litt. Zone: 44.8%			PCR 7.9 \pm 3.1%	PZS 1.6 \pm 1.6%	PRI 0.41 \pm 0.36
% of Lake Area: 13.7%			NAJ 6.3 \pm 3.1%		NAJ 0.33 \pm 0.34
Survey Criteria: Visible milfoil			ELD 1.6 \pm 1.6%		ELD 0.04 \pm 0.07
Weevil Damage Rating: 0.698 \pm 0.133			HET 1.6 \pm 1.6%		HET 0.04 \pm 0.07

Lake Harriet	% Vis MSP Cov	% Occurrence (Visual)	% Occurrence (Drop Hook)	Density Rating	n = 29
Date	n	Mean \pm 1 S.E.	Spp. % Occ. \pm 1 S.D.	Spp. % Occ. \pm 1 S.D.	Spp. Density \pm 2S.E.
10/9/97	72	52.2 \pm 3.8%	MSP 87.5 \pm 3.9%	MSP 86.1 \pm 4.1%	MSP 4.41 \pm 0.36
			CRT 8.3 \pm 3.3%	CRT 40.3 \pm 5.8%	CRT 2.21 \pm 0.49
Eurasian Watermilfoil:		HET 1.4 \pm 1.4%	PRI 1.4 \pm 1.4%	PRI 0.17 \pm 0.14	
Total Area:	28.6 ha.		PZS 1.4 \pm 1.4%	ELD 0.03 \pm 0.07	
% of Litt. Zone:	83.2%			NAJ 0.03 \pm 0.07	
% of Lake Area:	21.1%			PEC 0.03 \pm 0.07	
Survey Criteria: Visible milfoil					
Weevil Damage rating	0.507 \pm 0.072				

Date	n	Mean \pm 1SE	Spp. % Occ. \pm 1 SD	Spp. % Occ. \pm 1 SD	Spp. Density \pm 2SE
9/23/98	73	59.2 \pm 4.2%	MSP 84.9 \pm 4.2%	MSP 82. \pm 4.5%	MSP 3.81 \pm 0.68
			CRT 8.2 \pm 3.2%	CRT 39.7 \pm 5.7%	CRT 2.07 \pm 0.55
Eurasian Watermilfoil			PRI 6.8 \pm 3.0%	PRI 6.8 \pm 3.0%	PRI 0.26 \pm 0.31
Total Area: 23.1 ha.			NAJ 1.4 \pm 1.4%	NAJ 5.7 \pm 2.7%	PZS 0.19 \pm 0.26
% of Litt. Zone: 67.2%			PZS 1.4 \pm 1.4%	PEC 1.4 \pm 1.4%	NAJ 0.15 \pm 0.18
% of Lake Area: 17.1%				PZS 1.4 \pm 1.4%	PEC 0.07 \pm 0.10
Survey Criteria: Visible milfoil					HET 0.04 \pm 0.07
Weevil Damage Rating: 0.493 \pm 0.088					

Long Lake	% Vis MSP Cov	% Occurrence (Visual)	% Occurrence (Drop Hook)	Density Rating	n = 26
Date	n	Mean \pm 1 S.E.	Spp. % Occ. \pm 1 S.D.	Spp. % Occ. \pm 1 S.D.	Spp. Density \pm 2S.E.
9/26/97	81	41.5 \pm 4.0%	MSP 76.5 \pm 4.7%	MSP 81.5 \pm 4.3%	MSP 4.19 \pm 0.44
			CRT 6.2 \pm 2.7%	CRT 13.6 \pm 3.8%	CRT 1.12 \pm 0.55
Eurasian Watermilfoil:			NUP 3.7 \pm 2.1%	ELD 4.9 \pm 2.4%	ELD 0.31 \pm 0.35
Total Area:	26.3 ha.		PCR 3.7 \pm 2.1%	PCR 3.7 \pm 2.1%	NUP 0.12 \pm 0.17
% of Litt. Zone:	49.6%		PEC 3.7 \pm 2.1%	PEC 3.7 \pm 2.1%	PEC 0.12 \pm 0.17
% of Lake Area:	24.9%		ELD 2.5 \pm 1.7%	PFO 1.2 \pm 1.2%	LTR 0.04 \pm 0.08
Survey criteria:			LTR 2.5 \pm 1.7%		PZS 0.04 \pm 0.08
Milfoil at surface, some matted			NMA 1.2 \pm 1.2%		
Weevil Damage rating	0.086 \pm 0.036				

Table 15 Continued

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
			CRT	26.4 ± 5.2%	CRT	62.5 ± 5.7%	MSP	1.84 ± 0.53
			PZS	1.4 ± 1.4%	NAJ	2.8 ± 1.9%	PZS	0.04 ± 0.08
Eurasian Watermilfoil:					PZS	2.8 ± 1.9%		
Total Area:		14.3 ha.						
% of Litt. Zone:		39.7%						
% of Lake Area:		32.4%						
Survey Criteria: Visible milfoil								
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
			CRT	15.1 ± 4.2%	CRT	39.7 ± 5.7%	MSP	2.81 ± 0.69
Eurasian Watermilfoil					CHC	2.7 ± 1.9%	NAJ	0.08 ± 0.15
Total Area:		36.0 ha.			NAJ	2.7 ± 1.9%	CHC	0.04 ± 0.08
% of Litt. Zone:		100.0%			PEC	1.4 ± 1.4%	PCR	0.04 ± 0.08
% of Lake Area:		49.6%					PEC	0.04 ± 0.08
Survey Criteria: Visible milfoil								
Weevil Damage Rating: 1.411±0.320								
Gray's Bay		% Vis MSP Cov	% Occurrence (Visual)		% Occurrence (Drop Hook)		Density Rating n = 37	
Date	n	Mean ± 1 S.E.	Spp.	% Occ. ± 1 S.D.	Spp.	% Occ. ± 1 S.D.	Spp.	Density ± 2S.E.
8/15/97	97	17.6 ± 2.7%	MSP	54.1 ± 5.1%	MSP	49.0 ± 5.1%	MSP	1.92 ± 0.45
			CHA	1.0 ± 1.0%	CRT	42.9 ± 5.0%	NAJ	1.76 ± 0.41
Eurasian Watermilfoil			PAM	1.0 ± 1.0%	NAJ	38.8 ± 4.9%	CRT	1.59 ± 0.39
Total Area:		58.4 ha.	VAL	1.0 ± 1.0%	PRI	38.8 ± 4.9%	PRI	1.41 ± 0.43
% of Litt. Zone:		113.7%			PZS	25.5 ± 4.4%	PZS	0.92 ± 0.37
% of Lake Area:		82.5%			PEC	12.2 ± 3.3%	CHA	0.76 ± 0.41
Survey Criteria: Visible milfoil					PAM	11.2 ± 3.2%	PAM	0.46 ± 0.25
Weevil Damage rating 0.000±0.000					ELD	5.1 ± 2.2%	PEC	0.43 ± 0.24
					PFO	5.1 ± 2.2%	PFO	0.24 ± 0.18
					CHA	4.1 ± 2.0%	VAL	0.24 ± 0.20
					VAL	3.1 ± 1.7%	ELD	0.08 ± 0.09
					PCR	2.0 ± 1.4%	MSI	0.05 ± 0.08
							PCR	0.05 ± 0.08
Date	n	Mean ± 1SE	Spp.	% Occ. ± 1 SD	Spp.	% Occ. ± 1 SD	Spp.	Density ± 2SE
8/25/98	87	24.8 ± 3.3%	MSP	60.9 ± 5.2%	MSP	58.6 ± 5.3%	MSP	2.73 ± 0.60
			PRI	41.4 ± 5.3%	NAJ	55.1 ± 5.3%	NAJ	2.13 ± 0.63
Eurasian Watermilfoil			PAM	20.7 ± 4.3%	CRT	49.4 ± 5.4%	CRT	2.07 ± 0.57
Total Area:		14.2 ha.	VAL	19.5 ± 4.3%	PRI	37.9 ± 5.2%	PRI	1.97 ± 0.58
% of Litt. Zone:		27.6%	NAJ	18.4 ± 4.2%	PZS	16.1 ± 3.9%	PZS	1.03 ± 0.49
% of Lake Area:		20.0%	PEC	10.3 ± 3.3%	PAM	11.5 ± 3.4%	PAM	0.63 ± 0.44
Survey Criteria: Visible milfoil			PFO	5.7 ± 2.5%	VAL	11.5 ± 3.4%	VAL	0.63 ± 0.41
Weevil Damage Rating: 0.195±0.067			CRT	4.6 ± 2.2%	PFO	9.2 ± 3.1%	ELD	0.53 ± 0.30
			PNA	3.4 ± 2.0%	CHA	6.9 ± 2.7%	MSI	0.27 ± 0.32
			MGD	2.3 ± 1.6%	ELD	5.7 ± 2.5%	PEC	0.27 ± 0.16
			PZS	2.3 ± 1.6%	HET	5.7 ± 2.5%	PFO	0.27 ± 0.25
			HET	1.1 ± 1.1%	PEC	3.4 ± 2.0%	CHA	0.23 ± 0.28
			NMP	1.1 ± 1.1%	ALG	1.1 ± 1.1%	HET	0.20 ± 0.15
			PCR	1.1 ± 1.1%	MGD	1.1 ± 1.1%	MGD	0.13 ± 0.19
			PNO	1.1 ± 1.1%	MSI	1.1 ± 1.1%	LTR	0.03 ± 0.07
			RAN	1.1 ± 1.1%	RAN	1.1 ± 1.1%	PCR	0.03 ± 0.07
							RAN	0.03 ± 0.07

Table 15 Continued

St. Alban's Bay		% Vis MSP Cov	% Occurrence (Visual)		% Occurrence (Drop Hook)		Density Rating n = 28	
Date	n	Mean ± 1 S.E.	Spp.	% Occ. ± 1 S.D.	Spp.	% Occ. ± 1 S.D.	Spp.	Density ± 2S.E.
10/2/97	76	35.1 ± 3.8%	MSP	85.5 ± 4.0%	MSP	73.7 ± 5.1%	MSP	3.21 ± 0.55
			PRI	19.7 ± 4.6%	CRT	38.2 ± 5.6%	CRT	1.61 ± 0.57
			HET	10.5 ± 3.5%	NAJ	22.4 ± 4.8%	PRI	1.11 ± 0.59
			NAJ	9.2 ± 3.3%	HET	15.8 ± 4.2%	NAJ	0.89 ± 0.59
			VAL	7.9 ± 3.1%	PRI	13.2 ± 3.9%	HET	0.86 ± 0.46
			CRT	6.6 ± 2.8%	PRO	13.2 ± 3.9%	VAL	0.75 ± 0.47
			PRO	5.3 ± 2.6%	PZS	11.8 ± 3.7%	CHA	0.61 ± 0.36
			NMP	3.9 ± 2.2%	VAL	10.5 ± 3.5%	PZS	0.61 ± 0.33
			PEC	3.9 ± 2.2%	CHA	9.2 ± 3.3%	MGD	0.57 ± 0.48
			CHA	2.6 ± 1.8%	PEC	5.3 ± 2.6%	MSI	0.57 ± 0.49
			PAM	2.6 ± 1.8%	MSI	3.9 ± 2.2%	PRO	0.54 ± 0.38
			MSI	1.3 ± 1.3%	ELD	2.6 ± 1.8%	PGR	0.39 ± 0.44
			NUP	1.3 ± 1.3%	PAM	2.6 ± 1.8%	PAM	0.36 ± 0.33
			PZS	1.3 ± 1.3%	PGR	1.3 ± 1.3%	PEC	0.36 ± 0.23
							ELD	0.07 ± 0.10
							NUP	0.07 ± 0.14
Eurasian Watermilfoil:								
Total Area:	39.0 ha.							
% of Litt. Zone:	94.5%							
% of Lake Area:	58.7%							
Survey criteria:	Visible milfoil							
Weevil Damage rating	0.217±0.054							
Shady Island								
Date	n	Mean ± 1 S.E.	Spp.	% Occ. ± 1 S.D.	Spp.	% Occ. ± 1 S.D.	Spp.	Density ± 2S.E.
8/29/97	50	9.3 ± 2.9%	MSP	34.0 ± 6.7%	MSP	46.0 ± 7.0%	NAJ	2.13 ± 0.58
			NAJ	16.0 ± 5.2%	CRT	38.0 ± 6.9%	CRT	1.27 ± 0.66
			VAL	10.0 ± 4.2%	NAJ	30.0 ± 6.5%	UTV	1.20 ± 0.68
			UTV	6.0 ± 3.4%	CHA	22.0 ± 5.9%	PZS	1.13 ± 0.70
			PRI	4.0 ± 2.8%	PRI	22.0 ± 5.9%	VAL	1.13 ± 0.64
			PZS	4.0 ± 2.8%	PZS	20.0 ± 5.7%	CHA	1.07 ± 0.60
					VAL	10.0 ± 4.2%	MSP	1.07 ± 0.63
					ELD	8.0 ± 3.8%	PRI	0.93 ± 0.57
					UTV	6.0 ± 3.4%	ELD	0.53 ± 0.43
					PEC	4.0 ± 2.8%	PEC	0.40 ± 0.38
					PFO	4.0 ± 2.8%	PAM	0.27 ± 0.31
					ALG	2.0 ± 2.0%	PFO	0.27 ± 0.24
					BRA	2.0 ± 2.0%	MSI	0.07 ± 0.13
					PAM	2.0 ± 2.0%		
Eurasian Watermilfoil:								
Total Area:	8.6 ha.							
% of Litt. Zone:	45.0%							
% of Lake Area:	45.0%							
Survey criteria:	Visible milfoil							
Weevil Damage rating	0.000±0.000							
Date	n	Mean ± 1SE	Spp.	% Occ. ± 1 SD	Spp.	% Occ. ± 1 SD	Spp.	Density ± 2SE
8/27/98	64	26.3 ± 4.3%	MSP	67.2 ± 5.9%	MSP	59.4 ± 6.1%	MSP	3.38 ± 0.65
			VAL	21.9 ± 5.2%	NAJ	45.3 ± 6.2%	CRT	2.08 ± 0.67
			NAJ	17.2 ± 4.7%	CRT	40.6 ± 6.1%	NAJ	1.63 ± 0.67
			PRI	14.1 ± 4.3%	PZS	26.6 ± 5.5%	CHA	1.13 ± 0.56
			CRT	9.4 ± 3.6%	VAL	17.2 ± 4.7%	PRI	0.67 ± 0.48
			PAM	9.4 ± 3.6%	CHA	15.6 ± 4.5%	VAL	0.63 ± 0.46
			PZS	9.4 ± 3.6%	MGD	12.5 ± 4.1%	PZS	0.46 ± 0.34
			CHA	7.8 ± 3.4%	PRI	12.5 ± 4.1%	ELD	0.29 ± 0.22
			MGD	7.8 ± 3.4%	HET	7.8 ± 3.4%	MGD	0.25 ± 0.28
			NMP	6.3 ± 3.0%	PAM	6.3 ± 3.0%	PAM	0.25 ± 0.22
			NUP	4.7 ± 2.6%	ELD	4.7 ± 2.6%	HET	0.21 ± 0.29
			PEC	4.7 ± 2.6%	NMP	3.1 ± 2.2%	NUP	0.17 ± 0.33
			PNA	4.7 ± 2.6%	NUP	3.1 ± 2.2%	PPR	0.08 ± 0.17
			ELD	3.1 ± 2.2%	PEC	3.1 ± 2.2%	UTV	0.08 ± 0.12
			HET	1.6 ± 1.6%	PNA	1.6 ± 1.6%	RAN	0.04 ± 0.08
			PCR	1.6 ± 1.6%	RAN	1.6 ± 1.6%		
			PNO	1.6 ± 1.6%				
			SCR	1.6 ± 1.6%				

Table 15 Continued

L. Minnewashta		% Vis MSP Cov	% Occurrence (Visual)		% Occurrence (Drop Hook)		Density Rating n = 27	
Date	n	Mean ± 1 S.E.	Spp.	% Occ. ± 1 S.D.	Spp.	% Occ. ± 1 S.D.	Spp.	Density ± 2S.E.
9/22/97	69	24.1 ± 3.0%	MSP	39.8 ± 5.4%	MSP	55.4 ± 5.5%	MSP	3.11 ± 0.72
			PRI	19.3 ± 4.3%	CRT	49.4 ± 5.5%	CRT	2.44 ± 0.76
			CRT	13.3 ± 3.7%	PRI	21.7 ± 4.5%	PRI	1.00 ± 0.48
			NUP	8.4 ± 3.1%	CHA	12.0 ± 3.6%	CHA	0.56 ± 0.47
			NMP	7.2 ± 2.8%	LTR	10.8 ± 3.4	UTV	0.56 ± 0.48
			PEC	6.0 ± 2.6%	UTV	10.8 ± 3.4%	NAJ	0.44 ± 0.46
			PNA	6.0 ± 2.6%	PZS	9.6 ± 3.2%	PZS	0.44 ± 0.31
			BRA	3.6 ± 2.0%	NAJ	7.2 ± 2.8%	HET	0.26 ± 0.38
			LTR	3.6 ± 2.0%	HET	4.8 ± 2.4%	PAM	0.26 ± 0.27
			HET	2.4 ± 1.7%	VAL	4.8 ± 2.4%	JUN	0.19 ± 0.30
			MGD	2.4 ± 1.7%	PEC	3.6 ± 2.0%	VAL	0.19 ± 0.19
			PAM	1.2 ± 1.2%	ELD	2.4 ± 1.7%	PRO	0.15 ± 0.21
			PNO	1.2 ± 1.2%	MGD	2.4 ± 1.7%	ELD	0.11 ± 0.12
			PZS	1.2 ± 1.2%	NUP	2.4 ± 1.7%	MGD	0.11 ± 0.12
					PAM	2.4 ± 1.7%	PEC	0.11 ± 0.12
					PNA	2.4 ± 1.7%	LTR	0.07 ± 0.15
					BRA	1.2 ± 1.2%	NUP	0.04 ± 0.07
					PNO	1.2 ± 1.2%	PNO	0.04 ± 0.07
Eurasian Watermilfoil:								
Total Area:	142.6 ha.							
% of Litt. Zone:	95.0%							
% of Lake Area:	47.5%							
Survey criteria:	Visible milfoil							
Weevil Damage rating:	0.133±0.061							
Pierson Lake								
Date	n	Mean ± 1 S.E.	Spp.	% Occ. ± 1 S.D.	Spp.	% Occ. ± 1 S.D.	Spp.	Density ± 2S.E.
10/3/97	80	21.1 ± 3.4%	MSP	51.3 ± 5.6%	MSP	60.0 ± 5.5%	MSP	3.21 ± 0.59
			CRT	20.0 ± 4.5%	CRT	36.3 ± 5.4%	CRT	2.32 ± 0.73
			NMP	7.5 ± 2.9%	NMP	3.8 ± 2.1%	PGR	0.29 ± 0.29
			PEC	2.5 ± 1.7%	ELD	2.5 ± 1.7%	ELD	0.14 ± 0.20
			NAJ	1.3 ± 1.2%	HET	2.5 ± 1.7%	NAJ	0.14 ± 0.17
			PAM	1.3 ± 1.2%	NAJ	2.5 ± 1.7%	NMP	0.14 ± 0.22
			PCR	1.3 ± 1.2%	JUN	1.3 ± 1.2%	PEC	0.14 ± 0.20
			PGR	1.3 ± 1.2%	LMR	1.3 ± 1.2%	PAM	0.07 ± 0.14
			PRI	1.3 ± 1.2%	LTR	1.3 ± 1.2%	PCR	0.07 ± 0.14
					MGD	1.3 ± 1.2%	CHA	0.04 ± 0.07
					MSI	1.3 ± 1.2%	HET	0.04 ± 0.07
					PAM	1.3 ± 1.2%	UTV	0.04 ± 0.07
					PEC	1.3 ± 1.2%		
					PGR	1.3 ± 1.2%		
Eurasian Watermilfoil:								
Total Area:	27.8 ha.							
% of Litt. Zone:	57.7%							
% of Lake Area:	29.2%							
Survey criteria:	Visible milfoil							
Weevil Damage rating:	0.138±0.043							
Date	n	Mean ± 1SE	Spp.	% Occ. ± 1 SD	Spp.	% Occ. ± 1 SD	Spp.	Density ± 2SE
9/2/98	80	4.0 ± 1.5%	MSP	26.3 ± 4.9%	MSP	33.8 ± 5.3%	CRT	2.11 ± 0.64
			NMP	16.3 ± 4.1%	CRT	32.5 ± 5.2%	MSP	1.93 ± 0.70
			CRT	8.8 ± 3.2%	NMP	7.5 ± 2.9%	UTV	0.32 ± 0.36
			UTV	3.8 ± 2.1%	ELD	2.5 ± 1.7%	NUP	0.21 ± 0.30
			NUP	2.5 ± 1.7%	UTV	2.5 ± 1.7%	ELD	0.18 ± 0.29
			PAM	2.5 ± 1.7%	NAJ	1.3 ± 1.2%	NMP	0.18 ± 0.18
			PRI	2.5 ± 1.7%	PAM	1.3 ± 1.2%	NAJ	0.14 ± 0.17
			HET	1.3 ± 1.2%	PRI	1.3 ± 1.2%	VAL	0.11 ± 0.21
			PZS	1.3 ± 1.2%	PZS	1.3 ± 1.2%	HET	0.04 ± 0.07
					VAL	1.3 ± 1.2%	PEC	0.04 ± 0.07

Table 16. Mean estimated percent visual coverage (± 1 S.E.) of Eurasian watermilfoil by depth range. The total number of sites within the given depth range for the given lake is indicated by n.

Depth (m)	0.0 - 0.5	0.5 - 1.0	1.0 - 2.0	2.0 - 3.0	3.0 - 4.0	4.0 - 5.0	> 5.0
Lake Calhoun 1997	---	---	44.1 \pm 9.4%	34.1 \pm 5.5%	29.9 \pm 5.6%	15.6 \pm 3.8%	0.0 \pm 0.0%
n	0	0	15	16	22	13	3
Calhoun 1998	---	16.5 \pm 8.3%	59.8 \pm 6.7%	19.2 \pm 7.2%	5.4 \pm 2.4%	0.0 \pm 0.0%	---
n	0	13	23	15	11	1	0
Harriet 1997	80.0 \pm 0.0%	58.6 \pm 8.6%	77.5 \pm 4.4%	68.2 \pm 2.7%	32.0 \pm 8.1%	11.7 \pm 4.4%	0.0 \pm 0.0%
n	1	14	16	17	10	12	2
Harriet 1998	49.0 \pm 10.0%	60.5 \pm 9.3%	86.5 \pm 3.6%	62.7 \pm 6.5%	25.0 \pm 10.5%	0.0 \pm 0.0%	0.0 \pm 0.0%
n	5	10	27	15	8	6	2
Isles 1997	---	10.0 \pm 10.0%	36.3 \pm 12.1%	13.4 \pm 4.3%	11.1 \pm 8.3%	0.0 \pm 0.0%	0.0 \pm 0.0%
n	0	2	13	36	12	4	5
Isles 1998	25.1 \pm 9.0%	27.8 \pm 5.0%	5.5 \pm 2.7%	4.2 \pm 2.8%	0.0 \pm 0.0%	0.0 \pm 0.0%	0.0 \pm 0.0%
n	7	9	11	32	7	5	2
Long 1997	20.0 \pm 0.0%	42.3 \pm 8.4%	70.0 \pm 5.4%	21.0 \pm 4.0%	0.0 \pm 0.0%	---	---
n	1	19	29	24	8	0	0
Lake Minnetonka Gray's Bay 1997	---	2.3 \pm 2.0%	15.9 \pm 4.5%	27.0 \pm 4.6%	9.2 \pm 6.7%	0.0 \pm 0.0%	0.0 \pm 0.0%
n	0	10	37	39	5	5	1
Gray's 1998	---	9.5 \pm 6.3%	20.7 \pm 4.2%	37.1 \pm 6.6%	21.7 \pm 10.9%	---	---
n	0	8	49	27	3	0	0
St. Alban's 1997	---	10.3 \pm 5.5%	22.4 \pm 4.8%	54.5 \pm 6.3%	30.0 \pm 9.6%	23.3 \pm 23.3%	0.0 \pm 0.0%
n	0	3	31	30	8	3	1
Shady Island 1997	---	0.0 \pm 0.0%	8.9 \pm 4.4%	15.9 \pm 5.6%	11.0 \pm 9.5%	0.0 \pm 0.0%	---
n	0	3	29	11	3	4	0
Shady Island 1998	---	0.6 \pm 0.2%	27.8 \pm 5.6%	60.0 \pm 10.2%	16.0 \pm 13.6%	0.5 \pm 0.5%	---
n	0	10	38	9	5	2	0
L. Minnewashta n 1997	---	11.2 \pm 6.5%	24.7 \pm 4.3%	41.9 \pm 6.0%	12.7 \pm 4.1%	0.0 \pm 0.0%	0.0 \pm 0.0%
n	0	6	31	18	6	4	4
Pierson 1997	3.0 \pm 2.0%	12.5 \pm 5.6%	37.8 \pm 5.6%	5.8 \pm 3.7%	0.0 \pm 0.0%	0.0 \pm 0.0%	---
n	2	17	36	19	5	1	0
Pierson 1998	1.3 \pm 1.3%	8.5 \pm 6.1%	5.2 \pm 2.4%	0.1 \pm 0.1%	0.0 \pm 0.0%	0.0 \pm 0.0%	---
n	4	13	39	14	6	4	0

Weevil Introduction/Manipulation:

Milfoil density at the 20 Cedar Lake plots in early July 1998 (prior to weevil stocking) ranged from 1858 ± 581 g wet/m² (318 g dry/m²) to 3461 ± 771 g wet/m² (508 g dry/m²) (Table 17); this was somewhat lower than our estimates for similar sites in August 1997 (3988 ± 417 g wet/m²), but was similar to our Cedar Lake permanent transect site in 1998. At the end of the experiment in mid-September, milfoil biomass averaged 3032 ± 376 g wet/m² (N=60).

Table 17. Wet and dry biomass (g/m² \pm 1SE) of Eurasian watermilfoil (MSP) and non-milfoil plants, %Eurasian watermilfoil and mean number of species per sample for the cage experiment. The July sample was taken 2 weeks prior to stocking and the September sample was taken 8 weeks after initial stocking. Two samples per cage were taken in July and 3 samples per cage in September. N=5 replicate cages per treatment. Open cages allow fish entry, closed cages do not. A total of 130 adult weevils were stocked into each stocked cage.

Date	Cage Type	Stocked	MSP	NonMSP	%MSP	Mean No. spp.
07/07/98	Open	No	3461 ± 771	189 ± 82	$86.0 \pm 7.7\%$	2.20 ± 0.20
	Dry		508 ± 118	19 ± 8	$87.5 \pm 7.1\%$	
07/07/98	Closed	No	2347 ± 879	2035 ± 1244	$60.3 \pm 14.2\%$	2.80 ± 0.20
	Dry		372 ± 158	186 ± 110	$66.8 \pm 14.9\%$	
07/07/98	Open	Yes	1858 ± 581	1061 ± 615	$68.6 \pm 15.7\%$	2.40 ± 0.40
	Dry		318 ± 125	109 ± 65	$70.0 \pm 15.5\%$	
07/07/98	Closed	Yes	2823 ± 1044	249 ± 73	$88.1 \pm 4.6\%$	2.50 ± 0.22
	Dry		404 ± 158	21 ± 7	$91.2 \pm 3.9\%$	
09/17/98	Open	No	3475 ± 786	522 ± 228	$83.5 \pm 7.7\%$	1.93 ± 0.27
	Dry		441 ± 95	55 ± 22	$84.0 \pm 7.7\%$	
09/17/98	Closed	No	3191 ± 840	1579 ± 846	$73.5 \pm 11.0\%$	2.13 ± 0.08
	Dry		369 ± 106	142 ± 79	$75.7 \pm 11.4\%$	
09/17/98	Open	Yes	3213 ± 421	552 ± 529	$89.6 \pm 9.7\%$	1.47 ± 0.17
	Dry		366 ± 58	55 ± 53	$89.8 \pm 9.4\%$	
09/17/98	Closed	Yes	2247 ± 438	143 ± 46	$92.2 \pm 3.0\%$	1.80 ± 0.17
	Dry		283 ± 63	16 ± 6	$92.4 \pm 3.5\%$	

Weevil stocking was generally successful. Higher densities of weevils were found in stocked vs non-stocked cages during bi-weekly visual surveys (Table 18). It also appears that fish predation may be limiting weevil populations; counts were highest in the stocked closed cages and were generally higher in closed vs open cages. Analysis of variance showed some significant stocking effects but no significant cage effects. Numbers of weevil adults differed significantly on 7/31/98 ($P = 0.035$) but this may be due to stocking, which occurred only two weeks earlier. The number of weevil larvae ($P = 0.074$) and total weevils ($P = 0.066$) showed significant stocking effects on 8/10/98. The significant differences in the total number of weevils primarily reflects the higher density of larvae (Table 18).

Table 18. Visual counts (mean number per 100 stems and 1 SE) of weevils in stocked and unstocked cages (open and closed) at Cedar Lake in 1998. There were 5 reps of each treatment combination.

Date	Cage type	Stocked	Eggs	Larvae	Pupae	Adults	Total
07/31/98	Open	No	0.0	9.0	0.0	0.0	9.0
		1 SE	0.0	4.3	0.0	0.0	4.3
	Closed	No	0.0	2.8	0.0	0.0	2.8
		1 SE	0.0	2.3	0.0	0.0	2.3
	Open	Yes	1.4	8.8	0.0	0.4	10.6
		1 SE	1.4	3.6	0.0	0.2	5.1
08/10/98	Open	No	0.0	0.0	0.0	0.0	0.0
		1 SE	0.0	0.0	0.0	0.0	0.0
	Closed	No	0.0	3.2	0.0	0.2	3.4
		1 SE	0.0	1.5	0.0	0.2	1.5
	Open	Yes	0.4	10.0	0.0	0.0	10.4
		1 SE	0.4	2.8	0.0	0.0	3.0
08/21/98	Open	No	0.0	0.8	0.0	0.0	0.8
		1 SE	0.0	0.6	0.0	0.0	0.6
	Closed	No	0.0	1.8	0.0	0.4	2.2
		1 SE	0.0	0.8	0.0	0.3	0.9
	Open	Yes	0.3	7.2	0.3	0.7	8.4
		1 SE	0.3	3.3	0.2	0.3	3.7
09/01/98	Open	No	0.0	1.1	0.0	0.0	1.1
		1 SE	0.0	0.5	0.0	0.0	0.5
	Closed	No	0.0	2.0	0.5	0.4	2.9
		1 SE	0.0	1.3	0.5	0.4	1.8
	Open	Yes	0.0	6.3	1.3	0.8	8.4
		1 SE	0.0	1.9	0.7	0.4	2.1
Closed	Yes	0.4	18.1	1.3	0.8	20.7	
	1 SE	0.3	9.2	0.8	0.5	9.9	

Repeated measures analysis on weevil observations indicated significant differences in the number of weevil larvae ($P = 0.004$) and total weevils ($P = 0.002$) through time. Again, the total number of weevils probably reflects the increase in the number of larvae. These results show that weevils can be established in an area that previously showed no evidence of weevil populations.

Milfoil biomass generally increased in the cages after stocking, with the exception of the stocked-closed cages, where milfoil biomass declined an average of 580 g wet/m^2 (121 g dry/m^2). Analysis of variance indicated a significant block effect but no overall cage or stocking effects on wet biomass. An analysis of variance with the change in wet milfoil biomass (September biomass - July biomass) as the response, eliminated the block effect and also revealed no significant cage or stocking effect (all $P > 0.25$). However, a significant cage type by stocking interaction was found ($P = 0.062$) with closed cages showing the greatest reduction in milfoil wet biomass. These results suggest that the combination of cage type and stocking had a significant effect on milfoil biomass and indeed the closed cages stocked with weevils had a decline in biomass while biomass increased in the other cages. Although dry biomass decreased in most treatments, the greatest decline occurred in closed, stocked cages; however, ANOVA with dry milfoil biomass showed no

significant effects. Post hoc multiple comparisons indicated no significant difference ($P > 0.1$) among individual treatments, probably due to the relatively high variability.

Two-way ANOVA with the change in the number of weevils (September counts - July counts) from biomass samples as the response variable showed a significant ($p = 0.096$) stocking by cage interaction for weevil larvae. Mean counts generally indicated higher numbers of weevils from stocked cages, but the non-stocked closed cage mean was also high (Table 19). Weevil larvae per 100 stems also showed a significant ($p = 0.085$) stocking effect with more weevils in stocked cages. Some weevils were found in closed not-stocked cages, but not in the open not-stocked cages.

Table 19: Counts (mean number per $m^2 \pm 1$ SE) of weevils found in biomass samples from stocked and unstocked cages (open and closed) at Cedar Lake in 1998. There were 5 reps of each treatment combination.

Date	Cage Type	Stocked	larvae	pupae	adults.	Total
7/7/98	Open	No	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
	Closed	No	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
	Open	Yes	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
	Closed	Yes	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
9/17/98	Open	No	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
	Closed	No	1.3±1.3	0.7±0.7	0.0±0.0	2.0±1.3
	Open	Yes	2.0±1.3	0.0±0.0	0.0±0.0	2.0±1.3
	Closed	Yes	0.0±0.0	0.7±0.7	0.7±0.7	1.3±1.3

Overall, this experiment suggests that fish predation (open cages) can reduce weevil densities and that protected weevil populations can have an effect on milfoil biomass. The effects are not strong, however, and variability is high. We were not completely effective at removing all the fish in the closed cages and we have now figured out how to more effectively introduce and establish weevils in the cages. The cages were left in place and the experiment was repeated at the same plots in summer 1999, in part to further test the predation hypothesis and also to determine if sustained (over several years) higher weevil densities have a more pronounced effect on the milfoil. These results will be available in our spring 2000 progress report.

Influence of milfoil genotype and rearing sediment on weevil performance:

Weevil development time varied significantly between plant/sediment combinations (Table 20). The shortest total development (17.1 d) occurred with the Auburn sediment by Otter plant treatment (Table 21) and the longest development (20.6 d) occurred with the Otter sediment by Otter plant combination. Approximately 2 to 3 more days were required for full development for either plant grown on Otter Sediment (Table 21).

Weevil weight (Table 22) showed the same relationship as total development time, with a significant sediment effect and a plant by sediment interaction (Table 20). Plant quality influenced both development time and weight similarly: longer development times resulted in smaller adult weevils. The Otter sediment also produced a lower survival, with the highest mortality on the Otter plants grown in Otter Sediment (Table 22). Thus it appears that there may be significant differences in weevil developmental performance on plants in different lakes. The effect appears to be primarily due to a plant growing sediment effect rather than a plant genotype effect, however, weight and survival appear to be affected by both sediment and plant genotype. Sediment analyses indicated no difference in sediment ammonium levels or bulk density, but Otter sediment had higher organic content (Table 23). Somewhat surprisingly, initial nitrogen content was higher and phenolic content lower for Otter plants reared on Otter sediment, compared to the other plant-sediment combinations; weevils performed most poorly on these plants, suggesting that low nitrogen and high phenolics was not the cause of their poor performance. However, for the other three plant and sediment treatments, weevils appeared to perform better on higher nitrogen and lower phenolic plants. Trends with mined plants appear less clear, and are probably confounded by the effects of weevil mining.

The differences in development time, weight and survival could have significant influence on population levels in the field; the poorest performance of weevils on Otter plants grown in Otter sediment may explain the low densities of weevils seen in Otter Lake. Experiments conducted in 1999 suggest that plant size differences (not measured in 1998) rather than plant quality may have influenced the results. More work on the role of plant chemistry and quality, both in the lab and in the field, is needed.

Table 20. P-values and degrees of freedom from ANOVA analysis for development times and weights at eclosion (error df = 40).

	df	Hatch	Larva	Pupa	Total	Weight
Sediment	1	0.263	0.164	0.004	0.000	0.001
Plant	1	0.002	0.222	0.218	0.082	0.091
Sediment * Plant	1	0.801	0.633	0.125	0.265	0.003

Table 21. Average development times (days \pm 2SE) for each plant/sediment combination.

Plant	Sediment	Hatch	Larva	Pupa	Total
Auburn	Auburn	3.4 \pm 0.3	6.7 \pm 0.6	6.9 \pm 0.6	17.3 \pm 0.5
Auburn	Otter	3.5 \pm 0.4	7.1 \pm 0.5	7.6 \pm 0.7	18.7 \pm 0.6
Otter	Auburn	2.9 \pm 0.3	7.0 \pm 0.4	6.8 \pm 0.6	17.1 \pm 0.4
Otter	Otter	3.1 \pm 0.2	7.8 \pm 2.2	8.8 \pm 2.2	20.6 \pm 3.4

Table 22. Weevil weights (mg) and percentage mortality for each plant/sediment combination.

Plant	Sediment	Weight (mg)	Mortality
Auburn	Auburn	1.52 \pm 0.11	13.3 %
Auburn	Otter	1.48 \pm 0.14	20.0 %
Otter	Auburn	1.62 \pm 0.10	6.7 %
Otter	Otter	1.13 \pm 0.25	66.7 %

Table 23. Sediment ammonium (mg/L), bulk density (g dm/ ml) and organic matter, and plant nitrogen (% dry), C:N ratio and phenolics (μ M/g dry mass). Plant chemistry is for the top 20 cm of plants prior to being mined by larvae (initial condition) or at the end of the experiment after being mined by larvae. Measurements were made on 5 initial plants for each sediment and source and 7 mined plants for each sediment and source. Plant data provided by Dr. David Spencer, Exotic & Invasive Weed Research Unit, UC Davis.

Sediment chemistry		NH ₄ ⁺	Bulk Density	% Organic Matter	
Otter		0.452 \pm 0.346	1.112 \pm 0.008	3.41 \pm 0.18%	
Auburn		0.514 \pm 0.189	1.199 \pm 0.020	2.07 \pm 0.33%	
Plant	Sediment	Condition	N%	C:N	Phenolics
Auburn	Auburn	Initial	1.17 \pm 0.22	34.6 \pm 7.4	213.5 \pm 73.1
		Mined	1.49 \pm 0.20	27.2 \pm 4.4	216.6 \pm 33.4
Auburn	Otter	Initial	1.07 \pm 0.12	36.7 \pm 3.8	226.9 \pm 34.9
		Mined	1.38 \pm 0.23	30.5 \pm 7.0	205.6 \pm 42.9
Otter	Auburn	Initial	1.29 \pm 0.11	30.6 \pm 2.5	196.7 \pm 95.1
		Mined	1.23 \pm 0.19	33.2 \pm 4.9	137.0 \pm 34.7
Otter	Otter	Initial	1.39 \pm 0.38	30.3 \pm 10.2	114.8 \pm 46.3
		Mined	1.26 \pm 0.19	32.0 \pm 4.4	166.8 \pm 20.8

Effects of plant community on recolonization

We were able to alter plant communities with our removal manipulations (Table 24), however, both Eurasian milfoil and non-Eurasian milfoil mean dry mass generally declined in all treatments in both lakes. The exception was an increase in non-Eurasian watermilfoil mean dry biomass in the control and remove Eurasian watermilfoil plots in Lake Auburn. In both cases, the change was entirely due to an increase in the mean dry biomass of coontail (*Ceratophyllum demersum*). In the August samples, coontail constituted 96-98% of the non-Eurasian watermilfoil dry biomass; in the September samples, it averaged 100%. Due to its growth habit, it is difficult to separate how much of this increase is due to new growth and how much is due to migration of unrooted plants into the area. A substantial drop in water clarity was also noted in Lake Auburn through the growing season which may have favored coontail regrowth due to its tolerance for low light levels. The average number of species per m² also declined in all treatments at both lakes.

Table 24. Mean dry biomass (g/m²±1 SE) of Eurasian watermilfoil (MSP) and non-Eurasian watermilfoil, percent Eurasian watermilfoil, number of Eurasian watermilfoil stems and total number of species for the experimental plots on Lake Auburn and Otter Lake.

Lake Auburn

Date	Manipulation	MSP	non MSP	%MSP	Stem Counts	No. spp.
8/17/98	Control	98.±28	169.±73	39.0±11.0%	145.0±47.2	2.38±0.38
	Remove MSP	112.±38	124.±33	46.3±13.3%	137.5±53.3	1.88±0.13
	Remove Natives	81.±18	169.±34	37.6±9.1%	105.0±35.4	2.13±0.13
	Remove All	128.±44	171.±77	48.7±19.5%	151.3±56.3	2.00±0.41
9/21/98	Control	37.±18	176.±49	23.9±10.9%	82.5±45.4	2.00±0.00
	Remove MSP	58.±24	158.±56	36.7±17.9%	46.7±20.2	1.83±0.14
	Remove Natives	10.±4	71.±27	22.1±10.0%	13.8±12.1	1.63±0.13
	Remove All	26.±16	39.±24	32.0±19.7%	46.3±30.8	1.50±0.29

Otter Lake

Date	Manipulation	MSP	non MSP	%MSP	Stem Counts	No. spp.
8/12/98	Control	9.±6	191.±15	4.9±3.3%	16.3±7.5	5.88±0.24
	Remove MSP	11.±6	353.±53	4.4±2.4%	12.5±7.8	5.88±0.55
	Remove Natives	14.±9	196.±13	5.6±3.5%	28.8±16.9	5.50±0.54
	Remove All	7.±4	181.±61	6.4±4.1%	20.0±13.7	5.25±0.32
9/22/98	Control	6.±3	152.±45	8.5±5.1%	11.3±8.3	3.75±0.60
	Remove MSP	0.±0	250.±28	0.2±0.1%	0.0±0.0	4.83±0.38
	Remove Natives	6.±6	16.±11	16.3±14.3%	6.3±6.3	3.25±0.85
	Remove All	1.±0	18.±12	15.8±6.8%	1.3±1.3	3.13±0.55

For Lake Auburn, analysis of variance with average Eurasian watermilfoil dry biomass, average total plant biomass and number of Eurasian watermilfoil stems per m² as the response variables showed significant sampling session effects (all P< 0.01). These effects may be a direct result of the manipulations because re-sampling occurred only about five weeks after the manipulations took place and no significant treatment effects or session by treatment interactions were seen for any of the variables tested. There may not have been enough time for re-colonization to take place. The average number of species also showed significant session effects (p = 0.055) with decreased species richness in September samples. ANOVA with the change through time (August - September) as the response for all variables tested supported the previous results by showing no significant differences between treatments.

For Otter Lake, significant session and treatment effects were seen for a number of the response variables (Table 25). As with Lake Auburn, session effects may be the direct result of the manipulations. No session by treatment interactions were noted. However, ANOVA on the

differences (August - September) of the means for all variables showed significant differences for total dry mass ($p = 0.074$) and total non-Eurasian watermilfoil mass ($p = 0.100$). These values probably reflect the mean differences in dry mass between the control treatment plots and the other treatments (Table 26).

Table 25. P-values for two-way ANOVA on Otter Lake macrophyte dry biomass samples. All variables were averages in units per m^2 .

Variable	Session effects	Treatment effects
Total Dry Weight	< 0.001	< 0.001
MSP Dry Weight	0.081	NS
Number of MSP Stems	0.044	NS
Native Macrophyte Dry Weight	< 0.001	< 0.001
Coontail Dry Weight	0.003	NS
Percent of Natives That Was Coontail	NS	0.040
Number of Species	< 0.001	NS

Table 26. Differences between mean total ($g/m^2 \pm 1$ SE) and mean non-Eurasian watermilfoil dry biomass collected in August and September at Otter lake. Positive values reflect a decrease over time.

Treatment	Total dm	non-MSP
Control	42 \pm 29	40 \pm 32
Remove Eurasian watermilfoil	102 \pm 48	93 \pm 53
Remove non-Eurasian watermilfoil	188 \pm 23	180 \pm 17
Remove All	169 \pm 49	163 \pm 50

Average native macrophyte biomass decreased in all treatments, with the most pronounced decreases in the remove natives and remove all treatments. There was no significant difference between the change in mean native macrophyte biomass in the control and remove MSP treatments. The average percent contribution that coontail made to the native macrophyte community increased in all treatments except in the remove MSP plots where it decreased from 8.8 \pm 3.8% to 3.2 \pm 1.4%. The greatest increase in the mean percent contribution of coontail to the native macrophyte community was seen in the remove native treatment (16.2 \pm 6.3% in August and 35.6 \pm 5.0% in September). Unattached coontail migration may have accounted for some of these increases. Water clarity did not decline in Otter Lake as it did in Lake Auburn, so it is unlikely that a favorable change in light penetration was available for coontail.

No statistical analysis was done on weevil data for either lake. No weevils were found in any of the samples from Lake Auburn and only one individual was found in Otter Lake samples. This lone weevil larva was found in a remove-all plot during the August sampling session.

These results do not strongly support any conclusions about macrophyte community response to substrate disturbance. However, there is some evidence that coontail may be more effective at recolonizing areas that have been cleared of vegetation. There is also evidence to support the hypothesis that clearing lake-bottom vegetation can decrease species diversity and may eventually lead to a monoculture of the most effective competitor. A longer period of time between the manipulations and re-sampling would probably have refined the analysis by minimizing the variability due to the treatment itself.

We resampled the plots twice in summer 1999 to assess changes that may have occurred over the winter and since ice-out and to determine longer-term effects of community manipulation

Overwinter assessments:

Shoreline weevil densities in fall 1998 were lower than the preceding 3 years and were similar to 1994 (Fig. 5). This observation matches the low in-lake densities; our in-lake weevil surveys in Auburn revealed no weevils after mid-July, and no weevils were found in September in-lake samples at either Auburn or Smith's Bay. No weevils were found in soil at Lake Auburn in

spring 1999, suggesting few weevils for spring in-lake colonization. Smith's Bay overwinter densities were higher even though no weevils were found in the lake in September. Overwinter mortality was apparently quite low as 50 weevils per m^2 were found in spring 1999 compared to $61/m^2$ in fall 1998. Spring 1998 densities were also not as low as might have been expected based on the fall 1997 estimates, which suggests the mild winters in 1997-1999 were conducive to good shoreline survival. There was a significant correlation between Auburn and Smith's Bay shoreline densities over the past five years, suggesting climatic control of overwinter densities. No such correlations were seen with in-lake densities. The low fall in-lake densities support our previous contention that in-lake factors appear very important to weevil population levels.

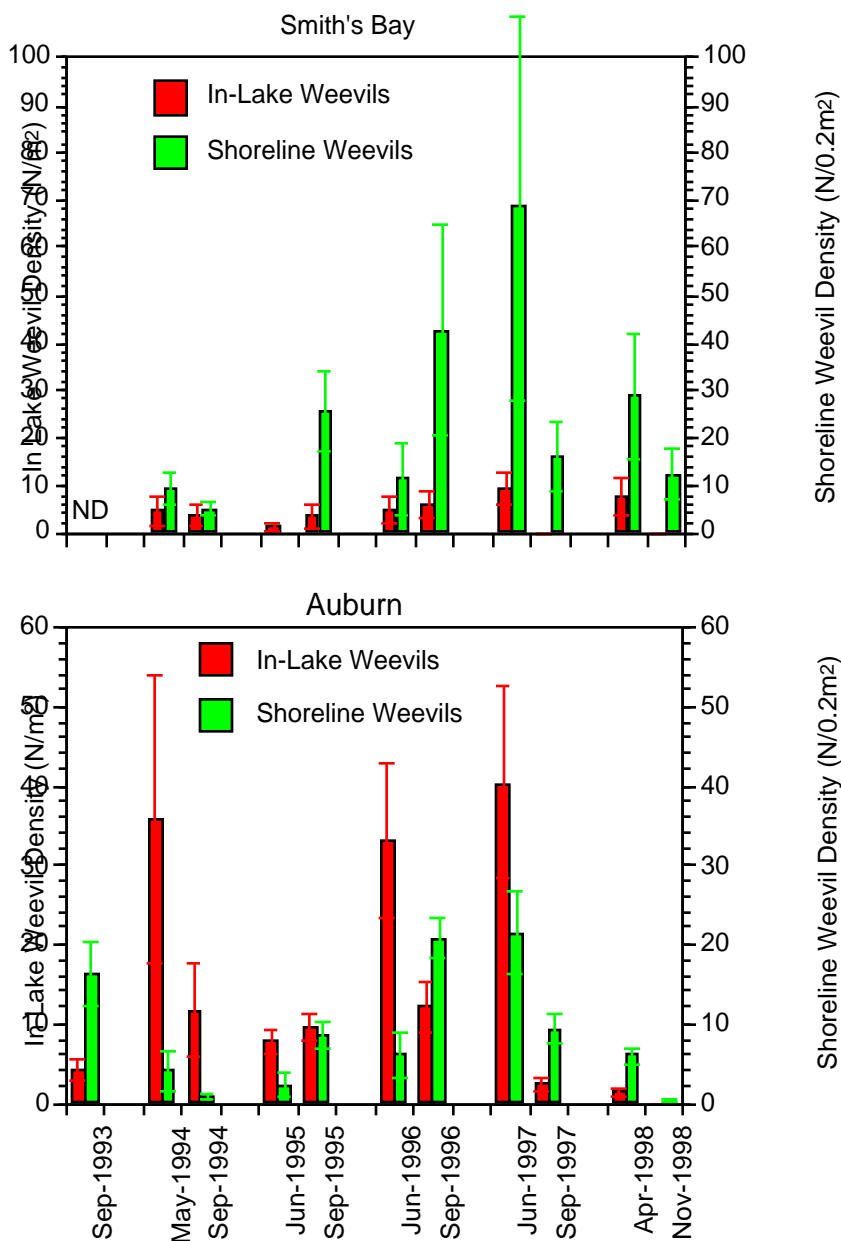


Fig. 4. Mean number of *E. lecontei* adults per $0.2 m^2$ shoreline litter samples at the peak for each sampling period and the corresponding in-lake density closest to the time of shoreline sampling at Lake Auburn and Smith's Bay. Vertical bars are 1 SE. Shoreline densities in April 1999 were $0/0.2m^2$ in Lake Auburn and $10 \pm 3.6/0.2m^2$ at Smith's Bay.

Temperature-development time relationships:

Weevil development followed a predictable relationship with temperature (Mazzei et al. 1999). Fastest development times were at 27-31 °C, with a peak at 29 °C and a decline above 29 °C. The 1997 data (21, 25 and 29 °C) fit well with the 1996 data. Development times ranged from 60d at 15 °C to 17d at 27-31 °C. All stages were influenced by temperature, but egg hatch showed the least increase in rate at the higher temperature. It should be noted that development was successful for about 75% of the weevils at temperatures above 15 °C, but only 4 weevils successfully developed at 15 °C and less than half the eggs hatched. Degree days required for development ranged from 78 degree days for hatch to 309 degree days for complete development with a minimum threshold temperature of about 10 °C (Table 27). Based on these data and analysis of continuous lake temperature data, weevils should complete development in about 17-25 days during June to mid-September. Damage rate (cm/d) by larvae increased with temperature but total damage incurred during the larval stage did not. Total damage averaged 15.1 ± 1.9 cm. These observations on development rate and damage agree with the results of our previous tank experiment where we saw new adults in 20 days and substantial mining of milfoil plants with about 2 weevils per stem.

We also determined that overwintering weevils will begin to develop and lay eggs after about 9 days of feeding on milfoil in the water at 15 °C; egg development occurred more rapidly at 20 °C (6 d), but weevils incubated at 10 °C failed to develop ova after more than 40 days. Thus, it appears that females will not develop eggs at temperatures ≤ 10 °C, but develop eggs within 1 to 2 weeks of feeding at 15-20 °C. Because weevils enter the water starting with ice out until mid-May, when water temperatures are below 15 °C, we suspect that water temperature alone, not entry to the water, will determine when egg laying starts.

Thermistors at 0.75m depth in Lakes Auburn and Smith's Bay showed that in 1996 mid-May minimum temperatures exceeded 10 °C in both lakes and by mid-June temperatures averaged 24-25 °C; temperature declined rapidly in mid-September from 25 to around 15 °C (Appendix II). Temperatures occasionally reached, but did not exceed, 31 °C. To provide a conservative estimate of accumulated degree days, we only included data from mid-May to mid-September when mean daily temperatures were above 15 °C (and minima well above 10 °C). In both lakes more than 1550 degree days (>10 °C, the lower thermal threshold) were accumulated, indicating a potential for development of five generations. Even when the accumulation was delayed for 10 days after a mean of 15 °C was reached (to account for egg development), enough degree days were accumulated to produce five generations. In 1998, even more degree days were accumulated: over 2000 degree days (>10 °C) were accumulated in both lakes (both surface and 0.75 m depth) before temperatures declined below 15 °C (Appendix II). When degree day accumulation was delayed for 10 days after 15 °C was reached, there were still adequate degree days to produce 6 or more generations in both lakes (7 in Lake Auburn). Even in 1997, when recording in Smith's Bay did not start until 9 June, over 1300 degree days were accumulated by mid-September and 1500 were accumulated before temperatures dropped below 15 °C.

Because milfoil weevils stop laying eggs in early-mid September, either in response to declining temperatures or daylength, the final generation may not be produced. However, it is likely that four generations can be regularly produced. Sheldon and O'Bryan (1996) suggested, based on field observations of patterns of egg and larval frequencies, that three generations were produced in Vermont lakes. Our results suggest that at least in the Midwest, the first wave of overwintering weevils can regularly produce four to five generations, although frequency distributions may only reveal three to four generations.

In 1998 we were also able to compare surface and subsurface (0.75 m depth) temperatures (recorder failure in 1996 prevented a complete comparison). Early in the spring, surface and subsurface temperatures were similar, although surface temperatures showed greater diel variation than subsurface temperatures. Later in the season, surface temperatures were 0.5 to 2.5 °C warmer; daily highs exceeded 30 °C regularly in the surface layer at Lake Auburn (area of matted milfoil), but rarely did so below the canopy. Still, surface temperatures never exceeded 33 °C and daily means remained below 31 °C. The warmer surface waters would provide (to the end of September) about 130 extra degree days in Smith's Bay and 150 degree days in Lake Auburn.

Larvae and adults may be able to take advantage of the warmer temperatures, but pupae are probably restricted to the 0.75 m depth temperatures.

Table 27. Parameter estimates from regression of development rate (1/d) on temperature ($^{\circ}\text{C}$), estimated lower threshold development temperature (T_0) and cumulative degree days (DD) required for development of *Euhrychiopsis lecontei*. Regressions are based mean rates over 7 temperatures (15-29 $^{\circ}\text{C}$). From Mazzie et al. (1999).

Stage	Y-Intercept	Slope	r^2	T_0 ($^{\circ}\text{C}$)	DD ($^{\circ}\text{C}\text{-day}$)
Egg	-0.1048	0.01281	0.91	8.2	78.0
(SE)	(0.0409)	(0.00177)		(2.1)	(10.8)
Larva	-0.0960	0.00959	0.89	10.0	104.3
(SE)	(0.0353)	(0.00153)		(2.1)	(16.6)
Pupa	-0.0887	0.00844	0.99	10.5	118.5
(SE)	(0.0061)	(0.00026)		(0.4)	(3.7)
Complete	-0.03156	0.00323	0.99	9.8	309.2
(SE)	(0.0033)	(0.00014)		(0.6)	(13.8)

Population synthesis:

The biweekly weevil surveys in Lake Auburn were instructive. Based on temperature-development predictions given above, the observation that egg development will not occur until temperatures exceed 10 $^{\circ}\text{C}$ (but will occur within 6-9 days \sim 15 $^{\circ}\text{C}$), and the 0.75 m depth recording thermistor in Lake Auburn, we estimated that the initial adults and larvae found on 8 May 1998 were from the overwinter generation. Furthermore, the larvae had likely just recently hatched. Appearance of pupae and reappearance of adults on 29 May matched our predictions for the first complete spring generation of weevils. These results suggest that the development and survival of the new generation was not good and this generation failed to produce a substantial second summer generation; adult progeny of the late May weevils should have appeared by the end of June. No weevils were spotted in Lake Auburn after July 10th 1998 (Tables 7 and 8) and shoreline overwinter densities were quite low (Fig. 5), suggesting an early summer demise of the population. A substantial drop in water temperature occurred between the end of May and 9 June (24 to 17 $^{\circ}\text{C}$), which may have affected weevil development; however a similar drop was noted in Smith's Bay (23 to 17 $^{\circ}\text{C}$), and although weevil populations failed to increase over the summer, weevils were detectible through early August (Table 7). In fact, bi-weekly surveys at Lake Auburn during the summer of 1999 revealed no weevils. The complete disappearance of weevils at Lake Auburn remains a mystery, although poor plant condition (due to early damage and poor water clarity) may also have been a factor. An augmentation or reintroduction in the spring of 2000 might be instructive; the lake has previously supported high densities of weevils and the lack of weevils in 1999 may be due to the lack of initial colonists (no weevils were found in the April shoreline samples). Augmentation may provide the initial boost needed at this site. Alternatively, if augmentation is not successful, that will suggest that conditions have changed making the lake less suitable for weevils. Either result will suggest factors that may be affecting development of adequate weevil populations.

It is important to note that in the lakes (and years) for which weevils appear to be controlling milfoil, populations of weevil persist throughout the summer or increase. In the other lakes, weevil populations do not increase over the summer, suggesting the importance of in lake limiting factors. Based on the insights gained from the regular sampling for all weevil life stages at Lake Auburn, we added two lakes to the biweekly survey series in 1999 (Cenaiko and Smith's Bay). The results from these surveys will be provided in our first progress report for the new biennium.

Based on our previous lab work (Newman et al. 1997a; Mazzei et al. 1999) survival rates for complete development should be above 50% and at least 4 generations should be completed per

summer. Our dissections indicate typically a 50:50 sex ratio, at least for newly eclosed weevils. Based on our observations and those of Sheldon (Sheldon and O'Bryan 1996, Sheldon 1997), females can lay 0.5-3 eggs per day with 1 egg per day being a conservative estimate. Assuming females that survive may have a 30 d life span, a female should produce 7.5 viable female adult progeny. The first laying females in the spring should therefore be able to result in over 3150 females (over 6250 adults) produced by the end of the summer. It should be noted that these initial numbers are somewhat validated by our tank experiment where 6 adults (3 females) resulted in about 30 adults in 28d (Newman et al. 1996). The above expectations would predict around 50 adults. However, we also had similar numbers of adults produced in the higher stocking densities, indicating population limitation, probably due to lack of meristems and suitable stems for complete development. Because we have not generally seen densities in the field over 1 or 2 per stem, it is unlikely that undamaged milfoil is limiting our field populations. In fact, our stem survey at Cenaiko Lake in early September 1998 revealed a very high weevil density (3.6 per stem) in spite of highly damaged stems and a seeming lack of good meristems. Higher mortality during egg-adult development would reduce the estimate but it is unclear what factors would significantly alter survival during development; host quality and host resistance are possible factors at least for some lakes (Tables 20-22). The poor survival noted for weevils reared on Otter Lake plants grown on Otter Lake sediment, suggests plant condition could be important. A two day reduction in development time will not have a large effect on summer-long population size given 4 generations per summer, however, large differences in survival from egg to adult would have profound impact on summer long population size (see below) and would appear to be key. It is not yet clear what a good indicator of plant quality is. We conducted a similar set of experiments in 1999 with Auburn and Cedar plants to further test the importance of plant condition; preliminary results from these experiments suggest that plant size differences rather than internal chemical differences may explain the observations in 1998. If so, it is less clear how this would translate into effects in the field where plants are generally much larger than those we can use for our laboratory experiments. Sharp temperature fluctuations, temperatures above 34 °C (Mazzei et al. 1999) and stem breakage due to wave disturbance are other possible factors that limit developmental survival and thus populations, however, it is not apparent how these factors differ among our sites.

Fish predation could be an important limiting factor, particularly for adults; larvae are less vulnerable and pupae seem invulnerable (Sutter and Newman 1997). Our fish exclusion results at Cedar Lake suggest that fish predation could be limiting weevil populations there. The effect of adult mortality, particularly lifespan of females could be very important. If for example, fish predation reduced average female lifespan to 5 days then the population would be just above a replacement rate. Similarly, if only half the females produced survived to reproduce, only 150 females per summer would be produced from a successful overwintering female. Because females lay on average around 1 egg per day, longevity becomes important to maintain or increase population size from a base of overwintering adults. Assuming a 50:50 sex ratio, 1 egg per day and 50% survival from egg to adult, a female must live about 4-5 days to provide a stable population. With four or more generations per summer, and increase in longevity to 8 days would result in about a 15-16 fold increase in population and a longevity of 16 days would result in over a 250 fold increase in population size. With the exception of Cenaiko, these summer long increases in population density have not been evident.

It is not clear what permits development of such high weevil populations in Cenaiko Lake, however, low predation by sunfish may be a factor. Minnesota DNR survey records (MN DNR 1999) from 1992 suggested little difference in panfish populations between Cedar and Cenaiko Lakes (about 70 sunfish per trapnet) and similar densities in Lake Auburn in 1995 (85/trapnet). However, personal observations suggest much higher sunfish densities in Cedar Lake than Cenaiko and a 1998 DNR survey report from Cenaiko showed much lower sunfish densities (5.1 per trapnet), in line with our visual observations. Thus reduced sunfish densities in Cenaiko may have permitted the development of high weevil populations that persist throughout the summer. In fact the apparent decline in sunfish abundance at Cenaiko between the 1992 and 1998 surveys may explain why milfoil had been quite dense in Cenaiko prior to our observations in 1996. Reduced sunfish densities may have permitted the weevil populations to increase to adequate levels to

control the milfoil. Unfortunately, fisheries data for 1993-1997 are not available so it is not clear when the decline in sunfish occurred. As noted above, relatively small increases in longevity or increases in adult or egg to adult survival can be major determinants of summer-long population density and a persistent summer long population may be required to affect control. Overwinter populations and the slower development of weevils at cool temperatures suggest that milfoil will be able to outgrow the weevils at the beginning of the summer. Given that weevils only mine about 15cm of stem to complete development, persistent stress and damage through the summer is likely to be required to cause declines.

The MILFO model just became available from the US Army Corps of Engineers (10 November 1999) and we have not had time to explore this model. Without a milfoil model we cannot explore adding a weevil component. However, our biweekly surveys from three lakes in summer 1999 will now permit us to compare weevil population predictions to field observations

Summary

We have documented one decline that is clearly attributable to weevil stem mining, and have evidence that weevil damage, at least in the shallower sites, at Lake Auburn and Smith's Bay have reduced milfoil abundance. The decline at Cenaiko Lake has persisted; an increase in milfoil in early summer 1998 was met with high weevil populations and a subsequent decrease of milfoil and the decline persisted through the summer of 1999 with milfoil biomass below 1g/m^2 (Newman and Biesboer, *in press*). It is not certain what permits development of such high weevil populations in Cenaiko Lake, however, low predation by sunfish appears to be a factor. If predation by sunfish is shown to be an important limiting factor, it may be feasible to explore fisheries enhancements to the sunfish population and size structure through enhancement of predator populations (e.g.,) or fishing regulations. It would be particularly fortuitous if enhancing sport fishing populations would aid in the biological control of Eurasian watermilfoil.

The longer and slower decline of Eurasian watermilfoil leveled at Smith's Bay; at the shallower sites milfoil remains suppressed and native plants have developed extensively. At deeper sites, with little evidence of weevil damage, Eurasian watermilfoil remains quite dense, but well beneath the surface. In Cedar Lake, the improved water clarity and very low weevil densities resulted in a continued increase in Eurasian watermilfoil that persisted through the summer. Milfoil is slowly recovering at Otter Lake, but still remains well below historic highs; the slow increase may be due to a combination of plant competition and herbivore pressure.

The response of Lake Auburn remains puzzling. The early season decline of milfoil in 1998 was associated with relatively low weevil densities but much apparent damage (personal observation). However, for some reason the weevil population crashed and the poor light probably prevented regrowth of milfoil and other plants. Due to poor visibility it is difficult to tell if sunfish populations are high, however surveys conducted by Pothoven (1996) in Cedar and Auburn suggest similar high densities of sunfish during 1993-1995, with sunfish increasing from 1993 to 1995. In some ways, the recent milfoil decline is similar to that observed in 1993; weevil populations declined in 1995 and milfoil increased to record levels. It remains to be seen if milfoil will continue suppressed in Lake Auburn, or if the milfoil will return in force with low weevils densities; the milfoil did not strongly rebound in 1999 (unpublished data), despite the absence of weevils, however, it was not until 1995 that the milfoil fully recovered from the 1993 decline. Continuation of our plant removal and competition experiments should shed light on the role of plant competition in suppressing milfoil.

Two conditions are needed for successful biological control of weeds: adequate agent densities and a negative response of the target to the control agent (Newman et al. 1998). The potential importance of plant community response to stress imposed on Eurasian watermilfoil was addressed above. It is also clear that at many of our sites weevil populations have not built to adequate densities; Cenaiko Lake provides a clear example of the potential for high weevil populations and subsequent effects on milfoil. Given the potential for population increase in the summer, and the lack of a strong correlation between in-lake and onshore densities, it does not appear that overwinter populations are the main limiting factor at least at Lake Auburn and Smith's Bay where detectible populations have been found in early summer each year. Fish exclusion

experiments suggest that fish predation could be one important factor and that milfoil genotype and sediment may also affect weevil performance.

It is clear that we do not yet have adequate information to reliably predict if and when insects will cause declines in milfoil populations or if the declines will persist. It is also clear that milfoil suppression can be obtained given adequate densities of weevils throughout the summer, and perhaps positive plant community response. On-going focused research should shed additional light on the factors that regulate weevil populations and their effects on plant communities. Once these factors have clearly been identified, management strategies, such as piscivore enhancement or water clarity improvements can be tested to determine their feasibility for enhancing the biological control of Eurasian watermilfoil.

Conclusions

- Declines in Eurasian watermilfoil biomass were seen at Cenaiko Lake and Lake Auburn in 1997-1998. Milfoil increased in Otter Lake but the native plant community remains healthy and milfoil is still 20% of total plant biomass. In Smith's Bay, milfoil remained suppressed at the shallower sites with high non-milfoil biomass and much evidence of weevil damage, but increased at the deeper sites that show little evidence of weevil damage. Milfoil biomass at Cenaiko Lake increased from 1997 to 1998, but by the end of the summer had declined to <7% of plant biomass; the decline also persisted through the summer of 1999. Native plants continued to increase at Cenaiko. A weevil survey indicated very high densities of weevils in September 1998 (3.6 total weevils per stem or 0.6 adults per stem).
- Milfoil biomass in Lake Auburn declined over the winter of 1997-1998 and continued to decline during the summer of 1998 to 48 g dry/m²; weevil damage appeared high in late spring, but by early summer the weevil population had disappeared. Milfoil biomass remained high in Cedar Lake during 1998, likely due to increased water clarity that persisted through the summer. Coontail makes up a large percentage of the non-milfoil plant biomass at both of these lakes and the lack of development of a rooted native plant community may reduce competitive stress on Eurasian watermilfoil.
- Milfoil biomass increased or remained the same at two of our three survey sites: Grays Bay, and Lake-of-the-Isles. Visual coverage at our survey sites ranged from 4 to 59%, with small increases at two lakes and small decreases at two others. A major decline occurred in 1998 at Piersons Lake which had about half the milfoil density that was found in 1997. It is not clear that this decline was due to herbivore activity.
- Shoreline weevil densities at Smith's Bay and Lake Auburn were low in fall 1998, being similar to our previous fall low in 1994, however, overwinter mortality was quite low at Smith's Bay and was low at both lakes during the recent mild winters of 1997-1999. Shoreline densities and overwinter survival may be controlled by regional climatic factors.
- A fish exclusion experiment suggested that fish predation may limit weevil populations and that introduced weevils protected from fish predation may reduce milfoil. These effects were weak and more experimentation is required.
- Weevil performance (developmental rate, size and survival) was influenced by rearing plant and rearing plant sediment. Sediment effects appear larger than plant genotype effects, and these results may explain differential performance of weevils in different lakes. Performance was poorest on Otter plants grown in Otter sediment. However, overall plant size may have influenced these results and it is not clear that internal plant quality affected survival and development.

- Weevil temperature-development models are useful for predicting trends and matching field observations. A combination of modelling, observation and experiment will help explain which stages are critical or what factors may be limiting populations. Adult survival, longevity and egg to adult survival will compound over the summer to greatly influence summer long population densities.
- Based on our laboratory results and life history information, weevil populations should reach much higher densities than we have seen at most sites except Cenaiko. Further work is needed to identify what is limiting weevil populations.

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Appendix I. Abbreviations and dry mass of plants collected.

Key to plant abbreviations used in this report.

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