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Distribution and Abundance of the Milfoil Weevil, *Euhrychiopsis lecontei*, in Lake Minnetonka and Relation to Milfoil Harvesting

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ABSTRACT

The milfoil weevil, *Euhrychiopsis lecontei* (Dietz), native to North America, is a potential biological control agent for Eurasian watermilfoil (*Myriophyllum spicatum* L.). The milfoil weevil has been shown to control the plant when sufficient densities are attained and maintained throughout the summer. Mechanical harvesting of Eurasian watermilfoil has been shown to locally reduce the density of weevils in harvested plots, but the effects of broad-scale harvesting have not been evaluated. We determined weevil densities in unharvested plots in early-, mid- and late-summer in nine bays of Lake Minnetonka that had a range of harvest levels. Weevil densities were significantly negatively related to proportion of the bay harvested ($r^2 = 0.55$. $p = 0.02$). No relationship between shoreline habitat and weevil density was found. Our results suggest that large-scale harvesting is detrimental to weevil populations and that harvesting and chemical control should be limited if the aim is to promote biological control.

Key words: biological control, *Myriophyllum spicatum*, conservation, mechanical harvesting.

INTRODUCTION

The milfoil weevil, *Euhrychiopsis lecontei* (Dietz), native to North America, is a potential biological control agent for Eurasian watermilfoil (*Myriophyllum spicatum* L.). The milfoil weevil can control the plant when sufficient densities are attained and maintained throughout the summer (Creed and Sheldon 1995, Newman 2004). However, in many lakes milfoil weevil populations are not sufficient (<0.25/stem or <25/m^2) to control the plant (Newman 2004). Predation by sunfish has been identified as an important factor in some lakes (Ward and Newman 2006), but lack of suitable overwinter habitat (Jester et al. 2000, Tamayo 2003), and mechanical harvesting (Sheldon and O'Bryan 1996a) may also be important limiting factors.

Sheldon and O'Bryan (1996a) showed that harvesting significantly reduced milfoil weevil abundance in harvested plots compared to adjacent unharvested plots. Because all summer life stages (eggs, larvae, pupae, and adults) reside in the top 0.5 to 1.5 m of the plant (Sheldon and O'Bryan 1996b), harvesting will remove almost all weevils present. However, the broad-scale effects of harvesting have not been evaluated. Although unharvested plots can sustain weevil populations and provide a refuge (Sheldon and O'Bryan 1996a), it is not known if long-term harvesting will diminish lake- or bay-wide weevil populations or populations in unharvested areas, or if weevils would concentrate in unharvested areas.

We measured the abundance of milfoil weevils in 9 bays of Lake Minnetonka to determine if weevil abundance is related to intensity of mechanical harvesting among bays. In addition, we assessed shoreline habitat to determine if it explained weevil density across our sites.

METHODS

Nine bays of Lake Minnetonka (Hennepin Co., MN) were chosen for sampling (Figure 1). Eurasian watermilfoil was first documented in the lake in 1987, and the milfoil weevil and other milfoil herbivores (*Cricotopus myriophylli, Acentria ephemerella,* and *Parapoynx* sp.) are present throughout the lake (Newman and Maher 1995). Milfoil in the lake has been managed primarily by harvesting since 1989 by the Lake Minnetonka Conservation District (LMCD) which maintains records of acres of milfoil harvested each year by bay. Based on previous harvesting records and consultation with the LMCD, an undisturbed and typically unharvested milfoil bed was located in each bay. The LMCD agreed to avoid harvesting within our sampling plots during the study; harvesting typically did not occur within 100 to 200 m of the plots. At each milfoil bed, a grid of 5 transects spaced 30-m apart along the shoreline with 3 stations positioned at the beginning (shallow), middle, and outer edge of the milfoil bed along each transect, was marked with a GPS. At each station, one sample consisting of the top 0.5 m of 10 Eurasian watermilfoil stems was collected and placed into a sealable plastic bag, resulting in 15 samples at each bay. Each bay was sampled 3 times during the summer (approximately every 3 weeks) between late June and mid-August 2004.

Samples were chilled on ice or refrigerated at 4 C until processing, generally within 24 hr. Stems and meristems were counted and examined for herbivores under lighted 2x magnification. Aquatic lepidopteran caterpillars and weevil eggs, larvae, pupae, and adults were enumerated and preserved in 80% ethanol.

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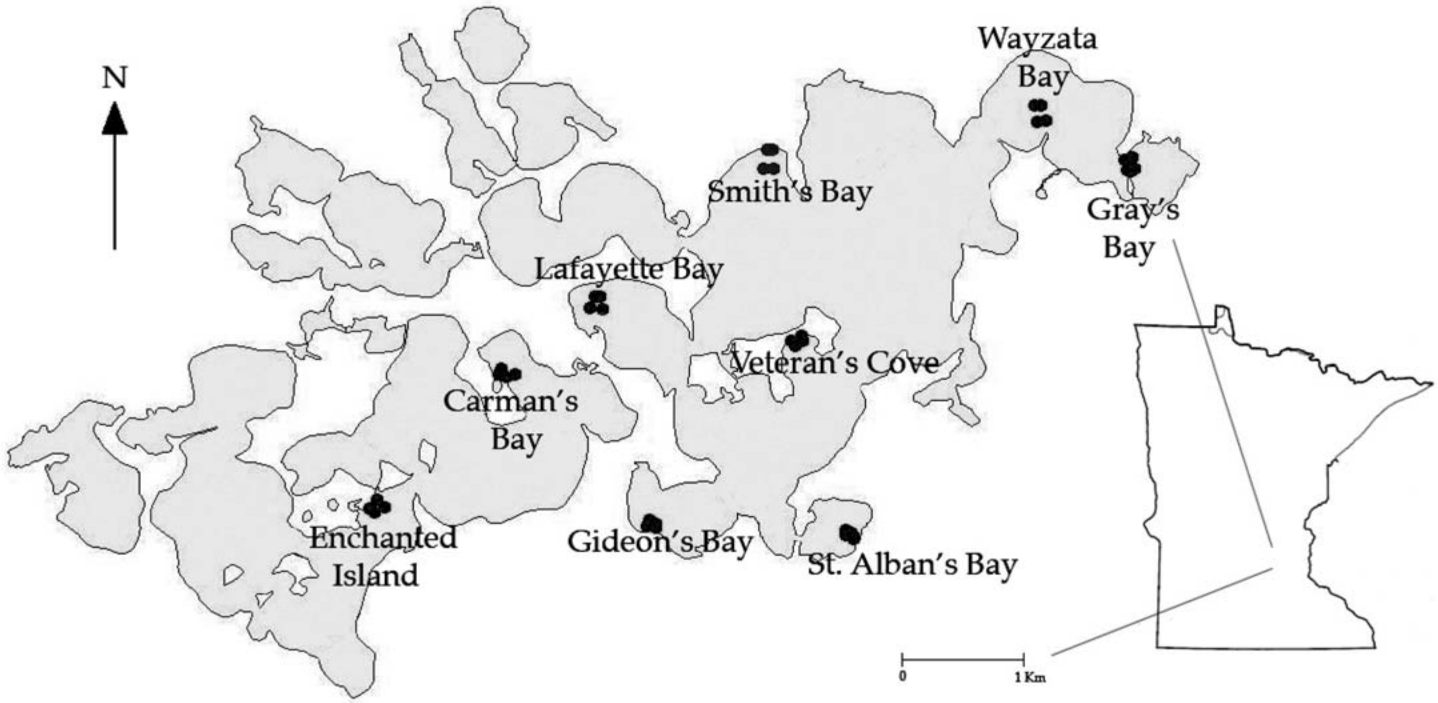

Figure 1. Map of Lake Minnetonka with sample locations.

In late August, visual estimates of shoreline (10-m nearest water) and upslope (10-100 m from water) habitat closest to the weevil survey plots were recorded. Shoreline habitat was classified as emergent vegetation (primarily cattails), wooded, shrubs, natural grass, lawn, riprap, or sandy beach. Upslope habitat was classified as wooded, shrubs, natural grass, lawn, or pavement (one site was along a causeway where pavement comprised all upslope habitat). For analysis, habitat was grouped into natural vegetation (all vegetation except lawn) or developed (lawn, pavement, riprap, and sandy beach).

Historical estimates of harvest in each bay were obtained from the LMCD (http://www.lmcd.org/pdf/EWM%20Harvesting%20Report/Historical%20Harvesting%20Acreage%20(web-ready).pdf; last accessed 6 July 2008). Areas harvested in 1989-2002 were visually estimated by the harvesting crews. Areas harvested in 2003 and 2004 were determined by LMCD with GPS units, and data were provided to us as ArcView shapefiles. We used these records along with LMCD estimates of the littoral area (<4.6 m depth) of each bay to determine the proportion of littoral area harvested each year (area harvested/littoral area). Littoral area of sampled bays ranged from 41 to 130 ha. For analysis, the proportion of littoral area harvested and proportion of shoreline landuse were arcsine square-root transformed.

RESULTS AND DISCUSSION

No aquatic lepidopterans were found. Weevil densities varied considerably among bays, ranging from zero at Gideons and Wayzata Bays to more than 0.5/stem on several dates at Smiths and Veterans Bays (Table 1). Overall, densities within bays were quite similar through the summer, although densities increased over the summer at St. Albans and Veterans Bays and decreased at Enchanted Island and Grays Bay. Densities at Smiths Bay were consistently high (0.4/stem to 0.6/stem) throughout the summer. We initially expected that sampling site or bay orientation might affect weevil densities due to prevailing winds; however, no such pattern was evident.

The relative proportion of each bay harvested was similar among years, so we used the average of the proportions harvested in 2000 to 2003 to represent harvest intensity. Summer weevil density (mean of the 3 sampling dates) was strongly negatively related to harvest intensity (Figure 2), which should reflect average longer-term harvest conditions. Similar negative relationships were found for weevil densities from each sampling session (June $p = 0.022$, $r^2 = 0.551$; July $p = 0.100$, $r^2 = 0.338$; August $p = 0.024$, $r^2 = 0.542$). Average summer weevil density was also strongly negatively related to harvest in 2004 ($p = 0.001$, $r^2 = 0.796$).

During the study no harvesting occurred within our sampling plots, with the exception of Enchanted Island, where a strip was harvested along the corner of the plot. Plants were not collected from the harvested area, and although weevil densities declined over the summer at Enchanted Island, weevil densities were intermediate at this site (fourth highest density, 0.13/stem). Records from 2003 indicate no harvesting at any of our sampling plots, and the plot areas have not been historically harvested. Thus the lower densities of weevils found with increasing levels of harvest are not due to directly harvesting the milfoil and weevils; rather they appear to be the result of a bay-wide decrease associated with harvesting. Smiths Bay, which has had limited harvesting since

TABLE 1. DENSITY (N/STEM AND 2SE) OF MILFOIL WEEVIL EGGS, LARVAE, PUPAE, AND ADULTS IN 9 BAYS OF LAKE MINNETONKA DURING SUMMER 2004.

Bay	Date	Eggs	Larvae	Pupae	Adults	Total
Carmans	7/5/04	0.008	0.000	0.000	0.000	0.008
	2SE	0.017	0.000	0.000	0.000	0.017
Carmans	7/19/04	0.031	0.008	0.008	0.000	0.046
		0.062	0.015	0.015	0.000	0.077
Carmans	8/10/04	0.018	0.009	0.000	0.000	0.027
		0.024	0.018	0.000	0.000	0.028
Enchanted Island	7/11/04	0.240	0.007	0.000	0.007	0.253
		0.117	0.013	0.000	0.013	0.122
Enchanted Island	7/29/04	0.023	0.031	0.008	0.031	0.092
		0.033	0.042	0.015	0.027	0.066
Enchanted Island	8/15/04	0.029	0.007	0.000	0.000	0.036
		0.025	0.014	0.000	0.000	0.034
Gideons	7/15/04	0.000	0.000	0.000	0.000	0.000
		0.000	0.000	0.000	0.000	0.000
Gideons	7/28/04	0.000	0.000	0.000	0.000	0.000
		0.000	0.000	0.000	0.000	0.000
Gideons	8/13/04	0.000	0.000	0.000	0.000	0.000
		0.000	0.000	0.000	0.000	0.000
Grays	6/26/04	0.113	0.100	0.073	0.000	0.287
		0.123	0.085	0.088	0.000	0.235
Grays	7/16/04	0.207	0.000	0.000	0.013	0.220
		0.066	0.000	0.000	0.027	0.076
Grays	8/1/04	0.047	0.013	0.000	0.007	0.067
		0.043	0.018	0.000	0.013	0.054
Laffayette	7/9/04	0.020	0.013	0.000	0.007	0.040
	2SE	0.029	0.018	0.000	0.013	0.043
Laffayette	7/22/04	0.013	0.000	0.000	0.000	0.013
		0.018	0.000	0.000	0.000	0.018
Laffayette	8/9/04	0.013	0.007	0.000	0.000	0.020
		0.018	0.013	0.000	0.000	0.021
Smiths	6/23/04	0.373	0.253	0.013	0.000	0.640
		0.203	0.158	0.018	0.000	0.301
Smiths	7/13/04	0.293	0.087	0.020	0.027	0.427
		0.141	0.075	0.021	0.041	0.219
Smiths	8/1/04	0.220	0.147	0.080	0.093	0.540
		0.224	0.085	0.062	0.104	0.363
St. Albans	7/15/04	0.000	0.000	0.000	0.000	0.000
		0.000	0.000	0.000	0.000	0.000
St. Albans	7/28/04	0.000	0.007	0.000	0.007	0.013
		0.000	0.013	0.000	0.013	0.018
St. Albans	8/12/04	0.029	0.007	0.000	0.007	0.043
		0.025	0.014	0.000	0.014	0.046
Veterans	6/30/04	0.080	0.027	0.060	0.007	0.173
		0.094	0.024	0.051	0.013	0.121
Veterans	7/19/04	0.340	0.113	0.047	0.080	0.580
		0.129	0.067	0.058	0.062	0.234
Veterans	8/10/04	0.190	0.200	0.030	0.020	0.440
		0.138	0.130	0.031	0.040	0.248

Table 1. (Continued) Density (N/stem and 2SE) of milfoil weevil eggs, larvae, pupae, and adults in 9 bays of Lake Minnetonka during summer 2004.

Bay	Date	Eggs	Larvae	Pupae	Adults	Total
Wayzata	6/26/04	0.000	0.000	0.000	0.000	0.000
		0.000	0.000	0.000	0.000	0.000
Wayzata	7/16/04	0.000	0.000	0.000	0.000	0.000
		0.000	0.000	0.000	0.000	0.000
Wayzata	8/1/04	0.000	0.000	0.000	0.000	0.000
		0.000	0.000	0.000	0.000	0.000

1994 (<12% and typically <5%) to permit assessment of undisturbed weevil populations (no harvesting has occurred within the sampling area), had the highest density of weevils. Weevil densities have been adequate to result in control of milfoil at shallower sites in Smiths Bay (Newman 2004).

Although it is possible that bays with naturally high densities of milfoil weevils have less need for control and thus less need for mechanical harvesting, we do not think such a relationship explains our results. The lack of harvesting at Smiths Bay was to enable assessment of weevil populations and milfoil control, and the relative amount of harvest in each bay was similar across a number of years, even though the LMCD rotates its harvest schedule each year to provide equitable treatment across the lake. Finally, with the exception of Smiths Bay, the LMCD has not made a conscious decision to not harvest areas with high weevil densities (Greg Nybeck, LMCD, pers. comm.), and lake-wide year-to-year variation in milfoil density has been more important to the harvesting program.

It is also possible that differences in sunfish abundance among the bays could explain the differences in weevil density (e.g., Ward and Newman 2006). Unfortunately, bay-specific sunfish abundances are not available for the years we sampled, but fisheries survey data for 8 of the 9 bays (all but

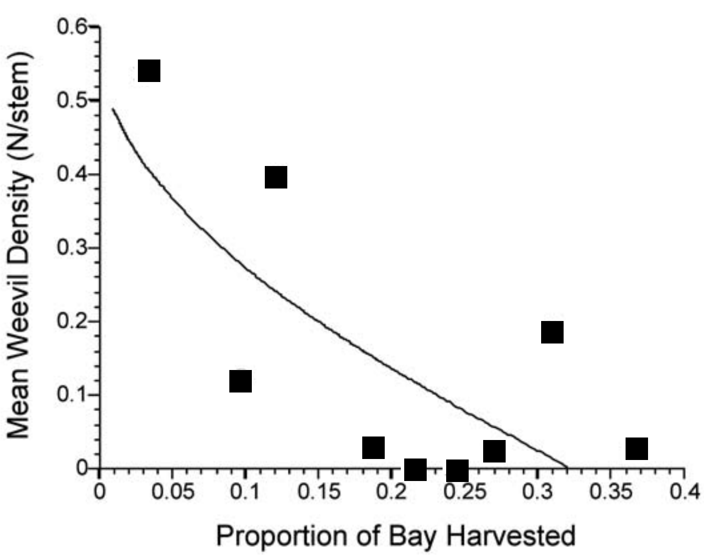

Figure 2. Relationship of mean summer weevil density (N/stem) and proportion of bay harvested. Regression of weevil density versus arcsine √ proportion of bay harvested (line depicted) was significant ($p = 0.02$, $r^2 = 0.55$; N/stem = 0.586-0.969 arcsine √ proportion of bay harvested).

Lafayette) were collected in 1997 (Taylor Polomis, Minnesota Department of Natural Resources, West Metro Office, unpubl. data). Sunfish (*Lepomis* spp.) relative abundance ranged from 45 per trapnet at Wayzata Bay to 147 per trapnet at Carman's Bay, and although abundances were relatively low at Smith's Bay and Veteran's Bay (46-50 per trapnet), no significant relationships of weevil density to sunfish abundance were found with or without Wayzata Bay included in the analysis (all $p > 0.1$). A more recent survey in 2007 was more limited, and surveys were only conducted in or near 4 of our bays. These surveys were quite variable and showed no relationship of sunfish abundance to weevil density; thus, we have no evidence that differences in sunfish abundance explain our results but recognize that sunfish abundance or predation intensity might be influenced by harvesting. Future studies should consider the potential interaction of sunfish abundance and harvesting.

Shoreline (overwintering) habitat has been shown elsewhere to be related to *E. lecontei* densities. Weevil densities have been positively related to percent natural shoreline and negatively related to sand and developed shoreline (Jester et al. 2000, Tamayo 2003). Although the 2 bays where no weevils were detected had little natural vegetation and highly developed shoreline (Table 2), no significant relationship between the proportion (arcsine square root) of adjacent shoreline ($p = 0.256$) or upslope habitat ($p = 0.61$) as natural vegetation and weevil density was found. Previous work in Minnesota also suggested that in-lake factors were more important than overwinter habitat at determining summer weevil densities (Newman et al. 2001); however, that study and the current study considered habitat within a lake rather than among lakes. Differences in lake-wide shoreline habitat may be important to overall densities within a lake, but local habitat differences may not be as important if sufficient overwintering habitat is available nearby. Also, because developed shoreline sites tend to also have more intensive plant management, effects of in-lake chemical and mechanical control should be separated from shoreline habitat.

Sheldon and O'Bryan (1996a) demonstrated that milfoil harvesting can directly reduce weevil density; weevil densities were significantly lower in plots that were harvested compared to control plots. Harvesting removes the top portions of the plant and thus all weevil life stages present in the harvested bed. In addition, because harvesting removes the meristems and places the top of the plants deeper in the water column (Getsinger et al. 2002), the regrowing, harvested plants may be less suitable habitat for milfoil weevils than unharvested plants. Our results suggest that the direct harvest effect may also reduce weevil densities beyond the immedi-

Table 2. Percentage of shoreline and uplands that was natural vegetation, mean (of all 3 sampling dates) summer density of *Euhrychiopsis lecontei* (all life stages; N/Stem) in 2004 and mean percentage of each bay harvested in 2000 to 2003 (% 00-03) and in 2004 (% 04).

				Harvested Area	
Bay	Shoreline	Uplands	N/stem	% 2000-2003	% 2004
Smiths	50%	100%	0.536	3%	0%
Veterans	100%	100%	0.398	12%	3%
Grays	100%	0%	0.191	31%	15%
Enchanted Island	45%	40%	0.127	10%	6%
Carmans	100%	100%	0.027	37%	25%
Lafayette	10%	100%	0.024	19%	15%
St. Albans	5%	100%	0.019	27%	16%
Wayzata	10%	15%	0.000	24%	13%
Gideons	20%	80%	0.000	22%	15%

ate area harvested and that repeated harvesting may reduce overall densities. Broad-scale chemical control that kills watermilfoil would likely have a similar effect by reducing host-plant availability. Thus if biological control is considered, mechanical and chemical control should be focused on small areas of intense use that require immediate control, and broad-scale treatment should be avoided.

If biological control is an objective, other management strategies such as mechanical or chemical control must be properly integrated so as not to negatively affect biocontrol agent populations (Newman et al. 1998, Getsinger et al. 2002). Integrated approaches are well developed in terrestrial systems, but less so in aquatic systems. As one approach to integrate harvesting with biological control, Sheldon and O'Bryan (1996a) suggested maintaining no-harvest areas in low use (undeveloped sites and public lands) areas and in areas that are too shallow to effectively harvest. Our results suggest that maintaining larger unharvested areas might be useful, and that strip cutting to allow access to docks and shore is preferable to larger clear cuts. In our study, no more than 35% of any bay was harvested, and density of weevils appeared to drop substantially after more than 15% of the bay was harvested (Figure 2). It is unclear, however, if weevil density declines linearly with area harvested or exponentially; more data are needed to adequately characterize the shape of the relationship. It is apparent that milfoil weevil populations are not showing compensatory increases at lower levels of harvest, and that low levels of harvest are not concentrating weevils in unharvested areas.

Our results suggest that broad-scale harvesting of Eurasian watermilfoil can reduce weevil densities, and harvesting should be limited if the goal is to promote biological control. Because intensive management may prohibit development of abundant natural weevil populations, and thus natural declines of milfoil (Creed 1998), managers should consider more targeted management to facilitate biological control.

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