Wisconsin Cooperative Fishery Research Unit
University of Wisconsin – Stevens Point
College of Natural Resources
Stevens Point, WI 54481

Wisconsin Cooperative Fishery Research Unit

Wisconsin Milfoil Weevil Project

1996 – 1998 Results

March 1999

Laura L. Jester and Michael A. Bozek
Wisconsin Cooperative Fishery Research
University of Wisconsin – Stevens Point

Daniel R. Helsel
Wisconsin Department of Natural Resources

ACKNOWLEDGEMENTS

We would like to thank all of the lake associations and other organizations that were involved with this study. Your financial support, generous donation of time, and high interest in this project were greatly appreciated! The study's success was in large-part due to your cooperation. In particular, we would like to thank: Beaver Dam Lake, Big Sand Lake, Eagle Lake, Gilbert Lake, Kangaroo Lake, Kusel Lake, Long-Trade Lake, Lorraine Lake, Lower Spring Lake, Nancy Lake, Pearl Lake, Waukesha County Parks System, and Whitewater Lake; the Wisconsin Department of Natural Resources especially Dick Lillie, Laura Herman, Frank Koshere, Jeff Kampa, Tim Rasman, Scott Szymanski, Deb Konkel, Jim Leverance and Jeff Bode; the University of Wisconsin – Stevens Point; the Wisconsin Cooperative Fishery Research Unit; the Midwest Aquatic Plant Management Society; and various "weevil researchers" around the country including Sallie Sheldon, Mariana Tamayo, Robert Creed, Robert Johnson, Bob Kirschner, Chip Welling, Ray Newman and John Madsen.

Table of Contents

Acknowledgments 2

Project Objectives and Design 4

Statewide Results 8

Study Lake Results 14

Weevil Stocking Recommendations 21

References 24

The Wisconsin Milfoil Weevil Project

An Assessment of Existing Weevil Populations and Experimental Weevil Stocking for Eurasian Water Milfoil Control

Project Objectives and Design

In 1996 information about a new biological control insect for Eurasian water milfoil (*Myriòphyllum spicatum*) was publicized in a number of newspapers and scientific newsletters. A native weevil, *Euhrychiopsis lecontei*, commonly referred to as the milfoil weevil, was reported to be associated with Eurasian water milfoil declines in a number of Vermont Lakes. Closer to home, a story appeared in the Chicago Tribune about the sharp decline of the milfoil at McCullom Lake in northern Illinois which was also attributed to the weevil. And in Wisconsin, the weevil was attributed to unexplained milfoil declines in Fish and Wingra Lakes (Dane County) and Whitewater Lake in Walworth County. Together, these projects generated interest among both lake organizations and within the Wisconsin Department of Natural Resources (DNR) to investigate the milfoil weevil as a biological control agent for Eurasian water milfoil.

In consultation with three research scientists,

- Dr. Sallie Sheldon from Middlebury College in Vermont, who pioneered weevil research,
- Dr. Michael Bozek from the University of Wisconsin-Stevens Point, an aquatic ecologist, and
- Richard Lillie, a DNR aquatic insect and milfoil scientist,

a framework for the Wisconsin Milfoil Weevil Project was developed. Announcements were sent to candidate lakes, with Eurasian water milfoil problems, soliciting participation in a pilot weevil project. Early in the project design, it was clear there were more lakes wishing to participate than the project could accommodate. In the end, twelve lakes were selected from more than twenty interested in this study (Figure 1).

The project framework included answering three questions:

1) What is the geographic distribution of the milfoil weevil across the State?

Prior to 1996, only four locations of the weevil's occurrence were on record for the State. There was concern that stocking the weevil in areas of the state where it was not present might upset the ecological balance of other aquatic insects or native aquatic plants. It was clear that if weevil stocking was to occur, we first had to document the distribution of the species.

We searched for weevils in 46 lakes of the more than 200 lakes known to contain Eurasian water milfoil in Wisconsin. In each lake we spent up to 4 man-hours examining Eurasian water milfoil plants for adult weevils or weevil damage. The weevil distribution information was also supplemented by weevil samples collected by regional DNR employees. The results of our distribution monitoring are summarized in the Statewide Results section of this report.

2) Are there specific lake characteristics (geography, shoreline, water chemistry, etc.) that are correlated with weevil densities?

By monitoring weevil densities across a wide range of lakes in the State, we were able to examine some of the lake characteristics that are associated with naturally high weevil densities. In turn, we might expect lakes with these characteristics to have a greater potential for higher weevil densities and therefore a greater potential for Eurasian water milfoil control.

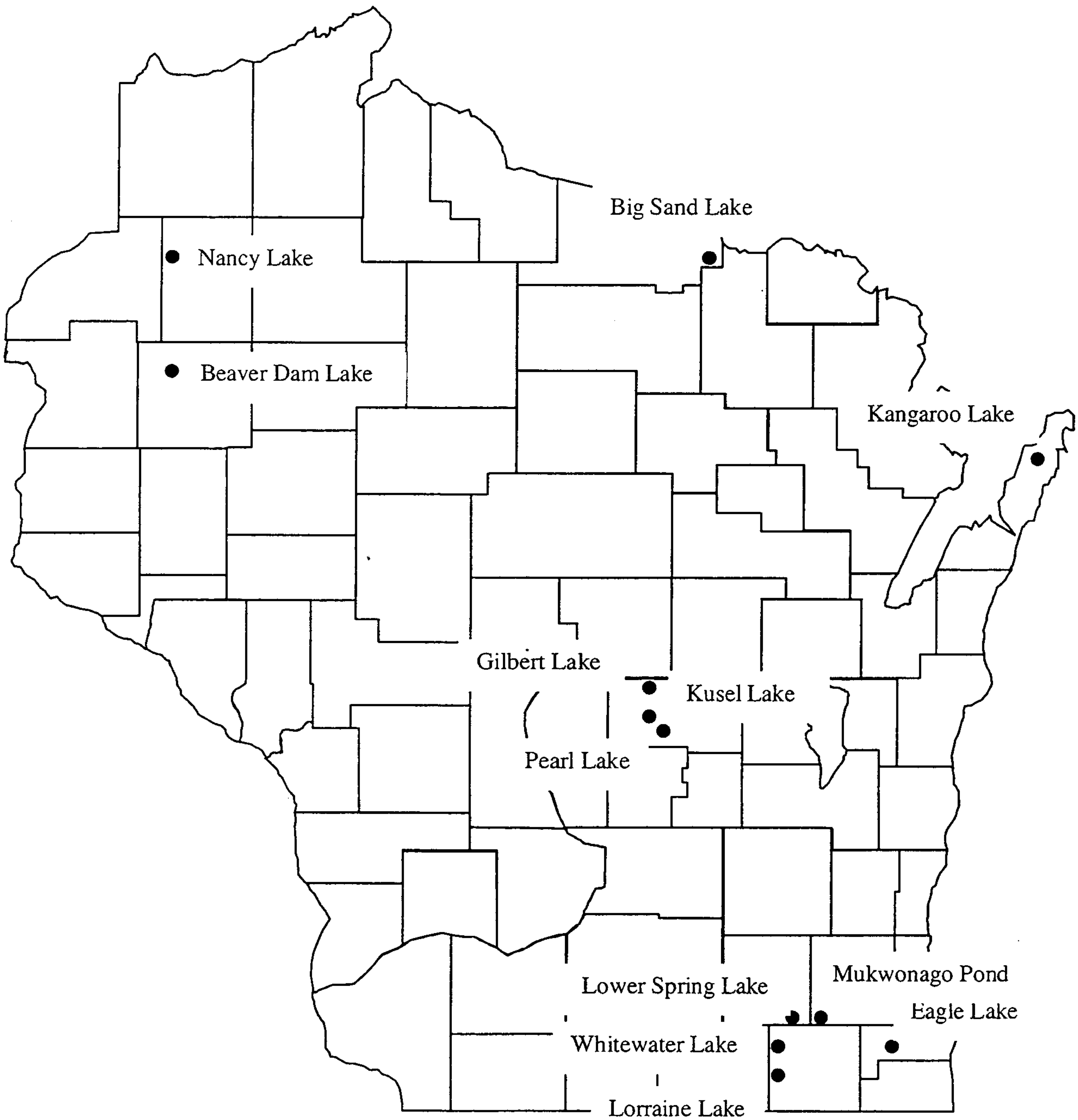

Figure 1. Wisconsin Milfoil Weevil Study Lakes

We sampled weevil densities in 31 lakes across Wisconsin between mid-July and mid-August in 1996 or 1997. In each lake we collected and examined 120 milfoil stems in order to obtain an accurate weevil density estimate (weevils per apical stem). The number of weevil adults, larvae, pupae, and eggs from inside and outside the stems were counted and preserved. In addition to weevil densities, information on a wide range of lake characteristics was also collected or gathered from existing data. These weevil densities and lake characteristics were examined for any patterns that might suggest what types of lakes produce higher weevil densities. The results of our weevil density and lake characteristics study are summarized in the Statewide Results section of this report.

3) Can stocking weevils in experimental plots increase natural weevil densities and cause a decrease in Eurasian water milfoil biomass?

Although the existing field and laboratory studies attribute many Eurasian water milfoil declines to the weevils, at the time we started this study there had been only one lake in Vermont where weevils had been stocked for potential milfoil control. The weevil stocking for our study was designed to provide an experimental test of the effectiveness of different levels of stocking in different types of lakes across a wide geographical range.

The original project design budgeted approximately $15,000 for the purchase of weevils to stock in experimental plots located within each of the 12 lakes. When the actual cost of the weevils was discovered to be approximately $0.40 each, we had to make a decision to 1) either substantially decrease the size of the experimental plots or 2) request additional funds from the lake organizations and expand the DNR grant amounts. In the end, the lakes organizations *"stepped up to the plate"* and we were able to purchase approximately 160,000 weevils for $45,000 from Dr. Sheldon's rearing facilities at Middlebury college in Vermont.

Weevils were stocked in three experimental plots in each study lake at one of three treatment levels: 1,2, or 4 weevils per milfoil plant. Depending on the density of milfoil plants in the lake, and the treatment level assigned, lakes received between 100 and 12,000 weevils per plot.

Statewide Project Results

Weevil Distribution

The milfoil weevil was found to be widely distributed across Wisconsin in lakes that were infested with Eurasian water milfoil. From Vilas and Forest Counties in the north, to Polk and St. Croix Counties in the west, to Kenosha and Racine Counties in the southeast, a total of 45 new records of the weevil were established across Wisconsin (Figure 2). In fact, only Silver Lake in Waupaca County was found to be absent of weevils after four man-hours of searching. In most lakes weevils were found within the first 10-20 minutes of searching. While adults weevils were the easiest life stage to find, in three of the 45 lakes, adults were not found, but weevil damages and larval lifestages were recorded.

Weevils were also found in three lakes that do not contain Eurasian watermilfoil: Upper Gresham Lake and Papoose Lake in Vilas County, and Perch Lake in St. Croix County. Weevils were found on the native northern watermilfoil (*Myriophyllum sibiricum*) in these lakes.

Weevil Density and Lake Characteristic Correlations

Weevil density (average number of weevils found on each milfoil stem) was sampled in 31of the lakes and varied from non-detectable densities to 2.5 weevils per apical stem (Figure 3). Only two of the 31 lakes had weevil densities greater than 2 per stem. Previous studies have indicated that densities greater than 2 weevils per apical stem are associated with Eurasian water milfoil declines. If that is correct, and our data is representative of the weevil densities across the state, weevil induced milfoil declines would rarely occur naturally. However, Robert Creed (1998) reports at least 10 naturally occurring Eurasian water milfoil declines in the state of Wisconsin in the past decades. Furthermore, 7 of these lakes are now known to harbor the milfoil weevil.

The evidence indicates that weevils can cause Eurasian water milfoil declines, but the density of weevils required to induce a milfoil decline seems to be highly lake specific. This leads us into the second part of the objective: are there lake specific characteristics that are correlated with weevil densities? For example, if there was a positive correlation between weevil density and lake size, our data would show, by more than a random chance, that a larger lake size would have a larger weevil density.

Based on the data from the 31 lakes, we found no correlation between weevil densities and the following lake characteristics:

- Geographic location (latitude)
- Time since Eurasian water milfoil first invaded the lake
- Lake depth, size or type (drainage or seepage)

Nor did weevil densities show a correlation with any of these water quality variables:

- Summer water temperatures
- Dissolved oxygen measurements
- Secchi disk measurements
- Nutrient concentrations (total phosphorus, nitrogen)
- Chlorophyll a
- Alkalinity, pH, conductivity

The lack of weevil density correlation with some of these parameters was surprising. Our data indicates that the productivity of a lake (i.e. nutrient levels) is not correlated to weevil densities. We also expected a positive relationship between water temperature and high weevil densities because temperature plays a large role in regulating aquatic insect reproduction and activity.

However, the percent of various weevil lifestages among all weevils collected per lake was significantly correlated with a few of the variables. For example,

- The percentage of eggs was positively correlated with summer water temperatures
- The percentage of larvae was negatively correlated with total phosphorus

Still, it is unclear if a correlation with a specific weevil lifestage might result in a direct correlation in weevil density. For instance, if warmer summer water temperatures are correlated with more weevil eggs, then we might expect more adults with warmer water temperatures. On the other hand, perhaps fish predation or motorboat impacts on the weevils also increase with warmer water temperatures so that weevil densities actually decrease. Certainly more information is needed about what controls the density of specific weevil lifestages and ultimately the weevil population itself.

Nonetheless, there were some variables that were significantly correlated with weevil densities. Weevil densities were positively correlated with the following variables:

- Distance from the middle of the milfoil bed to the shore
- Distance from the deep bed edge of the milfoil bed to the shore
- Percent of natural shoreline
- Number of apical tips (growing tips) per plant

And, weevil densities were *negatively* correlated with:

- Average depth of the milfoil bed

These correlations indicate that areas with natural shoreline have higher weevil densities than areas with rip-rap, sea walls, mown grass or sand at the shoreline. Knowing that weevils spend their winters in the leaf litter and mud along the shoreline, these results make sense. The data also suggest that there are higher numbers of weevils in large, shallow expanses of milfoil, and in milfoil with more apical tips or branches.

What Do Statewide Results Mean?

First, we found the weevil to be widely distributed across the State of Wisconsin. Therefore, stocking this insect for biological control of milfoil will not result in the introduction of an exotic insect species throughout Wisconsin. Second, a greater number of weevils are associated with large, shallow milfoil beds and areas of natural shoreline. Accordingly, this type of milfoil bed may potentially have the greatest vulnerability to weevil control.

For more information regarding weevil distribution and variable correlations see Laura Jester's M.S. Thesis (Jester 1998).

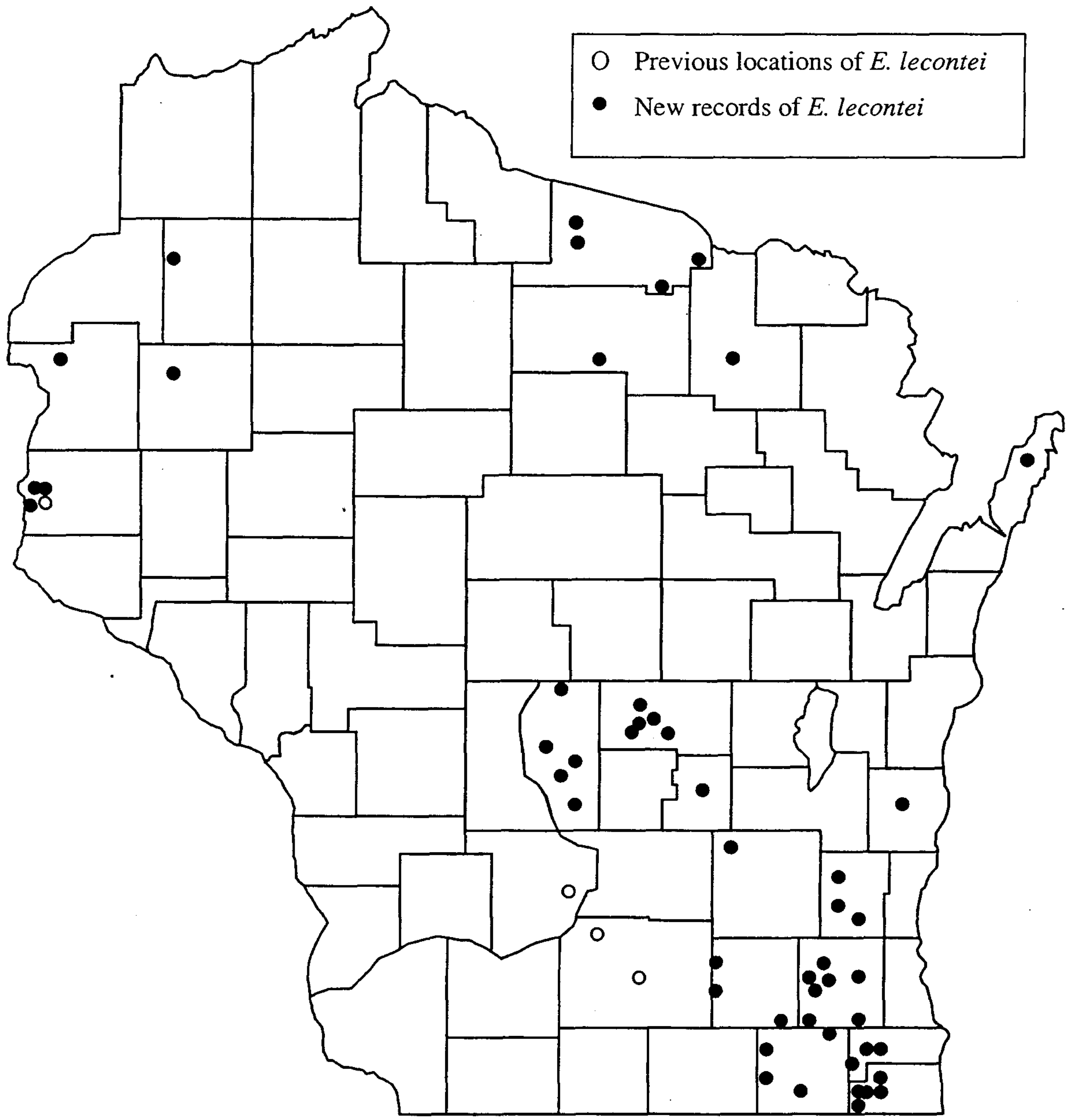

Figure 2. Known distribution of *E. lecontei* in Wisconsin. Previous locations referenced in Lillie (1991), Newman and Maher (1995), Lillie and Helsel (1997).

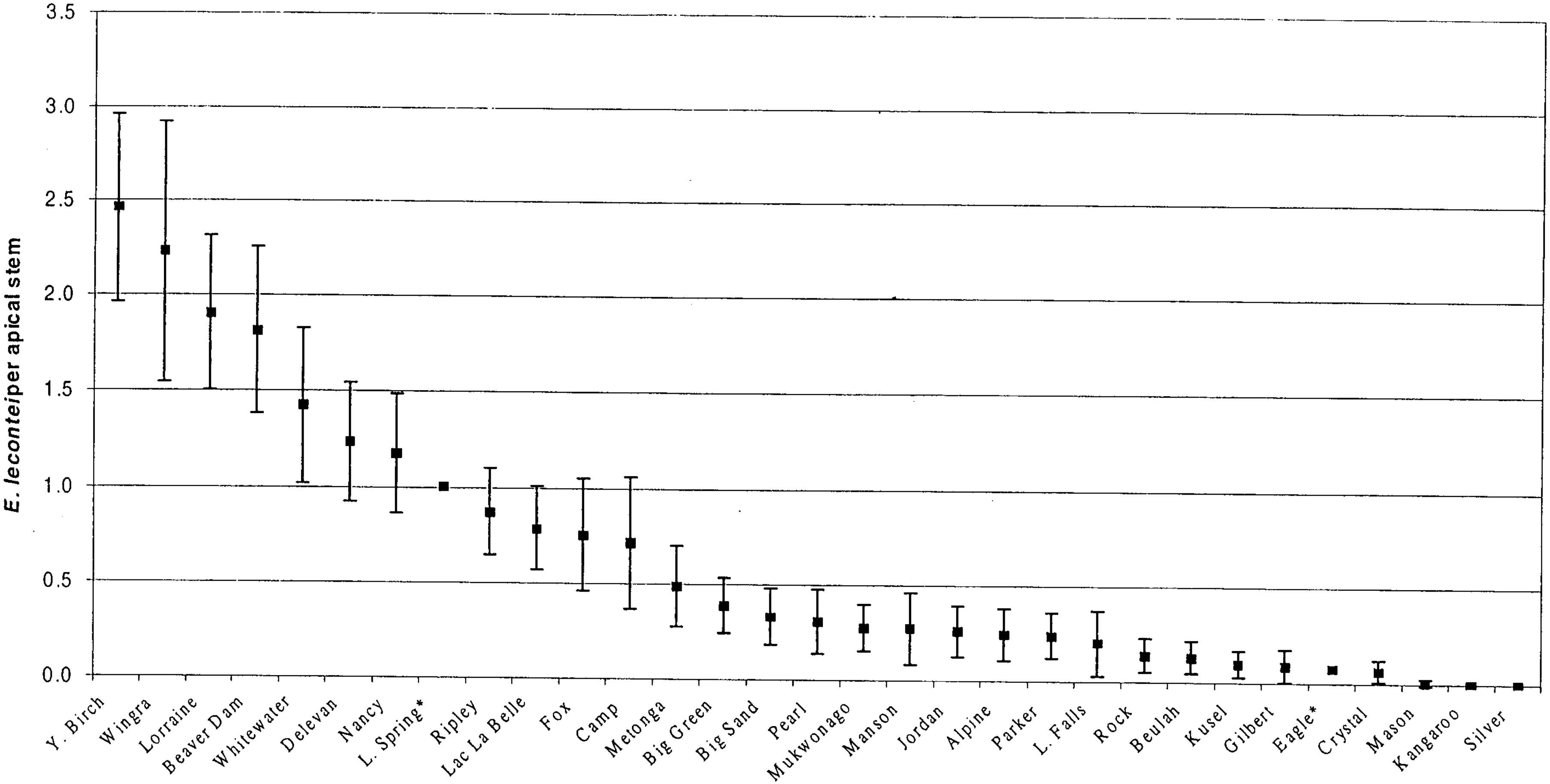

Figure 3. Density of milfoil weevils in Wisconsin lakes: all weevil lifestages combined. Values indicate the mean density of weevils per apical stem +/- 95% confidence intervals.

Study Lake Results

Background Weevil Densities

Background weevil densities were sampled in 1996 in each study lake as part of the study's second objective. Samples were collected along 12 transects throughout each lake and all weevil lifestages were counted in and on the stems in the laboratory. Background weevil densities in the study lakes ranged from non-detectable levels in Kangaroo Lake to 1.8 weevils per apical stem in Lake Lorraine (Figure 3).

Weevil Stocking

In each lake, four plots, 2 meters x 6 meters each, were established and marked with a center buoy in early 1997 in a pre-selected milfoil bed. Plots were situated end to end, and parallel to shore, usually 9 meters apart. Prior to stocking, weevil densities were collected in late June or early July 1997 by snorkeling short transects between the plots to determine the number of weevils needed to bring populations up to a treatment level of 1, 2, or 4 weevils per milfoil plant. Existing weevil densities were augmented to attain the desired treatment level. Each geographic region of study lakes (north, central and south) had at least one lake per treatment level. Treatment levels were randomly selected for each lake unless pre-stocking densities were already above a certain stocking level. (See Table 1 for stocking calculations.) Weevil eggs and larvae for stocking were cultured at Middlebury College in Vermont from adults collected in Fish Lake, Dane County, Wisconsin. Adults were shipped to Vermont in coolers, on ice via overnight express; cultured eggs and larvae were returned in the same manner.

In late June and early July 1997, weevil eggs and larvae were stocked in three plots in each lake; one plot in each lake was left as a control or reference plot and was not stocked. Stocking was done by tying small bundles of Eurasian water milfoil containing the eggs and larvae onto existing milfoil plants in the plots. Although boat traffic was encouraged to stay away from the plots by yellow signs at boat landings, neither enclosures nor exclosures were established. Therefore, weevils were allowed to move freely into the surrounding milfoil.

Approximately 5 weeks post-stocking, weevil density was measured again among the plots. Weevil densities were also measured a full year post-stocking in June and August 1998. Weevil densities varied greatly throughout the project among lakes and treatment levels (Figure 4). In most lakes, weevil densities did not increase to the intended treatment levels. One explanation for the low densities is the possibility that the weevils moved and became distributed throughout the milfoil beds during the weeks after stocking and/or did not return to the same plot areas after overwintering on shore. Additionally, there may have been unexpected mortality to the weevils during the stocking season and/or following seasons. However, the low densities were probably due to a combination of multiple factors.

Note: Weevils were stocked at a rate of weevils per plant, however, weevil densities were measured as weevils per apical stem. Eurasian water milfoil often grows with more than one apical stem per plant.

Table 1. Weevil stocking calculations.

WEEVILS IN PLOTS PRIOR TO STOCKING:

Number of tips / EWM plant:		Number of weevils / EWM tip:		Number of weevils / EWM plant:
(Collected August 1996)	X	(Collected June 1997)	=	(Calculated)
Number of weevils / EWM plant:		EWM plants / square meter:		Number of weevils / square meter:
(From above)	X	(Collected August 1996)	=	(Calculated as pre-stocking level)

TOTAL WEEVILS NEEDED FOR TREATMENT LEVEL ASSIGNED:

No. of EWM plants / sq. meter:		No. of square meters / plot:		No. of EWM plants / plot:
(Collected August 1996)	X	12	=	(Calculated)
No. of weevils needed in each plot for treatment level of 1 per plant:		Treatment level assigned:		Total number of weevils needed per plot for treatment level:
(From above)	X	1, 2, or 4	=	(Calculated)

STOCKING RATE PER PLOT:

Total number of weevils needed per plot for treatment level:		No. of weevils already in plots:		
(From above)	-	(No. from above x 12 m^2)	=	**No. of weevils to stock per plot**

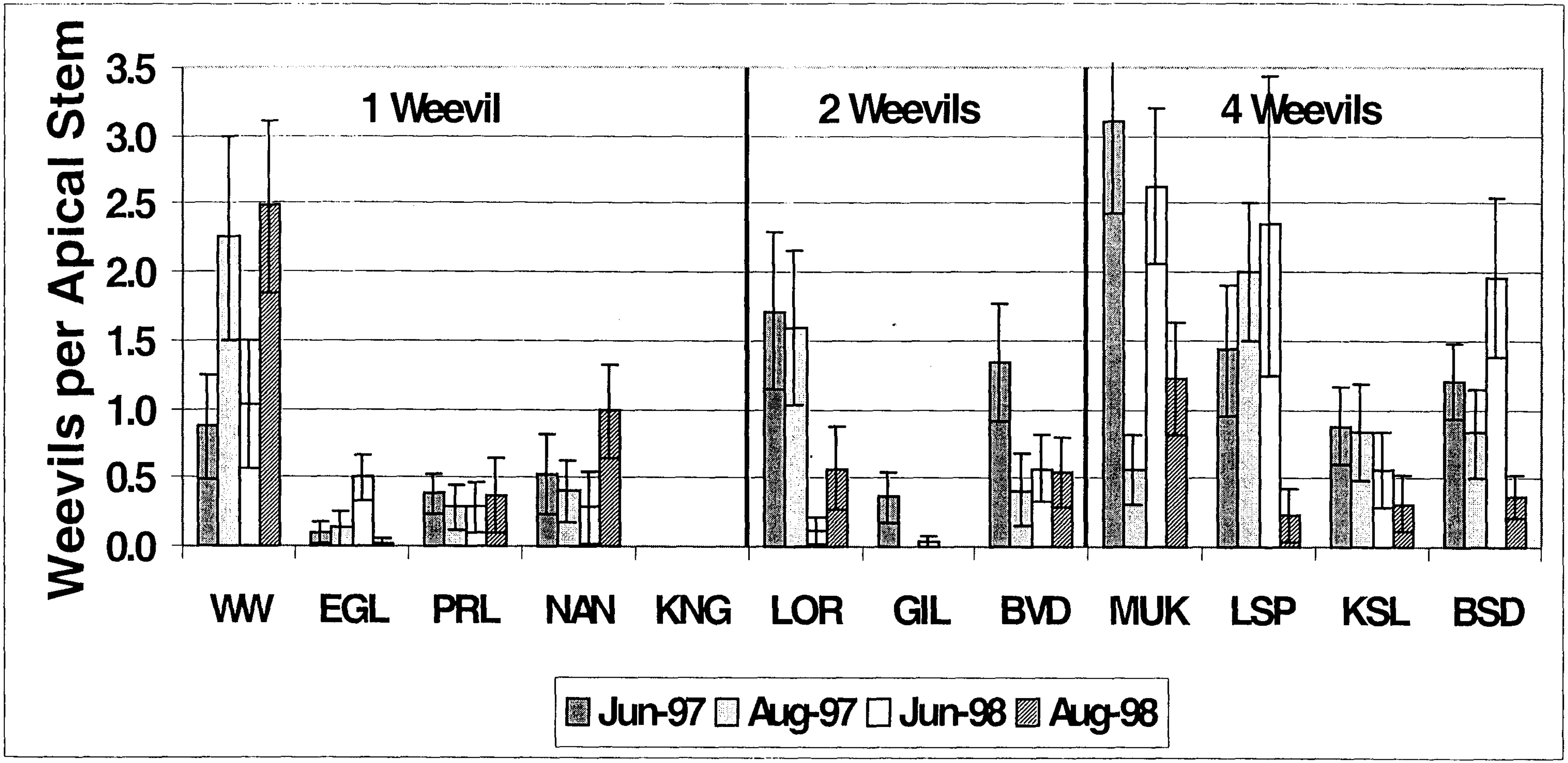

Figure 4. Weevil abundance in study lakes just prior to stocking (June 1997), approximately 5 weeks post-stocking (August 1997), and one year post-stocking (June and August 1998). All weevil lifestages included +/- 95% confidence intervals. Stocked treatment level is shown at top of graph.

Changes in Eurasian Water Milfoil

Weevil densities are just part of the story. The key to successfully using the weevil for biocontrol of Eurasian water milfoil is documenting the correlation between increased weevil densities and decreased Eurasian water milfoil biomass. Accordingly, we also looked at the pre- and post-weevil stocking milfoil biomass or weight per area.

Plants were sampled in the plot areas to determine differences in Eurasian water milfoil variables between pre-stocking (1996) and post-stocking (1997 and 1998) and between reference and treatment plots. This was done using a 0.15 m^2 quadrat sampler and SCUBA. In August 1996, the year before stocking, 16 samples were collected in the area where stocking plots would be placed the next year in each lake. In August 1997, approximately 5 weeks post-stocking, three randomly selected samples were collected from each of the four plots for a total of 12 samples per lake. Plants were collected again a full year post-stocking in August 1998.

Overall, there were some statistically significant changes to the milfoil in various study lakes from pre- to post-stocking (Table 2). However, most of these changes were localized and were not visually vident in the lakes. In most cases, the milfoil remained thick and near the surface; certainly nothing the public would consider a decline and successful milfoil control. It is interesting to note, however, that most of the significant decreases in milfoil measurements occurred in the lakes that received 4 weevils per plant.

In many of the lakes, such as Beaver Dam, Nancy, Big Sand, and Pearl, there was considerable weevil damage evident in the top few inches of the plants which did not allow the plants to flower. However, the weevil damage was usually confined to the upper portions of the plant and did not cause the milfoil to "crash" in the water column and sink out of sight. In fact, the lower portions of the plants often appeared healthy.

Table 2. Changes in milfoil measurements and native plant biomass in treatment plots (reference plots excluded) across 12 study lakes. "—" indicates a statistically significant decrease; "+" indicates a statistically significant increase. A blank indicates no significant change.

		1996 - 1997					1997 - 1998					1996 - 1998				
Lake	Treatment	EWM Biomass	Stem Length	Stem Density	Native Biomass	% Broken Tips	EWM Biomass	Stem Length	Stem Density	Native Biomass	% Broken Tips	EWM Biomass	Stem Length	Stem Density	Native Biomass	% Broken Tips
WW	1	--	--			+		--		+		--	--		+	+
EGL	1	--	--	--		+	--	--	--	+		--	--	--	+	+
PRL	1					+			--					--		+
NAN	1							--					--			+
KNG	1	--	--		--		+	+	+				+		--	
LOR	2	--		--		+						--		--		+
GIL	2	--	--					+					--			
BVD	2				+					--	+					+
MUK	4	--	--	+		+			--		--	--	--			+
LSP	4	--	--	--	+						--	--	--	--	+	
KSL	4	--	--	--				--	--		--	--	--	--		--
BSD	4	--	--	--		+	+	+			+		--	--		+

There were large-scale milfoil declines in the plot areas and beyond in three of the twelve lakes. Kusel Lake in central Wisconsin experienced a large-scale decline in Eurasian water milfoil between 1996 and 1997. Although we do not believe weevils played a major role in the initial decline, it appeared that weevils (both stocked and natural) were able to keep the small amount of returning milfoil from reaching nuisance levels in 1997 and 1998. It is unknown whether milfoil will again become a dominant part of the plant community in Kusel Lake in the future.

In Whitewater Lake weevil densities increased after stocking, and Eurasian water milfoil declined substantially in the plot areas and in other areas around the lake. However, it is unknown whether weevil densities will remain high enough to keep the milfoil at bay, or whether natural swings in weevil populations will allow the milfoil to rebound as early as next year. Whitewater Lake has a history of milfoil declines which appear to be due, at least in part, to the weevil.

Mukwonago Park Pond also experienced a major decline in milfoil between 1996 and 1997. This shallow, 16 acre pond has been full of surfacing milfoil for years, often appearing thick enough to walk across! In 1996, the pond received approximately 4,000 weevils as part of a pilot-stocking project. In June 1997, just prior to actual weevil stocking, weevil densities in Mukwonago Pond were over 3 weevils per apical stem and the milfoil was already declining. Throughout the summer of 1997, the milfoil continued to decline and did not surface anywhere in the pond. By 1998, some milfoil surfaced and flowered in small areas of the pond, but overall there was a significant decline in the milfoil biomass and health.

There were two observations made during this study might prove to be important in determining which lakes may experience a weevil-induced decline (either stocked or natural). First, weevils did not have a substantial negative effect in any lake where the milfoil itself was still expanding and claiming new territory within the lake. Perhaps weevil populations are not able to keep up with expanding milfoil beds fast enough to cause a decline. This would suggest that stocking weevils would be more effective in lakes where the milfoil had already reached a maximum distribution – and not in lakes with new milfoil infestations. Second, weevils did not establish populations of any size on milfoil that was heavily coated with calcium carbonate deposits. It is possible that the thick deposits make the milfoil unsuitable for weevil colonization.

Weevil Stocking Recommendations

The results and observations made during the weevil stocking study are not clear-cut. While a few lakes experienced large-scale milfoil declines, most lakes had slight localized effects and still others had no effect at all.

The high amount of damage in the top portions of the plants in the plots was a common observation among many study lakes. Dr. Raymond Newman of the University of Minnesota hypothesized that plant vigor, health, and possible resistance to weevil predation may be directly related to sediment nutrients. Perhaps more nutrient-rich sediments are able to support plants which are strong enough to resist weevil predation. Along the same line, this study found that higher weevil densities are significantly and positively related to the number of branches or apical tips on the plant. It is possible that plants are responding to increased stress from herbivores by producing more branches from the lower portions of the shoots. Thus, weevils would have an effect at the top of the plant, but could not keep up with the increasing biomass being produced below.

Unfortunately, weevil stocking does not appear to be a cost-effective method of milfoil control in many situations. These include lakes with expanding milfoil beds, lakes with high concentrations of calcium carbonate on milfoil plants, and in lakes where milfoil grows very deep (because only the top portions of the plants are affected by the weevils).

There are, however, a few cases where weevil stocking could be a viable method of milfoil control. These include lakes, ponds or bays with shallow milfoil and natural shorelines, and lakes which have already experienced a large-scale milfoil decline and need a way to keep the remaining milfoil under control.

Weevil stocking can be used in conjunction with other control methods such as mechanical harvesting and chemical herbicides as long as the treatment methods are not used in the same area. Harvesting and herbicides remove the portions of the plant where the weevils feed and reproduce and thus are not compatible with weevil control. Consideration should also be given to the amount of boat traffic that may go through potential weevil stocking areas. Boat motors often disrupt the top portion of the plants and may have a negative impact on weevil populations.

Commercially Available Weevil Stocking

Within the last year, EnviroScience, a company in Ohio, began to sell a commercial method of Eurasian water milfoil control involving weevil stocking. This process (marketed as the Middfoil™ process) involves weevil stocking planning, monitoring and stocking. Eagle Spring Lake (Southeast Wisconsin) contracted with EnviroScience for a project involved with the monitoring and stocking of approximately 5,000 weevils at a total cost of about $9,000. Since this is the first year of stocking, it is too soon to conclude whether this stocking was effective. We suggest carefully watching the results of weevil stocking efforts by EnviroScience in Wisconsin and other lakes across the mid-west. These stockings will provide additional case studies into the potential use of weevils to control milfoil and may begin to indicate what lake or milfoil characteristics are essential for successful control. Perhaps biological control with weevils will one day become cost-effective for lakes throughout the state, but at current market prices and unproved effectiveness, it is still a management tool which needs more research and development.

For Further Reading

Aiken, S. G., P. R. Newroth and I. Wile. 1979. The biology of Canadian weeds. 34. *Myriophyllum spicatum* L. Canadian Journal of Plant Science 59: 201-215.

Bates, A. L., E. R. Burns, and D. H. Webb. 1985. Eurasian watermilfoil (*Myriophyllum spicatum* L.) in the Tennessee Valley: an update on biology and control. Pages 104 – 115 in L. W. J. Anderson editor. Proceedings of the First International Symposium on the watermilfoil (*Myriophyllum spicatum*) and related Haloragaceae species. Aquatic Plant Management Society. Washington D.C.

Bode, J., S. Borman, S. Engel, D. Helsel, F. Koshere, and S. Nichols. 1993. Eurasian watermilfoil in Wisconsin: A report to the legislature. Wisconsin Department of Natural Resources.

Carpenter, S. R. 1980. The decline of *Myriophyllum spicatum* in a eutrophic Wisconsin lake. Canadian Journal of Botany 58: 527-535.

Couch, R. and E. Nelson. 1985. *Myriophyllum spicatum* in North America. Pages 8 –18 in L. W. J. Anderson editor. Proceedings of the First International Symposium on the watermilfoil (*Myriophyllum spicatum*) and related Haloragaceae species. Aquatic Plant Management Society. Washington D.C. 8-18.

Creed, R. P., Jr. 1998. A biogeographic perspective on Eurasian watermilfoil declines: additional evidence of the role of herbivorous weevils in promoting declines? Journal of Aquatic Plant Management 36: 16-22.

Creed, R. P, Jr. and S. P. Sheldon. 1993. The effect of feeding by a North American weevil, *Euhrychiopsis lecontei*, on Eurasian watermilfoil (*Myriophyllum spicatum*). Aquatic Botany 45: 245-256.

Creed, R. P, Jr. and S. P. Sheldon. 1995. Weevils and watermilfoil: did a North American herbivore cause the decline of an exotic plant? Ecological Applications. 5: 1113-1121.

Creed, R. P., Jr. , S. P. Sheldon and D. M. Cheek. 1992. The effect of herbivore feeding on the buoyancy of Eurasian watermilfoil. Journal of Aquatic Plant Management. 30: 75-76.

Crowder, L. B. and W. E. Cooper. 1982. Habitat structural complexity and the interaction between bluegills and their prey. Ecology 63: 1802-1813.

Diehl, S. 1988. Foraging efficiency of three freshwater fishes: effects of structural complexity and light. Oikos 53: 207-214.

Dionne, M. and C. L. Folt. 1991. An experimental analysis of macrophyte growth forms as fish foraging habitat. Canadian Journal of Aquatic Science. 48: 123-131.

Engel, S. 1990a. Ecosystem responses to growth and control of submerged macrophytes: a literature review. Technical Bulletin Number 170. Wisconsin Department of Natural Resources 20 pp.

Engel, S. 1990b. Ecological impacts of harvesting macrophytes in Halverson Lake, Wisconsin. Journal of Aquatic Plant Management. 28: 41-45.

Engel, S. 1994. Fish in troubled waters: Eurasian watermilfoil as a threat to Wisconsin sport fish. Wisconsin Department of Natural Resources Fish Research Highlights January 1994.

Engel, S. 1995. Eurasian watermilfoil as a fishery management tool. Fisheries 20(3): 20-27.

Grace J. B. and R. G. Wetzel. 1978. The production of Eurasian watermilfoil (*Myriophyllum spicatum* L.): A review. Journal of Aquatic Plant Management. 16: 1-11.

Hanson, J. M. 1990. Macroinvertebrate size-distributions of two contrasting freshwater macrophyte communities. Freshwater Biology 24: 481-491.

Jester, L. L. 1998. The geographic distribution of the aquatic milfoil weevil (*Eurhrychiopsis lecontei*) and factors influencing its density in Wisconsin lakes. M.S. Thesis. University of Wisconsin – Stevens Point, 78 pp.

Johnson, R. L., E. M. Gross, N. G. Hairston, Jr. 1998. Decline of the invasive submersed macrophyte *Myriophyllum spicatum* (Haloragaceace) associated with herbivory by larvae of *Acentria ephemerella* (Lepidoptera). Aquatic Ecology. *In press.*

Johnstone, D. M., R. T. Coffey, and C. Howard-Williams. 1985. The role of recreational boat traffic in interlake dispersal of macrophytes: a New Zealand case study. Journal of Environmental Management. 20: 263-279.

Keast, A. 1984. The introduced aquatic macrophyte, *Myriophyllum spicatum*, as habitat for fish and their invertebrate prey. Canadian Journal of Zoology. 62: 1289-1303.

Kimbel, J. C. 1982. Factors influencing potential intralake colonization by *Myriophyllum spicatum* L. Aquatic Botany 14: 295-307.

Kirschner, R. 1995. McCullom lake milfoil saga continues. Lake Waves 11: 1 - 5.

Lillie, R. A. 1991. The adult aquatic and semiaquatic Coleoptera of nine northwestern Wisconsin wetlands. The Coleopterists Bulletin 45: 101-111.

Lillie, R. A. and D. Helsel. 1997. A native weevil attacks Eurasian watermilfoil. Wisconsin Department of Natural Resources Bureau of Research Management Findings No. 40. 4 pp.

Lillie, R. A. and J. W. Mason. 1986. Historical changes in water quality and biota of Devils Lake, Sauk County, 1866-1985. Wisconsin Academy of Sciences, Arts and Letters 74: 81-104.

Madsen, J. D., L. W. Eichler, and C. W. Boylen. 1988. Vegetative spread of Eurasian watermilfoil in Lake George, New York. Journal of Aquatic Plant Management. 26: 47-50.

Madsen, J. D., J. W. Sutherland, J. A. Bloomfield, L. W. Eichler and C. W. Boylen. 1991. The decline of native vegetation under dense Eurasian watermilfoil canopies. Journal of Aquatic Plant Management 29: 94-99.

Maxnuk, M. D. 1985. Bottom tillage treatments for Eurasian watermilfoil control. Pages 163 – 172 *in* L. W. J. Anderson, editor. Proceedings of the First International Symposium on the watermilfoil (*Myriophyllum spicatum*) and related Haloragaceae species. Aquatic Plant Management Society. Washington D.C.

Newbrough, K. L. 1993. The effect of bluegills (*Lepomis macrochirus*) on the density and survival of an aquatic weevil. M.S. Thesis. University of Vermont, 55 pp.

Newman, R. M. and D. W. Ragsdale. 1995. Evaluation of biological control agents for Eurasian watermilfoil. Report to Minnesota Department of Natural Resources, Ecological Services, St. Paul MN. 21 pp.

Newman, R. M. and L. M. Maher. 1995. New records and distribution of aquatic insect herbivores of watermilfoils (Haloragaceae: *Myriophyllum* spp.) in Minnesota. Entomological News 106(1): 6-12.

Newman, R. M, D. W. Ragsdale, and D. D. Biesboer. 1996a. Can Eurasian watermilfoil be managed in Minnesota by biological control with native or naturalized insects? Second Progress Report submitted to Minnesota Department of Natural Resources, St. Paul, MN.

Newman, R. M., K. L. Holmberg, D. D. Biesboer, and B. G. Penner. 1996b. Effects of a potential biocontrol agent, *Euhrychiopsis lecontei*, on Eurasian watermilfoil in experimental tanks. Aquatic Botany 53: 131-150.

Newman, R. M., M. E. Borman and S. W. Castro. 1997a. Developmental performance of the weevil *Euhrychiopsis lecontei* on native and exotic watermilfoil host plants. Journal of the North American Benthological Society 16: 627-634.

Newman, R. M., D. W. Ragsdale, D. D. Biesboer. 1997b. Can Eurasian watermilfoil be managed in Minnesota by biological control with native or naturalized insects? Final Report submitted to Minnesota Department of Natural Resources, St. Paul, MN.

Newroth, P. R. 1985. A review of Eurasian watermilfoil impacts and management in British Columbia. Pages 139 – 153 *in* L. W. J. Anderson, editor. Proceedings of the First International Symposium on the watermilfoil (*Myriophyllum spicatum*) and related Haloragaceae species. Aquatic Plant Management Society. Washington D.C.

Nichols, S. A. and B. H. Shaw. 1986. Ecological life histories of the three aquatic nuisance plants, *Myriophyllum spicatum, Potamogeton crispus and Elodea canadensis*. Hydrobiologia 131: 3-21.

Perry, J. A. and B. G. Penner. 1995. Evaluation of insects as biological control agents for Eurasian watermilfoil. Report to Minnesota Department of Natural Resources, Ecological Services, St. Paul, MN.

Rawson, R. M. 1985. History of the spread of Eurasian watermilfoil through the Okanogan and Columbia River systems (1978-1984). Pages 35 – 38 *in* L. W. J. Anderson, editor. Proceedings of the First International Symposium on the watermilfoil (*Myriophyllum spicatum*) and related Haloragaceae species. Aquatic Plant Management Society. Washington D.C.

Reed, C. F. 1977. History and distribution of Eurasian watermilfoil in United States and Canada. Phytologia 36: 417-436.

Savino, J. F. and R. A. Stein. 1982. Predator-prey interaction between largemouth bass and bluegills as influenced by simulated, submersed vegetation. Transactions of the American Fisheries Society. 111: 255-266.

Sheldon, S. P. 1997. Investigations on the potential use of an aquatic weevil to control Eurasian watermilfoil. Journal of Lake and Reservoir Management 13: 79-88.

Sheldon, S. P. 1994. Invasions and declines of submersed macrophytes in New England, with particular reference to Vermont lakes and herbivorous invertebrates in New England. Lake and Reservoir Management. 10: 13-17.

Sheldon, S. P. and R. P. Creed, Jr. 1995. Use of a native insect as a biological control for an introduced weed. Ecological Applications 5: 1122-1132.

Sheldon, S. P. and L. M. O'Bryan 1996a. The life history of the weevil *Euhrychiopsis lecontei*, a potential biological control agent of Eurasian watermilfoil. Entomological News 107: 16-22.

Sheldon, S. P. and L. M. O'Bryan 1996b. The effects of harvesting Eurasian watermilfoil on the aquatic weevil *Euhrychiopsis lecontei*. Journal of Aquatic Plant Management 34: 76-77.

Smith, C. S. and J. W. Barko. 1990. Ecology of Eurasian watermilfoil. Journal of Aquatic Plant Management. 28: 55-64.

Soar, R. J. 1985. Laboratory investigations on ultrasonic control of Eurasian watermilfoil. Pages 173 – 186 *in* L. W. J. Anderson, editor. Proceedings of the First International Symposium on the watermilfoil (*Myriophyllum spicatum*) and related Haloragaceae species. Aquatic Plant Management Society. Washington D.C.

Solarz, S. L. and R. M. Newman. 1996. Oviposition specificity and behavior of the watermilfoil specialist *Euhrychiopsis lecontei*. Oecologia 106: 337-344.

Sutter, T. J. and R. M. Newman. 1997. Is predation by sunfish (*Lepomis spp.*) an important source of mortality for the Eurasian watermilfoil biocontrol agent *Euhrychiopsis lecontei*? Journal of Freshwater Ecology. 12: 225-234.