

Temporal and Spatial Changes in Milfoil Distribution and Biomass Associated with Weevils in Fish Lake, WI

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ABSTRACT

During the course of an eight year monitoring effort, the Wisconsin Department of Natural Resources documented a significant decline in milfoil biomass and distribution in Fish Lake, Wisconsin. Average milfoil biomass declined by 40-50% from 374-524 g dw m² during 1991-93 to 265 g dw m² during both 1994 and 1995. Milfoil recovered fully in 1996-98 to 446- 564 g dw m². The size of the milfoil bed, as discerned from aerial photographs, shrank from a maximum coverage of 40 ha in 1991 to less than 20 ha during 1995. During the "crash" of 1994-95, milfoil plants exhibited typical signs of weevil-induced damage, including darkened, brittle, hollowed-out growing tips, and the arching and collapse of stems associated with loss of buoyancy. Monitoring of weevils and stem damage during 1995-98 showed highest densities and heaviest damage occurred near shore and subsequently fanned out into deeper water from core infestation sites each spring. The extent of milfoil stem damage was positively correlated with weevil densities (monthly sampling). However, weevil densities and stem damage were lower during 1995 (when milfoil biomass was in decline) than during 1996-98 (when milfoil biomass was fully recovered).

Key words: *Euhrychiopsis lecontei*, Eurasian watermilfoil, *Myriophyllum spicatum*, decline, biological control.

INTRODUCTION

Fish Lake is a 100 ha, 19.5 m deep, seepage lake located in south-central Wisconsin (T9N R7E Sec 3; Lat. 43°17'14", Long. 89°39'08"). Fish Lake is moderately eutrophic² with an average summer chlorophyll *a* concentration of 9 µg L⁻¹, water clarity of 2.7 m, and spring total phosphorus concentration of 22 µg L⁻¹. Eurasian watermilfoil, *Myriophyllum spicatum* L., was introduced into Fish Lake during the early to mid 1960s and reached nuisance conditions in the early 1980s. By the early 1990s, Eurasian watermilfoil (hereafter referred to simply as milfoil) comprised over 90% of the total standing crop

of submersed vegetation in Fish Lake (Lillie 1996). Milfoil biomass and distribution of dense stands declined significantly in 1994 (Lillie 1996). The decline was believed attributable to the activities of the milfoil weevil, *Euhrychiopsis lecontei* (Dietz) (Lillie 1996). This paper summarizes earlier findings (1991-94) and updates the condition and extent of damage to milfoil beds in Fish Lake in recent years (1995-98)—the rest of the story.

METHODS

Plant Biomass and Distribution

The Wisconsin Department of Natural Resources (WDNR) conducted annual (1991-98) biomass surveys of floating-leaved and submersed macrophytes in late July using SCUBA. Divers collected above-ground shoots and stems of all plant species found within 0.1 m² quadrats placed at 5 or 10 m intervals along 21 permanent transects (19 transects in 1991 and 7 transects each in 1997 and 1998). Transects were positioned perpendicular to shore and spaced 200 m apart around the perimeter of the shoreline. In the lab, plants were separated by species, placed in paper bags, and weighed to the nearest 0.1 g after drying at 106 C for a minimum of 48 hrs. Biomass is reported as dry weight per unit area (g dw m²). Further details on sampling methodology are available in Lillie (1996). The locations and dimensions of the milfoil beds were mapped and measured each summer using image analysis computer software and aerial photographs taken with true-color, 35 mm film with a polarizing filter (see Unmuth et al. 1998 for further details).

Milfoil Weevil Damage Assessments

I conducted assessments of milfoil stem damage and weevil abundance monthly during the growing season (June through September) from 1995 to 1998. An initial assessment was conducted in August 1994 to develop sampling methods. On each sampling visit, I collected a random grab of the upper 50-60 cm of milfoil stems at paired stations at three sites along four transects (N = 24 total stations per sampling date). A fifth transect was added in August 1997 to bring the total to 30 stations per date. Stem sample sizes ranged from 63-87 stems per sampling date in 1995, 75-655 in 1996, 273-505 in 1997, and 471-779 in 1998. Stem counts include side branches or growing tips greater than 1 cm in length. The five transects represented the NE, NW, SW, SE, and N (added in 1997) shorelines or bays, and the three sites

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along each transect represented shallow (nearshore), middle, and deep (offshore) edge of the milfoil bed.

I placed plants in plastic bags and stored bags in coolers for transport to the laboratory. In the lab, I removed, counted, and preserved (in 75% ethanol) adult weevils found climbing to the tops of the bags. I then removed plants from the bags and examined each stem and growing tip under 5× magnification for larvae (found both inside and outside of stems), pupae (within pupal chambers), and additional adults; eggs were not counted. At the same time, I recorded the number of stems or tips examined and the number of stems exhibiting any sign of weevil-induced damage. Stem damage included the presence of darkening, brittleness, hollowed-out stems, pupal chambers, and chewing marks. The percent of stems exhibiting damage was used as a measure of relative stem damage. I report weevil densities as the number of weevils per stem examined. I did not measure areal milfoil stem densities or milfoil biomass at each of the 30 sampling stations on each date, so I can not provide accurate estimates of areal weevil densities. However, for those readers who are willing to make several assumptions, an estimate of areal weevil densities (individuals m²) may be made by multiplying the number of weevils per stem times an estimate of stem density based on the 1990-92 averages of 554 stems m² and 329 g dw m² reported for Fish Lake (Budd et al. 1995) and the mid-summer milfoil biomass as reported in this study. Although the milfoil stems were chosen at random, the sites were not; nor were the sites necessarily representative of the entire littoral zone milfoil biomass. Consequently, the weevil-milfoil damage data represent an index useful for illustrating trends, but extrapolation of the data to estimate lake-wide weevil densities is not recommended. The relations between stem damage, weevil density, and milfoil biomass were examined using Pearson product moment correlation and linear regression procedures of SigmaStat® (SPSS Inc. 1997). Differences are reported as significant at P < 0.05.

RESULTS & DISCUSSION

Milfoil Biomass Distribution

The milfoil bed covered approximately 40 ha or roughly 75% of the littoral zone of Fish Lake in 1991 (Figure 1). The milfoil bed was uniformly dense from the 1.5 m to 4.5 m depth contour intervals. During 1992, the bed along the south shoreline began to thin, and by 1993 a large area of the bed along the south shore was no longer visible from the air. The bed in the southwest bay also began to recede during 1993. By 1994, large areas of the north shore and smaller areas along the east and northwest bay had been impacted. During 1995, large areas of the east and south shores, and shallow areas along the north shore, were nearly devoid of milfoil. Property owners could swim, cast and retrieve a fishing lure, and otherwise enjoy the lake for the first time in almost 15 years. The size of the milfoil bed decreased by more than 50% from 1991 to 1994-95 (Figure 1), and the average milfoil biomass declined significantly (Figure 2). The milfoil bed rapidly recovered during 1996, and milfoil distribution remained extensive during 1997-98.

The observation that not all areas of the lake were impacted equally during the milfoil decline of 1994-95 is important

because it suggests that climate or whole lake mechanisms (e.g., change in water clarity or water levels) were not responsible for the observed decline. This is further illustrated by examining biomass data from individual transects (Figure 3). Milfoil biomass in beds along the north (H-L), east (transects C-G), and south (S-U, A-B) shores were heavily impacted during the 1994-95 decline. Milfoil beds along the west shoreline (M-O) and densely vegetated southwest bay (P-R) were not affected significantly. Additional evidence supporting weevils as the cause for the decline is provided by biomass profiles taken from shore to the deep edge of the bed along representative transects. For example, milfoil biomass began to decline at the edges of the bed along transect D in 1993, while milfoil in the center of the bed remained very dense (Figure 4). Prevailing southwesterly winds could have transported weevils from the heavily impacted south shore to the deep edge of the southeast shore bed in the vicinity of transect D (Figure 1). Weevils that had overwintered along the southeast shore could have been responsible for the impact along the nearshore areas of transect D. Milfoil biomass responded differently among and along other transects. In some instances only the shallow end of the transect was affected, while in others the deep end exhibited a decline in biomass. Other than the general overall decline in lake-wide average milfoil biomass during 1994-95, there was no consistent pattern or synchronization among transects or locations along transects.

Response of Native Plants

Native vegetation showed signs of beginning to recover in 1994 coincident to the decline in milfoil (Figure 2). The observed increase was produced almost exclusively by expansion of *Ceratophyllum demersum* L. into the gaps in the canopy created by thinning of the milfoil bed; the response by other taxa was not significant (Lillie 1996). Interestingly, native densities did not decline immediately following the apparent recovery of the milfoil during 1996-98.

Weevil Damage and Weevil Densities

Weevil damage averaged approximately 25% and weevil densities averaged 0.065 weevils per stem during 1995-98 (Figure 5). Weevil densities exhibited an inconsistent pattern, with numbers declining during the season in 1995 and fluctuating rapidly in other years. Stem damage generally increased from June to September and generally was heaviest at shallow or mid-bed stations (Figure 6). A set-back in the weevil population occurring between June and July of 1997 was reflected in lowered stem damage at all stations. Despite the considerable amount of variability in weevil densities, weevil damage was correlated positively with weevil densities ($r^2 = 0.37$, $P = 0.006$). *Euhrychiopsis lecontei* was the dominant weevil present at all times although *Phytobius leucogaster* (Marsham) was occasionally abundant.

Relationship Between Weevil Damage-Density and Annual Milfoil Biomass

I had expected to find a strong negative correlation between weevil densities and average milfoil biomass as record-

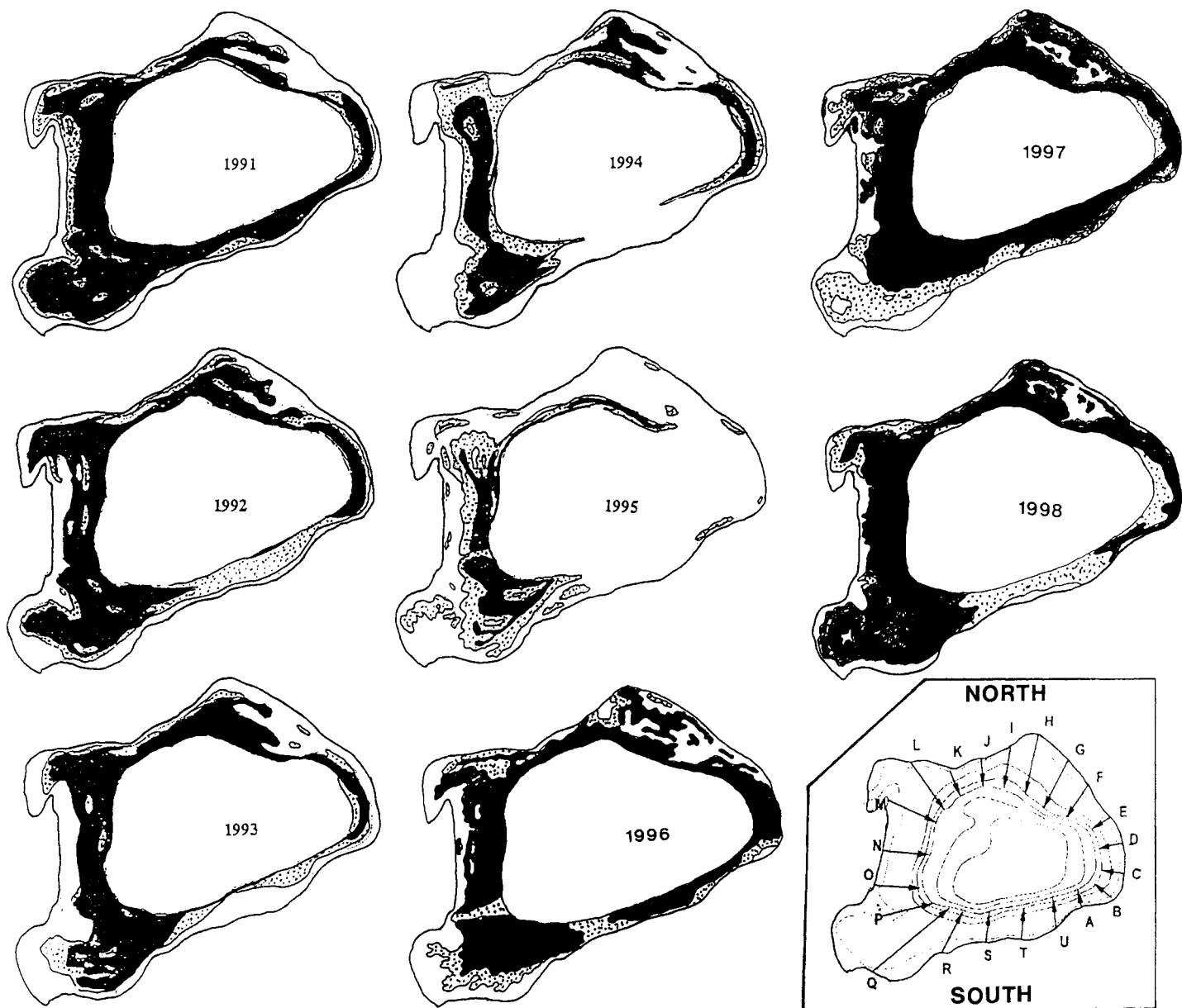


Figure 1. Changes in mid-summer milfoil bed distribution in Fish Lake from 1991 to 1998 as determined from aerial photographs and field observations. Dark shading represents very dense beds; stippled areas represent less dense to sparsely populated beds. The insert illustrates the location of plant survey transects and north-south orientation.

ed during the late July plant surveys. This was not the case. Annual variation in milfoil biomass was correlated significantly with weevil densities, but not in the direction anticipated (Figure 5). Weevil densities and stem damage were substantially lower during 1995 when milfoil biomass was also low, and high in 1996-98 when milfoil biomass was high. It is not readily apparent why weevil damage and weevil densities were low in 1995, but it may be possible that the thinning of the bed associated with the decline in milfoil biomass may have served as a negative feedback mechanism by disrupting weevil reproduction (e.g., mating or egg-laying) or by contributing to reduced larval survival or fitness. The wider spacing between milfoil stems may have effectively reduced the food supply available for larvae, which may normally move or

migrate among adjacent, densely-packed milfoil stems in search for food or pupation sites. In a similar fashion, wider spacing among milfoil stems may have permitted greater opportunities for small fish to gain access to both adult and larval weevils.

The low weevil densities observed during 1995 may have been an artifact of the sampling methodology used. Direct examination of stems and weevils near the water surface may not be an accurate measure of the total amount of damage to the milfoil bed. I may have seriously underestimated the true extent of damage in 1995 because I did not include damage to stems that lost buoyancy and collapsed to the lake bottom out of range of sampling or stems that had broken off at pupal chambers or weak points in hollowed-out stems and had

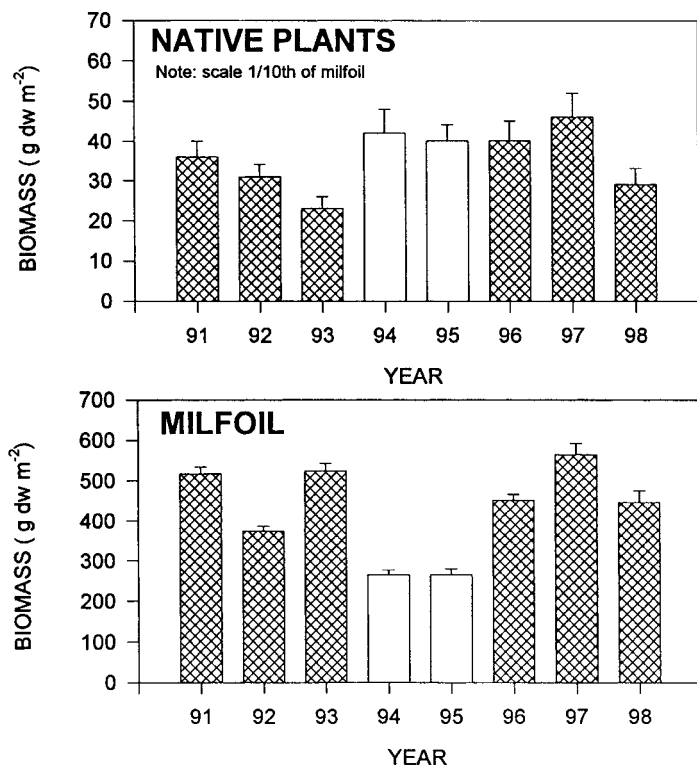


Figure 2. Changes in milfoil (bottom) and native (top) biomass during annual July SCUBA surveys along permanent transects. Data represent mean biomass in g dw m⁻² at all littoral zone sites (1 SE bar shown). Sample sizes are N = 620, 711, 669, 702, 683, 661, 223, and 207 for 1991-98, respectively. Bars for 1994-95 are not shaded to denote years of significantly reduced milfoil biomass.

drifted to shore. Consequently, I only may have sampled the “survivors”, which in many cases may represent healthy, widely-spaced, new-growth stragglers. This hypothesis corresponds with visual observations of the milfoil bed in Fish Lake during 1994-95, during which time the most obvious change was that the milfoil beds had “thinned-out”. Even in the most heavily affected areas of the bed, a few stragglers – usually single, healthy stems—were clearly visible by boat (not visible on aerial photos). Weevil damage-density samples collected during 1995 may have been from such heavily affected areas. Therefore sampling may have turned up few weevils and little stem damage relative to 1996-98 when the milfoil bed was more dense. Weevil damage-density samples collected during the later period may have been from areas in the process of being colonized or beginning to collapse. Such a scenario would support the findings of a positive association between weevil densities and weevil damage, and the negative association between weevil damage-density and milfoil biomass. These disparities in measurements and contradictions in findings stress the need for better, more accurate, means of monitoring damage and assessing weevil populations.

Why Weevils and Not Some Other Cause?

How do we know for certain that the observed decline in milfoil biomass during 1994-95 was attributable to *Euhrychiopsis lecontei*? We don't. In a natural environment the size of

Fish Lake (100 ha) it is difficult to prove conclusively that the milfoil decline was caused entirely by the feeding activities of the milfoil weevil alone (see Creed and Sheldon 1995). However, circumstantial evidence weighs heavily in favor of the weevil. In the fall of 1994, after it became apparent that a crash was in progress, researchers from the Waterways Experiment Station (WES), Vicksburg collected and analyzed milfoil and sediment samples from Fish Lake. No signs of pathogens, viruses or fungi, were found (J. Shearer, WES, pers. comm.), and the sediments fully supported milfoil growth in the laboratory (C. Smith, WES, pers. comm.). SCUBA divers reported large expanses of lake bottom covered with milfoil plants that had collapsed or were arched over, suggesting a loss in buoyancy as had been reported under laboratory conditions by Creed et al. (1992) and by Newman et al. (1996). Milfoil in many other areas of the lake exhibited early signs of arching or slumping as the bed canopy sunk below the lake surface and eventually disappeared from view as plants lost their buoyancy. Further support for weevils as the causative agent rests with the fact that the declines occurred in different portions of the bed at different times. In fact, aerial photographs suggest that waves of weevil activity spread across the bed from different points of origin along the shoreline. On almost all sampling occasions weevil damage (and weevil abundance) was highest in shallow, nearshore stations (Figure 6). Damage generally was greatest in September following reproduction and expansion of the weevil population. Finally, the least amount of damage and most stable milfoil beds were along the west shoreline and southwest bay—perhaps the result of prevailing winds blowing weevils away from this shore or due to disturbance of overwintering habitat in this, the most extensively developed shoreline area. The same prevailing southwesterly winds could have transported large numbers of weevils to the east shore causing the almost total disappearance of milfoil from that region during 1995.

Possible Factors Influencing Weevils and the Milfoil Recovery of 1996

The recovery of the milfoil bed in 1996 and continued high biomass during 1997-98 was a disappointment but not totally unexpected. Likely possible factors contributing to the recovery include weather (combination of wind, temperature, and precipitation influences) that may have interfered both with weevil reproduction and population dynamics early in 1996 or overwintering survival of adult weevils during the winter of 1995-96. A wind disturbance at an inappropriate time may have broken off large amounts of weakened milfoil stems with attached weevil eggs and larvae and thereby transported a majority of the weevil population to a different shoreline with an unfavorable overwintering site. Abnormalities in temperature or precipitation patterns may have directly set-back weevil populations (note the change between June and July 1997 in Figure 5) by disrupting mating or egg-laying, or by contributing to the direct death of adults following spring emergence or during winter hibernation. Conditions at the overwintering sites may be extremely significant in influencing survivability rates and deserve more attention. Annual redistribution patterns of weevils about the perimeter of the lake (spring migration to lake

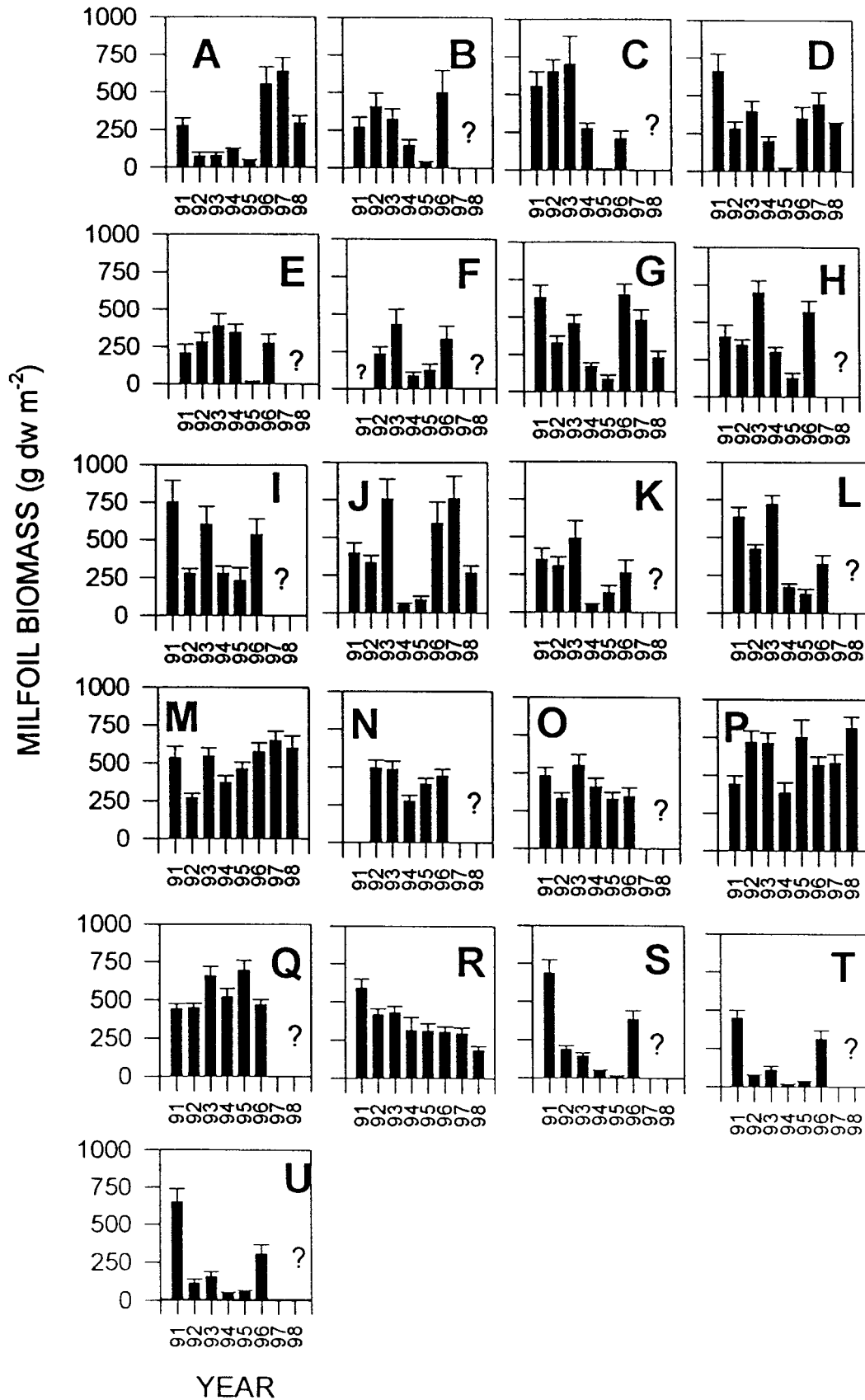


Figure 3. Average milfoil biomass (g dw m⁻² + 1 SE) at all littoral zone sites by transect and year in Fish Lake, 1991-96. See inset in Figure 1 for locations of transects. A "?" represents no data are available.

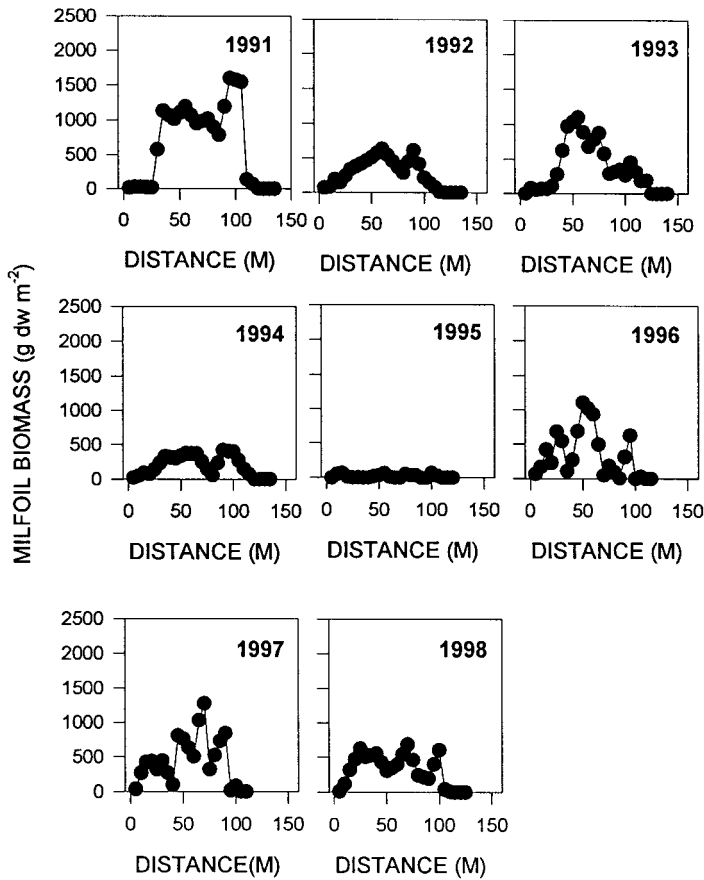


Figure 4. Actual milfoil biomass (g dw m^{-2}) measurements along transect D at 5 m intervals from shore to deep water for 1991 to 1998.

milfoil and spreading within the bed) are likely dependent upon a combination of spatial distribution and location of overwintering habitat and wind direction during migrations.

One reviewer of this paper suggested another possibility in that the low weevil densities (and stem damage) present during 1995 may have contributed directly to the recovery of the milfoil in 1996. Statistical analysis (linear regression) comparing weevil densities or stem damage in one year versus average annual milfoil biomass of the following year did not reveal any significant relations. However, this does not prove the hypothesis wrong. It is quite possible that the weevil densities observed during 1996-98, while apparently higher than numbers observed during 1995, were too low to control milfoil growth. Unfortunately, the single data point for 1994 and the lack of data for 1991-1993 prohibit further examination or clarification of this possible mechanism. Based on the large size of the littoral zone of Fish Lake and the limited amount of shoreline available for overwintering habitat, it may be a rare event (combination of factors) that allows the weevil population to expand to the point that it can keep the milfoil in check.

Another possible factor influencing weevil population dynamics in Fish Lake is predation by the large population of bluegill (Sutter and Newman 1997). The bluegill population in Fish Lake doubled from about 76,000 in 1992 to 141,000 in 1993 (Unmuth et al. 1999). No population estimate was

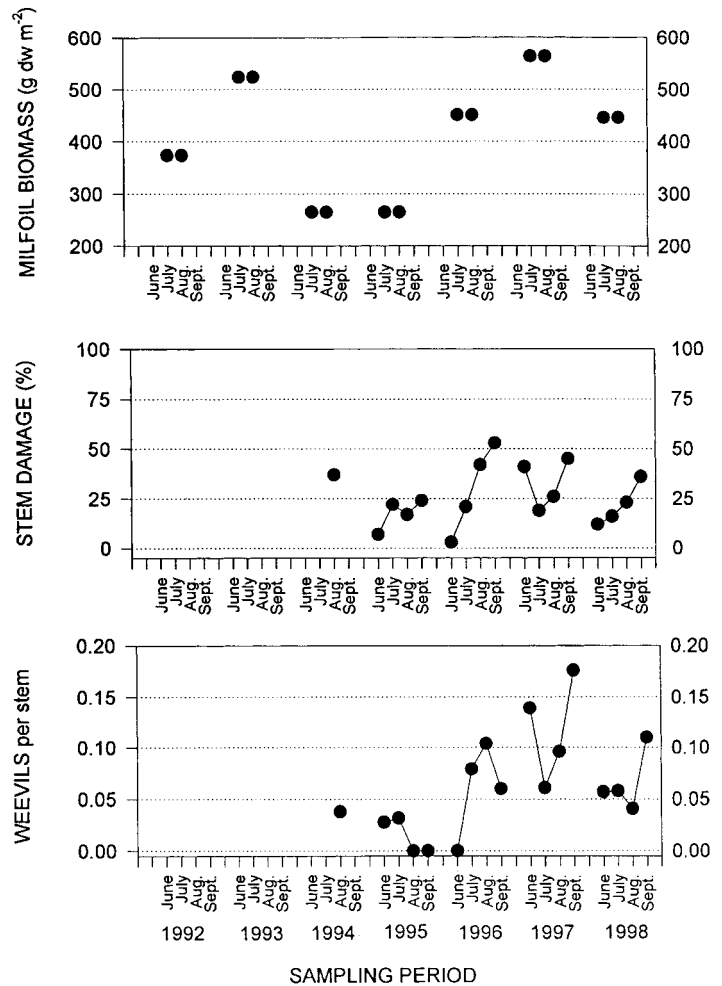


Figure 5. Monthly measurements of weevil densities (bottom), stem damage (middle), and annual average milfoil biomass (top). No weevil damage-density measurements were made before August 1994.

made during 1994, and the bluegill population in 1995-96 was similar to that recorded in 1992. What immediate impact, if any, the large population of bluegill present in Fish Lake had on weevils during 1993 is unknown because I did not start monitoring weevils until late 1994. However, if the impact had been significant, weevil densities should have declined and milfoil biomass should have increased relative to 1992 (as the result of decreased herbivore damage by weevils). Milfoil biomass did increase in 1993 relative to 1992 (Figure 2) supporting the possibility that weevils were kept in check during 1993 by the large population of bluegill present (or other factors). But, unless the bluegill population declined abruptly from 1993 to 1994, which would have allowed the surviving weevil population to expand very rapidly, this hypothesis has little support. Substantial areas of the milfoil bed were either nearly devoid of milfoil or exhibited signs of collapsing very early in the growing season of 1994, suggesting that either a very large population of weevils had overwintered from 1993 or that considerable damage had been inflicted to the milfoil bed after the July 1993 plant survey and that damage carried over into 1994. Perhaps the most vulnerable time for weevils to predation by bluegill is

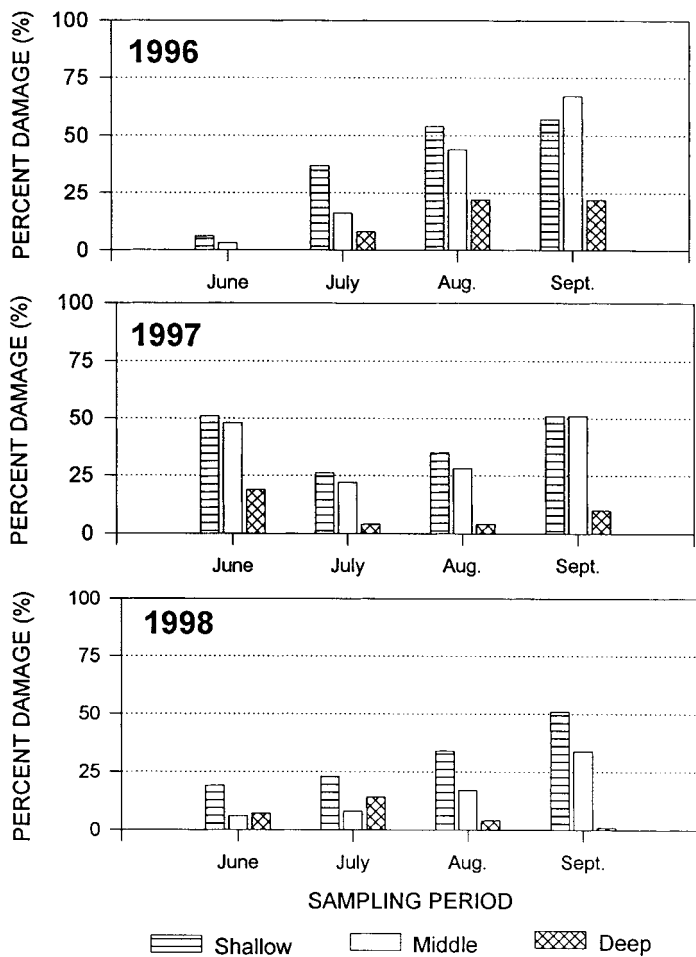


Figure 6. Comparisons of percent stem damage by month and depth position in milfoil bed during 1996 through 1998.

during the fall when weevils return to shore to overwinter. In Fish Lake, there is a gap of open water or sparse beds of native vegetation several meters wide between the shallow edge of the milfoil bed and the shoreline, across which the weevils must either swim or float on rafts of milfoil to reach their overwintering habitat. If predation on weevils by bluegill had been significant during the fall of 1993, weevil densities should have declined and milfoil biomass should have increased in 1994. Milfoil biomass declined significantly. Neither of the above scenarios appears to support the sustained reduction in milfoil biomass observed in Fish Lake during 1994-95. Bluegill do feed on adult *E. lecontei* weevils in Fish Lake (unpublished data, WDNR), but no cascade effect on milfoil biomass was observed. Obviously, the missing data (fish and weevil densities) prohibit further clarification and stresses the importance of and future research needs of multi-faceted, long term data bases.

Irrespective of the factors contributing to the observed large annual fluctuations in weevil damage to milfoil in Fish Lake, the decline and subsequent resurgence of milfoil was

not altogether unexpected (albeit disappointing) as this seems to be the pattern exhibited elsewhere where milfoil declines have occurred (Sheldon 1997). It is hoped that data from continuing monitoring efforts on Fish Lake will mirror the pattern seen on Brownington Pond and elsewhere.

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