J. Aquat. Plant Manage. 26: 3-12

Investigation into the Disappearance of Eurasian Watermilfoil from the Kawartha Lakes

D. S. PAINTER AND K. J. MCCABE[1]

ABSTRACT

Eurasian watermilfoil, (*Myriophyllum spicatum* L.), a nuisance aquatic plant, rapidly disappeared from three Kawartha Lakes for no apparent reason. The role of sediment in the growth and disappearance of milfoil was examined in Buckhorn, Chemung, and Scugog, three Kawartha Lakes, and Opinicon, a Rideau Lake. No correlation between milfoil abundance and sediment pore water chemistry, sediment redox potential, sediment geochemistry and milfoil tissue chemistry was observed from 49 sites. Milfoil growth on sediments from areas where milfoil had recently disappeared was compared to growth on sediments where milfoil was still abundant. No significant difference was evident between sites, nor did the addition of nutrients affect the growth rates; thus suggesting that the sediments were not responsible for the rapid decline of milfoil from the Kawartha Lakes. Circumstantial evidence suggests that insect grazing was responsible for the disappearance.

Key words: Myriophyllum spicatum insect grazing, sediment geochemistry, *Acentria nivea.*

INTRODUCTION

Eurasian watermilfoil (*Myriophyllum spicatum* L.), a nuisance aquatic macrophyte, was introduced to North America from Eurasia in the late 1800's (Reed, 1977). A typical invasion of milfoil is characterized by a pattern of explosive growth, persisting for 5 to 10 years, followed by declining abundance (Carpenter, 1980). This type of growth is commonly exhibited when introduced species invade an area and have left behind their natural competitors enabling them to compete with and often dominate existing native species.

The observed decline of milfoil has stimlated several researchers to examine possible factors responsible for the reduced abundance. In Lake Wingra, Wisconsin, milfoil dramatically declined in 1977 after being the dominant macrophyte since 1969 (Carpenter, 1980). Carpenter (1980) assessed the following plausible hypotheses to explain the decline: toxin accumulation, herbicides and harvesting, climate, nutrients, epiphytes, competition from other macrophytes, and parasites or pathogens. He concluded that no one factor alone could account for the decline of biomass and that a multifactor synergistic mechanism was involved. Jones et al. (1983) examined the possible role of phytoplankton as a factor in the decline of milfoil in Lake Wingra; however, the causal mechanisms remain in doubt since it is not known whether the phytoplankton increase preceded or followed the decline.

Carpenter and Adams (1977) determined the mineral content of *M. spicatum* to examine the possibility that nutrient limitation may explain the disappearance of milfoil in Lake Wingra. Based on Gerloff's critical phosphorus concentration of 0.07% for maximum growth, Carpenter and Adams (1977) concluded that although phosphorus was the most probable limiting mineral, macrophyte growth was not limited by nutrients in Lake Wingra. Schmitt and Adams (1981), however, showed that reduced photosynthetic rates of *M. spicatum* occurred at tissue phosphorus levels below 0.3% and pointed out that the data first thought to dispute the phosphorus deficiency hypothesis now indicates that phosphorus may, in fact, be limiting. Even though there is a discrepancy in the literature concerning the critical concentration of phosphorus required for optimal photosynthesis and yield, the data of seasonal tissue phosphorus concentrations from 1971 (Adams and McCraken, 1974), 1975, and 1977 (Carpenter, 1980) reveal that tissue phosphorus seasonal trends were similar in the three years which represents a time span from the beginning of the milfoil infestation in Lake Wingra to the year the milfoil declined. Thus, tissue phosphorus does not appear to be responsible for the disappearance of milfoil in Lake Wingra.

In Chesapeake Bay, Maryland, milfoil populations also declined dramatically (Bayley et al., 1968). Bayley and her coworkers believed that pathological diseases, namely Northeast disease and Lake Venice disease were responsible for the 95% decline in the milfoil population between 1965 and 1967. In a later investigation, Bayey et al. (1978) attributed the disappearance of milfoil to several interrelated environmental factors including tropical storms, turbidity, salinity, and disease. Increased turbidity and turbulence, resulting from unusual weather during the early growing season, was though to be responsible for the reduction of biomass in the Currituck Sound, North Carolina in 1978 (Davis and Carey, 1981). Stevenson and Confer (1978), however, suggest that the general decline of milfoil abundance in Chesapeake Bay cannot be attributed solely to turbidity; since in some subestuaries where milfoil has disappeared, turbidity has actually decreased.

An unexplained disappearance of milfoil occurred in Chemung Lake in 1977 (Wile et al., 1979) and as of 1986, the milfoil has not returned. Seasonal total macrophyte biomass, seasonal milfoil biomass in lower Chemung Lake, and the contribution of milfoil to the annual biomass from 1971 to 1978 is illustrated in Wile et al. (1979). From 1971 to 1976, milfoil contribution to the total annual submerged

---

[1] Lakes Research Branch, National Water Research Institute, Canada Centre for Inland Waters, Burlington, Ontario, Canada, L7R 4A6.

macrophyte biomass increased from 6.4% to 50.4%, and in 1977/78 drastically declined to approximately 4% of the total vegetation. In 1978, the seasonal standing crop of total vegetation was similar to preceding years, indicating that the sediments could support luxuriant submerged aquatic plant growth. Wile et al. (1979) discussed possible factors for the disappearance of milfoil such as limited tissue phosphorus and nitrogen concentrations. Tissue chemistry remained relatively constant and non-limiting from 1971 to 1977 and therefore could not explain the disapearance. Wile et al. (1979) observed leaf deformities and mentioned the possibility of a pathogen which was also described in Bayley et al. (1968). The fused-leaved symptoms have also been observed by Nagy et al. (1985) and were reportedly caused by sub-lethal exposures to 2,4-D (2,4-dichlorophenoxy acetic acid). Since the local cottage owners were using 2,4-D for shoreline control of milfoil, the observed deformities may have been caused by drift of the herbicide out of the treated area.

A rapid collapse in milfoil was reported by Carignan (1984) in Buckhorn Lake. He observed a dramatic decrease in an apparently healthy milfoil population at one station between early and mid-June with no recovery the next year. In an effort to identify the cause of the observed spatial and temporal variability, Carignan (1984) characterized the sediment geochemistry of several sites in Buckhorn Lake that sustained variable milfoil biomasses. He found that sediments sustaining low or declining biomasses were characterized by relatively high NH_4^+, K, DIC, and H_2S concentrations. Although most stations which sustained low macrophyte biomasses had very low pore water PO_4^{3-} and Fe, some stations which sustained similar biomasses had relatively high PO_4^{3-} and Fe concentrations. This contradiction led Carignan (1984) to suggest that some other chemical factors may be responsible for the apparent toxicity of some sediments to macrophytes.

One factor Carignan (1984) investigated was redox potential which he found to be linearly related to milfoil biomass. Carignan suggested that over time, decomposition of dense macrophyte stands elevates the labile organic matter influx to the sediment, which results in the accumulation of reducing end products, and subsequently lowers the redox potential.

Carignan (1984) also examined the possibility that Fe was limiting by performing a growth experiment using three sediments, two of which supported little or no milfoil biomass in the field. He found that Fe additions only slightly stimulated milfoil growth and that the differences in growth observed between "good" and "bad" sites could not be explained by Fe limitation alone.

Although poor growth of hydrophytes has been associated with H_2S build-up (Howes et al., 1981), Carignan (1984) ruled out H_2S toxicity as a factor explaining poor milfoil growth based on growth experiments he conducted using sediment from a site which sustained high milfoil biomass.

Barko (1983) found that reduced milfoil biomass occurred in areas with high sediment organic content, and that additions of organic matter to the sediment could potentially inhibit milfoil growth. It has been recognized that as lakes age, the sediment organic matter increases and submersed aquatic plants eventually decline (Wetzel, 1979; Carpenter, 1981). Barko and Smart (1986) suggested in their most recent paper that the influence of sediment density is greater than the influence of sediment organic content in regulating macrophyte growth. They speculated that sediment density regulates nutrient uptake by influencing nutrient diffusion distances, and consequently, influences growth. They concluded that growth appears to be governed by the availability of nutrients in sandy and organic sediments.

Nutrient limitation of milfoil growth was tested *in situ* by Anderson and Kalff (1985) in an experiment involving nitrogen, phosphorus, and potassium enrichment. The growth response to fertilization in Lake Memphremagog revealed that milfoil was limited by sediment nitrogen. No response to additions of phosphorus and potassium were observed. Average increases in milfoil biomass were 30-40% upon addition of ammonia, but only 7-17% of the variance in the milfoil biomass indicators could be explained by measurements of exchangable nitrogen. Anderson and Kalff (1986), in another report, attempted to relate species distribution and abundance in Lake Memphremagog to sediment nutrient chemistry and concluded that milfoil presence or absence was not related to sediment nutrient chemistry; milfoil abundance was not significantly related to exchangable nitrogen; and only 14% of the variance in milfoil abundance could be explained by exchangeable phosphorus, the only significant relationship observed for milfoil. Both Barko's work and Anderson and Kalff's work suggest that a nutrient-limited condition in the sediment will determine the possible standing crop of milfoil. Additions of organic material over time in the form of milfoil litter will encourage a nutrient-limited condition in the sediment, and therefore, a gradual reduction in milfoil standing crop. The disappearances of milfoil from several lakes, however, have been observed to involve the complete disappearance of milfoil over a very short period of time. Could biological control by insects or pathogens explain the rapid rate of disappearance?

During a site inspection of Scugog Lake in the fall of 1985, severe grazing damage was observed on the milfoil plants. Most plants were missing the apical tip and many of the stems were bare. Closer examination of the plants revealed the presence of insect larvae, which were tentatively identified as the aquatic larva of the moth, *Acentria nivea.* Specimen identification was verified by US Army Engineer, Waterways Experiment Station, Environmental Laboratory (Vicksburg, Miss.).

Just as Eurasian watermilfoil is an introduced plant specie from Eurasia, *Acentria nivea* is a native moth of Europe and was first observed on the North American continent in Montreal in 1927 (Sheppard, 1945). Judd (1950) subsequently reported the moth in the St. Lawrence River and in the vicinity of Lakes Ontario and Erie. Lekic and Mihajlovic (1970) studied insect grazers of milfoil in Yugoslavia and recommended that *Acentria* be considered as a possible biological control agent for milfoil. In a study of insects and other macroinvertebrates associated with Eurasian watermilfoil in the United States, Balciunas (1982) concluded that aquatic moth larvae fed on milfoil voraciously and caused the most severe damage of any insect group. The moth's life cycle appears to be adequately suited to control milfoil. Milfoil, typically, has two standing crop peaks during the growing season, one in June and the other in September (Adams and McCracken, 1974) which coincides with periods of active feeding by the moth larva. Batra (1977) described the life cycle of the moth and, in our climate, only one generation per year occurs with the larval stage lasting 10.5 months. Buckingham et al. (1981) examined the possibility of biological control of milfoil using *Acentria*. They found that the larvae fed on other aquatic plants as well as milfoil, and the populations may be limited by natural enemies. They also found that *Acentria* already occurs in the northeastern U.S. in many areas where milfoil is problematic. Balciunas (1982) stated that although an individual *Acentria* larva can cause considerable damage, it remains to be determined whether populations occurring in the field are high enough to measurably reduce milfoil levels. Balciunas concluded that the use of *Acentria* as a biological control agent may be limited.

The rate of disappearance and the visual observations of heavy insect grazing damage encouraged us to investigate the possibility that the moth larvae were responsible for the rapid disappearance of the milfoil we were observing at our field sites. Since it is not yet clear what role the sediment plays in the disappearance of milfoil, we chose also to examine the hypothesis that either an inhibiting or a toxic substance, or the development of a nutrient limitation in the sediment may be responsible for the decline of milfoil from several Kawartha Lakes in Ontario. The information in this paper is contained in a larger NWRI technical report (Painter and McCabe, 1987).

METHODS

Lake surveys for milfoil areal distribution and abundance were conducted each fall during the peak in standing crop. The entire lake was surveyed by boat and the areal extent of the milfoil weed beds was marked on the navigational maps. The extent of the lake's surface occupied by milfoil was ranked into four cover-abundance categories (Heavy, >75% cover; Moderate, 25-75%; Light, 1-25%; and None, <1%). One site in Buckhorn was sampled monthly from 1979 to 1984 during the growing season, and once in 1986, for milfoil seasonal standing crop estimates using plant density and plant weight measurements to calculate areal standing crop as described by Painter (1986).

The potential of different sediments to support healthy milfoil growth rates was examined using "good" sediments versus "bad" sediments. "Good" sediments were defined as those which supported heavy milfoil growth *in situ* and "bad" sediments were those which had little or no growth. All sediments were tested unamended and amended with a complete nutrient solution (Long Ashton Solution, Hewitt, 1966) to determine if the sediment nutrients were limiting. Sediments were obtained from Buckhorn, Chemung, and Scugog Lakes from a total of 21 locations using an Eckman grab sampler. Three replicate, 2 liter pots were planted with five, 10 cm apical milfoil tips. The growth experiments were performed in a greenhouse over a 37 day period. Stem length was measured at the beginning, middle, and end of the experiment and growth rates were calculated as the average stem length increase per day. The experimental design had approximately 30% error associated with the calculated growth rates.

Nutrient status of sediment pore water, sediment cores, and milfoil tissue was assessed for 41 sites in Buckhorn, Chemung, and Opinicon Lakes which supported varying densities of milfoil. Pore water samples were obtained using an *in situ* sampler consisting of dialysis tubing inserted inside perforated 12″ ABS pipe sections. The sampler was pushed down into the sediment close to the milfoil root mass and left to equilibrate for 48 hours. Pore water was analyzed for PO_4, NO_3, Ca, K, Na, Mg, DIC, pH, Mn and S. Sediments were sampled using a plexiglass corer with rubber stoppers fitted into the ends. Samples were extruded immediately after the sampling, so that depth profiles of redox and *in situ* pH could be determined. Redox measurements were made at 0, 5, 10, 15, and 20 cm depths. Eh readings were corrected for the calomel reference (+244 mV). Samples were homogenized, sieved to pass through a 1mm mesh screen, dried, ground, and later analyzed for ionic content. Sediment samples were analyzed for P, N, Ca, K, Na, Mg, and Mn. Sediment density and loss on inition (LOI) were determined by drying and igniting a known volume of sediment at 550 C for two hours. Sediment phosphorus fractions were analyzed according to the method described in Mayer and Williams (1981). Bioloically-availabe phosphorus was determined using the 0.1 N NaOH extraction procedure described by Williams et al. (1980). Total phosphorus was determined on a 1 N HCl extract of an ashed sample.

Plant material for tissue analysis was dried, ground in a Wiley mill, and extracted with 6N HCl for analysis. Plant material was analyzed for Na, K, Mg, P, Ca, and Mn.

Cations were analyzed on the Jarrell-Ash Atomic Absorption Spectrophotometer. Phosphate and nitrogen was analyzed by colorimetric and semi-micro Kjeldahl methods respectively.

Fifteen lakes in the Kawartha and Rideau Waterways were surveyed for insect grazing damage and the abundance of two known herbivores of milfoil, the aquatic caterpillar of *Acentria nivea* and the aquatic larva of the weevil, *Litodactylus leucogaster*. Five sites per lake were sampled and five, 25 cm apical tips of milfoil were collected per site and preserved in Kahle's Solution. Insect grazing damage was qualitatively estimated using the following rating scheme: 0—no damage; 1—one of either necrotic spots, leaves eaten, or stem bore holes; 2—two of the previous symptoms; 3—three of the symptoms; 4—the apical tip missing; 5—apical tip missing plus one of the symptoms; 6—apical tip missing plus two of the symptoms; and 7—apical tip missing plus three of the symptoms. Aquatic caterpillar and weevil larvae were counted. At five locations in Buckhorn Lake, a further twenty-two, 25 cm apical tips were examined at each site to estimate the aquatic caterpillar abundance.

The impact of varying aquatic caterpillar densities on milfoil growth was determined using ten, 10 cm mifoil tips incubated in Long Ashton Solution in an incubator. Four,

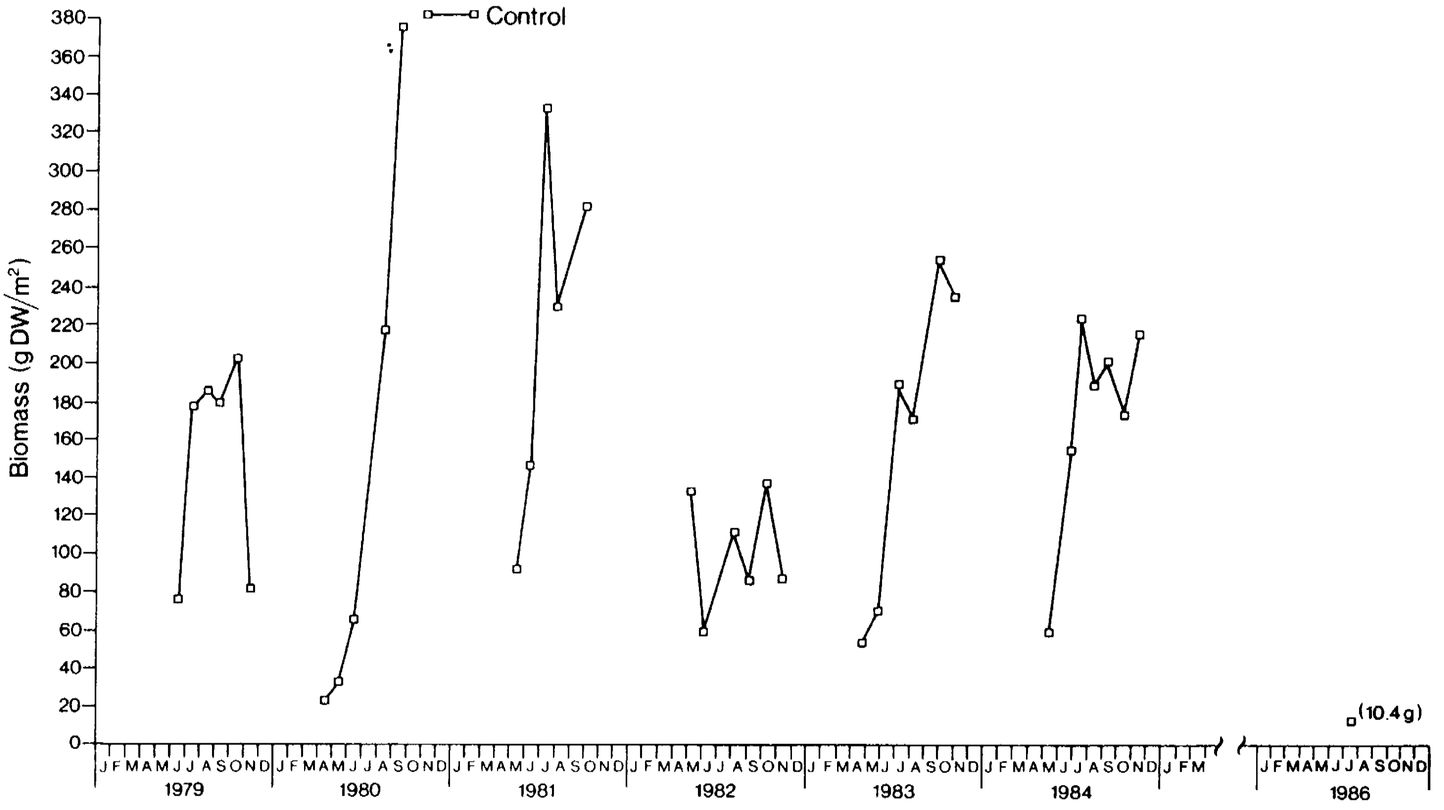


Figure 1. Milfoil biomass (g DW/m^2) at a Buckhorn Lake site from 1979 to 1986. 1 standard error = 23% of the mean.

eight, thirteen, and eighteen larvae were added to the 8 litre Belco flasks containing the milfoil. Milfoil fresh weight was determined every four days for sixteen days.

RESULTS AND DISCUSSION

Milfoil was the dominant aquatic plant in Buckhorn Lake in 1972 (Wile, 1976) and therefore her map of total aquatic vegetation can be assumed to represent milfoil distribution in Buckhorn. Areal cover of milfoil in Buckhorn Lake observed between 1972 and 1986 declined from 78% to 1% with significant changes in 1979 (69 to 32%) and 1986 (21 to 1%). Milfoil biomass at one site in Buckhorn Lake was monitored regularly between 1979 and 1984. Even though fluctuations of biomass did occur at this site from year to year, no gradual decline was evident; but by 1986, the milfoil had virtually disappeared (Figure 1). Tissue phosphorus concentrations of milfoil collected from the site did not decline during the period prior to the disappearance (Painter, 1986). Surficial sediment was analyzed for phosphorus fractions from 1979 to 1986 and no depletion of sediment phosphorus was evident (Table 1). Snowpack, snowfall, heating and growing degree days data from 1970 to 1986 for the area do not correlate with the disappearances of milfoil from Chemung and Buckhorn Lakes. The areas where milfoil has disappeared are now vegetated by native plant species. Wile et al. (1979) also observed the return of native aquatic plants in Chemung Lake in 1977 and 1978 suggesting that the sediment and water quality conditions can support plant growth.

During the course of our sediment experiments, a disappearance of milfoil was also observed from many areas in Lake Scugog in 1986. Three locations monitored in early May were estimated to have 75-100% milfoil cover, but by mid-July the plants appeared unhealthy. Estimates of milfoil cover abundance revealed that two of the three previously dense milfoil stands were completely decimated by early September and the other site dropped to 25-50% cover abundance. These observed declines contradict past seasonal trends because early September is usually the time of year when milfoil biomass peaks (Adams and McCracken, 1974).

Table 1. Spring surficial sediment phosphorus fractions (µg/g) from one site in Buckhorn Lake (BB1) from 1979 to 1986. CDB-P is citrate-dithionate-bicarbonate extractable inorganic phosphorus. NaOH-P is 1 N sodium hydroxide extractable phosphorus. Apatite-P is 1 N HCl extractable phosphorus. Total P is 1 N HCl extractable phosphorus on an ashed sample. TIP is total inorganic phosphorus. BAP is biologically-available phosphorus extracted with 0.1 N NaOH. 1 Standard Error = 13.7% of the reported value.

	CDB-P	NaOH-P	Apatite-P	Total P	TIP	BAP
	C	C	C	C	C	C
1979	89.9	23.4	140.3	1113.2	415.5	
1980	49.4	77.6	105.0	1175.9	360.8	
1981	317.7	84.7	102.9	1581.3	498.9	212.4
1982	176.4	80.6	110.1	1542.6	394.9	182.9
1983	94.7	73.6	74.5	1565.7	422.0	452.5
1984	329.6	89.5	105.0	1262.0	430.9	303.0
1986				1400.0	450.0	

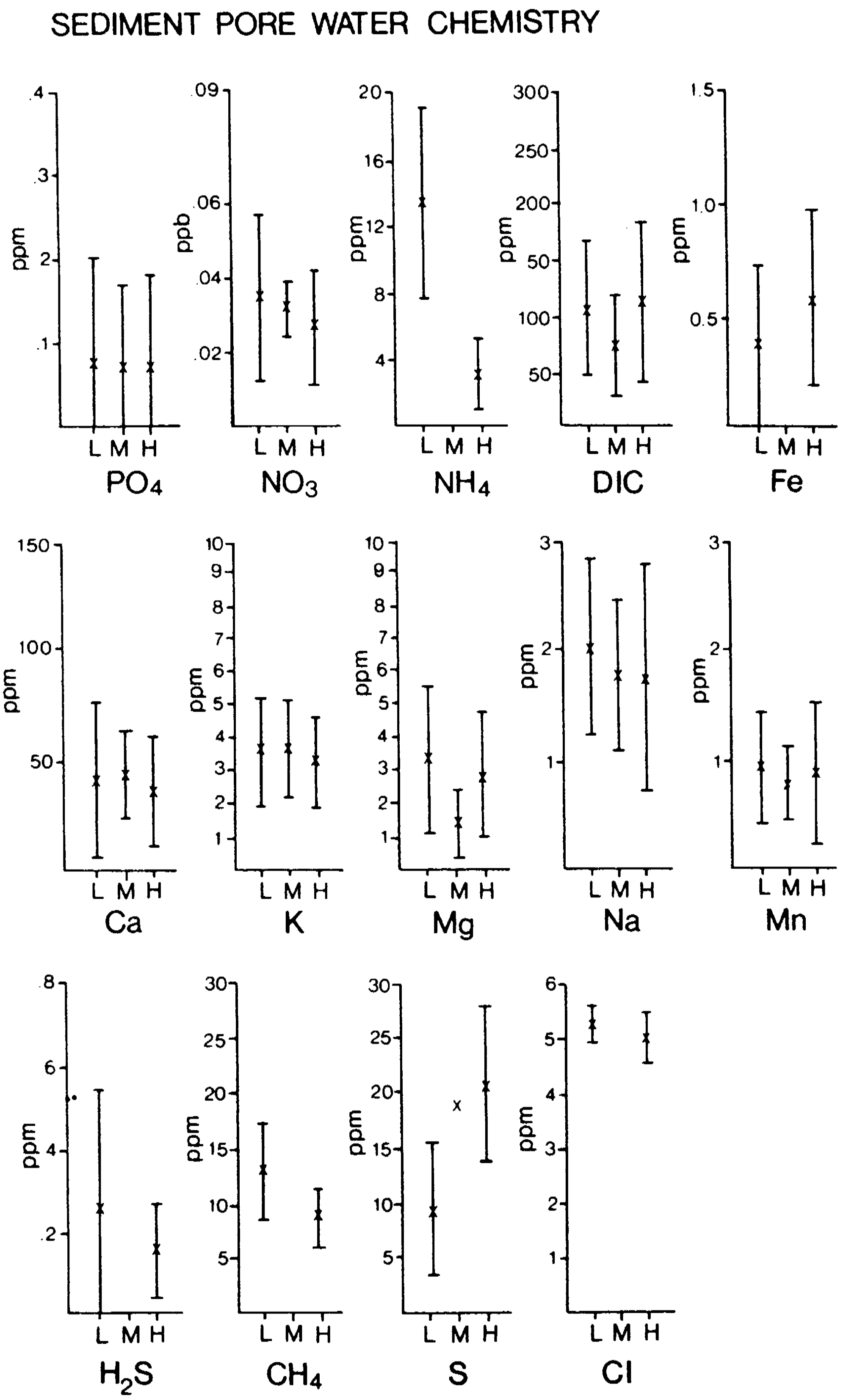


Figure 2. Sediment Pore Water chemistry from 49 sites in Lakes Buckhorn, Chemung, and Opinicon in three milfoil abundances groupings.

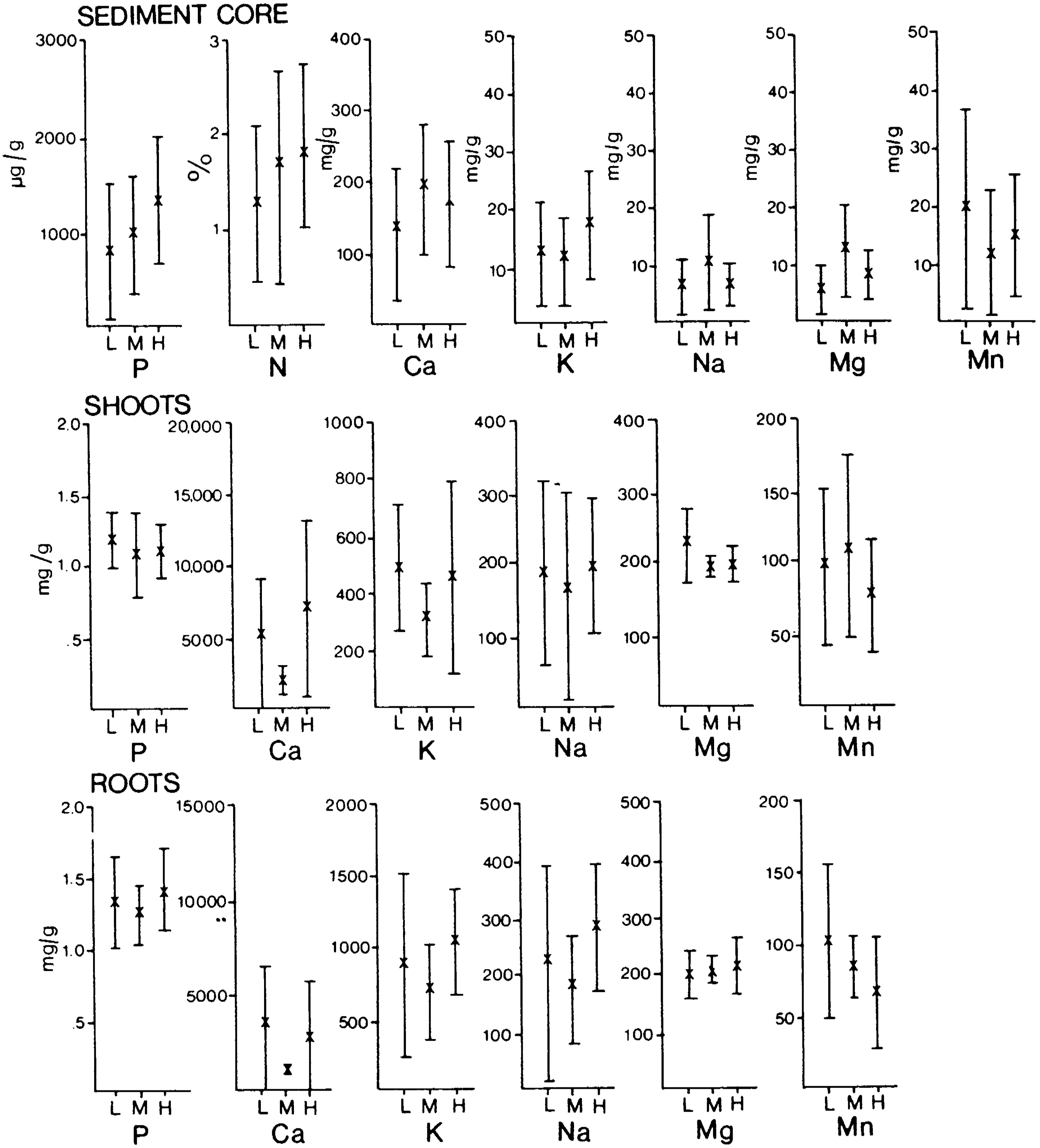


Figure 3. Sediment, shoot, and root chemistry from 49 sites in Lakes Buckhorn, Chemung, and Opinicon in three milfoil abundance groupings.

Carignan (1984) observed a relationship between redox potential and milfoil biomass in Buckhorn Lake. To determine if the relationship extended to other sediments in other lakes we determined the sediment redox potential at thirty-four stations in Buckhorn, Chemung, and Opinicon Lakes with varying milfoil biomasses. The sediments with low, medium, and high milfoil densities had average redox potentials of + 151, + 103, and + 141 respectively, and the standard deviations indicate no significant differences.

Based on Carignan's (1984) findings that elevated NH_4^+ levels were present in sediments sustaining little or no milfoil biomass, we conducted NH_4^+ toxicity bioassays to determine if NH_4^+ concentrations could be reached which would prove detrimental to the growth of milfoil. All plants demonstrated healthy growth (2 cm/day) over the course of the experiment, even at the highest concentration of NH_4^+ (5450 μM) which was approximately 13 times greater than the natural NH_4^+concentrations observed in Buckhorn Lake (400 μM). When comparing shoot (fresh weight, dry weight and length) and root (fresh weight, dry weight) biomass measurements to the NH_4^+ concentrations, we concluded that a 4 to 13 fold increase in NH_4^+ concentration above natural levels in Buckhorn Lake did not influence the growth of milfoil ($p<0.05$).

In an attempt to determine if the decline of milfoil biomass in Buckhorn, Chemung and Opinicon Lakes was a function of limiting sediment nutrients, we examined 41 sites with varying milfoil abundances. At the same time, Carignan (1984) was also investigating the sediment geochemistry at 8 sites in Buckhorn Lake. The pore water chemistry from both studies was pooled together and split into three categories based on milfoil cover abundance. Concentrations of PO_4, NO_3, Ca, K, Na, Mg, DIC, S, Mn, H_2S, CH_4, NH_4, Fe, Cl, and pH in sediment pore water were compared among sites with varying milfoil cover abundances (Figure 2). Concentrations of P, N, Na, Mg, Ca, K and Mn obtained from sediment cores were also compared among sites with varying milfoil cover abundances (Figure 3). It appears that milfoil abundance is not related to sediment pore water chemistry or sediment chemistry since the nutrient concentrations of cover abundance groupings range considerably and overlap. Pore water ammonia is the only exception to this trend. High levels of ammonia were found in areas of low milfoil abundance, but ammonia was measured at only 8 stations; and we experimentally determined that elevated ammonia concentrations did not affect milfoil growth. The low ammonia concentrations in high milfoil biomass locations are likely due to root uptake of ammonia from the pore water.

Shoots and roots of milfoil were analyzed for tissue nutrients (P, Mg, Mn, Na, K, and Ca) since they can be used as an index of nutrient availability for plant growth (Gerloff and Krombholz, 1966). Ranges in concentration of these nutrients did not vary greatly and the standard deviations between sites of differing milfoil biomass overlapped (Figure 3). In a recent report, Barko and Smart (1986) also found a poor relationship between nutrients in macrophyte shoots and macrophyte growth. They did find, however, that growth was highly correlated with nutrient accumulation which takes both tissue mass and nutrient concentrations into account to give a better representation of the plant's responsiveness to sediment conditions. Anderson and Kalff (1985) observed a 30-40% increase in biomass upon the addition of ammonia to the sediments and yet only 7-17% of the variance in milfoil biomass indicators could be explained by measurements of exchangable nitrogen. One could conclude that the difficulty in relating submergent plant growth to sediment characteristics is in knowing what to measure in the sediments and pore water.

Since researchers have been unable to isolate a specific factor responsible for the observed disappearances of milfoil across North America, we felt it was necessary to examine sediment from lakes where milfoil had experienced a sudden decline to see if we could find any differences in the sediment's ability to support milfoil growth. Sediment was collected from both "good" and "bad" sites of Lakes Scugog, Buckhorn, and Chemung. Milfoil growth experiments were conducted on sediments from "bad" sites (locations that recently supported dense milfoil stands but no longer sustain milfoil growth) and compared to milfoil growth rates observed on sediments collected from "good" sites (locations which still support dense milfoil stands).

Healthy growth rates were observed and are plotted in ascending order in Figure 4. If sediment chemistry was responsible for the observed disappearances of milfoil then the "bad" sediments should have had slow growth rates and, therefore, clustered to the left in the graph and the "good" sediments should have had fast growth rates and arranged to the right. Since "good" and "bad" sediments had growth rates which spanned the entire range of observed rates, sediment chemistry does not appear to explain the disappearance of milfoil from those locations. Nutrient additions to the same sediments did not improve the growth rates which also suggests that a nutrient limitation can not explain the disappearance of milfoil. The sediments chosen had wide ranges in sediment density (.04-.11 g DW/ml), organic matter content (22.2-63.9% LOI), total phosphorus (350-1400 ppm) and total inorganic phosphorus (40-480 ppm). "Good" and "bad" sediments were not statistically different in the above parameters. In conclusion, sediment does not appear to be responsible for the rapid declines of mifoil in three Kawartha Lakes.

Fifteen lakes were surveyed in August 1986 to determine the geographical extent of insect grazing damage on milfoil. Figures 5 and 6 illustrate the median insect grazing damage estimate for the 25 apical tips sampled per lake. Ten of the fifteen lakes surveyed had severe grazing damage based upon our ranking scheme. Lakes with a median ranking of 4 had missing apical tips and a ranking of 5 meant that the 25 plants examined had missing apical tips plus one other damage symptom. When comparing the numbers of the aquatic moth larvae (*Acentria*) to the weevil larvae (*Litodactylus*), the moth larva occurred in greater numbers in 13 of the lakes. An initial survey of Buckhorn Lake observed 72 of 135 (53%) apical tips with larvae feeding at the apical tip and making cases by breaking off the tips, bending them back and cementing the tip to the remaining stem. In the ten lakes where the moth larvae were predominant and caused significant grazing damage, 122 moth larvae and 364 larval shelters were observed on 206, 25 cm apical tips (6 larvae and 17.7 larval shelters per 10 tips). Batra (1977) observed approximately 46% of 154

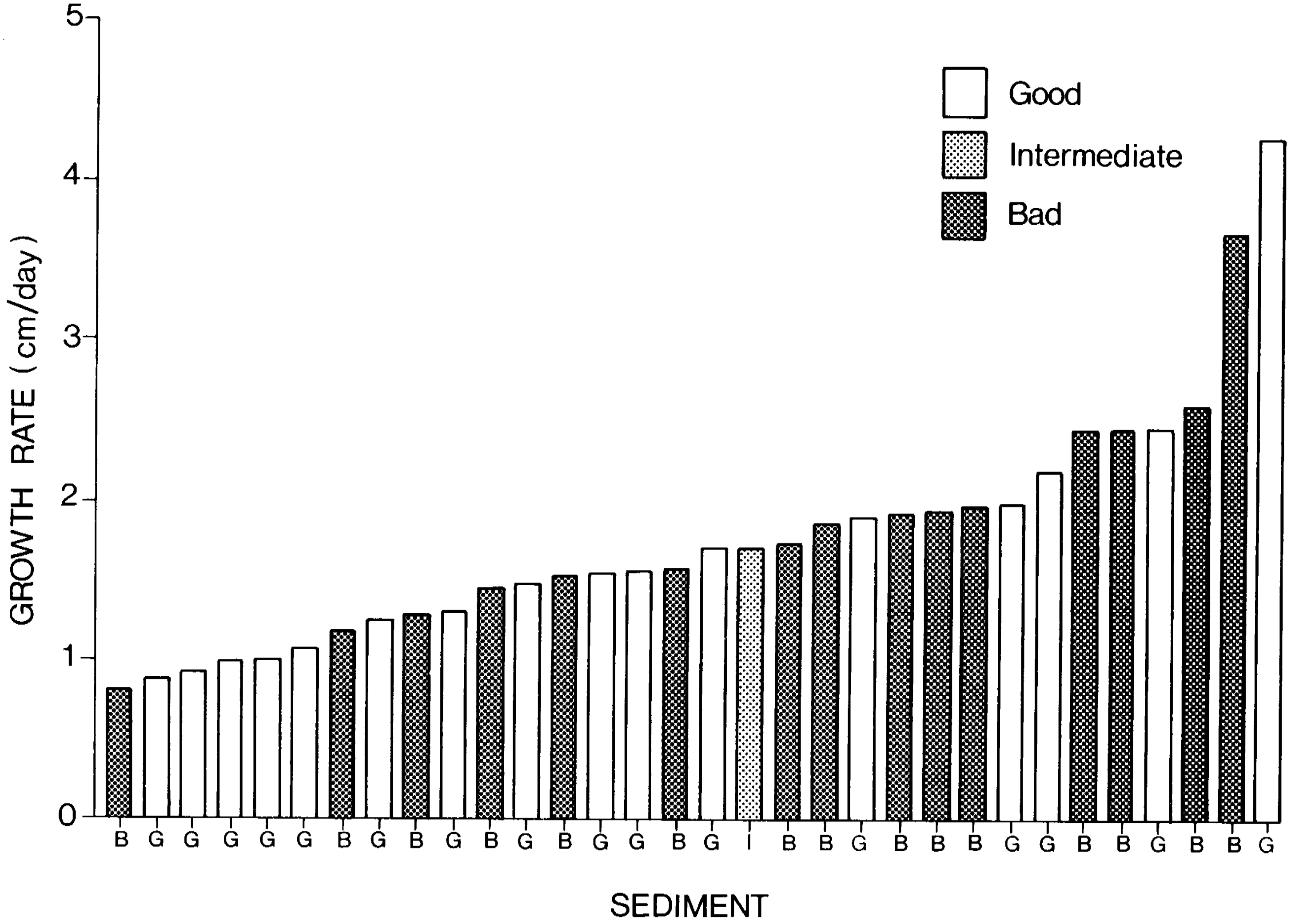


Figure 4. Growth rate of milfoil in "good", "intermediate", and "bad" sediments collected from Lakes Buckhorn, Chemung, and Scugog.

apical tips to have larval shelters. We observed approximately 4 times as many larval shelters as Batra observed. Our feeding trial experiments indicated that milfoil growth could cope with 4 larvae per 10 tips but larval abundances greater than 8 larvae per 10 tips had a severe impact (Figure 7). In the five lakes that did not experience significant insect grazing damage, only 6 larvae and 11 larval cases were observed on 79, 25 cm apical tips (0.76 larvae and 1.4 larval shelters per 10 tips).

Given the rapid disappearance of the milfoil from several locations in Scugog and Buckhorn Lakes during 1986, the insect grazing damage estimates for those lakes, and the high population of *Acentria* larvae relative to previously published population estimates, we conclude that insect grazing by the moth caterpillar was responsible for the disappearance of milfoil from Scugog and Buckhorn Lakes in 1986.

At present (fall 1987), milfoil is still declining in abundance in Scugog and Buckhorn Lakes, presumably due to continued grazing pressure by the moth. Aquatic vegetation, in general, in both lakes appears healthy, diverse and abundant. The milfoil appears to have been selectively controlled.

LITERATURE CITED

Adams, M. S. and M. D. McCracken. 1974. Seasonal production of the Myriophyllum component of the littoral of Lake Wingra, Wisconsin. J. Ecol. 62:457-467.

Anderson, R. M. and J. Kalff. 1985. Nutrient limitation of *Myriophyllum spicatum* growth *in situ. In:* Proc. 1st International Symposium on Watermilfoil (*Myriophyllum spicatum*) and Related Haloragaceae Species, Vancouver, B.C., Canada. pp. 95-103.

Anderson, M. R. and J. Kalff. 1986. Regulation of submerged aquatic plant distribution in a uniform area of a weedbed. J Ecol. 74:953-961.

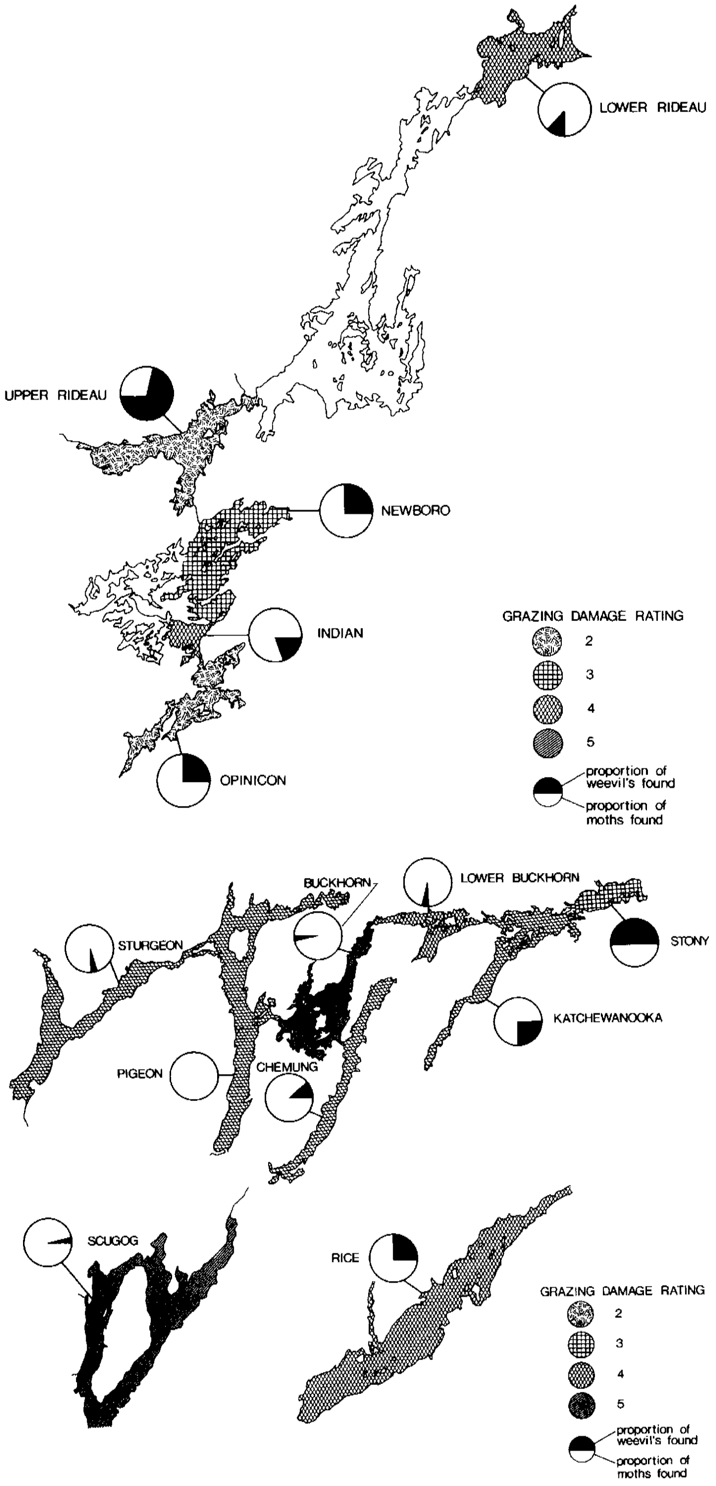
Balciunas, J. K. 1982. Insects and other macroinvertebrates associated with Eurasian watermilfoil in the United States. Technical report A-82-5, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Barko, J. W. 1983. The growth of *Myrioophyllum spicatum* L. in relation to selected characteristics of sediment and solution. Aquat. Bot. 15:91-103.

Barko, J. W. and R. M. Smart. 1986. Sediment-related mechanisms of growth limitation in submersed macrophytes. Ecology 67:1328-1340.

Batra, S. W. T. 1977. Bionomics of the aguatic moth, *Acentropus niveus* (Oliver), a potential biological control agent for Eurasian watermilfoil and hydrilla. New York Entomol. Soc. 85:143-152.

Bayley, S., H. Rabin, and C. H. Southwick. 1968. Recent decline in the distribution and abundance of Eurasian milfoil in Chesapeake Bay. Chesapeake Science 9:173-181.



Figures 5 (Top) and 6. Insect grazing damage estimates for several Rideau and Kawartha Lakes and the proportion of weevil larvae versus moth larvae and cases observed.

Bayley, S., V. D. Stotts, P. F. Stinger, and J. Steenis. 1978. Changes in submersed aquatic macrophyte populations at the head of the Chesapeake Bay, 1958-1975. Estuaries 1:73-84.

Buckingham, G. R., C. A. Bennett, and B. M. Ross. 1981. Investigation of two insect species for control of Eurasian watermilfoil. Technical report A-81-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

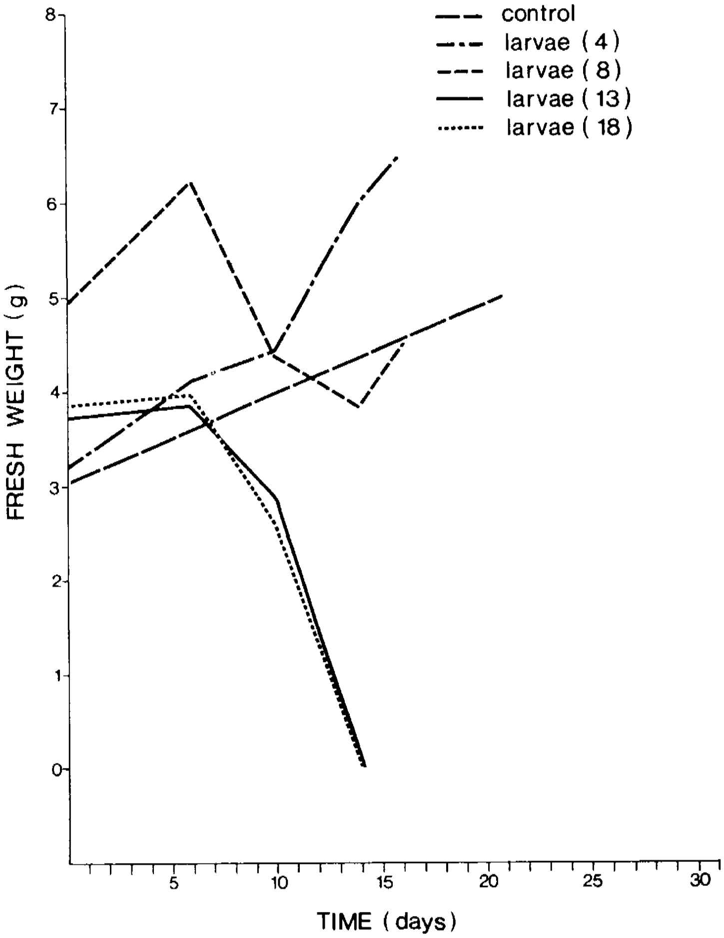


Figure 7. Fresh weight of milfoil grazed upon by varying moth larvae densities versus time.

Carignan, R. 1984. Sediment geochemistry in a eutrophic lake colonized by the submersed macrophyte *Myriophyllum spicatum*. Verh. Internat. Verein. Limnol. 22:335-370.

Carpenter, S. R. 1980. The decline of *Myriophyllum spicatum* in a eutrophic Wisconsin Lake. Can. J. Bot. 58:527-535.

Carpenter, S. R. 1981. Submersed vegetation: an internal factor in lake ecosystems succession. Amer. Naturalist 118:372-383.

Carpenter, S. R. and M. S. Adams. 1977. The macrophyte tissue nutrient pool of a hardwater eutrophic lake: implications for macrophyte harvesting. Aquat. Bot. 3:239-255.

Davis, G. J. and D. F. Carey. 1981. Trends in submersed macrophyte communities of the Currituck Sound: 1977-1979. J. Aquatic Plant Manage. 19:3-8.

Gerfoff, G. C. and P. H. Krombholz. 1966. Tissue analysis as a measure of nutrient availability for the growth of angiosperm aquatic plants. Limnol. and Oceanogr. 11:529-537.

Hewitt, E. J. 1966. Sand and water culture methods used in the study of plant nutrition. Tech Comm. #22. Commonwealth Agricultural Bureaux, Farnham Royal. Bucks. England.

Howes, B. L., R. W. Howarth, J. M. Teal, and I. Valiela. 1981. Oxidation-reduction potentials in a salt marsh: Spatial patterns and interactions with primary production. Limnol. Oceanogr. 26:350-360.

Jones, R. C., K. Walti, and M. S. Adams. 1983. Phytoplankton as a factor in the decline of the submersed macrophyte *Myriophyllum spicatum* L. in Lake Wingra, Wisconsin, U.S.A. Hydrobiologia 107:213-219.

Judd, W. W. 1950. *Acentropus niveus* (Oliv.) (Lepidoptera: Pyralidae) on the north shore of Lake Erie with a consideration of its distribution in North America. Can. Entomol. 82:250-252.

Lekic, M. and L. Mihajlovic. 1970. Entomofauna of *Myriophyllum spicatum* L. (Haloragidaceae), an aquatic weed on Yugoslav territory. J. for Sci.

Agr. Res. 82:59-74. Translation of Arhiv za Poljoprivredne Nauke 82:63-76.

Mayer, T. and J. D. H. Williams. 1981. Modified procedure for determining the forms of phosphorus in freshwater sediment. Tech. Bull. #119. IWD Environment Canada, CCIW, Burlington, Ont., Canada.

Nagy, E., D. S. Painter, and B. F. Scott. 1985. Fate and Impact of 2,4-D in a pond ecosystem. *In:* Proc. 1st International Symposium on Watermilfoil (*Myriophyllum spicatum*) and Related Haloragaceae Species. pp. 202-213.

Painter, D. S. 1986. Long-term effects of mechanical harvesting on Eurasian watermilfoil. NWRI Rep. # 88-140. NWRI. Environment Canada, Burlinton, Ontario, Canada.

Painter, D. S. and K. J. McCabe. 1987. Invstigation into the Disappearance of Eurasian watermilfoil from the Kawartha Lakes. NWRI Rep. # 87-71. NWRI Environment Canada, Burlington, Ontario, Canada.

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

Schmitt, M. R. and M. S. Adams. 1981. Dependence of rates of apparent photosynthesis on tissue phosphorus concentrations in *Myriophyllum spicatum* L. Aquat. Bot. 11:379-387.

Sheppard, A. C. 1945. A new record for Canada (Lepidoptera). Can. Entomol. 77:55.

Stevenson, J. and N. M. Confer. 1978. Summary of available information of Chesapeake Bay submerged vegetation. U.S. Fish and Wildlife Service, Annnopolis, Md. 335 pp.

Wetzel, R. G. 1979. The role of the littoral zone and detritus in lake metabolism. Archiv fur Hydrobiologie. 13:145-161.

Wile, I. 1976. The macrophytes of the Kawartha Lakes—1972. *In:* The Kawartha Lakes management study—water quality assessment (1972-1976), Ontario Ministry of the Environment. pp. 69-82.

Wile, I., G. Hitchin, and G. Beggs. 1979. Impact of mechanical harvesting on Chemung Lake. *In:* Aquatic Plants, Lake Management, and Ecosystem Consequences of Lake Harvesting Proc. of Conf. at Madison, Wis. Feb. 14-16, 1979. pp. 145-159.

Williams, J. D. H., H. Shear, and R. L. Thomas. 1980. Availability to *Scenedesmus quadricauda* of different forms of phosphorus in sedimentary materials from the Great Lakes. Limnol. Oceanogr. 25:1-11.

J. Aquat. Plant Manage. 26: 12-17

Integrated Control of Eurasian Water Milfoil, *Myriophyllum spicatum*, by a Fungal Pathogen and a Herbicide

K. K. SORSA, E. V. NORDHEIM AND J. H. ANDREWS[1]

ABSTRACT

Factorial experiments were conducted on rooted Eurasian water milfoil grown in a biphasic culture system to evaluate the impact of the fungal pathogen *Colletotrichum gloeosporioides*, the herbicide Endothall at 0.65, 1.29 and 2.58 ppm and high or low phosphorus conditions on growth. Growth, measured as post-treatment biomass increase, declined significantly ($p<0.01$) from the untreated control levels under all treatment conditions. Growth decline of 42-90% (shoot) or 41-88% (shoot and root biomass) was observed as herbicide concentration was increased (from 0.65-2.58 ppm Endothall). Fungal inoculation alone depressed biomass increment values to 90% (for both shoots alone and shoots plus roots). Complementary growth assessments, based on incremental biomass and total biomass increase from the start of the experiments, confirmed the effect of the herbicides ($p<0.001$) or pathogen alone ($p<0.01$) or combined ($p<0.05$). Low phosphorus conditions further reduced biomass for all treatments, but the data were otherwise consistent with that for the high phosphorus regimen. The results suggest that pathogens even if marginally effective alone, could accentuate the impact of chemical control and offer promise for integrated control based on biological, chemical, and physiological components.

Key words: Biocontrol, *Colletotrichum gloeosporioides*, Endothall, milfoil growth.

INTRODUCTION

Eurasian water milfoil (*Myriophyllum spicatum* L.) (hereafter called "milfoil") ranks among the most aggressive nuisance aquatic weeds in Norh America (Grace and Wetzel 1978). The plant is adaptable, grows rapidly, and reproduces prolifically thereby displacing native vegetation. Since being introduced in the early 1800's (Reed 1977), milfoil continues to expand its geographic range. As a submersed weed, it possesses most, if not all, the detractions of the emersed group and additionally it impedes water flow more severely and is less amenable to control.

The traditional control methods for milfoil are mechanical harvesting or use of herbicides (Dunst and Nichols 1979). The former is costly (Koegel and Livermore 1979); the latter is controversial because of the real or perceived threat to human health and the environment. Since our studies (Andrews and Hecht, 1981; Andrews et al. 1982) indicate that milfoil is susceptible to fungal infections, there is the prospect for integrated control using a fungal pathogen and modified herbicide program, to-

---

[1] Postdoctoral Research Associate, Department of Soil Science, University of Wisconsin-Madison, Madison, WI 53706; Associate Professor, Department of Forestry and Statistics, University of Wisconsin-Madison, Madison, WI 53706: Professor, Department of Plant Pathology, University of Wisconsin-Madison, Madison, WI 53706.