D. Timothy Gerber

Floating-leafed and Submersed Aquatic Macrophyte Distribution and Abundance, With Emphasis on Eurasian Watermilfoil *(Myriophyllum spicatum)* in Forest Lake, Fond Du Lac County, Wisconsin

Abstract *Exotic species invasions play an important role in reducing native biodiversity. Tracking the spread, distribution, and abundance of the exotic submersed aquatic macrophyte eurasian watermilfoil* (Myriophyllum spicatum) *in Wisconsin and cataloging native biodiversity within the lakes it invades is of interest to state aquatic biologists, lake managers, and lake property owners. The purpose of this paper is to assess, through the use of a nondestructive sampling method, both the spread and distribution of this exotic species and the distribution of native aquatic flora in Forest Lake, Fond du Lac County, Wisconsin. I found twenty-two species of aquatic macrophytes, including eurasion watermilfoil, within the lake. Some significant differences in abundance and depth distribution were found for six of the most dominant aquatic species. Although eurasion watermilfoil was not listed in previous plant surveys of Forest Lake, it has become well established. An additional exotic emergent aquatic species, purple loosestrife* (Lythrum salicaria), *was also found, and its distribution was determined.*

Exotic species invasions have historically played an important role in reducing native biodiversity (Devine 1998). Since the early 1960s, invasion of the exotic Eurasian watermilfoil (*Myriophyllum spicatum*, hereafter EWM) in southern Wisconsin (Engel 1993) has negatively affected native aquatic macrophyte communities and thus has had an impact on many organisms that interact with these plants. Tracking the spread, distribution, and abundance of EWM in

Wisconsin and cataloging native biodiversity within the lakes it invades is therefore of interest to aquatic biologists, lake managers, and lake users.

Forest Lake (T13N, R19E, sec. 12, Hydrologic unit 04040003, Fond du Lac County, WI) is a 20.4-ha kettle lake located in the terminal moraine of the Green Bay glacier. This single basin lake receives no permanent surface water inflow and has no stream outlet (Wisconsin Department of Natural Resources 1970, U.S. Geological Survey 1994). With a mean depth of 3.3 m, Forest Lake supports a diverse assemblage of rooted, floating-leafed and submersed aquatic plant species that cover much of the lake's bottom. The 47.6-ha watershed surrounding Forest Lake is moderately to steeply sloped with a loam soil that supports primarily woody vegetation (47 ha). The remaining area (0.6 ha) is marsh and shrub wetland (Wisconsin Department of Natural Resources 1970). The watershed has been extensively developed on the northern and eastern sides (private homes and cottages) where shoreline disturbance (sand beach development) is greatest. During the 1960s, dredging at the northern end of the lake caused additional disturbance to the native aquatic plant community.

As of 1968 (Wisconsin Department of Natural Resources 1970), EWM was not found in Forest Lake; however, since then this exotic species has become a problem. Because of interest in exotic species distribution and control in Wisconsin, a systematic survey of Forest Lake's aquatic macrophyte community was conducted to determine the extent of the EWM invasion. The purpose of this paper is to (1) quantitatively and qualitatively document the native aquatic macrophytes and EWM in Forest Lake, (2) describe the within-lake distribution of native macrophytes and EWM at present, (3) assess if changes in macrophyte distribution have occurred since the 1968 survey, (4) determine if other exotic species occur, and (5) determine sediment characteristics within disturbed areas of the lake.

Methods

Data Collection

A qualitative and quantitative aquatic vegetation survey was conducted during July 1993. To minimize disturbance to aquatic plant beds, a nondestructive sampling technique (Titus 1993) was used. Twenty evenly spaced (approximately 107 m between) transects were established perpendicular to the shoreline to assess species composition, frequency, and abundance (Figure 1). Four 0.25-m^2 sample sites were located along each transect, one site at each depth interval (0.5, 1, 2, and 3 m) for a total of 80 sample sites. The maximum depth interval was set at 3 m because aquatic plant growth was limited to 3.7 m (Wisconsin Department of Natural Resources 1970). Each transect was assessed visually for the presence or absence of plants and percent cover of each species using snorkel or SCUBA equipment. An abundance score was determined for each site based on the percent cover for each species (see below). Voucher specimens of each species were deposited in the University of Wisconsin-Milwaukee herbarium.

To determine the range of sediment characteristics under which EWM grows within the most disturbed extreme northern region of Forest Lake, six 200-g samples of sediment were randomly collected within EWM beds at 1-2 m depth during September 1993. Each sample was dried and sent to the University of Wisconsin-Extension Soil and Plant Analysis Lab (5711 Mineral Point Road, Madison, WI) for analysis of pH, organic matter (percent organic matter

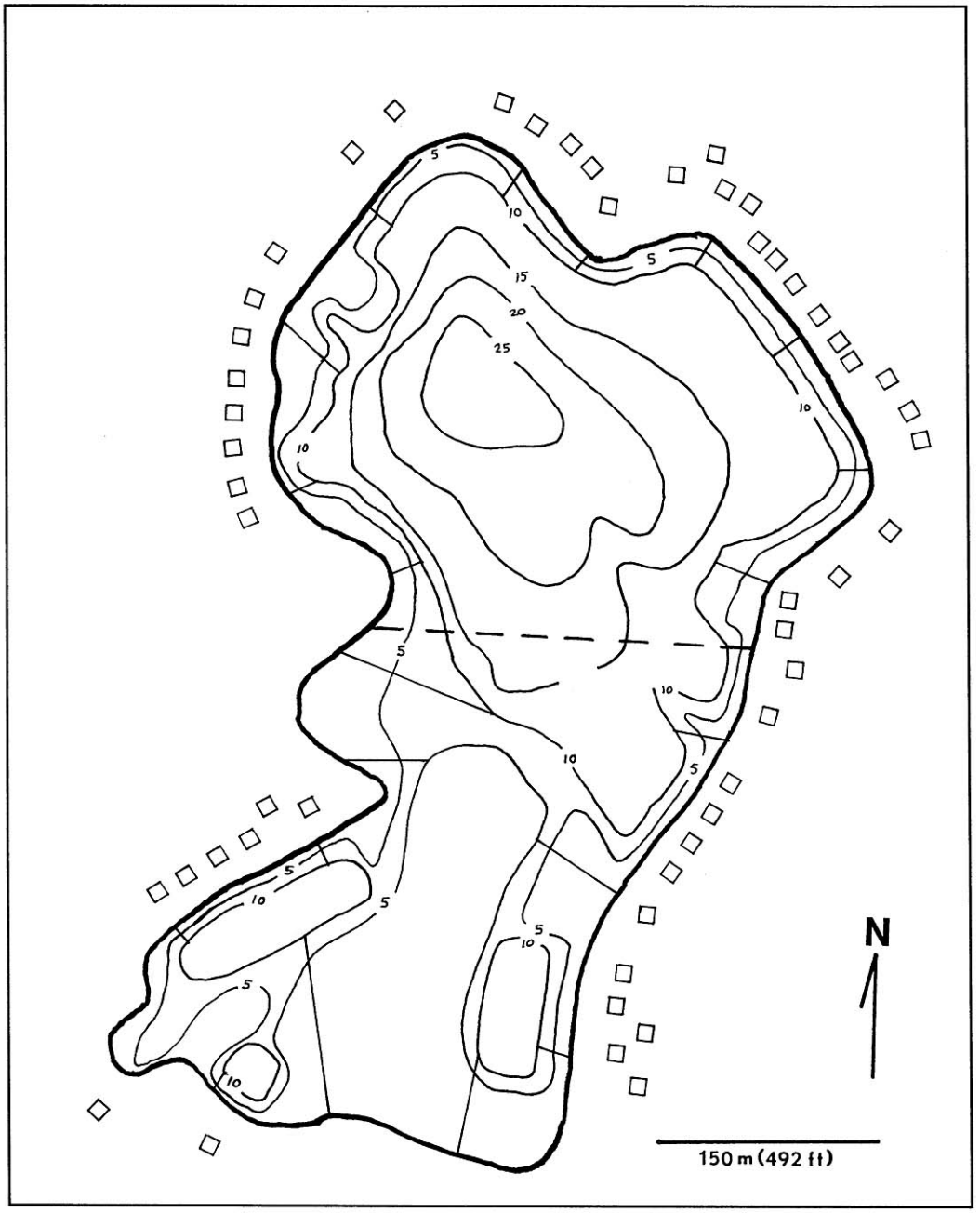

Figure 1. Locations of the 20 transects (lines perpendicular to shore) used for the vegetation survey of Forest Lake. Squares represent private homes or cottages on the lake. The dotted line separates the lake into northern and southern regions. Contour lines are drawn at 5 ft (1.5 m) intervals.

by titration), texture (percent silt, percent sand, percent clay), and mineral content.

Analyses

In a 1968 Department of Natural Resources aquatic plant survey (Wisconsin Department of Natural Resources 1970), differences were found between the northern and southern regions of Forest Lake; therefore, the lake was again divided into northern and southern regions for this study. Abundance, relative abundance, frequency, and relative frequency were calculated using an abundance score (modification of Titus 1993) to determine how common each species was in the northern versus southern regions and within the whole lake. For each sample site, an abundance score was determined in the field for each species using the following designations: 0 (Absent); 1 (Present) = single plant to plants covering < 1% of 0.25-m^2 sampling area; 2 (Abundant) = plants covering 1-50% of sampling area; 3 (Common) = plants covering > 50% of sampling area. Mann-Whitney U tests were performed on the most abundant species to determine if significant differences exist for abundance between northern and southern regions. Abundance differences were also determined for the most dominant species at two depth levels for the entire lake: shallow (0.5 m and 1 m depths combined) and deep (2 m and 3 m depths combined). Wilcoxon's Signed Ranks tests were performed on depth distribution (shallow vs. deep) within the entire lake.

Results

Twenty-two aquatic macrophyte species were found within Forest Lake (Table 1). Three native emergent species (*Sagittaria* sp.,

Table 1. Aquatic macrophyte species in Forest Lake, Fond du Lac County, Wisconsin (taxonomy follows Gleason and Cronquist 1991) by region. N = northern, S = southern.

Scientific Name	*Common Name*	*Region*
Ceratophyllum demersum L.	Coontail	N, S
Chara sp.	Muskgrass	N, S
Eleocharis acicularis (L.) Roemer & Schultes.	Spike Rush	N, S
Lythrum salicaria L.	Purple Loosestrife	N, S
Myriophyllum sibericum Komarov	Northern Watermilfoil	N, S
Myriophyllum spicatum L.	Eurasian Watermilfoil	N, S
Najas flexilis (Willd.) Rostk. & Schmidt	Bushy Pondweed	N, S
Nuphar variegata Durand	Yellow Water Lily	N
Nymphaea oderata Aiton	White Water Lily	S
Polygonum amphibium L.	Water Smartweed	S
Potamogeton amplifolius Tuckerman	Large-leafed Pondweed	N, S
Potamogeton foliosus Raf.	Leafy Pondweed	N
Potamogeton gramineus L.	Variable-leaf Pondweed	N, S
Potamogeton natans L.	Floating-leaf Pondweed	S
Potamogeton pectinatus L.	Sago Pondweed	N, S
Potamogeton pusillus L.	Slender Pondweed	N, S
Potamogeton zosteriformis Fern.	Flat-stemmed Pondweed	N, S
Sagittaria sp.	Arrowhead	N, S
Scirpus validus Vahl	Soft-stem Bulrush	N, S
Typha sp.	Cattail	S
Vallisneria americana L.	Water-celery	N, S
Zosterella dubia (Jacq.) Small.	Water star-grass	N, S

Scirpus validus, and *Typha* sp.) and one exotic emergent species (purple loosestrife, *Lythrum salicaria*) were excluded from abundance and frequency analyses. The native floating-leafed *Nuphar variegata,* found in the lake but not within any sampling sites, was also excluded from analyses. Only the seventeen true aquatic species (i.e., floating-leafed and submersed) found within sampling sites were considered for abundance and frequency analyses. The number of species at individual sampling sites ranged from zero (8 sites) to six (1 site).

Six dominant species (RA_W > 10% or RF_W > 10%; Tables 2 and 3) were found within Forest Lake: *Chara* sp., *Najas flexilis, Myriophyllum sibiricum, Myriophyllum spicatum* (EWM), *Potamogeton pusillus,* and *Vallisneria americana.* Significant differences ($P \leq 0.05$) in abundance among these six species existed between the northern and southern halves of Forest Lake. EWM (P = 0.004) was significantly more abundant in the northern region, whereas *Najas flexilis* (P = 0.002) and *Potamogeton pusillus* (P = 0.001) were more abundant in the south. No significant differences in abundance between northern and southern regions were found for *Myriophyllum sibiricum* (P = 0.971), *Chara* sp. (P = 0.684), and *Vallisneria americana* (P = 0.529). Of aquatic macrophytes other than the six dominant species, *Potamogeton foliosus* was present in the northern region but absent in the southern region. *Nymphaea odorata, Polygonum amphibium,* and *Potamogeton natans* were present in the southern region but not the northern region.

Species abundance differs at different depths in Forest Lake. Within the entire lake, *Myriophyllum sibiricum* (P = 0.015), *Chara* sp. (P = 0.017), and *Potamogeton pusillus* (P = 0.023) were found in higher abundance in deep water. No significant differences in abundance for depth were found for *Najas flexilis* (P = 0.134), EWM (P = 0.279), and *Vallisneria americana* (P = 0.209).

Purple loosestrife, an exotic emergent aquatic species, was found growing in sparse patches within the lake and in dense patches in surrounding wetlands. A visual inspection of the wetlands was made to determine distribution of this species. Because of the interest in exotic species control, distributions for both EWM and purple loosestrife were mapped (Figure 2).

Sediments found within EWM plant beds at the extreme northern end of Forest Lake were assigned a designation of sand to sand-loamy. Sediment texture composition ranged from 95–85% sand, 14–6% silt, and <1% clay. Organic matter content was low (4.24–0.97%). This was probably due to human disturbance along the northern lake shore, where property owners use sand to maintain beaches. Sediment pH values ranged from 7.2–6.7. Sediment mineral ranges are given in Table 4. Water mineral ranges are taken from U.S. Geological Survey (1994) data and Wisconsin Department of Natural Resources (1970) data (Table 4).

Discussion

Within the last 30 years, EWM has become well established in Forest Lake, and purple loosestrife has become well established in the surrounding wetlands. Neither exotic species was found during the 1968 Wisconsin Department of Natural Resources survey (1970), but EWM has now become the most dominant true aquatic macrophyte species within the northern region of Forest Lake and the fifth most abundant species within the entire lake. EWM distribution within the lake is not uniform, however; its greatest concentration was at the 2-m depth

Table 2. Abundance (A = sums of abundance scores) and relative abundance (RA) of floating-leafed and submersed species of the northern region (N), southern region (S), and whole lake (W) for Forest Lake, Fond du Lac County, Wisconsin. A_W = 0 (absence), 1 (present), 2 (abundant), or 3 (common) for each occurrence in a 0.25 m^2 area and $\%RA_W = (A/A_{Total})*100$ for 80 sample sites; A_N , A_S , $\%RA_N$ and $\%RA_S$ are calculated similarly for 40 sample sites each.

Species	A_N	$\%RA_N$	A_S	$\%RA_S$	A_W	$\%RA_W$
Ceratophyllum demersum	3	2.2	3	1.8	6	2.0
Chara sp.	25	18.7	20	12.1	45	15.1
Eleocharis acicularis	1	0.7	2	1.2	3	1.0
Myriophyllum sibericum	26	19.4	24	14.5	50	16.7
Myriophyllum spicatum	35	26.1	2	1.2	37	12.4
Najas flexilis	14	10.4	43	26.1	57	19.1
Nymphaea oderata	0	0	5	3.0	5	1.7
Polygonum amphibium	0	0	2	1.2	2	0.7
Potamogeton amplifolius	2	1.5	3	1.8	5	1.7
Potamogeton foliosus	1	0.7	0	0	1	0.3
Potamogeton gramineus	4	3.0	4	2.4	8	2.7
Potamogeton natans	0	0	3	1.8	3	1.0
Potamogeton pectinatus	1	0.7	4	2.4	5	1.7
Potamogeton pusillus	4	3.0	36	21.8	40	13.4
Potamogeton zosteriformis	3	2.2	4	2.4	7	2.3
Vallisneria americana	14	10.4	9	5.5	23	7.7
Zosterella dubia	1	0.7	1	0.6	2	0.7
Total	**134**	**100**	**165**	**100**	**299**	**100**

Table 3. Frequency (F) and relative frequency (RF) of floating-leafed and submersed species of the northern region (N), southern region (S), and whole lake (W) for Forest Lake, Fond du Lac County, WI. F_W = no. of occurrences/80 sample sites; $\%RF_W = (F/F_{Total})*100$; F_N , F_S , $\%RF_N$ and $\%RF_S$ were calculated similarly for 40 sample sites each.

Species	F_N	$\%RF_N$	F_S	$\%RF_S$	F_W	$\%RF_W$
Ceratophyllum demersum	3.8	3.4	2.5	1.9	6.3	2.6
Chara sp.	17.5	15.8	10.0	7.7	27.5	11.5
Eleocharis acicularis	1.3	1.2	1.3	1.0	2.6	1.1
Myriophyllum sibericum	17.5	15.8	16.3	12.6	33.8	14.1
Myriophyllum spicatum	23.8	21.5	2.5	1.9	26.3	11.0
Najas flexilis	13.8	12.5	33.8	26.2	47.6	19.9
Nymphaea oderata	0	0	6.3	4.9	6.3	2.6
Polygonum amphibium	0	0	2.5	1.9	2.5	1.0
Potamogeton amplifolius	2.5	2.3	3.8	2.9	6.3	2.6
Potamogeton foliosus	1.3	1.2	0	0	1.3	0.5
Potamogeton gramineus	5.0	4.5	5.0	3.9	10.0	4.2
Potamogeton natans	0	0	3.8	2.9	3.8	1.6
Potamogeton pectinatus	1.3	1.2	5.0	3.9	6.3	2.6
Potamogeton pusillus	3.8	3.4	18.8	14.6	22.6	9.4
Potamogeton zosteriformis	3.8	3.4	5.0	3.9	8.8	3.7
Vallisneria americana	13.8	12.5	11.3	8.7	25.1	10.5
Zosterella dubia	1.3	1.2	1.3	1.0	2.6	1.1
Total	**110.5**	**100**	**129.2**	**100**	**239.7**	**100**

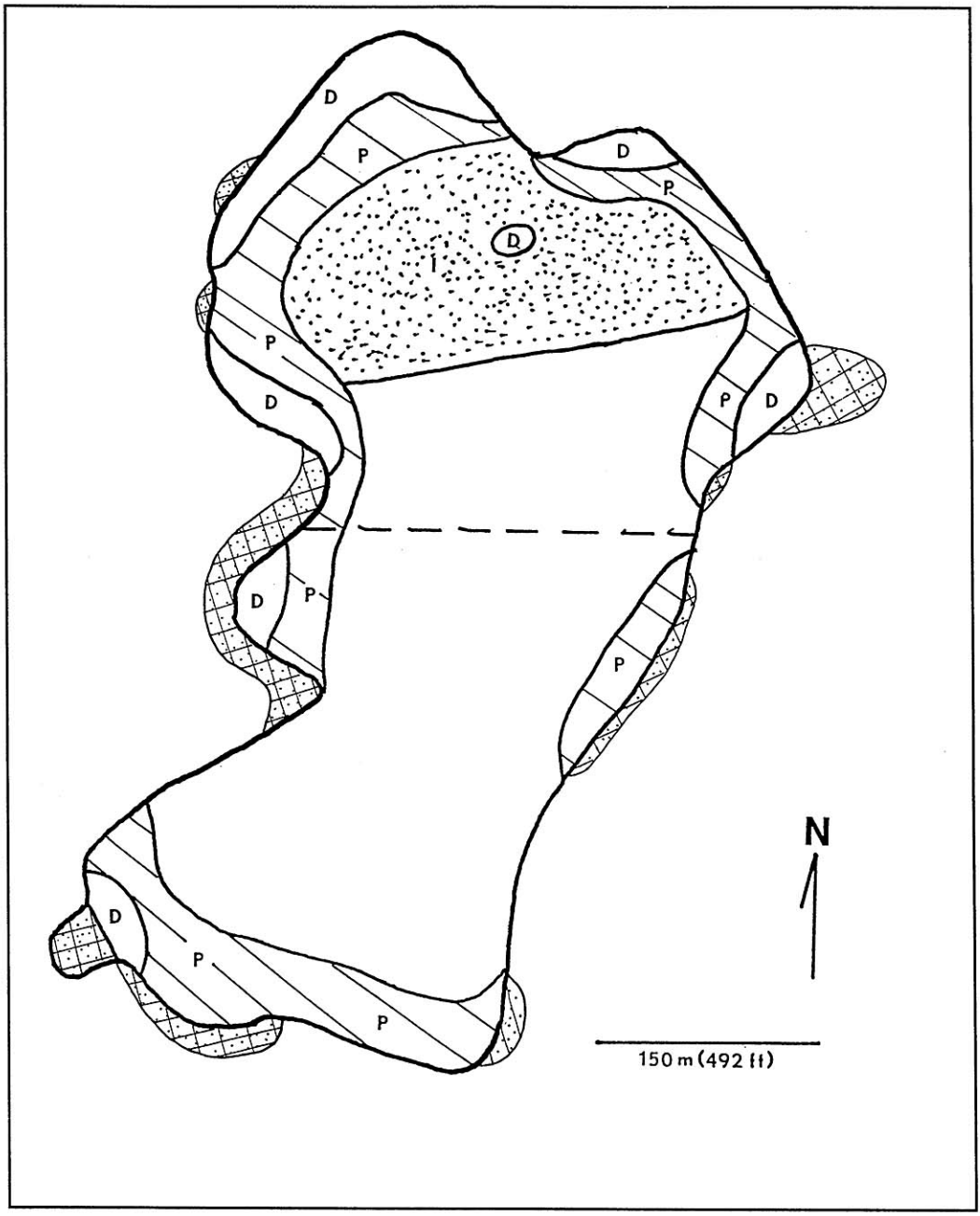

Figure 2. Distributions of EWM and purple loosestrife within and surrounding Forest Lake. Areas with dense (D) or patchy (P) stands of EWM are shown. The stippled deep water area contains patches of dense EWM stands that reach the surface later in the growing season. The cross-hatched, stippled areas identify loosestrife stands.

Table 4. Range of sediment (see collection site information in text, N = 6) and water mineral characteristics (N = 2, one shallow and one deep water sample, unless otherwise indicated; taken on May 3 [USGS 1994]) at the north end of lake; and mean water mineral characteristics (N = 1) on April 1968 (modified from WDNR 1970) of Forest Lake, Fond du Lac County, Wisconsin.

		Water, dissolved (ppm)	
Characteristic	*Sediment (ppm)*	*1994*	*1968*
Calcium	94,800 – 81,400	26	10.8
Magnesium	59,300 – 50,100	15	18.3
Iron	5,000 – 2,800	<50	0.01
Aluminum	3,800 – 2,000	—	—
Sulfur	501 – 103	4–5 (sulfate)	17.0
Potassium	468 – 128	<1	1.7
Phosphorus	247 – 155	<1 (total P; N = 8)	0.12
Sodium	231 – 173	2.4	8.7
Manganese	106 – 76	<40	—
Zinc	51 – 29	—	—
Copper	9 – 5	—	—
Boron	5 – 3	—	—

interval, which is consistent with other reports for this species (Nichols 1992, Deppe and Lathrop 1993, Lillie 1996). Purple loosestrife is restricted to shallow areas, and a visual inspection of surrounding wetlands suggests that this species warrants consideration to contain further spread.

As reported for other Wisconsin lakes (Nichols 1988), EWM was found in greatest abundance in the most disturbed areas of Forest Lake. Dense concentrations of EWM, often in pure stands, were found where the greatest number of sand beaches were located and also were growing from the shoreline to a depth of 4 m in previously dredged areas of the lake. Four sampling sites along beach areas had monotypic stands of EWM. *Chara* and *Vallisneria americana* were the only other species found in monotypic stands at one sample site each.

Changes in native aquatic plant distribution and abundance are evident within Forest Lake in the last 30 years. Several notable differences were found when comparing this report with the 1968 survey. *Potamogeton amplifolius,* once common within the northern lake region, is now much less abundant. Although *Chara* is still found along the northern shore, the thick growths of this species previously reported in the 1968 survey were not found in this survey. Within the southern region, *Potamogeton pectinatus* and *Potamogeton zosteriformis* are now found in comparatively low abundance but were previously listed as dominant species. *Najas flexilis,* while common in this report, was not mentioned in the 1968 survey. Interestingly, *Najas flexilis* has also been identified as a species that does well in disturbed areas (Nichols 1988).

While EWM is considerably less abundant in the southern half of the lake, its spread into this region has been noticed within the last several years (personal communication, C. Kendziorski). Previous research (Nichols 1990, Nichols and Buchan 1997) suggests that certain aquatic macrophytes show significant habitat associations with EWM. Three of these "indicator species" (e.g., *Najas flexilis, Myriophyllum*

sibiricum, Potamogeton gramineus) are dominant in the southern region of Forest Lake. Fish Lake (Dane County, WI), similar to Forest Lake in aquatic macrophyte species composition, has shown a drastic increase in EWM over the last two decades (Nichols 1984, Lillie 1996). Although Fish Lake at present has shown some decline in EWM, it is still by far the most dominant species within the lake (Lillie 1996).

Physical and chemical sediment characteristics influence the distribution of rooted, submersed and floating-leafed aquatic macrophytes (Sculthorpe 1967). EWM has been shown to colonize many different sediment types, from high organic-mucky to low organic-sandy sediments (Nichols 1971, Lillie and Barko 1990, Gerber and Les 1996, Nichols and Rogers 1997). In Forest Lake, the northern shoreline has been disturbed by the development of sandy beach areas with sandy sediments to a depth of >2 m. These sandy sediments are colonized in monotypic or mixed stands by EWM, *Najas flexilis, Chara, Ceratophyllum demersum,* and *Vallisneria americana.* These species, excluding *Chara,* are described by Nichols (1988) as being tolerant of disturbance.

Determination of native and exotic plant abundance, frequency, and distribution are important for understanding plant community dynamics and for developing an aquatic plant management program aimed at slowing EWM spread. Helsel et al. (1996) have shown that when physical and chemical control techniques are used in combination, native plants can recover and reestablish after EWM eradication. However, minimizing lake disturbance and maintaining a healthy native macrophyte standing crop are probably the best preventative measures to keep exotic species from establishing or spreading within a lake. Within Forest Lake, changes in the native species assemblage may be a harbinger of EWM dominance in southern Forest Lake. The southern end of the lake shows fewer signs of disturbance; however, now that EWM has established in the northern end its spread will probably continue.

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***D. Timothy Gerber** is a member of the River Studies Center and assistant professor in the Biology Department at the University of Wisconsin-La Crosse. **Address:** Department of Biology, University of Wisconsin-La Crosse, 1725 State Street, La Crosse, WI 54601.*
***Email:** gerber.dani@uwlax.edu*