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Predicting Invasion Success of Eurasian Watermilfoil

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ABSTRACT

A better understanding of factors related to invasion and colonization success of exotic species might improve both the planning and implementation of management for invasions in new areas. Data from lakes containing Eurasian watermilfoil were evaluated to compare the extent of Eurasian watermilfoil dominance to common limnological parameters. The best predictors of Eurasian watermilfoil dominance were water column total phosphorus and Carlson's Trophic State Index. This analysis corroborates observations that Eurasian watermilfoil appears most abundant in mesotrophic lakes and moderately eutrophic lakes.

Key words: Myriophyllum spicatum, nonindigenous aquatic plant, exotic aquatic macrophyte, colonization.

INTRODUCTION

Littoral zone plants are an important component of the lake ecosystem (Ozimek et al. 1990), providing food and habitat for macroinvertebrates and fish (Cyr and Downing 1988, Savino and Stein 1989), stabilizing bottom sediments and binding nutrients (Maceina et al. 1992), and reducing turbidity in the water column by increasing sedimentation rates (Petticrew and Kalff 1992). Nevertheless, the introduction of nonindigenous aquatic plants into littoral zone environments may alter the complex web of biotic and abiotic interactions. Dense stands of some mat-forming plant species reduce oxygen exchange, deplete available dissolved oxygen, and increase water temperatures, and increase internal loading rates of nutrients (Frodge et al. 1991, 1995, Seki et al. 1979). Dense canopies formed by some nonindigenous species reduce native plant diversity and abundance (Madsen et al. 1991). The reduction of habitat complexity results in reduced macroinvertebrate diversity and abundance (Krull 1970, Keast 1984), and also reduces growth of fishes (Lillie and Budd 1992). The advent of nonindigenous plant species is not only deleterious to human use of aquatic systems but detrimental to the native ecosystem.

Eurasian watermilfoil (*Myriophyllum spicatum* L.) was first introduced to the United States in the 1940's (Couch and Nelson 1985). Presently, it is found in 44 of the lower 48 states[2] and several Canadian provinces from Quebec to British Columbia (Aiken et al. 1979, Couch and Nelson 1985). Eurasian watermilfoil is a perennial herbaceous submersed plant which forms a dense canopy of branches at the surface (Aiken et al. 1979, Smith and Barko 1990). Eurasian watermilfoil spreads from one lake to another by mass flow of water and by accidental introduction on boats and boat trailers (Aiken et al. 1979, Newroth 1993). Spread between lakes and within lakes is predominantly by vegetative fragments (Kimbel 1982, Madsen et al. 1988). Localized spread is by root crowns and runners (Madsen et al. 1988, Madsen and Smith 1997). Although viable seeds are formed, they are not generally significant in the perennation or spread of the plant (Madsen and Boylen 1989, Hartleb et al. 1993).

The invasion process for nonindigenous species follows a progression from introduction, establishment, and colony formation stages. Each step of this process, and subsequent growth, is moderated by environmental factors affecting the outcome. The subsequent growth of the colony is affected by a broad suite of abiotic and biotic factors. The abundance of the invading plant can be described by a Gaussian relationship (Figure 1A). The curved solid line represents the upper boundary of abundance. Plant abundance also occurs below the line when limited by other environmental parameters limiting to growth, biotic activity, disturbance occurring to reduce abundance, or insufficient time elapsing to reach maximal levels. If the maximal level is of interest, then the best approach is to approximate an upper boundary to the plant abundance (Figure 1A, dashed line).

The goals of this study were to correlate limnological parameters to Eurasian watermilfoil dominance, and from these relationships to develop estimates predicting invasion success. This tool would then be used to allocate resources towards monitoring and managing lakes most likely to develop problem populations of Eurasian watermilfoil.

MATERIALS AND METHODS

A literature review of lakes with Eurasian watermilfoil populations resulted in data for over 300 lakes from 30 publications and 14 unpublished sources that indicated both Eurasian watermilfoil dominance and relevant limnological data. Details of this data set are given elsewhere[3]. Data was obtained for lakes in Vermont, New York, Michigan, Wisconsin, Minnesota, Washington, Oregon, Alabama, Ontario, and British Columbia. Typically, only one year of data was obtained for each lake.

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[2] U.S. Geological Survey, Biological Resources, Gainesville, FL. August 1997. Worldwide Web Homepage: http://nas.nfrcg.gov/dicots/.

[3] Madsen, J. D. 1997. Predicting Eurasian Watermilfoil Invasion Success for Minnesota Lakes. Letter report, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. In preparation.

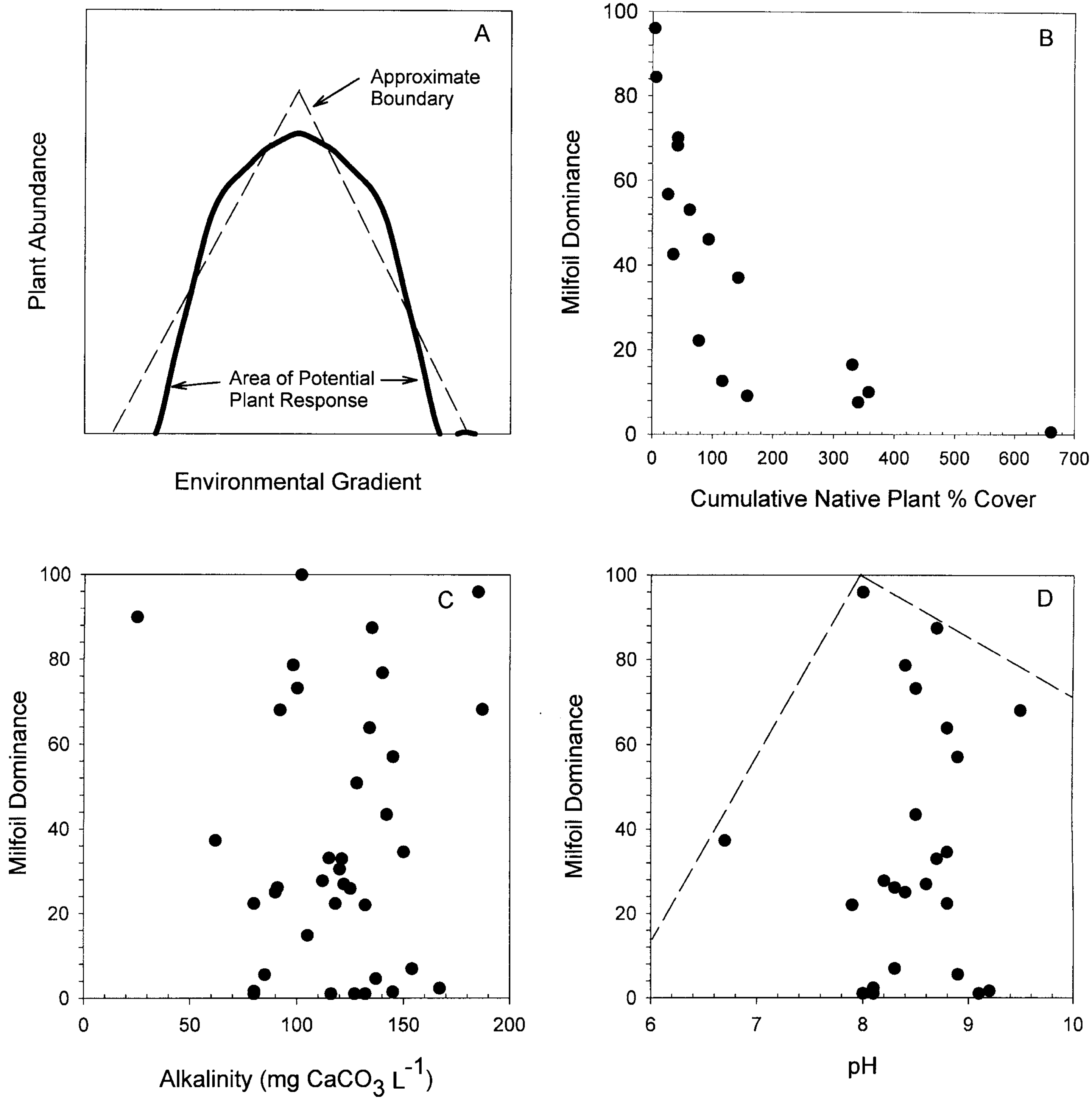

Figure 1. A) Diagram of a theoretical Gaussian distribution of plant abundance along an environmental gradient (solid line), and an approximated boundary (dashed line); B) Relationship between Eurasian watermilfoil dominance (as percent of littoral zone with Eurasian watermilfoil) and native plant cover in 17 lakes; C) Relationship between Eurasian watermilfoil dominance and alkalinity (mg $CaCO_3$ L^{-1}) in 39 lakes; D) Relationship between Eurasian watermilfoil dominance and pH in 25 lakes, with an approximate boundary indicated with a dashed line.

Plant abundance and distribution were measured in various ways and reported in different units. These diverse methods have been converted into a measure of Eurasian watermilfoil dominance, which is computed as the proportion, or percent, of the littoral zone in which Eurasian watermilfoil was found. The necessity of restricting Eurasian watermilfoil data to this measure resulted in the discarding of some lakes and studies from consideration. A total of 102 lakes had sufficient data to calculate the estimate of Eurasian watermilfoil dominance. Plant community data included:

aquatic plant species presence and/or abundance, Eurasian watermilfoil biomass, Eurasian watermilfoil percent cover, native plant percent cover, Eurasian watermilfoil cover area (littoral zone), native plant cover area (littoral zone). Lake morphometry information for each lake included: maximum depth, average depth, area, littoral zone area, and shoreline development. Limnological data sought included: Secchi disk depth, light attenuation coefficient, alkalinity, total P, P loading rate, total N, N loading rate, Trophic State, Carlson's Trophic State Index (TSI, Carlson 1977), dissolved inorganic carbon and acid neutralizing capacity. Other information that was included: state, county, township, geoposition (latitude, longitude), glaciated vs. unglaciated, soils, soil erosion rate, sedimentation rate, and land use. For most variables, insufficient data were found to continue analysis. Of the 31 parameter groups investigated, data will be presented for seven: cumulative native plant cover (the sum of the cover of native plant species), Secchi Disk depth, alkalinity, pH, sediment sand content, water column total phosphorus, and Trophic State Index. Since not all lakes in the ensuing analysis had data for the above parameters available, the number of lakes per plot were not constant. No lakes were deleted as outliers.

RESULTS AND DISCUSSION

Before discussing the relationship of Eurasian watermilfoil to the environment, one other relationship bears examination. The abundance of Eurasian watermilfoil was inversely related to cumulative native plant cover (Figure 1B). Lakes with more than 50% Eurasian watermilfoil dominance were found to have less than 60% cumulative native plant cover. Although this has been quantitatively documented in one instance for a given lake over time (Madsen et al. 1991) and reported as occurring in other systems (Aiken et al. 1979, Grace and Wetzel 1978, Smith and Barko 1990), this documents a relationship for many lakes over a range of Eurasian watermilfoil dominance.

Dissolved organic carbon or alkalinity has often been cited as a parameter associated with the success of Eurasian watermilfoil in lakes (Grace and Wetzel 1978, Smith and Barko 1990). In fact, the photosynthetic rate in Eurasian watermilfoil has been correlated to dissolved inorganic carbon for a group of Italian lakes (Adams et al. 1978). Nevertheless, the present study indicated abundant Eurasian watermilfoil across a broad range of alkalinity (Figure 1C). Other studies have also observed the occurrence of Eurasian watermilfoil across a broad range in alkalinity, but have not generally measured Eurasian watermilfoil abundance[4]. A similar plot of Eurasian watermilfoil dominance versus pH appears to give a relationship (Figure 1D), but pH is a highly variable parameter. Likewise, the low number of lakes at the low end of the pH spectrum severely limit the usefulness of this relationship. Eurasian watermilfoil is not typically found in abundance in either clearwater or brownwater acid lakes (Warrington 1985).

Light is often recognized as a parameter that controls the presence of submersed aquatic plants (Barko et al. 1986), but it is a poor predictive tool for Eurasian watermilfoil dominance relative to native plants due to its widespread effect on all plants. A plot of Eurasian watermilfoil dominance versus Secchi Disk depth, as a measure of lake transparency, indicates that Eurasian watermilfoil is abundant in some very low transparency lakes (Figure 2A).

Sediment fertility has also been evaluated related to the growth of Eurasian watermilfoil, as with other submersed macrophytes (Smith and Barko 1990). Growth limitation of Eurasian watermilfoil due to insufficient sediment nitrogen has been documented (Anderson and Kalff 1986). Unfortunately, few lakes are monitored for sediment nitrogen levels. One possible correlate is the percent composition of sand in sediment. Sandy sediments are known to be of low fertility (Barko et al. 1986). A plot of Eurasian watermilfoil dominance versus percent sand composition of sediments (Figure 2B) indicates a potential maximal limit which increases from 10% sand to 18% sand, possibly indicating the low growth potential of plants rooted in highly organic sediments. Above 18% sand, the upper limit of Eurasian watermilfoil dominance declines, which may be indicative of reduced fertility and growth rates. The upper limit of Eurasian watermilfoil dominance is still 80% when the sediment composition is essentially 100% sand. This plot demonstrates a very low potential to discriminate between high and low dominance of Eurasian watermilfoil and relies too heavily on only four points for its shape. One confounding factor in this instance is that groundwater often percolates through sandy sediments, which may replenish the concentrations of nutrients in these sediments (Loeb and Hackley 1988, Lodge et al. 1989).

Eurasian watermilfoil dominance exhibits possibly the most distinct and predictive relationship with total water column phosphorus (Figure 2C). The shape of this relationship most closely approximates that expected in a theoretical Gaussian relationship, being broad at the base and narrow at the top. Eurasian watermilfoil dominance increases sharply as water column phosphorus increases from oligotrophic (<10 µg L^{-1}) through mesotrophic (<30 µg L^{-1}) concentrations, and decreases above 50 µg L^{-1}, in what is considered moderately eutrophic lakes (Wetzel 1983, Carlson 1977). Eurasian watermilfoil, however, is probably not responding directly to water column phosphorus. Experimental studies have indicated that Eurasian watermilfoil is generally limited by nitrogen availability, (Barko 1983, Anderson and Kalff 1986), and that phosphorus is taken up from the sediment rather than water column (Carignan and Kalff 1979, 1980, Barko and Smart 1981). Total water column phosphorus may be a correlative variable for several environmental factors, including sedimentation (which initially stimulates plant growth) and phytoplankton abundance, which would shade Eurasian watermilfoil (Jones et al. 1983).

The plot of Eurasian watermilfoil dominance versus Carlson's Trophic State Index (TSI, Carlson 1977, Figure 2D) indicates a narrower margin of abundant Eurasian watermilfoil than might be expected. Eurasian watermilfoil was found in lakes ranging from 35 (transitional oligotrophic) to 70 (moderately eutrophic). Mesotrophic lakes are typically

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[4] Crow, G. E. and C. B. Hellquist. 1983. Aquatic Vascular Plants of New England: Part 6. Trapaceae, Haloragaceae, Hippuridaceae. New Hampshire Agricultural Experiment Station Bulletin 524, University of New Hampshire, Durham, NH. 26 p.

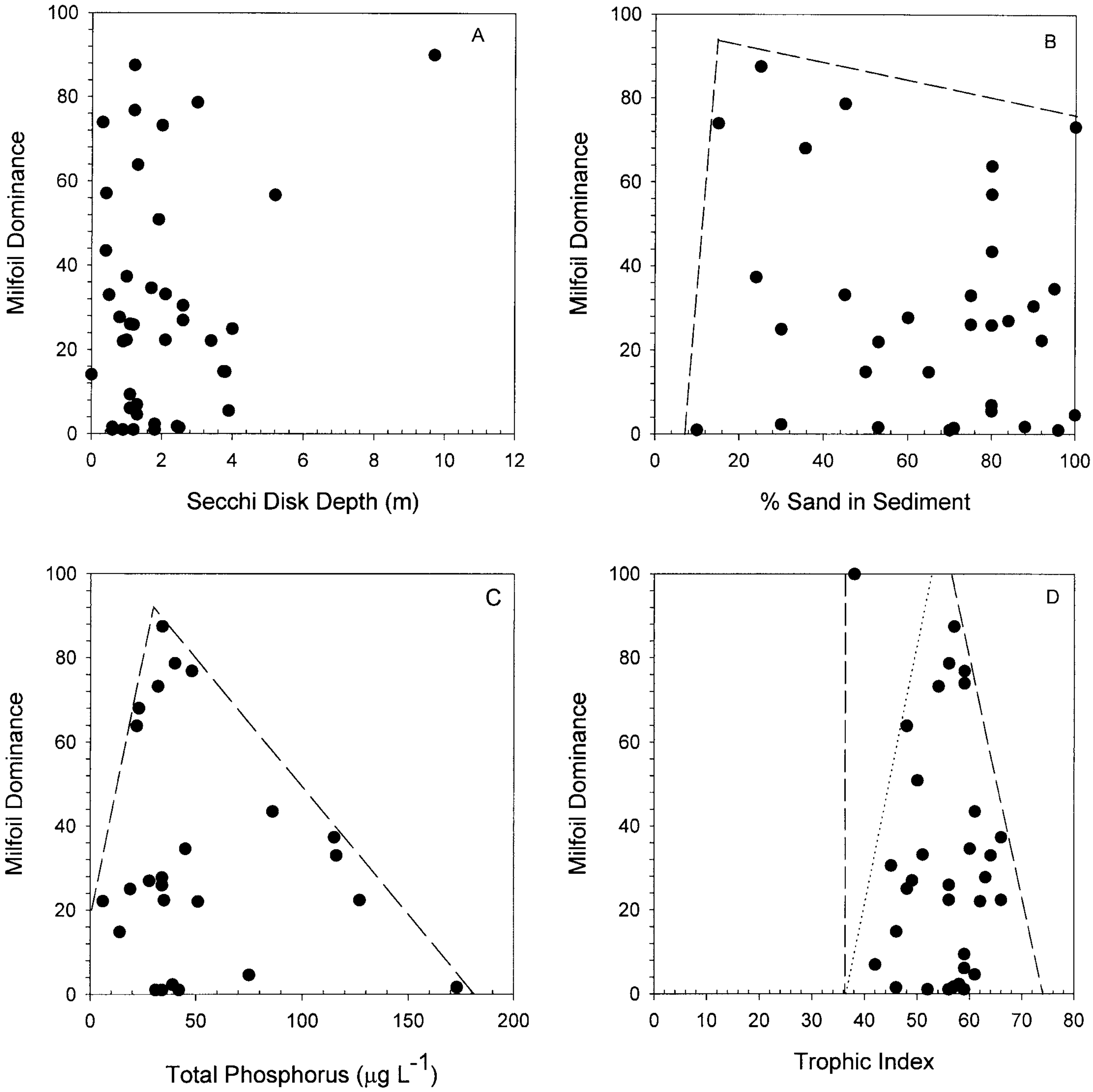

Figure 2. A) Relationship between Eurasian watermilfoil dominance (as percent of littoral zone with Eurasian watermilfoil) and Secchi Disk depth (m) for 42 lakes; B) Relationship between Eurasian watermilfoil dominance and percent sand content of sediment for 33 lakes, with an approximate boundary indicated with a dashed line; C) Relationship between Eurasian watermilfoil dominance and water column total phosphorus (μg L^{-1}) for 25 lakes, with an approximate boundary indicated with a dashed line; and D) Relationship between Eurasian watermilfoil dominance and Carlson's trophic index for 34 lakes, with an approximate boundary indicated with a dashed line, and an additional approximate lower boundary disregarding one point indicated with a dotted line.

between 40 to 50 TSI (Cooke et al. 1986). This analysis corroborates observations that Eurasian watermilfoil actually appears most abundant in mesotrophic lakes and moderately eutrophic lakes (Smith and Barko 1990). If the abundant Eurasian watermilfoil lake at 35 TSI is excluded, then the remaining relationship indicates a sharp increase in abundance from 35 TSI to 55 TSI, and a decline from 55 TSI to 75 TSI.

In a preliminary attempt to identify factors that might predict the eventual success of Eurasian watermilfoil in infested lakes, total water column phosphorus and Carlson's TSI were identified as potential indicators of lakes at risk. From this analysis, lakes with a TP of 20-60 µg L^{-1} or a Carlson's TSI of 45-65 were most at risk of dominance by Eurasian watermilfoil. Using this type of tool, monitoring and management resources might be allocated to those lakes most likely to develop substantial nuisance growths of Eurasian watermilfoil, with the accompanying impacts to both human use and the lake ecosystem.

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