Richard A. Lillie

Eurasian Watermilfoil as a Fishery Management Tool

(Left) A summer canopy of Eurasian watermilfoil sports branching shoots and aerial flowers.

By Sandy Engel

ABSTRACT

Eurasian watermilfoil (*Myriophyllum spicatum* L.) poses new challenges to fishery managers as it continues to spread and multiply in North American waters. Some of its effects can be detrimental to fisheries. When dense, the plant obstructs swimming space of pelagic fishes, shelters too many juvenile fishes, and disrupts foraging movements of piscivores. In replacing native plants that harbor a diverse array of invertebrates, watermilfoil creates food shortages for fishes. By blocking sunlight penetration and water movements, it depletes dissolved oxygen inshore that can cause fish kills when shoots decay in autumn. Therefore, lakes with healthy native plants should be left undisturbed and guarded against infestations of Eurasian watermilfoil. But the same plant in other lakes can improve fish production, especially in waters too turbid to support native plant growth. By increasing the surface area for invertebrate colonization, Eurasian watermilfoil expands the food base for benthivores and protects emerging year classes from piscivores. Through seasonal growth and senescence, it creates a dynamic littoral zone where openings in plant beds appear and disappear, cruising lanes for piscivores come and go, and edge effect for crappies expands and shrinks.

Sandy Engel *is a senior scientist in the Fish Research Section, Wisconsin Department of Natural Resources, 8770 County Hwy. J, Woodruff, WI 54568.*

Through integrated fish-plant management, Eurasian watermilfoil can be managed to enhance fish growth and recruitment by encouraging plant growth in nursery areas to protect juvenile fishes, cutting channels in plant beds for foraging piscivores, and removing plant beds in weedy bays to expose overabundant forage fishes. An integrated program would include hand raking and bottom screening inshore, mechanical plant harvesting offshore, judicious use of narrow-spectrum herbicides such as 2,4-D, and removal of overabundant rough fishes. Such a program would (a) hold surface growth to 10%–40% of lake surface area, (b) eliminate Eurasian watermilfoil in high-use areas, (c) maintain intermediate densities of watermilfoil in other areas, and (d) create access channels and openings in plant beds. The program can be expanded by planting native pondweeds (*Potamogeton*) in areas freed of Eurasian watermilfoil, dredging shallow bays to reduce canopy growth, and using removable fiberglass screens to form channels across weed beds. To implement such an integrated program will require fishery managers to work closely with water resource managers, regulatory authorities, and the public. The real challenge is getting fishery managers to think of plants such as Eurasian watermilfoil as management tools.

How can dense growths of Eurasian watermilfoil (*Myriophyllum spicatum* L.) affect sportfishes in lakes and rivers? Like any large aquatic plant (macrophyte), Eurasian watermilfoil can affect fisheries through its growth and metabolic activity and its role as habitat for fishes and their prey. Knowing how this weed spreads and grows can give fishery managers a tool to rehabilitate warmwater fisheries.

Spreading Patterns

Eurasian watermilfoil is an aquatic flowering plant native to Europe, Asia, and northern Africa. Once thought to have been introduced to the Potomac River around 1880 (Bayley et al. 1968; Reed 1977), the plant was confused with native watermilfoils for nearly a century (Nichols 1984; Couch and Nelson 1992). But examination of more than 15,000 watermilfoil specimens in 173 herbariums revealed that authentic Eurasian watermilfoil in North America dates to a Washington, DC, pond in 1942 (Couch and Nelson 1985). In the next 50 years, the species spread across the Ohio River Valley into midwestern states and along Atlantic and Gulf coasts into northeastern and southern states (Fig. 1). Today, it has colonized three Canadian provinces and 39 states, but its spread within provinces and states has not been straightforward: southern Wisconsin gained the weed in approximately 1960—more than 25 years before it first appeared a few hundred miles away in northern Wisconsin (Engel 1993).

Eurasian watermilfoil spread along highways as well as waterways.

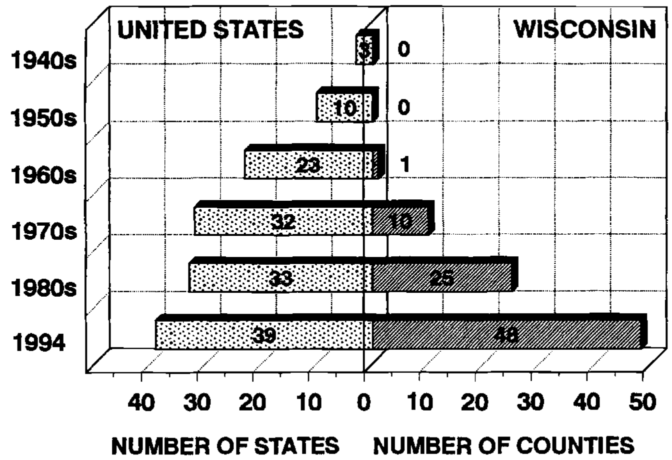
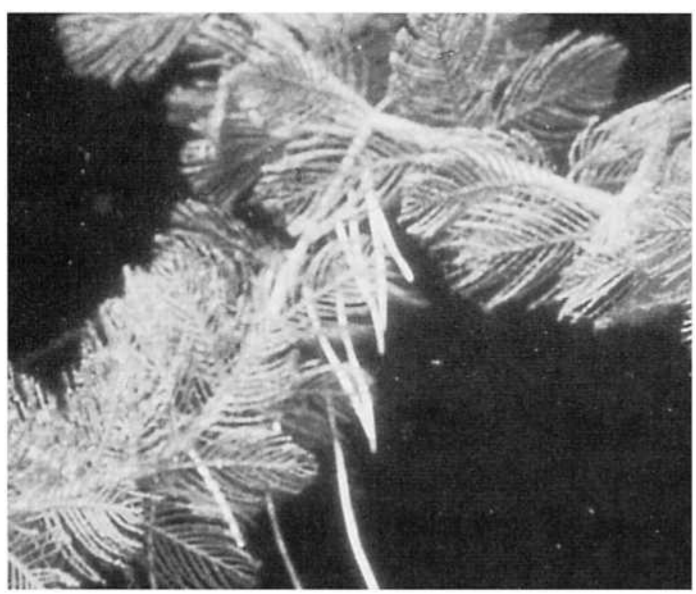


Figure 1 shows Eurasian watermilfoil distribution by number of states (left) and Wisconsin counties (right). Only Colorado, Hawaii, Maine, Montana, Nevada, New Mexico, North Dakota, South Dakota, Utah, and Wyoming report no Eurasian watermilfoil; *M. spicatum* reported for northern Alaska (Holmquist 1971) is probably the native *M. sibiricum* Komarov. U.S. data for the 1940s–1980s came from Couch and Nelson 1985.

People carried fragments of the plant on boats, trailers, and motor propellers (Newroth 1990). Fragments dropped at boat landings took root and grew runners (stolons) that formed new shoots and more fragments. The fragments started colonies on new shores and drifted downstream to new waters. The runners crept across lake bottoms, claiming territory inch by inch and crowding out native plants (Madsen et al. 1988). These winter-hardy colonies thrived from year to year (Coffey and McNabb 1974) until long-established communities of broadleaf and narrowleaf plants were replaced by monocultures of watermilfoil.

Without relying on winter-resting buds (Aiken et al. 1979) or seeds (Coble and Vance 1987), this evergreen perennial survives northern winters and spurts to the water surface in early spring. Nonstructural carbohydrates formed in spring and summer from photosynthetic upper shoots (Adams and Prentki 1982) are transferred in the fall to basal shoots and roots (Madsen 1991), which survive the winter on this food cache. After ice-out, new shoots grow from old root crowns and divide repeatedly. The shoots form leaf canopies in turbid water (Fig. 2) that shade underlying plants still germinating from seeds (Madsen et al. 1991).



Susan C. Borman

(Left) Adventitious roots on drifting shoots help Eurasian watermilfoil colonize new sites.

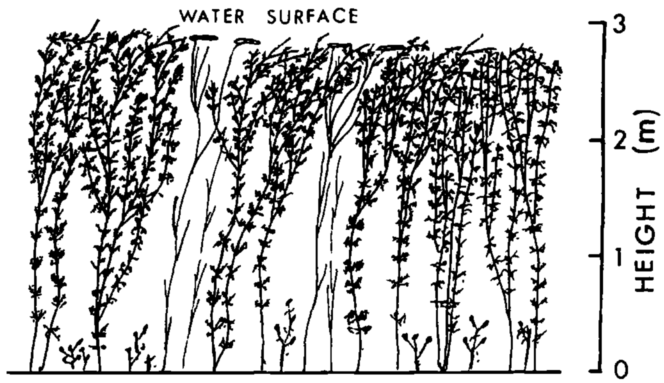


Figure 2. A watermilfoil bed sketched from underwater photographs shows canopy growth at the water surface has almost eliminated floating-leaf pondweed (*Potamogeton natans* L.) and bottom-growing coontail (*Ceratophyllum demersum* L.). *Sketched in Fish Lake, Dane County, Wisconsin, by Sandy Engel.*

These canopies even shade out their own lower leaves, much as pine trees do in a plantation. They also choke off shallow bays, impairing recreational boating.

More Than a Barrier

Eurasian watermilfoil can physically affect sportfishes by obstructing predation, sheltering panfishes, and covering spawning areas (Hinkle 1986). Rank growths of watermilfoil reduce open water areas in lakes and rivers, even closing channels that would give large fishes access to inshore prey (Engel 1990). The plant's interlacing leaves and branching stems (Fig. 3) act as a screen to shelter forage fishes (Engel 1985), decreasing fish mortality (Rozas and Odum 1988) and increasing fish abundance (Holland and Huston 1985). For example, bluegills (*Lepomis macrochirus* Raf.) school at the edge of sparse plant beds but seek the center of dense ones (Savino et al. 1985). Such dense cover offers bluegills refuge from predator fishes (Gotceitas and Colgan 1987) and access to plant-dwelling prey (Schramm and Jirka 1989a). In another example, survival and standing crop of young-of-year largemouth bass (*Micropterus salmoides* [Lacepède]) increased with modest plant growths in lakes from Florida (Moxley and Langford 1982), Texas (Durocher et al. 1984), and West Virginia (Smith and Orth 1990).

But forage fishes sheltered by Eurasian watermilfoil can become so crowded they overgraze plant-dwelling prey such as larvae of midgeflies (Diptera) and caddisflies (Trichoptera) and thus experience poor growth and lower fecundity when fishes mature at smaller size (Janecek 1988). The growth and condition of largemouth bass declined in a 134-ha Florida lake that became covered with 30% (bass > 250 mm TL) to 50% (bass < 250 mm) of hydrilla (*Hydrilla verticillata* Royle), a submersed rooted plant native to Africa but introduced from South America (Haller 1978; Colle and Shireman 1980; Colle 1982). Thick plant cover can also restrict bluegill feeding on invertebrate prey (Mittlebach 1981), though bluegill growth can remain unchanged as plant density increases if the density and availability of invertebrate prey also increases (Savino et al. 1992). Some generalized feeders can switch during weedy periods from eating plant-dwelling prey to pelagic zooplankton (Carpenter et al. 1985), putting them in competition with offshore planktivores such as yellow perch (*Perca flavescens* [Mitchill]) and young-of-year wall-eyes (*Stizostedion vitreum* [Mitchill]). Yet, extensive weed growth can impair planktivores by restricting open water and inhibiting vertical migrations of zooplankters, including *Chaoborus* larvae (Shireman et al. 1979). Such plant growth also can limit phytoplankton growth and thus herbivorous zooplankton, by assimilating nutrients such as nitrogen and phosphorus from lake water or sediments (DeMarte and Hartman 1974; Barko et al. 1991). Extensive growths of hydrilla in an 80-ha Florida lake decimated populations of threadfin shad (*Dorosoma cepedianum* [Lesueur]), a pelagic zooplanktivore (Maceina and Shireman 1982).

Dense watermilfoil beds can impair piscivore feeding and growth. Foraging success declines when plants become so crowded that predators lose sight of prey and must dodge plant stems when attacking prey (Savino and Stein 1982). Largemouth bass switch from cruising for prey to ambushing them, a strategy more effective against minnows than against bluegills (Savino et al. 1985). But largemouth bass spend more time and energy searching for prey as plants become crowded (> 200 stems/m^2) and thus grow slower during their early years (Savino and Stein 1982). Such slow growth not only can delay recruitment to reproductive size but lower recruitment caused by poor winter survival of young-of-year fishes. When hydrilla covered more than 50% of an 80-ha Florida lake, black crappies (*Pomoxis nigromaculatus* [Lesueur]) reached harvestable size (>228 mm TL) one to two years later than they did during years of sparse growth (Maceina and Shireman 1982).

Growth and senescence of watermilfoil foliage also can impair fish growth and survival by altering the underwater environment (Smith and Barko 1990). Dense beds of watermilfoil reduce sunlight penetration for sight-feeding predators and deplete dissolved oxygen levels a night through intense

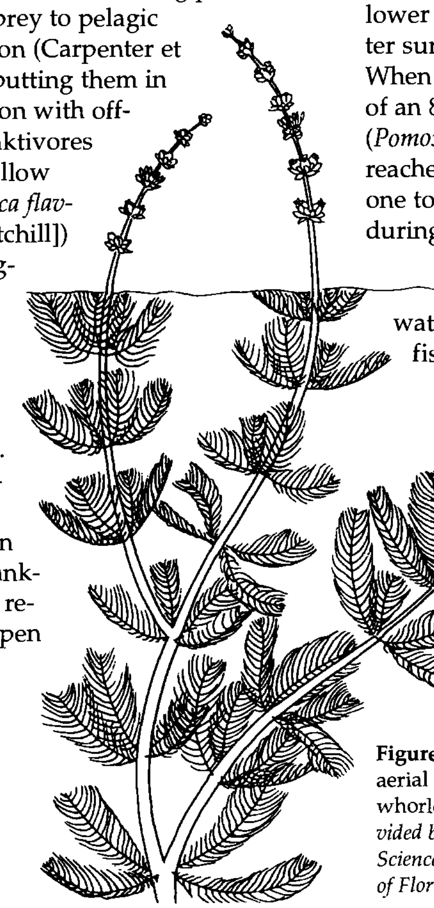


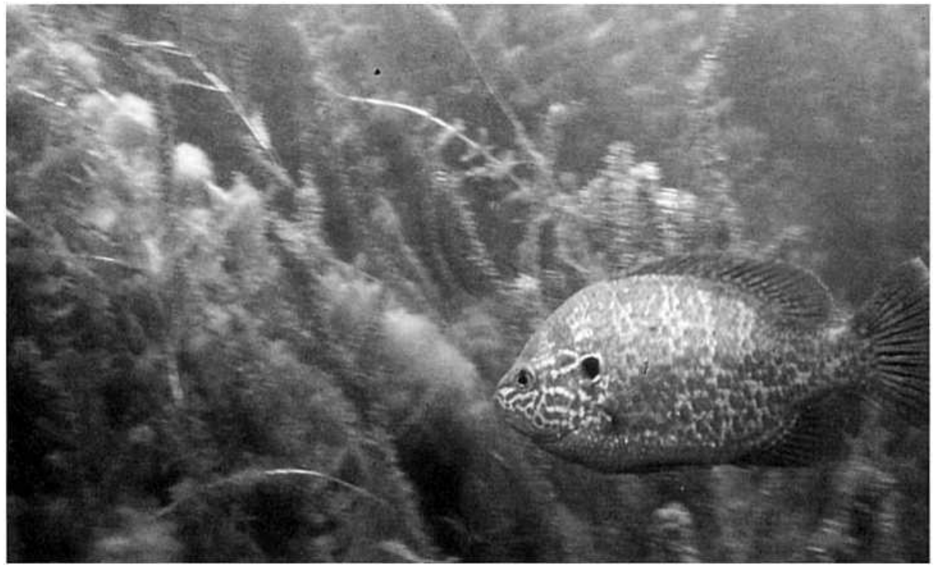
Figure 3. Eurasian watermilfoil typically has aerial flower bracts and underwater stems whorled by feathery leaves. *Illustration provided by the Institute of Food and Agricultural Sciences, Center for Aquatic Plants, University of Florida, Gainesville.*

respiration (Engel 1990). Largemouth bass fry, tolerant of dissolved oxygen dips to 1 mg/L in midsummer (Kramer and Smith 1962), could face longer oxygen depletions during fall senescence of the watermilfoil canopy. The decomposing foliage also releases stored phosphorus that can stimulate algal blooms (Landers 1982; Carpenter and Lodge 1986), further reducing water clarity for sight feeders.

Adding Needed Habitat

Eurasian watermilfoil can provide needed habitat, especially in turbid lakes unable to sustain native plant beds. Inshore vegetation supports higher densities of amphipods, insect larvae, leeches, and naidid worms than do open water habitats (Pardue and Webb 1985) and exposed lake bottoms (Schramm and Jirka 1989b). Plant beds attract young-of-year largemouth bass (Strange et al. 1982) and permit resource segregation among species of sunfish (Werner and Hall 1979). Foliose plants such as watermilfoil expand the surface area of a flat lake bottom by 30–50 times (Edwards and Owens 1965), thus expanding the area for young fishes to forage (Engel 1990). The finely dissected shoots of watermilfoil offer greater surface area than do the flat leaves of wild celery (*Vallisneria americana* Michaux) and many native pondweeds (*Potamogeton*) (Krecker 1939; Mrachek 1966). Even plastic imitations of watermilfoil harbor more macroscopic invertebrates (macroinvertebrates) than do real flat-leaved plants (Gerrish and Bristow 1979). Moreover, watermilfoil shoots support periphyton (Eminson and Moss 1980) and collect detritus (Adams and Prentki 1982; Pieczyska 1993), food resources for insect larvae eaten by fishes. Benthic cladocerans, such as *Chydorus* and *Alonella* (Crustacea), are also attracted to plant leaves (Rabe and Gibson 1984), providing initial prey for fry. Organic sediments formed beneath plant beds can support more tubificid worms (Annelida) than found in profundal sediments (Janecek 1988).

By producing a leaf canopy in early spring from wintering shoots and root crowns that store carbohydrates, Eurasian watermilfoil can thrive in lakes and rivers too turbid for many native plants. A light compensation point of only 1%–2% enables watermilfoil to photosynthesize in deeper water than other rooted plants, while its near-zero CO_2 compensation point and ability to store respired CO_2 in tissue spaces permit growth in soft waters having little dissolved inorganic carbon (Stanley and Naylor 1972; Grace and Wetzel 1978). Like many rooted plants, Eurasian watermilfoil can assimilate such nutrients as nitrogen and phosphorus not only from the water column but also from bottom sediments (Nichols and Keeney 1976; Smith and Adams 1986), reducing competition with phytoplankton (Fitzgerald 1969). The plant even adapts to gradients in sediment fertility, increasing the sites it can colonize, though it avoids rich organic deposits (Smith and Barko 1990). Thus, it can establish prey habitat and fish cover where native plants cannot grow or where they once grew.



David W. Marshall

A pumpkinseed (*Lepomis gibbosus* [L.]) forages at the edge of dense Eurasian watermilfoil bent by water movements.

Integrating Fishery Management

Knowing how Eurasian watermilfoil spreads and grows, fishery managers can manage plant beds to enhance sportfishing, especially in lakes already overgrown with the weed. Fishing pressure and sportfish harvest can become depressed when exotic weeds spread, despite increases in total fish standing crop (Colle et al. 1987). An integrated fish-plant management program (Engel 1989; De Steno 1992) can be developed that would manage Eurasian watermilfoil to enhance sportfishing, fish growth, and adult recruitment by cutting channels in watermilfoil beds for inproving angler access, removing plant beds in weedy bays for exposing overabundant forage fishes, and encouraging native plant growth in nursery areas for protecting nongame fishes as well as juvenile sportfishes. Plant beds would be maintained at modest densities to maximize bluegill growth and largemouth bass predation (Crowder and Cooper 1982; Wiley et al. 1984).

Such an integrated program requires work from fishery managers, lake managers, and the public. Volunteer citizens will need to monitor shorelines for early signs of Eurasian watermilfoil (De Steno and Larson 1990), remove watermilfoil fragments from boats and motors (Bode et al. 1993), and transplant native foliage for a more diversified plant community. Fishery managers will need to survey the abundance and biomass of fish and plant species at least every few years to assess long-term community dynamics and to determine what species need further stocking or control. Lake managers may need to control nuisance plant beds by hand raking inshore and mechanical harvesting offshore (Engel 1990). For example, mechanical harvesting of hydrilla in a

134-ha Florida lake improved mean condition factor of bluegills and largemouth bass (Colle and Shireman 1980). Lake managers should also experiment with phenological plant control: treating watermilfoil before shoots fragment in summer or carbohydrates translocate to lower shoots in fall (Madsen 1993).

Canopy growth of watermilfoil can be reduced by dredging shallow bays to increase water depth. Strips of removable fiberglass screens (Mayer 1978; Perkins et al. 1980; Engel 1984) anchored to the lake bed can convert weed beds into swimming beaches, boating channels, and fish cruising lanes (Engel 1989). Bottom screening or mechanical harvesting can even create openings (windows) in plant beds to give anglers and foraging piscivores better access to plant-dwelling prey. Such openings increase the density of bottom-dwelling prey such as tubificid worms (Janecek 1988). Connecting these openings to cruising lanes can facilitate diel onshore-offshore movements of some fish species (Keast 1978) and improve overall edge effect.

Skillful planning and selective plant control can be combined with rough fish control to turn a liability (rank plant growth) into an asset (enjoyable sportfishing).

But mechanical harvesting or applications of narrow-spectrum herbicides (i.e., 2,4-D) may be needed to hold Eurasian watermilfoil to a surface cover of 10%–40% and an intermediate density of less than 52 g dry weight/m^2 (Wiley et al. 1984) or 111 stems/m^2 (Crowder and Cooper 1979). However, habitat suitability index models (Schamberger et al. 1982) suggest optimum plant cover varies with fish species, ranging from 15%–30% for bluegills (Stuber 1982) to 80% or more for northern pike (*Esox lucius* L.) (Inskip 1982). Largemouth bass growth improved in Florida lakes when hydrilla growth decreased to 10% (Moxley and Langford 1982), 20% (Durocher et al. 1984), or 30% (Colle and Shireman 1980) of surface area. Thinning the same plant in nursery areas improved growth and recruitment of young-of-year black crappies (Maceina and Shireman 1982). Intermediate plant cover and density improve fish growth by balancing shelter for panfish against prey access for piscivores (Crowder and Cooper 1982).

An integrated fish-plant management program can be expanded by planting native pondweeds (*Potamogeton*) in areas freed of Eurasian watermilfoil (Engel 1994). In one Ontario lake, mixed pondweed-wild celery beds supported three to eight times as many fishes and macroscropic invertebrate prey as did monotypic stands of Eurasian watermilfoil (Keast 1984). Replacing these watermilfoil beds with native transplants—to create natural underwater gardens through aquascaping (Miller 1988; Pullman 1989; Butts et al. 1991)—usually requires improvement in water quality, such as reducing water turbidity by controlling bullheads (*Ameiurus*), carp (*Cyprinus carpio* L.), soil erosion, and nutrient runoff (Davis and Brinson 1980). The reward can be the restoration of diverse and structurally complex fish habitats.

Not For Every Lake or Manager

Not all lakes respond alike to Eurasian watermilfoil control, and some scentists doubt such management can change fish and invertebrate populations (Barko and Smart 1986). Lakes with steep shorelines and low fertility will be least affected by Eurasian watermilfoil and least able to support plant habitat. In shallower waters, Eurasian watermilfoil growth can decline 10–15 years after reaching dominance (Smith and Barko 1992) as watermilfoil depletes nutrients stored in lake sediments (Prentki 1978; Smith and Barko 1990), becomes overgrazed by herbivorous insects (Painter and McCabe 1988; Lodge 1991; Creed and Sheldon 1994) or snails (Sheldon 1987), or declines for unknown reasons (Carpenter 1980; Trebitz et al. 1993). However, drought and plant control could delay these declines by opening sites (invasion windows) for watermilfoil expansion (Smith and Barko 1990). Fish growth and predation may not even respond to modest plant control (Savino et al. 1992) or become masked by year-class fluctuations (Porak et al. 1990). For example, northern pike remain effective piscivores regardless of plant densities (Savino et al. 1985).

Despite such vagaries in fish response, Eurasian watermilfoil can become a tool for fishery managers. Skillful planning and selective plant control can be combined with rough fish control to turn a liability (rank plant growth) into an asset (enjoyable sportfishing). To implement such an integrated program, fishery managers will need to work closely with shoreland zoning authorities, other managers, and the public. That means fishery managers must become people managers, and everyone involved must think of plants when they think of fishes. Perhaps the real challenge is getting fishery managers to think of plants such as Eurasian watermilfoil as management tools.

Acknowledgments

I thank fishery scientists Lloyd M. (Duke) Andrews, Steven P. AveLallemant, and Michael D. Staggs of the Wisconsin Department of Natural Resources (WDNR) for reviewing earlier drafts. Goldie and Jennie Engel pawed over the final draft. I also thank three *Fisheries* reviewers for urging a balanced and documented discussion and suggesting references. Although I wrote this article on my own time, page and reprint costs were funded by the WDNR Fish Research Section.

References

Adams, M. S., and **R. T. Prentki.** 1982. Biology, metabolism and functions of littoral submersed weedbeds of Lake Wingra, Wisconsin, U.S.A.: a summary and review. Arch. Hydrobiol./ Suppl. 62:333–409.

Aiken, S. G., P. R. Newroth, and **I. Wile.** 1979. The biology of Canadian weeds. 34. *Myriophyllum spicatum* L. Can. J. Plant Sci. 59:201–215.

Barko, J. W., D. Gunnison, and **S. R. Carpenter.** 1991. Sediment interactions with submersed macrophyte growth and community dynamics. Aquat. Bot. 41:41–65.

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

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

Bode, J., S. Borman, S. Engel, D. Helsel, R. Korth, F. Koshere, and **S. Nichols.** 1993. Eurasian water milfoil in Wisconsin: a report to the legislature. Lake Management Section report, Wisconsin Department of Natural Resources, Madison.

Butts, D., J. Hinton, C. Watson, K. Langeland, D. Hall, and **M. Kane.** 1991. Aquascaping: planting and maintenance. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville. Circ. No. 912.

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

Carpenter, S. R., J. F. Kitchell, and **J. R. Hodgson.** 1985. Cascading trophic interactions and lake productivity. BioScience 35:634–639.

Carpenter, S. R., and **D. M. Lodge.** 1986. Effects of submersed macrophytes on ecosystem processes. Aquat. Bot. 26:341–370.

Coble, T. A., and **B. D. Vance.** 1987. Seed germination in *Myriophyllum spicatum* L. J. Aquat. Plant Manage. 25:8–10.

Coffey, B. T., and **C. D. McNabb.** 1974. Eurasian water-milfoil in Michigan. Mich. Bot. 13:159–165.

Colle, D. E. 1982. Hydrilla—miracle or migraine for Florida's sportfish. Florida Aquatic Plant Management Society. Aquatics 4(2):6.

Colle, D. E., and **J. V. Shireman.** 1980. Coefficients of condition for largemouth bass, bluegill, and redear sunfish in hydrilla-infested lakes. Trans. Am. Fish. Soc. 109:521–531.

Colle, D. E., J. V. Shireman, W. T. Haller, J. C. Joyce, and **D. E. Canfield,** Jr. 1987. Influence of hydrilla on harvestable sport-fish populations, angler use, and angler expenditures at Orange Lake, Florida. N. Am. J. Fish. Manage. 7:410–417.

Couch, R., and **E. Nelson.** 1985. Myriophyllum spicatum in North America. Pages 8-18 *in* L. W. J. Anderson, ed. Proceedings of the first international symposium on watermilfoil (*Myriophyllum spicatum*) and related Haloragaceae species. Aquatic Plant Management Society, Vicksburg, Mississippi.

_______. 1992. The exotic *Myriophyllums* of North America. Pages 5-11 *in* Proceedings of a national conference on enhancing the states' lake management programs: monitoring and lake impact assessment, 16–17 May 1991, Chicago, Illinois. U.S. Environmental Protection Agency, North American Lake Management Society, and Northeastern Illinois Planning Commission; Chicago, Illinois.

Creed, R. P., Jr., and **S. P. Sheldon.** 1994. The effect of two herbivorous insect larvae on Eurasian watermilfoil. J. Aquat. Plant Manage. 32:21–26.

Crowder, L. B. and **W. E. Cooper.** 1979. Response of fish to habitat structure in standing water. Pages 2–10 *in* D. L. Johnson and R. A. Stein, eds. American Fisheries Society, North Central Division, Special Publication 6, Bethesda, MD.

_______. 1982. Habitat structural complexity and the interaction between bluegills and their prey. Ecology 63:1802–1813.

Davis, G. J., and **M. M. Brinson.** 1980. Responses of submersed vascular plant communities to environmental change. U.S. Fish and Wildlife Service, Biological Service Progress Report No. FWS/OBS-79/33, Washington, DC.

DeMarte, J. A., and **R. T. Hartman.** 1974. Studies on absorption of ^{32}P, ^{59}Fe, and ^{45}Ca by watermilfoil (*Myriophyllum exalbescens* Fernald). Ecology 55:188–194.

De Steno, F. M., and **L. J. Larson.** 1990. Using citizen monitors to protect a lake from Eurasian watermilfoil. Florida Aquatic Plant Management Society. Aquatics 12(2):19–32.

De Steno, F. M. 1992. Controlling Eurasian watermilfoil infestations using an integrated approach. Florida Aquatic Plant Management Society. Aquatics 14(2):4,6, 8.

Durocher, P. P., W. C. Provine, and **J. E. Kraai.** 1984. Relationship between abundance of largemouth bass and submerged vegetation in Texas Reservoirs. North Am. J. Fish. Manage. 4:84–88.

Edwards, R. W., and **M. Owens.** 1965. The oxygen balance of streams. Pages 149–192 *in* G. T. Goodman, R. W. Edwards, and J. M. Lambert, eds. Ecology and the industrial society: a symposium of the British Ecological Society, Swansea, 13–16 April 1964. John Wiley, New York.

Eminson, D., and **B. Moss.** 1980. The composition and ecology of periphyton communities in freshwaters. I. The influence of host type and external environment on community composition. Br. Phycol. J. 15:429–446.

Engel, S. 1984. Evaluating stationary blankets and removable screens for macrophyte control in lakes. J. Aquat. Plant Manage. 22:43–48.

______. 1985. Aquatic community interactions of submerged macrophytes. Technical Bulletin 156. Wisconsin Department of Natural Resources, Madison.

______. 1989. Lake use planning in local efforts to manage lakes. Pages 101–105 *in* Proceedings of a national conference on enhancing states' lake management programs, 12–13 May 1988, Chicago, Illinois. U.S. Environmental Protection Agency, North American Lake Management Society, and Northeastern Illinois Planning Commission, Chicago, Illinois.

______. 1990. Ecosystem responses to growth and control of submerged macrophytes: a literature review. Technical Bulletin 170. Wisconsin Department of Natural Resources, Madison.

______. 1993. Status of Eurasian watermilfoil in Wisconsin. North American Lake Management Society. LakeLine 13(2):10–13.

______. 1994. Fighting Eurasian watermilfoil in Wisconsin. Florida Aquatic Plant Management Society. Aquatics 16(1):10–13.

Fitzgerald, G. P. 1969. Some factors in the competition or antagonism among bacteria, algae, and aquatic weeds. J. Phycol. 5:351–359.

Gerrish, N., and **J. M. Bristow.** 1979. Macroinvertebrate associations with aquatic marophytes and artificial substrates. J. Great Lakes Res. 5:69–72.

Gotceitas, V., and **P. Colgan.** 1987. Selection between densities of artificial vegetation by young bluegills avoiding predation. Trans. Am. Fish. Soc. 116:40–49.

Grace, J. B., and **R. G. Wetzel.** 1978. The production biology of Eurasian watermilfoil (*Myriophyllum spicatum* L.): a review. J. Aquat. Plant Manage. 16:1–11.

Haller, W. T. 1978. Hydrilla: A new and rapidly spreading aquatic weed problem. University of Florida Institute of Food and Agricultural Sciences, Gainesville. Circ. No. S-245.

Hinkle, J. 1986. A preliminary literature review on vegetation and fisheries with emphasis on the largemouth bass, bluegill, and hydrilla. Florida Aquatic Plant Management Society, Gainesville. Aquatics 8(4):9–14.

Holland, L. E., and **M. L. Huston.** 1985. Distribution and food habits of young-of-the-year fishes in a backwater lake of the Upper Mississippi River. J. Freshwater Ecol. 3:81–91.

Holmquist, C. 1971. Northerly localities for three aquatic plants, *Lemna trisulca* L., *Ceratophyllum demersum* L., and *Myriophyllum spicatum* L. Botaniska Notiser 124:335–342.

Inskip, P. D. 1982. Habitat suitability index models: northern pike. U.S. Fish and Wildlife Service, Washington, DC. Report No. FWS/OBS-82/10.17.

Janecek, J. A. 1988. Literature review on fishes interactions with aquatic macrophytes with special reference to the Upper Mississippi River system. Upper Miss. River Cons. Comm., Fish. Sec., Rock Island, Illinois.

Keast, A. 1978. Trophic and spatial interrelationships in the fish species of an Ontario temperate lake. Environ. Biol. Fish. 3:7–31.

Keast, A. 1984. The introduced aquatic macrophytes, *Myriophyllum spicatum*, as habitat for fish and their macroinvertebrate prey. Can. J. Zool. 62:1289–1303.

Kramer, R. H., and **L. L. Smith, Jr.** 1962. Formation of year classes in largemouth bass. Trans. Am. Fish. Soc. 91:29–41.

Krecker, F. H. 1939. A comparative study of the animal population of certain submerged aquatic plants. Ecology 20:553–562.

Landers, D. H. 1982. Effects of naturally senescing aquatic macrophytes on nutrient chemistry and chlorophyll *a* of surrounding waters. Limnol. and Oceanogr. 27:428–439.

Lodge, D. M. 1991. Herbivory on freshwater macrophytes. Aquat. Bot. 41:195–224.

Maceina, M. J., and **J. V. Shireman.** 1982. Influence of dense hydrilla infestations on black crappie growth. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 36:394–402.

Madsen, J. D. 1991. Resource allocation at the individual plant level. Aquat. Bot. 41:67–86.

______. 1993. Control points in the phenological cycle of Eurasian watermilfoil. U.S. Army Corps of Engineers, Aquat. Plant Control Res. Prog. Rep. A-93-1.

Madsen, J. D., L. W. Eichler, and **C. W. Boylen.** 1988. Vegetative spread of Eurasian watermilfoil in Lake George, New York. J. Aquat. Plant Manage. 26:47–50.

Madsen, J. D., J. W. Sutherland, J. A. Bloomfield, L. W. Eichler, and **C. W. Boylen.** 1991. The decline of native vegetation under dense Eurasian watermilfoil canopies. J. Aquat. Plant Manage. 29:94–99.

Mayer, J. R. 1978. Aquatic weed management by benthic semi-barriers. J. Aquat. Plant Manage. 16:31–33.

Miller, W. 1988. Aquascaping freshwater ecosystems: the Florida experience. North American Lake Management Society, Merrifield, Virgina. LakeLine 8(2):4–5, 17.

Mittlebach, G. G. 1981. Foraging efficiency and body size: a study of optimal diet and habitat use by bluegills. Ecology 62:1370–1386.

Moxley, D. J., and **F. H. Langford.** 1982. Beneficial effects of hydrilla on two eutrophic lakes in central Florida. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 36:280–286.

Mrachek, R. J. 1966. Macroscopic invertebrates on the higher aquatic plants at Clear Lake, Iowa. Iowa Acad. Sci. 73:168–177.

Newroth, P. R. 1990. Prevention of the spread of Eurasian water milfoil. Pages 93–100 *in* Proceedings of a national conference on enhancing states' lake management programs, 18–19 May 1989, Chicago, Illinois. U.S. Environmental Protection Agency, North American Lake Management Society, and Northeastern Illinois Planning Commission, Chicago, Illinois.

Nichols, D. S., and **D. R. Keeney.** 1976. Nitrogen nutrition of *Myriophyllum spicatum*: variation of plant tissue nitrogen concentration with season and site in Lake Wingra. Freshwater Biol. 6:137–144.

Nichols, S. A. 1984. Phytochemical and morphological differentiation between *Myriophyllum spicatum* L. and *Myriophyllum exalbescens* Fern in two Wisconsin lakes. Trans. Wis. Acad. Sci., Arts and Lett. 72:153–156.

Painter, D. S., and **K. J. McCabe.** 1988. Investigation into the disappearance of Eurasian watermilfoil from the Kawartha lakes. J. Aquat. Plant Manage. 26:3–12.

Pardue, W. J., and **D. H. Webb.** 1985. A comparison of aquatic macroinvertebrates occurring in association with Eurasian watermilfoil (*Myriophyllum spicatum* L.) with those found in the open littoral zone. J. Freshwater Ecol. 3:69–79.

Perkins, M. A., H. L. Boston, and **E. F. Curren.** 1980. The use of fiberglass screens for control of Eurasian watermilfoil. J. Aquat. Plant Manage. 18:13–19.

Pieczyska, E. 1993. Detritus and nutrient dynamics in the shore zone of lakes: a review. Hydrobiologia 251:49–58.

Porak, W. F., S. Crawford, D. Renfro, R. L.Cailteux, and **J. Chadwick.** 1990. Largemouth bass population responses to aquatic plant management strategies. Florida Game and Fresh Water Fish Commission. Federal Aid in Sport Fish Restoration, Completion Report, Study No. 13. Wallop-Breux Project F-24-R.

Prentki, R. T. 1978. Depletion of phosphorus from sediment colonized by *Myriophyllum spicatum* L. Pages 135–157 *in* Synthesis report on the efficacy and potential consequences of macrophyte harvesting in Lake Wingra. University of Wisconsin-Madison Center of Biotic Systems and Institute of Environmental Studies, Madison.

Pullman, G. D. 1989. The waterside landscape. North American Lake Management Society, Merrifield, Virginia. LakeLine 9(3):2–3, 22–23, 27–28.

Rabe, F. W., and **F. Gibson.** 1984. The effect of macrophyte removal on the distribution of selected invertebrates in a littoral environment. J. Freshwater Ecol. 2:359–371.

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

Rozas, L. P., and **W. E. Odum.** 1988. Occupation of submerged aquatic vegetation by fishes: testing the roles of food and refuge. Oecologia 77:101–106.

Savino, J. F., E. A. Marschall, and **R. A. Stein.** 1992. Bluegill growth as modified by plant density: an exploration of underlying mechanisms. Oecologia 89:153–160.

Savino, J. F., and **R. A. Stein.** 1982. Predator-prey interaction between largemouth bass and bluegills as influenced by simulated, submersed vegetation. Trans. Am. Fish. Soc. 111:255–266.

Savino, J. F., R. A. Stein, and **E. A. Marschall.** 1985. Management of macrophyte communities to enhance largemouth bass and bluegill populations at Clark Lake. Ohio Department of Natural Resources and Ohio State University, Columbus. Federal Aid in Sport Fish Restoration, Project F-57-R, Study No. 9. Final Rep.

Schamberger, M., A. H. Farmer, and **J. W. Terrell.** 1982. Habitat suitability index models: introduction. U.S. Fish and Wildlife Service, Washington, DC. Rep. No. FWS/OBS-82-10.

Schramm, H. L., Jr., and **K. J. Jirka.** 1989a. Epiphytic macroinvertebrates as a food resource for bluegills in Florida lakes. Trans. Am. Fish. Soc. 118:416–426.

_______. 1989b. Effects of aquatic macrophytes on benthic macroinvertebrates in two Florida lakes. J. Freshwater Ecol. 5:1–12.

Sheldon, S. P. 1987. The effects of herbivorous snails on submerged macrophyte communities in Minnesota lakes. Ecology 68:1920–1931.

Shireman, J. V., D. E. Colle, and **R. G. Martin.** 1979. Ecological study of Lake Wales, Florida, after introduction of grass carp (*Ctenophargynodon idella*). Pages 49–89 *in* J. V. Shireman, ed. Proceedings of the grass carp conference. Aquatic Weeds Research Center, University of Florida, Gainesville.

Smith, C. S., and **M. A. Adams.** 1986. Phosphorus transfer from sediments by *Myriophyllum spicatum*. Limnol. and Oceanogr. 311:1312–1321.

Smith, C. S., and **J. W. Barko.** 1990. Ecology of Eurasian watermilfoil. J. Aquat. Plant Manage. 28:55–64.

Smith, C. S., and **J. W. Barko.** 1992. Submersed macrophyte invasions and declines. U.S. Army Corps of Engineers, Aquatic Plant Control Research Program, Vicksburg, Mississippi. Rep. No. A-92-1.

Smith, S. M., and **D. J. Orth.** 1990. Distributions of largemouth bass in relation to submerged aquatic vegetation in Flat Top Lake, West Virginia. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 44:36–44.

Stanley, R. A., and **A. W. Naylor.** 1972. Photosynthesis in Eurasian watermilfoil (*Myriophyllum spicatum* L.). Plant Physiol. 50:149–151.

Strange, R. J., W. B. Kittrell, and **T. D. Broadbent.** 1982. Effects of seeding reservoir fluctuation zones with young-of-the-year black bass and associated species. N. Am. J. Fish. Manage. 2:307–315.

Stuber, R. J. 1982. Habitat suitability index models: black bullhead. U.S. Fish and Wildlife Service, Washington, DC. Rep. No. FWS/OBS-82/10.14.

Trebitz, A. S., S. A. Nichols, S. R. Carpenter, and **R. C. Lathrop.** 1993. Patterns of vegetation change in Lake Wingra following a *Myriophyllum spicatum* decline. Aquat. Bot. 46:325–340.

Werner, E. E., and **D. J. Hall.** 1979. Foraging efficiency and habitat switching in competing sunfishes. Ecology 60:256–264.

Wiley, M. J., R. W. Gorden, S. W. Waite, and **T. Powless.** 1984. The relationship between aquatic macrophytes and sport fish production in Illinois ponds: a simple model. North Am. J. Fish. Manage. 4:111–119.