J. Aquat. Plant Manage. 36: 44-49

Techniques for Establishing Native Aquatic Plants

R. MICHAEL SMART,[1] G. O. DICK,[2] AND R. D. DOYLE[1]

ABSTRACT

Man-made aquatic systems such as reservoirs are particularly vulnerable to infestations of weedy species because early in their existence they typically lack aquatic vegetation of any kind. Establishment of native aquatic plants in such systems could be an important deterrent to the spread of exotic weeds. This article describes a new Aquatic Plant Control Research Program (APCRP) work unit to develop methods for large-scale establishment of desirable native aquatic plants in man-made systems. The article discusses the need for work in this area, identifies the approach and research objectives, and describes early progress. An example project (Lake Conroe) is briefly described.

Key words: aquatic habitat, herbivory, lake restoration, plant production, plant propagation, revegetation.

INTRODUCTION

Justification. Good integrated pest management requires that affected niches are never left unoccupied. An empty niche invites colonization by undesirable species and is a primary cause of recurring aquatic plant management problems. Man-made aquatic systems such as reservoirs are highly susceptible to infestations of weedy species because, early in their existence, they generally lack aquatic vegetation of any kind. Many of these systems have extensive littoral areas capable of supporting diverse native plant communities that would enhance the structure and function of the entire ecosystem. Unfortunately, because natural establishment of native aquatic plant species is a relatively slow process, in many reservoirs nuisance exotic species often arrive first, establish, and spread to excess.

In this research we are developing methods for large-scale establishment of desirable native aquatic plants. This article briefly describes the concept of vegetating reservoirs by establishing founder colonies of desirable species and discusses production of plant propagules and planting methods.

Reservoir situations. Three situations occur in large, multipurpose reservoirs that might interest managers in establishing native aquatic plants.

1. An absence of vegetation (or greatly limited quantities),
2. low species diversity, or
3. the reservoir is infested with nuisance exotic plants.

In the first two situations, we merely need to add native aquatic plants, while in the latter we must first address control of the nuisance exotic species.

Removal of established exotic weeds is covered adequately in other papers and will not be discussed here. In this paper we concern ourselves only with unvegetated reservoirs, including those from which aquatic weeds have been removed.

[1]USAE Waterways Experiment Station, Lewisville Aquatic Ecosystem Research Facility, RR 3 Box 446, Lewisville, TX 75056.

[2]Institute of Applied Science, University of North Texas, PO Box 13078, Denton, TX 75203. Received for publication December 19, 1997 and in revised form February 10, 1998.

Among reservoirs that can support aquatic vegetation, many are vegetated almost exclusively with exotic, weedy species. These weedy species are highly adapted for exploiting disturbed conditions (Smart and Doyle 1995). Several of the world's most problematic aquatic weeds are well-established in the United States, and these often arrive and establish before propagules of native species ever reach a new reservoir. Once established, in the absence of competition, exotic weeds often form large, monospecific beds and can prevent subsequent establishment of native plants, regardless of propagule availability.

One of the major vectors for the spread of exotic weedy species is human activity. The first sites colonized by exotics are often located near boat ramps, and transport by boats or boat trailers is considered one of the primary modes of spread of exotics from lake to lake. As an example, Texas Utilities Electric Company operates 16 power plant cooling lakes. Of these 16 lakes, 11 are open to the public and are infested with hydrilla (*Hydrilla verticillata* (L.f.) Royle.) while five of the lakes are closed and do not have hydrilla[3].

In addition to accidental spread of exotics, there is an alarming number of cases where individuals or clubs have intentionally planted hydrilla in unvegetated reservoirs to "improve habitat". These individuals believe that exotic plants, such as hydrilla, benefit largemouth bass (*Micropterus salmoides*) and/or waterfowl.

Benefits of aquatic plants. Native aquatic plants provide valuable fish and wildlife habitat (Savino and Stein 1982, Heitmeyer and Vohs 1984, Dibble et al. 1996), improve water clarity and quality, reduce rates of shoreline erosion and sediment resuspension, and help prevent spread of nuisance exotic plants (Smart 1995). Water quality improvements arise from stabilization of deposited sediments (James and Barko 1995), filtration of suspended materials from the water, absorption of excess nutrients from the water (James and Barko 1990), and absorption (and sometimes detoxification) of some pollutants. Establishment of native aquatic plants can help prevent the spread of nuisance exotic plants directly by the principle of competitive exclusion (Smart 1995), and indirectly by eliminating the impetus for their intentional introduction by sportsmen.

Rationale. The aquatic plant communities that we observe in natural lakes have developed over hundreds of years. In many man-made reservoirs, there has not been enough time for a diverse community of native aquatic plants to develop. Because reservoirs are often constructed in areas that lack natural lakes, they may be remote from populations of aquatic plants that could serve as sources of propagules. As a result, many reservoirs receive only limited inputs of seed and other plant propagules.

Some reservoirs exhibit environmental conditions that may impede development of aquatic plant communities. Large water level fluctuations are common in many multipurpose reservoirs, and establishment of aquatic plants from seed or fragments will be difficult in such reservoirs. Small seedlings and developing young plants are especially vulnerable to conditions that place them in water that may be either too deep to allow for adequate light penetration or so shallow as to expose them to either turbulence or desiccation.

Unvegetated reservoirs are often characterized by turbid waters and shifting, unconsolidated sediments. Small aquatic plants may not receive enough light to sustain photosynthesis rates needed for successful establishment under these conditions. Plants may also be adversely impacted by sediments coating the leaves or, in the worst cases, completely burying young plants.

Biotic disturbance represents a major factor that may affect establishment of aquatic plant communities. Fish and other organisms that feed or 'root' in sediments easily dislodge seedlings and other small, young plants. Also, herbivory by turtles, crayfish, insect larvae, muskrats, nutria, and beaver has been shown to be a significant factor affecting establishment and/or growth of submersed aquatic plant communities (Lodge 1991, Dick et al. 1995, Doyle and Smart 1995, Doyle et al. 1997). These animals are all highly mobile and many are widely distributed throughout river systems. Also, many of them are omnivores, so their presence is not entirely dependent on the prior availability of plants. As a result of their widespread distribution and mobility, these omnivores are generally present in sufficient numbers to prevent, or at least delay, establishment of aquatic vegetation. In some systems, grass carp (*Ctenopharyngodon idella* Val.) have been used to control aquatic weed infestations, and their continuing presence may prevent establishment of any aquatic plant species for many years (Van Dyke et al. 1984).

In summary, the problem—a lack of aquatic vegetation (particularly submersed aquatic vegetation)—can be attributed to three major factors:

1. A paucity of plant propagules,
2. adverse abiotic conditions, and/or
3. biotic disturbances.

RESEARCH APPROACH

To overcome the above limitations, establishment of submersed aquatic plant communities in unvegetated reservoirs will require introduction of suitable plant propagules, into protected environments, at times and locations that will minimize adverse environmental conditions during early establishment.

Because many of our multipurpose reservoirs are quite large and have extensive littoral zones, it would be prohibitively expensive to plant even a small fraction of the ultimate aquatic plant habitat available. A more effective and practical approach is to ensure establishment of "founder colonies" in strategic locations within the reservoir and to rely on these colonies to produce the propagules that will ultimately vegetate the littoral zone of the entire reservoir (Smart et al. 1996). The successful spread of exotic species from single sites of introduction attests to the validity of the founder colony approach.

It is always tempting to use seeds to establish vegetation over large areal expanses. If the lack of vegetation was simply the result of a lack of plant propagules, seed could be a relatively easy and inexpensive method of introducing desirable species into the reservoir. However, as previously mentioned, turbid, unvegetated reservoirs are inhospitable environments for seedling establishment, and development of plant

[3]Gary Spicer, Texas Utilities Electric Company, Personal communication.

communities from seed may require a considerable length of time even in the presence of a steady input of seeds. The low probability of seedling establishment is reflected in the rarity of sexual reproduction as compared to vegetative reproduction in most submersed aquatic plant species (Les 1988, Titus and Hoover 1991, but see Brock 1983). In this regard it is interesting to note that the most problematic of the exotic submersed plant species (hydrilla, Eurasian watermilfoil (*Myriophyllum spicatum* L.), and *Egeria densa* Planch. in the U.S. and *Elodea canadensis* Michx. in Europe and Japan) very rarely or never reproduce by seed (Sculthorpe 1967, Aiken et al. 1979, Pieterse 1981, Reimer 1984, Haramoto and Ikusima 1988). Although considerably more effort is involved, the use of mature transplants or robust propagules (tubers, root crowns, etc.) may considerably reduce the time required to successfully establish founder colonies, particularly in inhospitable reservoir environments.

The founder colony approach (Smart et al. 1996) involves the establishment of small colonies of several aquatic plant species by planting transplants or robust propagules. These propagules are more tolerant of both abiotic and biotic stresses than seedlings or sprigs (Titus and Hoover 1991, Doyle and Smart 1993). Species are selected based upon past, current, and expected environmental conditions. Locations determined to be most suitable for a particular plant's growth are chosen, and each species is planted within protected plots to reduce herbivory and biotic disturbance. Once successfully established, founder colonies will spread beyond their protective borders to adjacent, unvegetated areas of the reservoir (Figure 1). Ultimately, these founder colonies will provide a continuing source of propagules to the reservoir, eventually filling empty aquatic plant niches (Smart et al. 1996).

PROPAGULE ACQUISITION

Propagules of some aquatic plant species may be purchased from commercial suppliers. However, many submersed species are not commercially available. To secure robust propagules of suitable aquatic plant species, producing planting stock by using locally-collected (and locally-adapted) plant materials may be preferable.

Large-scale restoration efforts require dedicated outdoor tanks or ponds for mass culture of plants. Plants may be grown to produce seed, tubers, stem fragments, or to be used as transplants. Tuber-forming species may be grown to produce tubers in containers held in large outdoor tanks or ponds. After the plants senesce, the containers can be removed from water and stored for several months until tubers are needed. Mature transplants can be produced by

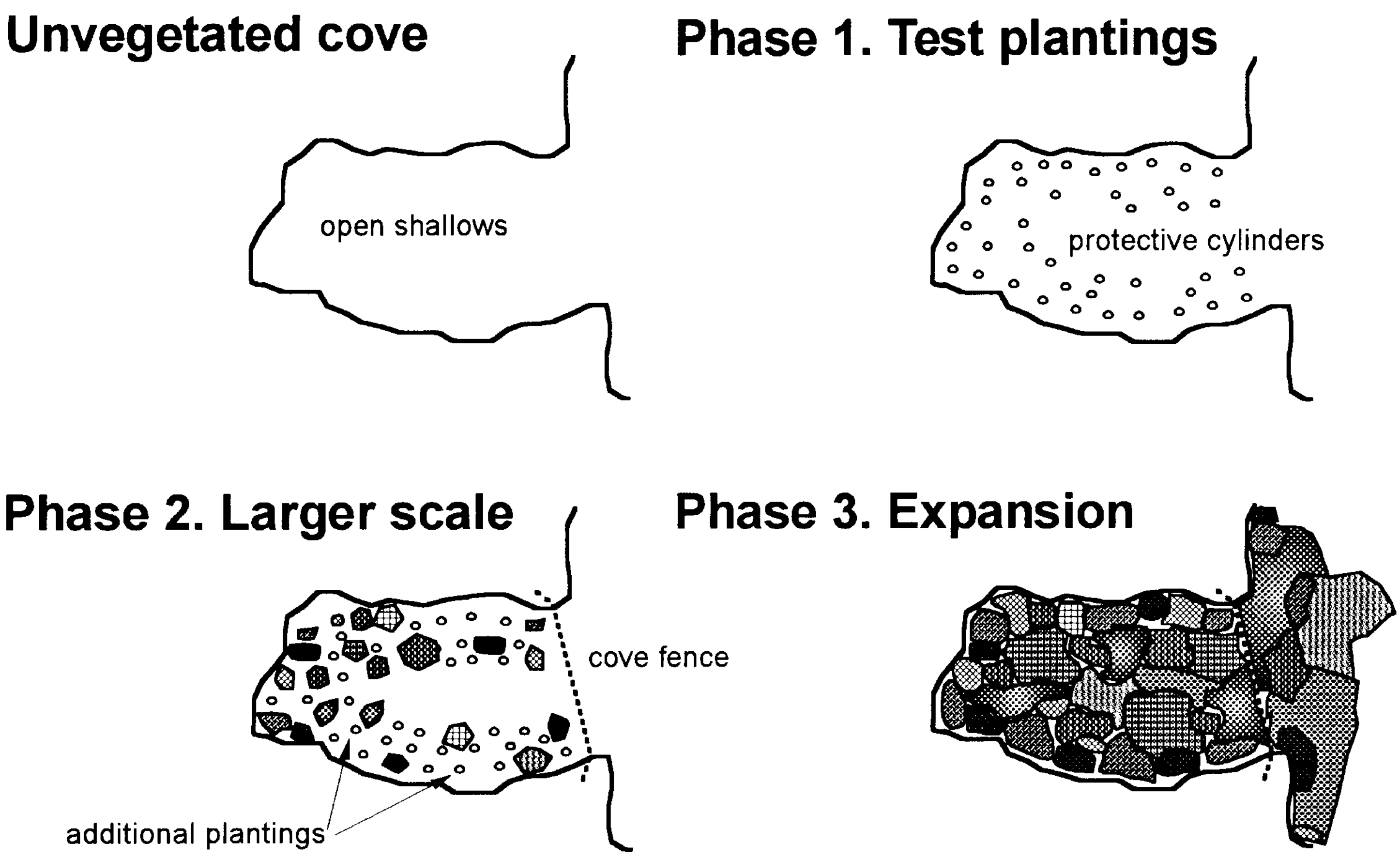

Figure 1. Diagrammatic representation of founder colony approach. Phase 1 involves planting of test plants within small protective exclosures. During the second growing season (Phase 2), a larger scale fenced area is constructed, if necessary, and additional plantings of the most suitable species are made. During the third and subsequent growing seasons (Phase 3), the founder colonies vegetate the rest of the reservoir.

growing plants in nursery pots held in large outdoor tanks or ponds. Smart et al. (1996) proposed that plant production requires the provisions of fertile sediments, low phosphorous water (<10 μg/L) to prevent excessive algal growth, moderate temperatures (20-28 C) and adequate light levels (35-65% of full sunlight).

HERBIVORE PROTECTION

Establishment of new colonies of aquatic plants in unvegetated reservoirs requires protection from herbivores. This conclusion is based upon our experiences (Smart et al. 1996, Doyle et al. 1997) and those of others who have attempted to establish submersed aquatic plants in lakes and reservoirs in several states. We have used several types of protective exclosures, depending on the expected level of herbivory. Site visits, discussions with lake and fisheries managers, and trapping can provide preliminary estimates of the densities of herbivorous species that may be encountered.

1. **Individual plant protection**—A cylinder, 60 to 90 cm in diameter by 91 or 122 cm (3 or 4 ft) high, constructed from 2" by 4" mesh welded-wire fencing and anchored with 152- or 183-cm (5- or 6-ft) lengths of rebar. The cylinder can be closed at the top by cinching opposite sides together and securing with wire ties. This exclosure is designed to protect single transplants from larger omnivores such as adult turtles, carp, nutria etc. If protection from juvenile turtles and/or crayfish is needed, exclosures can be made from smaller mesh size material.
2. **Multiple plant protection**—A square cage, 150 or 180 cm (5 or 6 ft) on a side, constructed of 122- or 183-cm (4- or 6-ft) high, 1.5" mesh orange plastic construction fencing, rebar, and PVC piping (Smart et al. 1996). These exclosures are usually planted with four or five transplants and may be suitable for harsh environments where survival of an individual transplant may be in doubt. The larger area of the resultant population may also sustain a higher grazing pressure than would an individual plant unit. The smaller mesh size of the construction fencing also provides more complete protection from most herbivores and omnivores. An additional advantage is the high visibility of the material, making the plantings easy to find for monitoring and evaluation and also easy for boats to avoid. Drawbacks include greater expense and difficulty of construction and less durability in comparison with the welded wire mesh exclosure design above.
3. **Fenced plots**—Square or rectangular fenced areas measuring 3.5 m or greater on a side and constructed from 122- or 183-cm (4- or 6-ft) high, 2" by 4" mesh welded-wire fencing.
4. **Shoreline fences**—A three-sided modification of the above fenced plot design. These are irregular in size, extending from the shoreline out to, for example, the 1-m contour and then along that contour parallel to the shore. These are also constructed of 122- or 183-cm (4- or 6-ft) high, 2" by 4" mesh welded-wire fencing.
5. **Fenced coves**—Cove areas isolated from the main body of the reservoir by fences constructed of 2" by 4" mesh welded-wire fencing placed across the mouths of small coves.

The above small-scale exclosures (1, 2, and 3) can provide near-complete protection from herbivory if constructed of appropriate mesh size material and deployed properly. However, because exclosures 1 and 2 protect only a single, relatively small clump of plants, they may be most useful in situations where herbivory is low to moderate. Larger herbivore exclosures (3, 4, and 5) offer protection from omnivores such as carp and other rough fish. These are used in situations where rough fish population densities are expected to be high, or in reservoirs stocked with grass carp.

Because fenced coves and shoreline fences do not exclude herbivores that can move over land (turtles, nutria, muskrat, beavers), these may require a double-layer of herbivore protection (individual plant exclosure plus fenced cove or shoreline).

IMPLEMENTATION

A diagrammatic representation of the founder colony approach is given in Figure 1. A suitable cove (one with an expanse of shallow water, suitable sediments, and a relatively protected location) is identified. Phase 1 involves planting and monitoring (over a full growing season) of test plants of a variety of species within small protective exclosures. Assuming suitable sediments, water quality, and water levels, these plants will establish and expand beyond their protective cages, depending on the level of herbivory. During Phase 1, the level of herbivory should be noted and, if possible, the sizes and types of herbivores.

In most unvegetated reservoirs, expansion of the plantings will require provision of a larger-scale protected environment such as a fenced cove. In Phase 2, those species performing best during Phase 1 should receive additional plantings. Phase 2 (if required) includes construction of a fence across the cove mouth to exclude carp and other rough fish in combination with additional plantings of selected or preferred species. Phase 2 should result in the successful establishment of founder colonies of several species. During Phase 3, the colonies expand to fill the niche within the fenced cove, and begin to spread into unprotected areas by vegetative and/or sexual modes of reproduction.

LAKE CONROE EXAMPLE

Background. Shortly after its impoundment, Lake Conroe was invaded by hydrilla. This aggressive exotic plant soon choked the lake with dense mats of vegetation and the state of Texas approved a one-time stocking of 270,000 herbivorous exotic fish (grass carp) to control the growth of hydrilla in Lake Conroe. The grass carp quickly consumed all of the hydrilla and for over 15 years have prevented the establishment of aquatic vegetation of any kind. A multi-agency project involving state, local, and Federal organizations has been initiated to study and demonstrate methods for establishing native aquatic vegetation in the lake. Native plants would provide much-needed fish habitat and would help prevent a re-infestation of the lake by hydrilla.

Project description. The Lake Conroe Revegetation project consists of four phases: test plantings, larger-scale demonstration sites, development of a on-site plant production nursery, and full-scale implementation. The first two phases correspond to Phases 1 and 2 described previously (Figure 1). In August of 1995 (Phase 1) test plantings were conducted at 15 locations in the lake. Plants were planted inside protective cages to determine which native plant species were best suited for conditions occurring in Lake Conroe. The test plantings also served as a gauge for evaluating the effects of the grass carp population.

Results. The three submersed species, American pondweed (*Potamogeton nodosus* Poiret), water star grass (*Heteranthera dubia* (Jacq.) Macm.), and wild celery (*Vallisneria americana* Michx.) readily established in the protective exclosures. Although each of these species exhibited repeated attempts to spread beyond the confines of the exclosures via vegetative growth, the grass carp effectively prevented any significant expansion.

Because grass carp were found to be a significant factor in preventing expansion from small-scale plantings, larger protected areas were employed in Phase 2. Six cove sites were selected from the 15 original sites and were fenced off in March of 1996. These sites received additional plantings of American pondweed (one site), water star grass (one site) or wild celery (four sites) in April, 1996. Single mature transplants were planted within individual plant protection cylinders at each of the sites. Site 1 received 30 American pondweed plants; Site 2 received 40 water star grass plants; and Site 5 received 20 wild celery plants.

We assessed survival and growth (expansion) bimonthly, in June, August, and September, 1996. Survival of the transplants was 97, 95, and 100%, for American pondweed, water star grass and wild celery, respectively. Expansion of the plants is shown in Figure 2. Both American pondweed and wild celery spread very rapidly, achieving mean colony diameters greater than 2.5 m. This indicates that planting on 3-m centers could provide nearly complete coverage in just a single growing season. Water star grass did not expand as rapidly as the other two species. The slower lateral expansion rate of water star grass was expected because this species grows by proliferation of shoots within the root crown and spreads by fragmentation. We observed many new colonies of water star grass within the fenced coves. These new colonies likely resulted from shoot fragments that broke off, drifted a short distance, and rooted. These results indicate that establishment of founder colonies can be quite rapid. In addition to the three species directly planted, we also observed an abundant growth of annual species. Both musk grass (*Chara* sp.) and southern naiad (*Najas guadalupensis* Spreng.) were present as either plants and/or seeds in the transplant materials. These pioneer species benefitted from the protected environment and spread very rapidly.

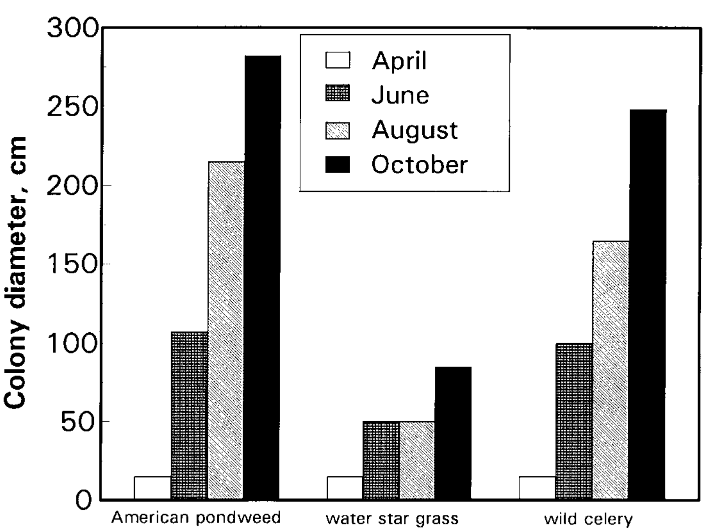

Figure 2. Vegetative expansion of individual transplants of American pondweed, water star grass, and wild celery in selected fenced coves in Lake Conroe during 1996. Values are means of 30, 40, and 20 replicate transplants, respectively.

FUTURE RESEARCH

Research on methods of producing transplant materials (both at remote sites and within-lake) continues. Research on methods of protecting transplants from herbivory also continues. Several lake restoration projects have been initiated using the techniques described here. These include the following reservoirs: Arcadia Lake (Oklahoma), El Dorado Lake (Kansas), and Lake Livingston (Texas).

ACKNOWLEDGMENTS

This research was conducted under the U.S. Army Corps of Engineers Aquatic Plant Control Research Program, U.S. Army Engineer Waterways Experiment Station. Permission to publish this information was granted by the Chief of Engineers.

LITERATURE CITED

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.

Brock, M. A. 1983. Reproductive allocation in annual and perennial species of the submerged aquatic halophyte *Ruppia*. J. Ecol. 71: 811-818.

Dibble, E. D., K. J. Killgore, and S. L. Harrel. 1996. Assessment of fish-plant interactions. In L. E. Miranda and D. R. DeVries (eds.) Multidimensional Approaches to Reservoir Fisheries Management. Amer. Fish. Soc. Symp. 16: 347-356.

Dick, G. O., R. M. Smart, and E. D. Keiser. 1995. Populations of turtles and their potential impacts on aquatic plants in Guntersville Reservoir, Alabama. Joint Agency Guntersville Project Aquatic Plant Management, Tennessee Valley Authority Report. 49 pp.

Doyle, R. D. and R. M. Smart. 1993. Potential use of native aquatic plants for long-term control of problem aquatic plants in Guntersville Reservoir, Alabama. Report 1. Establishing native plants. Miscellaneous Paper A-95-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. 66 pp.

Doyle, R. D. and R. M. Smart. 1995. Competitive interactions of native plants with nuisance species in Guntersville Reservoir, Alabama. In Proceedings, 29th annual meeting, Aquatic Plant Control Research Program. Miscellaneous Paper A-95-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. pp. 237-242.

Doyle, R. D., R. M. Smart, C. Guest, and K. Bickell. 1997. Establishment of native aquatic plants for fish habitat: Test plantings in two north Texas Reservoirs. Lake and Reserv. Manage. 13: 259-269.

Haramoto, T. and I. Ikusima. 1988. Life cycle of *Egeria densa* Planch., an aquatic plant naturalized in Japan. Aquat. Bot. 30: 389-403.

Heitmeyer, M. E. and P. A. Vohs, Jr. 1984. Distribution and habitat use of waterfowl wintering in Oklahoma. J. Wildl. Manage. 48: 51-62.

James, W. F. and J. W. Barko. 1990. Macrophyte influences on the zonation of sediment accretion and composition in a north-temperate reservoir. Arch Hydrobiol. 120: 129-142.

James, W. F. and J. W. Barko. 1995. Effects of submersed macrophytes on sediment resuspension in Marsh Lake, Minnesota. In Proceedings, 29th annual meeting, Aquatic Plant Control Research Program. Miscellaneous Paper A-95-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. pp. 168-175.

Les, D. H. 1988. Breeding systems, population structure, and evolution in hydrophilous angiosperms. Ann. Missouri Bot. Gard. 75: 819-835.

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

Pieterse, A. H. 1981. *Hydrilla verticillata* - A review. Abstr. Trop. Agric. 7: 9-34.

Reimer, D. N. 1984. Introduction to Freshwater Vegetation. AVI, Westport, CN. 207 pp.

Savino, J. F. and R. A. Stein. 1982. Predator-prey interactions between largemouth bass and bluegills as influenced by simulated, submerged vegetation. Trans. Amer. Fish. Soc. 111: 225-266.

Sculthorpe, C. D. 1967. The Biology of Aquatic Vascular Plants. Arnold, London, 610 pp.

Smart, R. M. 1995. Preemption: An important determinant of competitive success. In Proceedings, 29th annual meeting, Aquatic Plant Control Research Program. Miscellaneous Paper A-95-3, U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS. pp. 231-236.

Smart, M. and R. Doyle. 1995. Ecological theory and the management of submersed aquatic plant communities. Aquatic Plant Control Research Program Bulletin A-95-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. 8 pp.

Smart, R. M., R. D. Doyle, J. D. Madsen, and G. O. Dick. 1996. Establishing native submersed aquatic plant communities for fish habitat. In L. E. Miranda and D. R. DeVries (eds.) Multidimensional Approaches to Reservoir Fisheries Management. Amer. Fish. Soc. Symp. 16: 347-356.

Titus, J. E. and D. T. Hoover. 1991. Toward predicting reproductive success in submersed freshwater angiosperms. Aquat. Bot. 41: 111-136.

Van Dyke, J. M., A. J. Leslie, Jr., and L. E. Nall. 1984. The effects of grass carp on the aquatic macrophytes of four Florida lakes. J. Aquat. Plant Manage. 22: 87-95.