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October 1993

**US Army Corps
of Engineers**
Waterways Experiment
Station

Aquatic Plant Control Research Program

Potential Use of Native Aquatic Plants for Long-Term Control of Problem Aquatic Plants in Guntersville Reservoir, Alabama

Report 1
Establishing Native Plants

by *Robert D. Doyle, R. Michael Smart*
Environmental Laboratory

Prepared for Headquarters, U.S. Army Corps of Engineers

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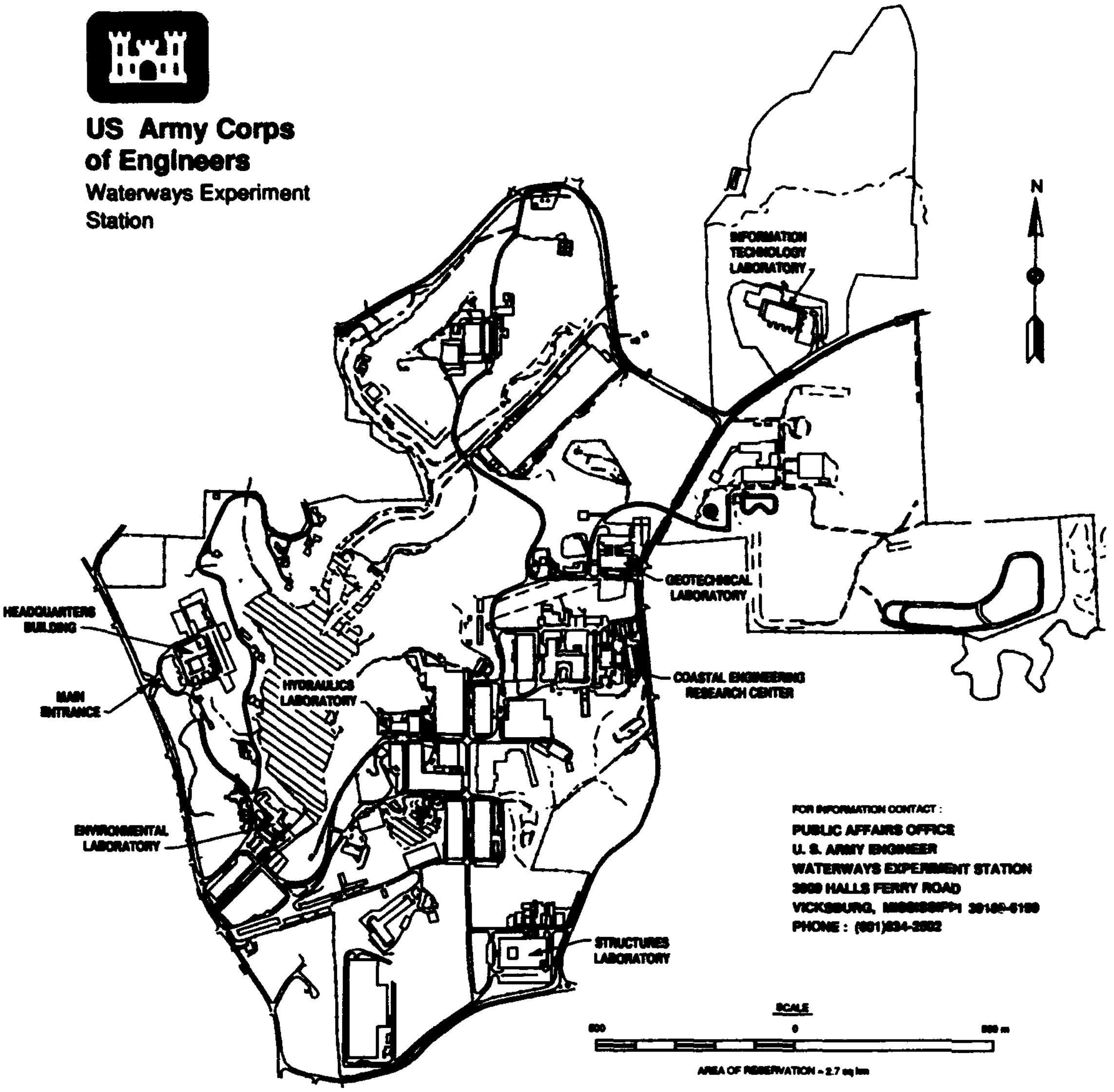
Waterways Experiment Station



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Preface

The work reported herein was conducted as part of the Aquatic Plant Control Research Program (APCRP), Work Unit 32736. The APCRP is sponsored by the Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to the U.S. Army Engineer Waterways Experiment Station (WES) under the purview of the Environmental Laboratory (EL). Funding was provided under Department of the Army Appropriation Number 96X3122, Construction General. The APCRP is managed under the Environmental Resources Research and Assistance Programs (ERRAP) by Mr. J. L. Decell, Program Manager. Mr. Robert C. Gunkel was Assistant Manager, ERRAP, for the APCRP. Technical Monitor during this study was Ms. Denise White, HQUSACE.

Principal Investigator for this study was Dr. R. Michael Smart, Ecosystem Processes and Effects Branch (EPEB), Environmental Processes and Effects Division (EPED), Environmental Laboratory (EL), WES. The report was prepared by Dr. Robert D. Doyle assigned to the EPED under an Interpersonal Act Agreement (IPA) with the Institute of Applied Science, University of North Texas, Denton, Texas, with contributions from Dr. Smart. Experimental design, data analysis, and interpretation were provided by the authors. Dr. David Webb and Mr. Doug Murphy, both of the Aquatic Biology Department, Tennessee Valley Authority, contributed to experimental design and field data collection. Logistical support was provided by TVA, and TVA's Guntersville Reservoir Aquatic Research Facility (GRARF) at Murphy Hill was used to support field operations. Technical assistance was provided in the field by Messrs. Murphy, David Brewster, Mark Dowdey, Stewart Goldsby, Jim Luken, and Larry Mangum and Dr. Wayne Poppe, TVA. Laboratory operations, data analysis, and report preparation were conducted at the WES Lewisville Aquatic Ecosystem Research Facility (LAERF) in Lewisville, TX. Technical assistance in the laboratory was provided by Mr. David Honnell, ASCI Corporation, and Ms. Aleida Eubanks, Ms. Susan Dutson, Ms. Karen Kuhler, and Ms. Cristi Brandon, all of LAERF. Mr. Stephen McClintick, University of North Texas, provided assistance with data analysis and graphics. The report was reviewed by Drs. Webb (TVA) and John D. Madsen (EPED, EL).

This investigation was performed under the general supervision of Dr. Richard E. Price, Chief, EPEB, Mr. Donald L. Robey, Chief, EPED, and Dr. John Harrison, Director, EL.

At the time of publication of this report, Dr. Robert W. Whalin was Director of WES. COL Bruce K. Howard, EN, was Commander.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	**By**	**To Obtain**
acre	4046.873	square meters
acre-feet	1233.489	cubic meters
feet	0.348	meters
inches	0.0254	meters
miles (U.S. statute)	1.609347	kilometers

1 Introduction

Background

The prolific growth of problem species of submersed aquatic macrophytes such as *Myriophyllum spicatum* (Eurasian watermilfoil) and *Hydrilla verticillata* (hydrilla) results in a serious threat to the navigational, economic, recreational, and aesthetic values of Guntersville Reservoir and other public water bodies in the southeast. The success of these problem species is due to their adaptations for colonizing new and/or disturbed substrates rather than to their competitive abilities. There is little documented evidence that these problem species displace actively growing, native vegetation in the absence of some disturbance which initially creates an opening for invasion. However, Madsen et al. (1991) report an apparent example of such displacement.

Therefore, the spread of these problem species depends, in large part, on the availability of open (nonvegetated) habitats for initial establishment and development. Such disturbed areas are common within reservoirs because of the water level fluctuations and herbicide treatments required to maintain a balance among numerous, and often conflicting, uses of the reservoir such as flood control, water supply, and recreation.

Guntersville Reservoir has been plagued with an overabundance of nuisance species of submersed aquatic plants for many years. *Myriophyllum* has been the dominant nuisance species since the 1960's, but *Hydrilla* populations were spreading rapidly in the period between 1982 and 1990. Although the seasonal growth of both of these plants can be controlled by chemical treatment, regrowth or subsequent re-invasion makes repeated treatments necessary. The removal of existing vegetation, by opening up new areas for colonization, may actually increase the rate of colonization by these nuisance species. Once open habitat is created, rapid colonization and growth of nuisance species often results in near monospecific stands. A more effective and long-term solution to the problem may be to establish populations of more desirable, native species in areas of the reservoir where *Myriophyllum* colonization is likely. Within existing *Myriophyllum* beds, it may be possible to follow conventional control operations with the establishment of competitive, native species. These desirable species would occupy the area thereby preventing, or at least delaying, the return of *Myriophyllum* to problem levels.

Another aquatic plant problem in Guntersville Reservoir is the widespread occurrence of floating mats of the filamentous blue-green alga *Lyngbya wollei*. These algal mats develop on the sediment surface in shallow waters and can achieve considerable mass before floating to the surface and becoming visible. *Lyngbya* is difficult to control because chemical treatments generally affect only the top, actively growing layer of the mat. Filaments deeper within the mat continue to be viable and grow, and even the strands of dead filaments remain intact for long periods due to a strong, calcified sheath which surrounds the filaments. A more effective control for *Lyngbya* would be to prevent the initial subsurface development of the mats by establishing populations of desirable plants in *Lyngbya*-prone areas of the reservoir. Within existing *Lyngbya* mats, the establishment of desirable, native plants may minimize the further growth of the mats by shading the incident sunlight and intercepting nutrients diffusing from the sediments.

Aquatic Plant Problems in Guntersville Reservoir

Guntersville Reservoir

Guntersville Reservoir is the second largest of the mainstem Tennessee River reservoirs operated by the Tennessee Valley Authority (TVA) and is located in northeastern Alabama and southeastern Tennessee. The dam impounds a 75.7-mile-long[1] reservoir that provides a maximum volume of 1,018,000 acre-feet (TVA 1992b). This multipurpose reservoir was designed for and is routinely operated to provide navigation, flood control, and power production. Secondary benefits of the project include recreation, water supply, and fish and wildlife habitat.

The limited amplitude of water level fluctuations and the extensive, overbank habitat within the reservoir are conducive for establishment and growth of aquatic macrophytes. In addition, routine monitoring of physical (temperature) and chemical (nutrient) parameters in the lake revealed no major impediments to the establishment and proliferation of aquatic plants (Appendix A).

During 1991 and 1992 the reservoir elevation fluctuated between 594 and 595.5 ft above mean sea level (msl) throughout most of the macrophyte growing season (May-September) with fluctuations in water level occurring on both a weekly and seasonal basis (Figure 1). Weekly fluctuations of 6 to 8 in. were related to hydropower generation and mosquito control. Seasonal drawdowns of about 2 to 3 ft occur in the winter for flood control or, infrequently, during the summer months the reservoir may be drawn down 3 ft for aquatic plant management (Webb 1990). Nearly two-thirds of the 67,900 acres inundated by

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[1] A table of factors for converting non-SI units of measurement to SI units is presented on page viii.

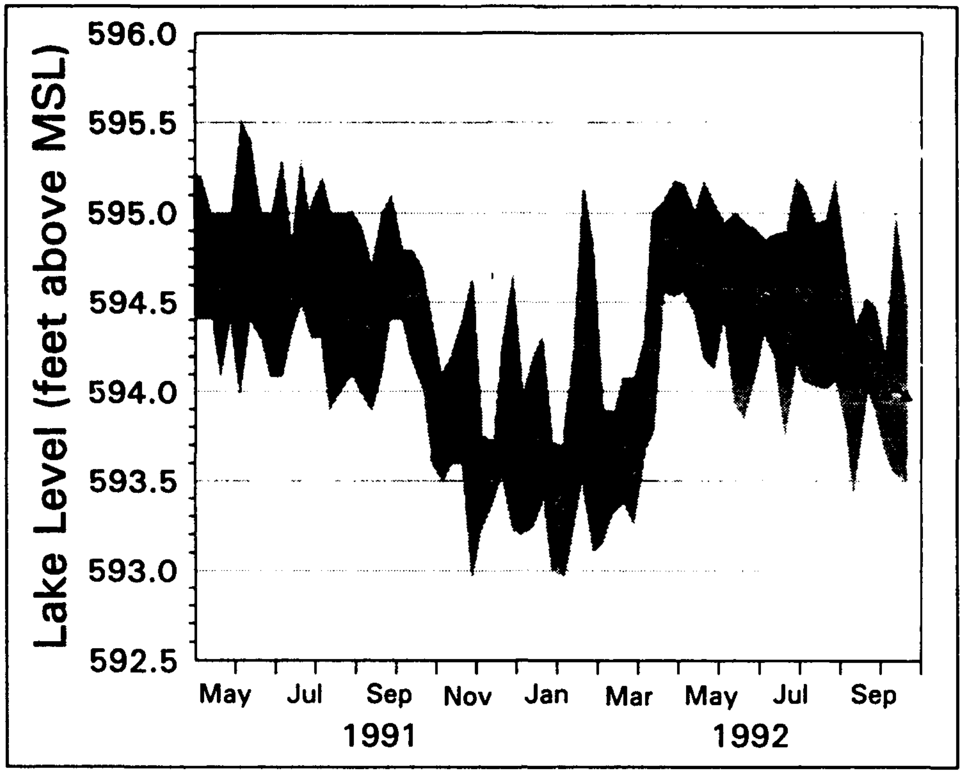

Figure 1. Seasonal pattern of water elevation of Guntersville Reservoir at the dam. Hourly values have been averaged over 1-week intervals (triangles) and the observed maximum and minimum elevation values are shown (shaded area)

the reservoir is less than 18 ft in depth and therefore potential habitat for aquatic plants (TVA 1992a).

Because of these factors, Guntersville Reservoir has the most significant aquatic plant infestation of the reservoirs within the Tennessee River system. Of particular concern in Guntersville have been the submersed macrophytes *Myriophyllum* and *Hydrilla* and a noxious, mat forming blue-green alga *Lyngbya*.

***Myriophyllum spicatum* L.**

Infestations of *Myriophyllum spicatum* in North America are among the most troublesome aquatic plant management problems. The prolific growth of this plant adversely affects the recreational, aesthetic, and economic values of lakes (Grace and Wetzel 1978, Newroth 1985). The recent review of the ecology of this species (Smith and Barko 1990) highlights the impact of many management strategies (harvesting, dredging, drawdowns, etc.) required to balance conflicting uses of the reservoir. Furthermore, the review speculates that because this species responds positively to disturbance, these disturbance-oriented actions may actually promote the persistence and further spread of *Myriophyllum*.

Within the TVA reservoir system *Myriophyllum* has been the most troublesome of the nuisance species and reached its greatest coverage in Guntersville Reservoir. Introduction of this species into Guntersville Reservoir occurred in the 1950's and vigorous *Myriophyllum* populations have spread within the reservoir over the years, despite intensive management of the system. In 1988 at the peak of macrophyte coverage, almost 20,000 acres were colonized with submersed species, primarily *Myriophyllum* and *Hydrilla*. This corresponds to about 29 percent of the total reservoir area and 44 percent of the available area for macrophyte growth (TVA 1992b).

Hydrilla verticillata L.f. Royle

Hydrilla was first discovered in Guntersville Reservoir in 1982 and within the next six years expanded to cover an area of about 3,000 acres (TVA 1992b). Because of the difficulty and expense of controlling this species in other regions (Pieterse 1981, Langeland 1990), efforts were initiated immediately to control this plant. In 1990 TVA stocked 100,000 sterile grass carp in the reservoir (Bates, Decell, and Swor 1991), primarily as a control agent for *Hydrilla*. At present, *Hydrilla* is no longer a problem in Guntersville Reservoir, due to the significant reduction associated with climatic factors and the introduced grass carp. In fact, it is difficult to find areas of sufficient size for experimental work. The competitive replacement of *Hydrilla* is being considered in other work units (McCreary, McFarland, and Barko 1991, Smart, Barko, and McFarland in press). For these reasons *Hydrilla* has not been considered in the current work unit.

Lyngbya wollei (Farlow ex Gomont) *comb. nov.*

In recent years there has been an increasing awareness of the nuisance potential of the filamentous blue-green alga *Lyngbya wollei* in the southeastern United States (Speziale, Turner, and Dyck 1988, Bowes, Spencer, and Beer 1990). When well established as a benthic mat, *Lyngbya* dry weight biomass is reported to be as high as 1.0 to 1.44 $kg \cdot m^{-2}$ (Beer, Spencer, and Bowes 1986, Speziale, Turner, and Dyck 1988, 1991), a value higher than that of most submersed and many emergent macrophyte species. In heavily infested areas, *Lyngbya* exists as a monoculture and is a formidable competitor to more desirable macrophyte species. Dense mats of *Lyngbya* may virtually preclude the establishment of higher plants by natural (i.e. seeds or fragments) means.

Once established, there are currently no generally effective biological or chemical methods for controlling this organism (Cullimore and McCann 1977, Speziale, Turner, and Dyck 1988, Dick 1989). However, preliminary research indicates that cyanophages (Montegue and Phlips 1991), mechanical harvesting

(Ritter 1982, cited by Speziale, Turner, and Dyck 1988), grass carp (Zolcynski and Smith 1980), commercial shading compounds (Martin, Martin, and Perez-Cruet 1987), and herbicides (Leland and Carter 1984) are all potential control agents. Anecdotal evidence also suggests that established macrophyte stands are effective in preventing the establishment of the *Lyngbya* mats (Dick 1989).

Lyngbya's success in becoming established is apparently related to several "opportunistic" traits exhibited by this species including: a low light requirement for photosynthesis, high temperature optimum, insensitivity of photosynthesis to high O_2 concentrations, and the ability to utilize HCO_3^- (Speziale, Turner, and Dyck 1988, 1991, Beer, Holbrook, and Bowes 1990). *Lyngbya*'s low light requirement seems especially important. Beer, Spencer, and Bowes (1986) report light compensation and light saturation levels of only 20 and 150 $\mu E \cdot m^{-2} \cdot s^{-1}$, respectively. *Lyngbya* can also survive for up to one year in complete darkness (Speziale, personal communication). These low light requirements of *Lyngbya* allow establishment and survival for long periods on the sediment surface, either beneath macrophytes or in deep or turbid water, and await more favorable conditions. These conditions may be provided by some disturbance to the macrophyte community. Dick (1989) provides anecdotal evidence for just such a scenario. *Lyngbya* was present in small quantities in the Crystal River, Florida, when the dominant macrophyte *Hydrilla* was eliminated by an unusual saltwater intrusion into the river. In the absence of macrophyte cover, *Lyngbya* quickly spread throughout the system and soon became a navigational and recreational nuisance.

Lyngbya differs from other filamentous algae primarily in the unusual resilience of the established mats. Unlike most algae, *Lyngbya* behaves like a perennial, with virtually all of the summer biomass accumulation overwintering as a benthic mat (Speziale, Turner, and Dyck 1991). The strength of these mats is derived from thick, nonliving sheaths composed primarily of $CaCO_3$ that encase the unusually large cells. These sheaths become tangled and bind the filaments together, forming the characteristic mats.

As in many other southeastern lakes, *Lyngbya* is perceived to be a growing aquatic plant problem in Guntersville Reservoir due to the noxious growth which limits recreational use of the reservoir and seriously detracts from the aesthetic appeal of shallow water habitats. In addition, lakeshore property owners object to the strong earthy odors emitted by the mats.

Objectives and Scope

The overall objective of the work reported here was to develop operational techniques and guidelines for establishing beneficial native, non-problem species, thereby slowing the spread of the problem species.

This report will summarize the results of some of the studies performed in Guntersville Reservoir and at the Lewisville Aquatic Ecosystem Research Facility between 1990 and 1992. The results of some of the ongoing research projects will be presented in the final report, Report 4, due in September 1994. Report 4 will cover the topics presented in Reports 2 and 3 as outlined below:

Report 2. Initial report on experiments conducted to evaluate the abilities of established populations of *Vallisneria americana* and *Potamogeton nodosus* to resist invasion by *Myriophyllum spicatum*. This report will deal with the first phase of the research where populations of *Vallisneria* and *Potamogeton* were established in the Chisenhall embayment of Guntersville Reservoir, an area historically dominated by *Myriophyllum*. The ability of these established populations to withstand re-invasion by *Myriophyllum* will be documented and presented in the final report.

Report 3. Initial report on experiments conducted in Guntersville Reservoir to determine the potential use of native aquatic plants to ameliorate the noxious, undesirable consequences of *Lyngbya* infestations. This interim report will deal with the first phase of the research where the potential for establishment and growth of seven desirable, native species of aquatic macrophytes in *Lyngbya*-infested regions of the reservoir was tested. Work currently under way to explore the competitive interactions between *Lyngbya* and three macrophyte species successfully established within the *Lyngbya*-infested areas will be presented in the final report in 1994.

2 Establishment of *Vallisneria americana* and *Potamogeton nodosus* Populations in Guntersville Reservoir

Experimental Objective and Design

The objective of this study was to evaluate the ability of small, established *Vallisneria americana* and *Potamogeton nodosus* populations to withstand reinvasion by *Myriophyllum spicatum.* We wished to first establish small populations of the desirable plant species within an area dominated by *Myriophyllum*, and then monitor the ability of these populations to resist reinvasion by *Myriophyllum.* This report will focus on the first phase of research where we attempted to establish *Vallisneria* and *Potamogeton* populations within a *Myriophyllum*-dominated environment.

The experimental design was to establish 24 1.5- by 1.5-m plots within a larger exclosure. The experimental treatments involved plantings of *Vallisneria* or *Potamogeton* (eight replicates of each species), mixed plantings of both species (four replicates), or unplanted controls (four replicates).

Methods

This research was conducted in Chisenhall embayment (Figure 2), a shallow cove dominated by *Myriophyllum.* An exclosure measuring 20 by 30 m was constructed with 5-cm mesh galvanized fencing to exclude grass carp and other herbivores. The exclosure was located at an elevation of 590.7 ft above msl, which corresponded to a depth between 1.15 and 1.30 m during most of the growing season and was densely vegetated with *Myriophyllum* at the beginning of the experiment. The exclosure was treated with 2,4-D herbicide on 1 May 1991, to eliminate the *Myriophyllum* population. Previous work in a pond near the reservoir had shown that the use of a benthic barrier was of no benefit in

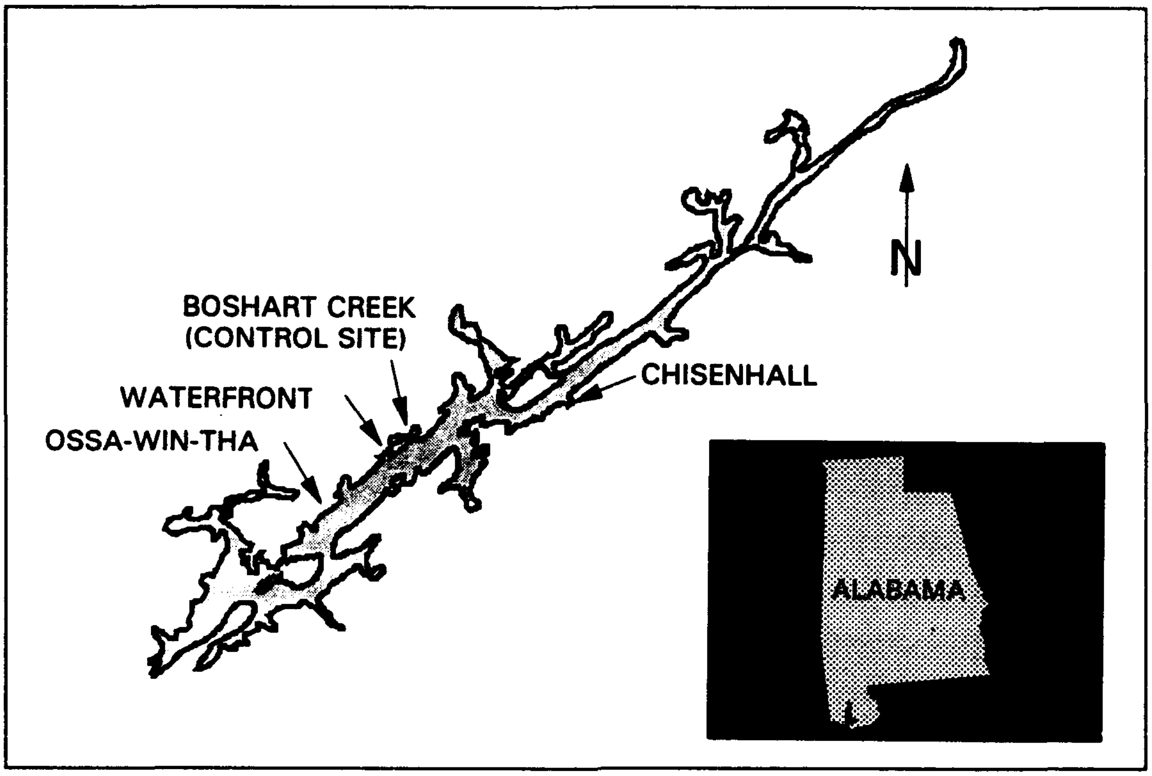

Figure 2. Map of Guntersville Reservoir showing locations of the various sites utilized for establishing native macrophytes

establishing populations of desirable plants within *Myriophyllum* beds (Appendix B). Therefore, this technique was not utilized in the reservoir.

Twenty-four 1.5- by 1.5-m experimental plots delineated by frames constructed of PVC pipe were established within the exclosure. Each plot was subdivided into 100 planting cells (15 by 15 cm) by stringing nylon cord across the plot frame. The frames were anchored to the sediment and plant species were randomly assigned to the plots and planted on 3 June 1991, by SCUBA divers. *Vallisneria* plots were planted with small transplants obtained a few days earlier from the Holston River in northeastern Tennessee. *Potamogeton* was planted as dormant tubers (winterbuds) collected in February from Cedar Creek Reservoir, Alabama, and refrigerated moist at 7 °C prior to planting.

Visual observations of the planted plots were made by divers at approximately monthly intervals during both 1991 and 1992. In addition, plant harvests were made bimonthly during the growing seasons to document standing crop biomass within the plots. For each harvest, all plants within 9 of the 100 15- by 15-cm subplots within each plot were collected by divers. The plants were sorted by species, dried at 60 °C to a constant weight, and weighed.

Light (photosynthetically active radiation, PAR) within the plots was monitored approximately monthly during both years. Monthly light profiles were measured within numerous plots by lowering a flat LiCor underwater quantum sensor through the water column. Simultaneous measurements were made of the incident surface light with a second flat LiCor sensor calibrated for use in air. Seven to ten paired measurements were made at each depth as the sensor was slowly moved around within the plot. This method allowed a more accurate integration of the variable light fields within the macrophyte plots than would a single point measurement. Data from these sensors were stored on a LiCor data logger and expressed as a percent of incident surface light. Light profiles were measured between 10 am and 3 pm.

Average daily water temperature was measured at the site with a Omnidata ES-60 thermistor deployed beneath the water surface and attached to a LiCor Easylogger datalogger. The sensor was scanned every 5 min throughout the day and the daily average recorded at midnight.

Results and Discussion

Environmental conditions

The light conditions within the exclosure were apparently sufficient to support growth and reproduction of established *Vallisneria* and *Potamogeton* populations. Extinction coefficients were high (1.6 to 3.5) due to the turbidity of the water, but because of the shallow depths 5 to 15 percent of the incident light reached the sediment surface throughout the study (Figure 3) corresponding to maximum midday PAR levels of 100 to 300 $\mu E \cdot m^{-2} \cdot sec^{-1}$. *Vallisneria* is a plant adapted to low light conditions with a half saturation constant (K_m) of 25 $\mu E \cdot m^{-2} \cdot s^{-1}$ and a light compensation point of only 10 $\mu E \cdot m^{-2} \cdot s^{-1}$ (Madsen et al. 1991). Korschgen (1988) reports that maximum midday levels of about 125 $\mu E \cdot m^{-2} \cdot sec^{-1}$ are adequate for *Vallisneria* establishment from winterbuds. This suggests that light levels were high enough for establishment of the plants. However, if suspended sediments settle on the leaf surfaces, the plants would actually receive much less light than these profiles indicate (Smart, Barko, and McFarland, in press). Kollar (1986) reports the best transplant success for mature *Vallisneria* plants in areas of the Chesapeake Bay overlaid by sand and attributes part of this success to adequate light levels and the reduced sediment re-suspension at the site.

Average daily water temperatures during the growing season at Chisenhall varied between 17 and 31 °C (Figure 4). Such temperatures fall well within the tolerance range for growth and reproduction of *Vallisneria*, which has an optimum temperature of about 28 °C (Barko, Hardin, and Mathews 1982, 1984). Maximum summer temperatures were about 31 °C and minimum winter temperatures were about 5 °C.

The substrate at the site was largely unconsolidated sediment with a high silt content (muck). Although not ideal for the establishment of *Vallisneria*

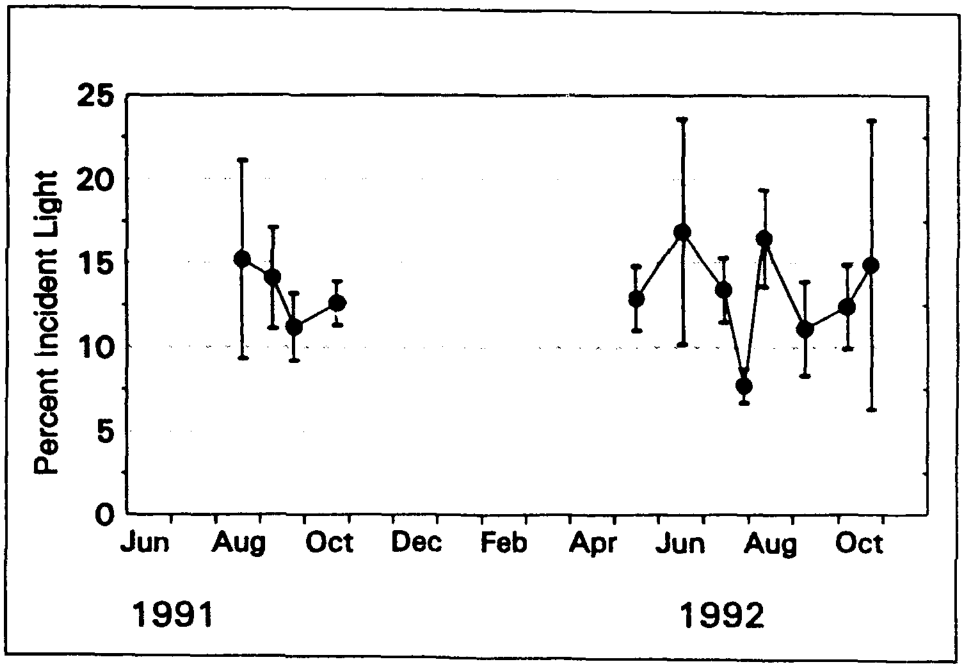

Figure 3. Percent incident light reaching sediment surface at Chisenhall embayment (1991-1992)

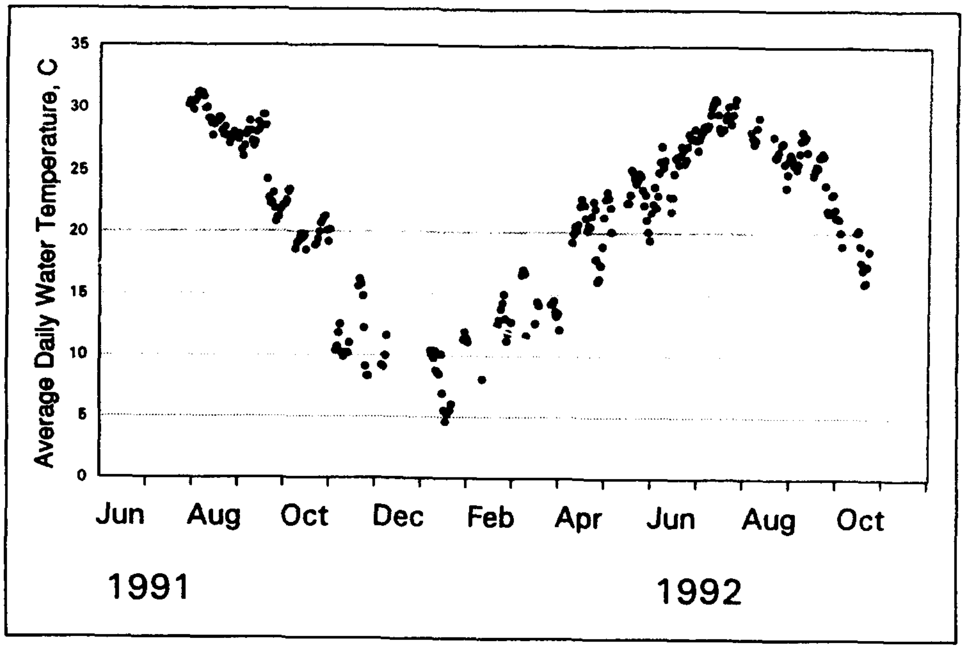

Figure 4. Average daily water temperature in upper water column at Chisenhall embayment

(Korschgen 1988), this substrate is probably acceptable for the establishment of *Vallisneria* and *Potamogeton*. Hunt (1963) reports that *Vallisneria* grows in very diverse substrates and that only impervious or soft shifting substrates preclude establishment. In addition, the fact that *Myriophyllum*, a plant with habitat requirements similar to *Vallisneria* and *Potamogeton* (Korschgen 1988), has historically dominated this embayment implies that the sediment characteristics were not a major obstacle in establishing the plants.

Vallisneria and *Potamogeton* plantings

Major changes took place in the Chisenhall embayment about 1991. While this embayment historically supported dense populations of *Myriophyllum*, aerial photos revealed that the population declined dramatically near the beginning of this experiment and was virtually absent during all of 1991 and 1992 (David Webb, personal communication). Within the exclosure, however, we did observe sporadic regrowth of *Myriophyllum* (Figure 5), although never to the levels prior to 1991. Rooted *Myriophyllum* plants outside the exclosure were rare in 1991 and were never observed within the embayment except within the exclosure during 1992.

Within four weeks of initial plantings in 1991, *Potamogeton* reached the surface of the water and was beginning to send stolons and new shoots out of the planted plots. At the first harvest (26 July 1991), the biomass within the plots was high, but declined throughout the summer due to periodic grazing from herbivores (Figure 5). We frequently observed rafts of *Potamogeton* floating at the surface and attributed this damage to muskrats. Also, turtles captured in traps placed within the exclosure confirmed that despite great care to exclude these herbivores, some were still inside the fenced area.

At the end of the 1991 growing season there was still appreciable *Potamogeton* biomass; therefore, we did not replant the plots in spring of 1992 in order to measure the overwintering success of the plants. In May 1992, we observed *Potamogeton* growing well and reaching the surface of the water, indicating good overwintering success. However, before the first scheduled harvest in June 1992, we saw a dramatic decline in the *Potamogeton* biomass. This decline was again attributed to muskrats, and so baited steel traps were set within the exclosures. During the remainder of 1992 a total of five muskrats and numerous turtles were captured from within the exclosure. In early July 1992 we observed that the *Potamogeton* plots had, once again, been seriously damaged by herbivory. However, upon visual inspection we saw that despite the grazing, the *Potamogeton* plants were still alive and regrowing from the stems. We elected not to replant and saw a slow regrowth during the remainder of 1992. Biomass at the last harvest date in 1992 (27 September) was still quite low compared to 1991.

Survival of the *Vallisneria* transplants from the Holston River was very low, and we replanted with transplants obtained from a nearby locality within Guntersville Reservoir. Replanting took place on 27 June 1991. These

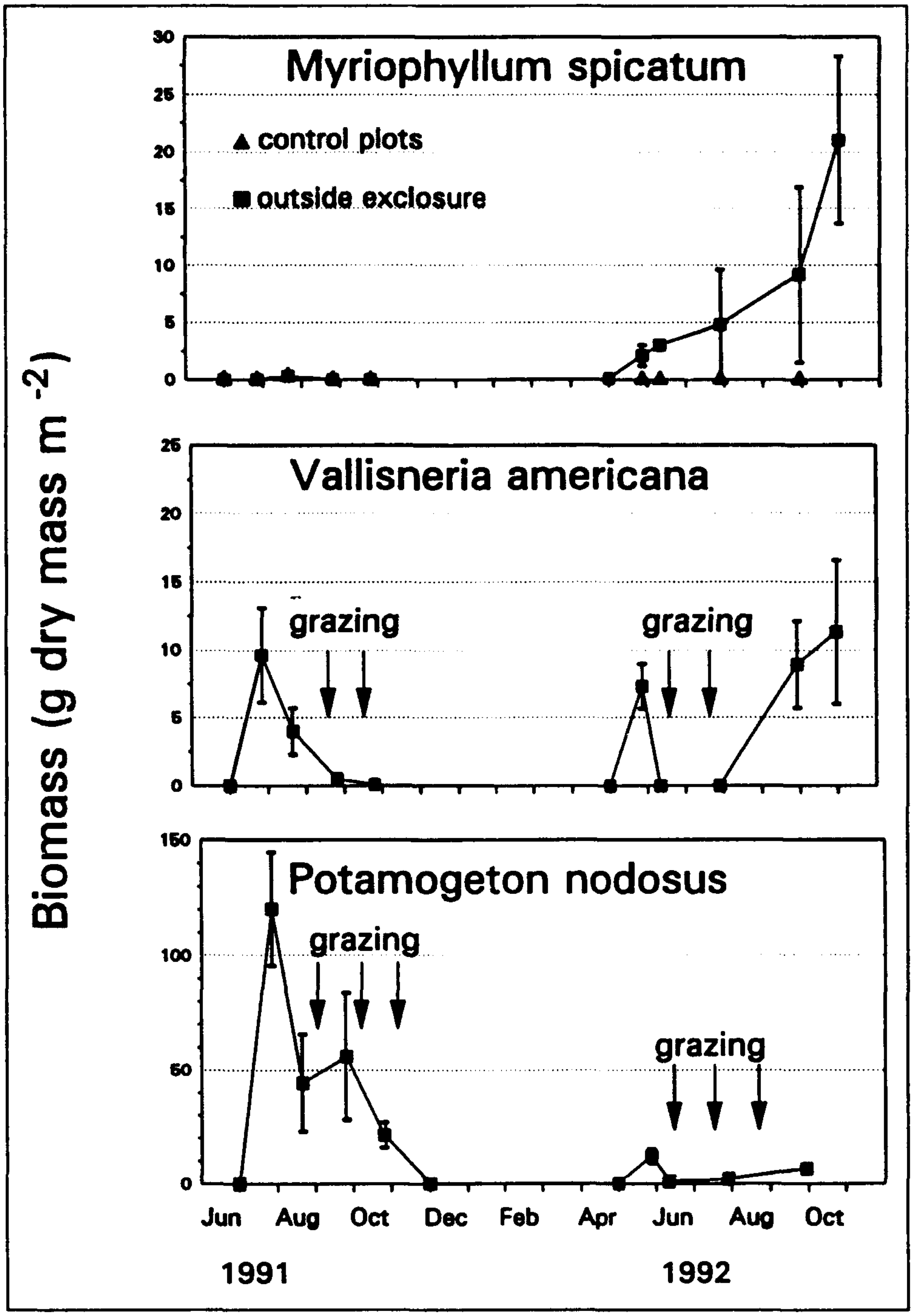

Figure 5. Average biomass (g dry mass·m^{-2}) of plants at Chisenhall embayment: (TOP) *Myriophyllum spicatum* within control plots (triangles) and outside exclosure (squares): (MIDDLE) *Vallisneria americana* within *Vallisneria* plots: (BOTTOM) *Potamogeton nodosus* within *Potamogeton* plots (note scale change)

transplants began to grow, but were virtually decimated by the same grazing that depleted the *Potamogeton* populations (July 1991, Figure 5). By the end of 1991 there was only a very small amount of *Vallisneria* remaining in the plots. On 6 May 1992, the *Vallisneria* plots were replanted with dormant winterbuds purchased from a commercial collector in Wisconsin (Wildlife Nurseries, Inc., Oshkosh, WI). Visual observations by divers in early June 1992 confirmed that these plants began to grow well. However, the plants were soon destroyed by herbivores, and in the July 1992 harvest there was no *Vallisneria* biomass in any of the plots.

In early August 1992, we replanted the *Vallisneria* plots with transplants from the Lewisville Aquatic Ecosystem Research Facility (LAERF) in Lewisville, TX. Previous work at LAERF had shown that transplants of *Vallisneria* utilizing peat pots were easier to establish under field conditions than bare-rooted transplants (Appendix C). The plants were shipped to Guntersville in peat pots and planted within 2 days of arrival. At that time we also decided to fence each of the individual plots with wire poultry netting. We again observed good growth from these plots and by October 1992, *Vallisneria* in several plots was near the surface and growing vigorously. Each plant was sending out numerous stolons and forming daughter plants. Visual observations confirm that the *Vallisneria* plots were still doing well in January 1993. However, substantial protection was needed to achieve this result: (a) large exclosure fencing, (b) turtle and muskrat traps within the exclosure, and (c) poultry wire surrounding individual 1.5- by 1.5-m *Vallisneria* plots.

Although perhaps accentuated by the recent introduction of large numbers of grass carp, the herbivore problems encountered in establishing populations of native submersed macrophytes in Guntersville Reservoir are not unique. Virtually all reports of reestablishment efforts indicate varying degrees of interference by herbivores or omnivores. For example, Kollar (1988) reports that after several years of work and transplanting over 200,000 specimens of native submersed plants (mostly *Vallisneria*) into the Susquehanna Flats area of the Chesapeake Bay, the only successes were in areas where partial protection from herbivores was offered by either submersed rock breakwaters or established *Myriophyllum* populations. Carter and Rybicki (1985) also attempted to establish *Vallisneria* into the upper Chesapeake Bay (tidal Potomac area) and report that only populations protected by herbivore exclosures survived the first two years. The most commonly reported interference in establishing new colonies of submersed macrophytes is disturbance by carp, which uproot and damage plants as they roil in the sediments. Commonly, establishment success is higher in plots enclosed by wire fencing.

Lathrop et al. (1991), however, reported poor establishment success of *Potamogeton* in Lake Mendota in both control and enclosed plots. Because carp apparently were successfully excluded from the enclosed plots, the lack of survival was attributed to wave disturbance. Although our plots were likewise enclosed (primarily as a deterrent to grass carp feeding), we attribute our results to herbivores other than grass carp, which were effectively excluded from our plots. Other herbivores in Guntersville include turtles, waterfowl, muskrats, and perhaps crayfish. Lathrop et al. (1991) did not record the presence of other herbivores.

The ecological and wildlife benefits of establishing viable populations of native aquatic plants are many. However, achieving this objective in Chisenhall embayment will be very difficult. The unexplained demise of the *Myriophyllum* population within the embayment resulted in increased turbidity in the water column due to both increased wind mixing and destabilized sediments. Increased herbivore pressure on plants within our experimental plots due to the lack of alternative food sources may also have been a factor.

Recommendations for Future Research

If we are successful in establishing these populations of native plants, we will be in a position to test two important questions facing reservoir managers: (1) Is it possible to establish pockets of native, desirable plant species within "open" habitats? (2) If so, will these pockets of desirable plants spread throughout the habitat quickly enough to occupy the niche and preempt the resources?

We plan to continue our efforts to establish desirable native plants within the Chisenhall embayment. Our focus will be threefold: first, to document the level of effort necessary to establish *Vallisneria* and *Potamogeton* in habitats subject to high herbivore pressure; second, to monitor the spread of these populations to adjacent "open" habitats; and finally, to monitor the persistence of this population in the event that *Myriophyllum* recolonizes to the embayment.

3 Establishment of Native Aquatic Macrophytes in *Lyngbya*-Dominated Littoral Environments

Experimental Objective and Design

The objective of this study was to investigate the ability of emergent and floating-leaved, native aquatic macrophytes to ameliorate the undesirable consequences of *Lyngbya* infestations. *Lyngbya* infestations affect the economic, recreational, and aesthetic values of Guntersville Reservoir by forming extensive, foul-smelling, floating mats which impede recreational uses such as swimming and fishing. In addition, these mats are a continual nuisance to lakefront property owners due to the pernicious smell of the decomposing mats and navigational impediments around boat docks.

Our long-term goal is to establish desirable species of rooted macrophytes in *Lyngbya*-infested areas to compete for sunlight and sediment nutrients. By reducing levels of both, we hope to reduce the magnitude of *Lyngbya* problems in shallow regions of Guntersville Reservoir (Figure 6).

This research consists of two phases. Phase I was conducted in 1991 and 1992 with the objective of testing numerous native aquatic plant species for suitability for growth in *Lyngbya*-infested areas of the reservoir. Small plots of desirable species were established in both *Lyngbya*-infested and open (non-infested) areas of the reservoir. The survival and development of the plants within the plots were then monitored over one or two growth seasons. The results of Phase I are the subject of the current report. Phase II was initiated in 1992 and seeks to evaluate the competition for light and nutrients between *Lyngbya* and the macrophyte species successfully established within *Lyngbya* infestations. This second phase of research will continue through 1994 and will be included in the final report.

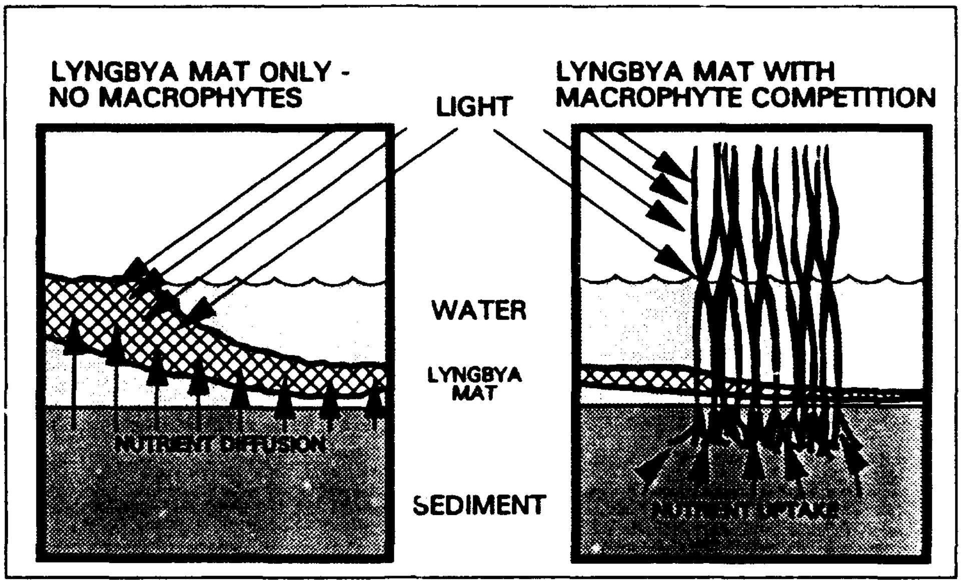

Figure 6. Conceptual premise of macrophyte-*Lyngbya* competition. In the absence of macrophytes, the *Lyngbya* mat receives abundant light and nutrients, but when present the macrophytes reduce available light and take up nutrients from the sediment before they can diffuse out and become available to the *Lyngbya* mat

Methods

Two *Lyngbya*-dominated sites (Waterfront and Ossa-Win-Tha) and one control site (Boshart Creek) were selected for this research (Figure 2). The Boshart Creek site was free of *Lyngbya* growth and had no known history of *Lyngbya* infestations at the time the sites were selected. Waterfront was the site most heavily infested with *Lyngbya.* Dr. Larry Dyck of Clemson University, who has been studying *Lyngbya* in Guntersville Reservoir for the past 2 years, describes this site as a **permanent** *Lyngbya* site where the mats actively grow and develop *in situ*, and the biomass accumulates from year to year. The Ossa-Win-Tha site had an intermediate level of *Lyngbya* infestation and is described by Dr. Dyck as a **transient** *Lyngbya* site. A transient site is one where the mats are formed primarily by clumps of *Lyngbya* floating in from other portions of the reservoir rather than *in situ* growth.

At each site a single 10- by 20-m exclosure was erected to exclude grass carp and other herbivores. The sides of the exclosures were made of 5-cm mesh galvanized fencing. The fencing was secured with iron posts and extended from 15 cm below the sediment to 30 cm above the water surface. In addition to the fencing, fall-in turtle traps were deployed within each exclosure to remove herbivorous turtles which were occasionally observed inside the exclosures. The turtles entered the exclosure either by climbing the fencing (turtles hanging from the fencing were observed numerous times during the study) or burrowing beneath the fencing.

Water depths within the exclosures at each site were similar, with average depths over the growing season (May-September) ranging from 0.51 to 0.67 m at Ossa-Win-Tha, 0.51 to 0.72 m at Waterfront, and 0.51 to 0.74 m at Boshart Creek along the elevational gradients. Due to the fluctuating water levels that resulted from the reservoir operation, minimum and maximum water levels over the same period were 34 cm lower and 28 cm higher than the averages. Within each exclosure we established fourteen 1.2- by 2.4-m experimental plots delineated by frames constructed of PVC pipe (Figure 7). Each plot was divided into thirty-two 30- by 30-cm or eight 60- by 60-cm planting cells by stringing nylon cord across the plot frames. The frames were then anchored to the sediments.

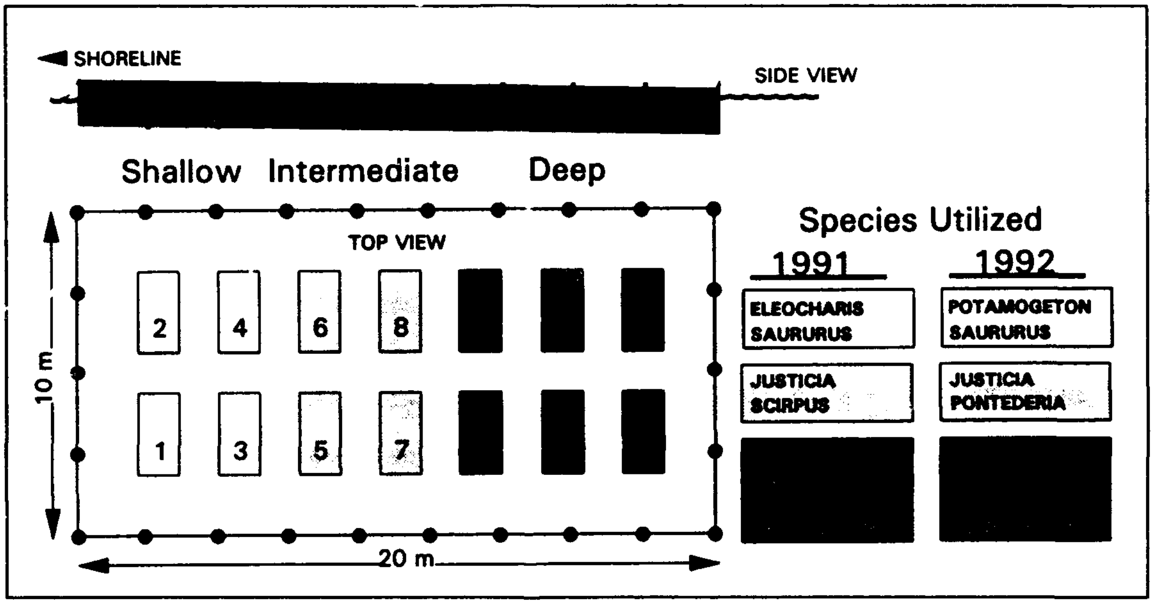

Figure 7. Layout of 1.2- by 2.4-m plots within the larger exclosure. Species planted in the shallow, intermediate, and deep blocks are shown for both 1991 and 1992

Five emergent and two floating-leaved species were selected based on their desirability for creating habitat, ease of control or lack of problem-causing potential, expected ability to grow in *Lyngbya*-dominated areas, and occurrence within the Guntersville Reservoir region. The species (all native to the United States) included *Eleocharis quadrangulata* Michx. (spikerush), *Saururus cernuus* L. (lizard's tail), *Scirpus validus* Vahl. (softstem bulrush), *Justicia americana* (L.) Vahl (American waterwillow), *Pontederia cordata* L. (pickerelweed), *Nelumbo lutea* (Willd.) Pers. (American lotus), and *Potamogeton nodosus* Poiret (American pondweed).

The experimental treatment for both 1991 and 1992 included replicated plots of each plant species as well as two control (unplanted) plots within the exclosures at each of the three sites. Six species were selected and planted in 1991 and five in 1992. The species were planted in different blocks along a depth gradient (Table 1) based on the observed depths of natural populations within the reservoir.

Table 1
Average Water Depth During Growing Season and Planting Schedule for Each of the Native Plants Utilized

Average Plot Depth	Genus	Years Planted	Cell Size (cm)	Type of Propagule	# per Cell
Shallow (51 cm)	*Saururus*	91 & 92	30 X 30	Transplant	1
	Eleocharis	91	30 X 30	Transplant	1
	Potamogeton	92	30 X 30	Winterbud	3
Intermediate (58 cm)	*Justicia*	91 & 92	30 X 30	Transplant	1
	Scirpus	91	30 X 30	Transplant	1
	Pontederia	92	30 X 30	Rhizome	1
Deep (71 cm)	*Potamogeton*	91 & 92	30 X 30	Winterbud	3
	Nelumbo	91 & 92	60 X 60	Seed	3-5
	control	91 & 92	30 X 30		

In 1991 the plots were first planted 26 and 27 June. Transplant stocks of each species except *Potamogeton* had been obtained a few days earlier from locations within Guntersville Reservoir (Table 2). Dormant *Potamogeton* winterbuds were collected from Cedar Creek Reservoir in northwestern Alabama in March 1991, and stored moist in a refrigerator at 7 °C prior to planting. In 1992 only five species of plants were utilized, again with propagules obtained from local or regional sources (Table 2). Plantings were made earlier in 1992 than in 1991 in the hopes of reducing transplant shock by using less mature plants. The plots were replanted in 1992 as summarized in Table 3.

In 1992, in addition to replanting the existing plots within the exclosures, 14 unprotected plots were also established to evaluate the need for herbivore protection. These plots were outside but adjacent to the exclosure at the Ossa-Win-Tha site, duplicating the plantings made inside the exclosure. These plots were identical to the others except that they were not protected by a fenced exclosure.

After planting, the growth and development of the plants was evaluated every two weeks during the remainder of the growing season by visual inspection from the surface. Parameters recorded included apparent percent survival ((# plants visible/# planted plots)*100 percent) and percent surface cover (percent of 1.2- by 2.4-m plot covered by the planted species) of the planted species. The survival of the transplants is referred to as **apparent** survival because only plants actually visible from the surface were recorded. Other living plants may have been in the plots but were not visible from the surface due to turbidity or *Lyngbya* coverage.

Table 2
Type of Propagule Used Each Year for Each Species of Native Plant

Genus	Year	Propagule Type and Collection Methods
Eleocharis	1991	Transplants were collected from the Mud Creek embayment in Guntersville Reservoir. Small plants with intact roots and associated sediment were collected and replanted within 6 hr of collection.
	1992	Discontinued from experimental design for 1992.
Scirpus	1991	Rhizomes of actively growing plants were collected from within Guntersville Reservoir. Special care was taken to ensure that each rhizome section had an undamaged terminal bud. Existing stems were trimmed to 30 cm.
	1992	Discontinued from experimental design for 1992.
Saururus	1991	Actively growing plants were collected from a roadside wetland in Guntersville Reservoir and trimmed to about 15 cm in height. Care was taken to ensure well-developed roots were present on each plant propagule. Transplants were made within 2 days of collection during which period the plants were kept moist and shaded.
	1992	Rhizomes just breaking dormancy were collected from the same site as the 1991 propagules. Transplants were made within 6 hr of collection.
Justicia	1991	Actively growing plants were collected from the shoreline of Guntersville Reservoir. Growing tips were not trimmed.
	1992	Growing plants were collected in the fall of 1991 and overwintered in pots placed in shallow water of a pond at GRARF. The plants were just beginning to grow at the time of transplant.
Nelumbo	1991	Initial plantings were made from transplants of actively growing plants from within Guntersville Reservoir. A section of the plants rhizome was collected for transplant. Care was taken to ensure that each propagule had at least one undamaged leaf and an undamaged terminal bud. Replanting later in the year was made with seeds scarified by soaking in concentrated sulfuric acid for 4 hr.
Nelumbo	1992	All *Nelumbo* plots were replanted with acid-scarified seed even though some plants had apparently successfully overwintered at both Ossa-Win-Tha and the control site.

(*Continued*)

Table 2 (Concluded)

Genus	Year	Propagule Type and Collection Methods
Potamogeton	1991	Winterbuds were collected from the dewatered shoreline of Cedar Creek Reservoir in March 1991. Winterbuds were kept refrigerated at 7 °C until planted.
	1992	None of the plots planted with *Potamogeton* in 1991 required replanting in 1992 since all had good plant establishment and formation of winterbuds. However, a second pair of plots was established to replace the discontinued *Eleocharis* plots. These were planted in March 1992 with winterbuds collected in February 1992 from Cedar Creek Reservoir.
Pontederia	1991	This species was not planted in 1991.
	1992	In 1992 *Pontederia* was planted in the plots used for *Scirpus* in 1991. Dormant rhizomes were collected from Reelfoot Reservoir, TN in the fall of 1991. The rhizomes were kept outdoors, buried in sand at the GRARF. The plants were still dormant at the time of transplanting to the field (March 1992).

Table 3
1992 Planting Summary

1991 Plot	Actions Taken in 1992
Eleocharis	Discontinued from experimental design. Plots replanted with *Potamogeton* winterbuds
Scirpus	Discontinued from experimental design. Plots replanted with *Pontederia* rhizomes
Saururus	Empty cells replanted with sprouting rhizomes
Justicia	Empty cells replanted with transplants
Nelumbo	All cells replanted with acid-scarified seeds
Potamogeton	These *Potamogeton* plots at the deeper end of the exclosure were not replanted because of excellent survival and winterbud formation

Results and Discussion

Evaluation of herbivore exclosures

All plants within all of the unprotected plots at Ossa-Win-Tha which were planted in March 1992 were consumed before May 1992. The plots did not seem to be disturbed by humans, and there was visual confirmation that the plants had begun to grow. This result reinforces the findings of numerous other researchers that herbivore exclosures are essential for establishing small plots of plants (Kollar 1986, 1988; Carter and Rybicki 1985).

Planting success

***Eleocharis* and *Scirpus*.** The transplant success for these two species was very good at the Boshart Creek control site (Figures 8 and 9), indicating that the transplant methodology was acceptable. The apparent survival of these species was high (80 to 100 percent), and the surface cover increased throughout the year indicating continued growth. The results were quite different at the *Lyngbya*-dominated sites. The apparent survival of *Eleocharis* and *Scirpus* at the end of the growing season was less than 10 percent at both *Lyngbya* sites, and the surface cover was also very low. The survival of these transplants at the *Lyngbya* sites was in doubt from the very beginning. Shortly after planting, the *Lyngbya* mats floated up to the water surface, and there was an immediate, precipitous decline in numbers of surviving plants of both species (Figures 8 and 9). We observed that the rigid, emergent stems of these species were being broken by the frequent horizontal and vertical movement of the surface mat of *Lyngbya* that was present at both sites. The horizontal movement was caused by the wind blowing the floating mats around within the exclosure. However, the movement of the floating mat relative to the macrophytes caused by changing lake levels (Figure 10) seemed particularly damaging. The floating mats would float up and in (landward) with rising water levels, and down and out (lakeward) as the water levels dropped. During such cycles, the heavy *Lyngbya* mat would bend and crush the hollow, rigid, and brittle stems of the *Eleocharis* and *Scirpus* plants.

Based on the results of the 1991 field season, *Eleocharis* and *Scirpus* were eliminated from further consideration for establishment in the *Lyngbya*-infested areas. The plots of these species were examined in early March 1992, and all overwintering root crowns (if any) were removed from the plots. To replace these species we added a pair of plots of *Potamogeton* in the shallower end of the exclosures to further test the utility of this apparently successful species under two different water depths. *Potamogeton* winterbuds were planted in the former *Eleocharis* plots. *Pontederia cordata* was selected to replace *Scirpus* because of its ability to grow in highly organic muck sediments and because the strong emergent stems and leaves would probably be able to withstand the movements of the *Lyngbya* mats.

***Justicia* and *Saururus*.** The apparent survival and surface coverage of *Saururus* and *Justicia* were much better than those of *Eleocharis* and *Scirpus*, but were lower at the *Lyngbya* sites than at the control site. While both of these species were subject to the same movement of the floating *Lyngbya* mat which decimated the *Scirpus* and *Eleocharis* plots, the more solid, flexible stems characteristic of these plants were apparently better suited to withstand that movement.

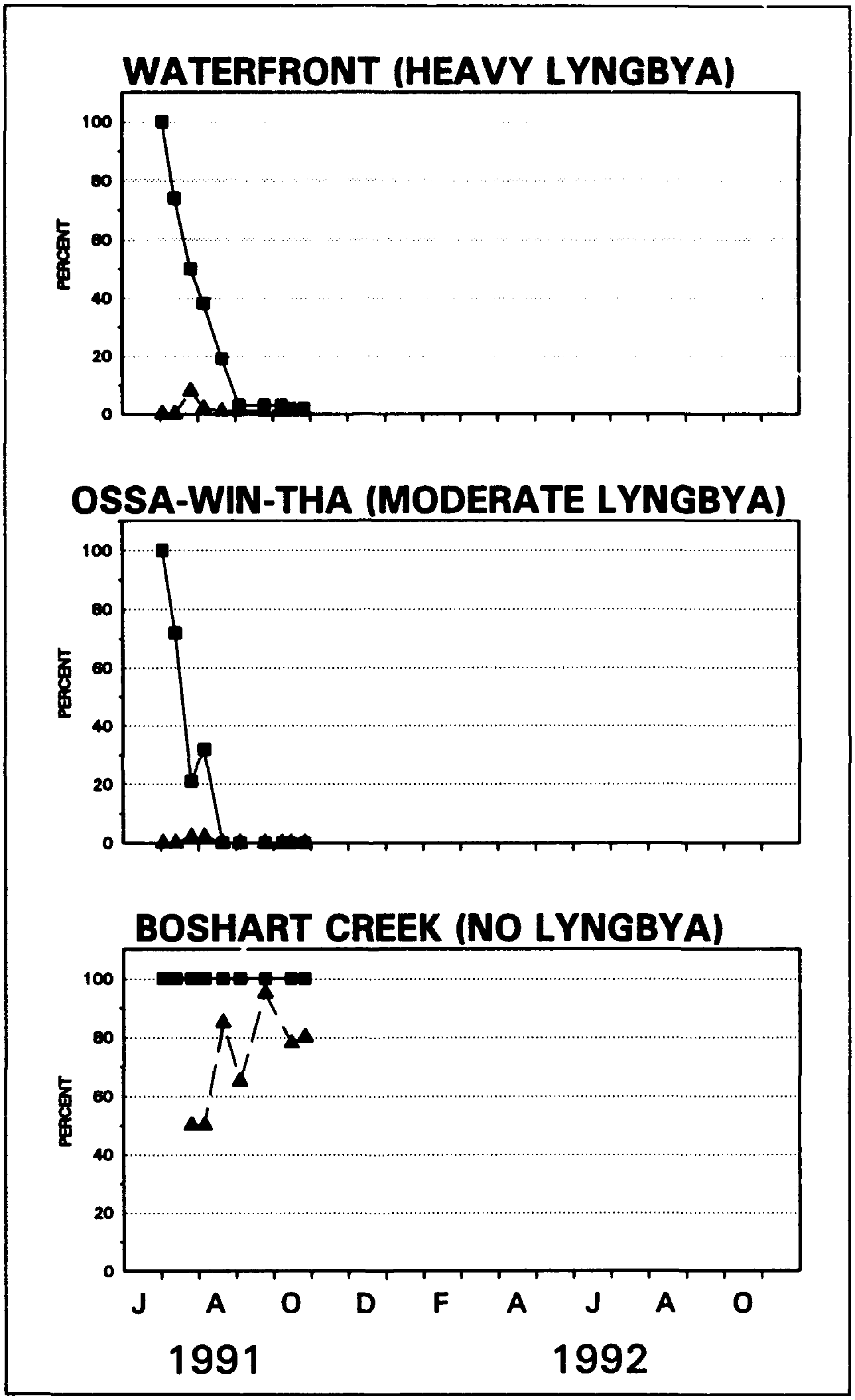

Figure 8. Percent apparent survival (squares) and percent surface coverage within plots (triangles) of *Eleocharis quadrangulata* at the control site (Boshart Creek) and the two *Lyngbya* sites

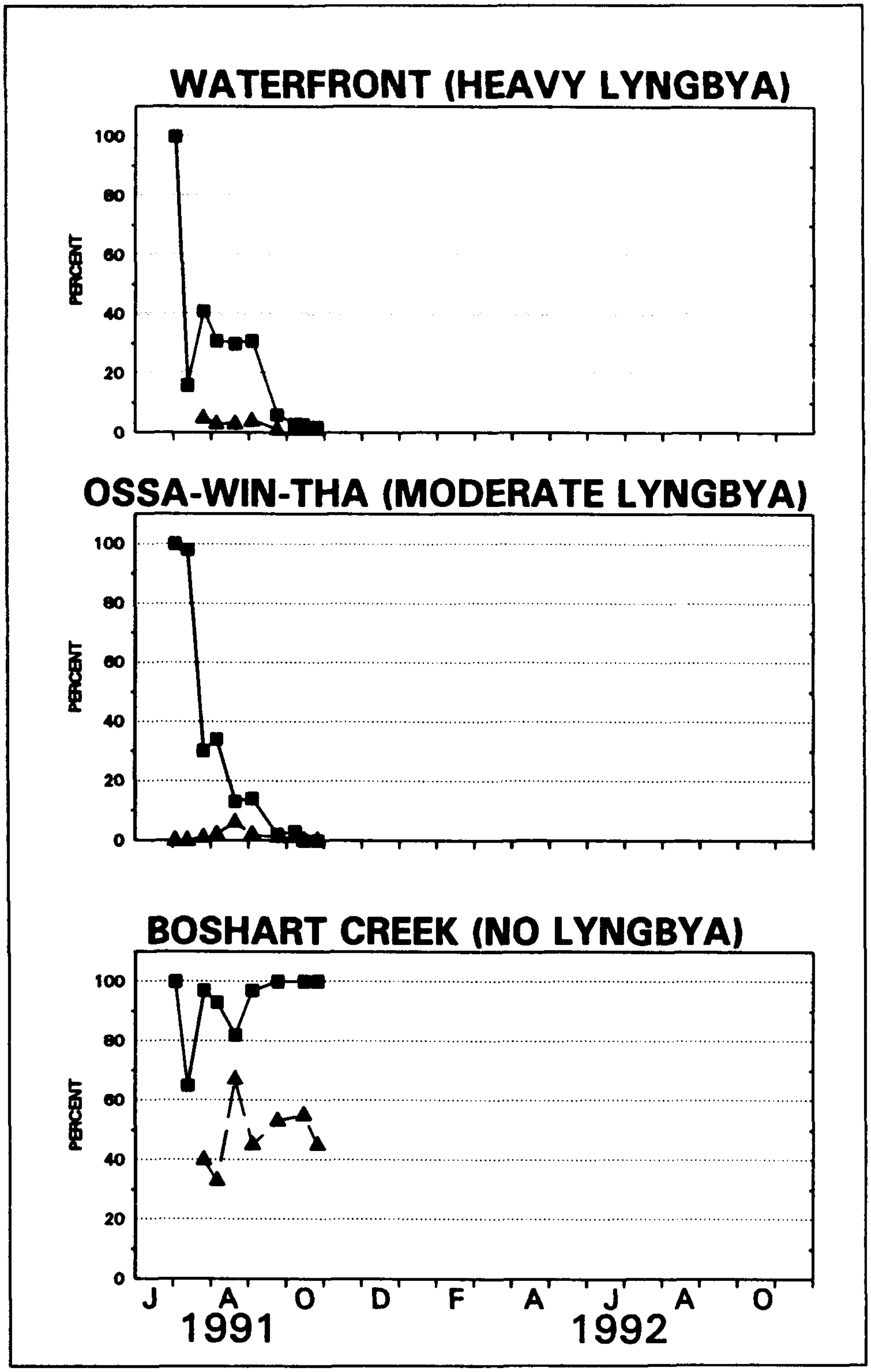

Figure 9. Percent apparent survival (squares) and percent surface coverage within plots (triangles) of *Scirpus validus* at the control site (Boshart Creek) and the two *Lyngbya* sites

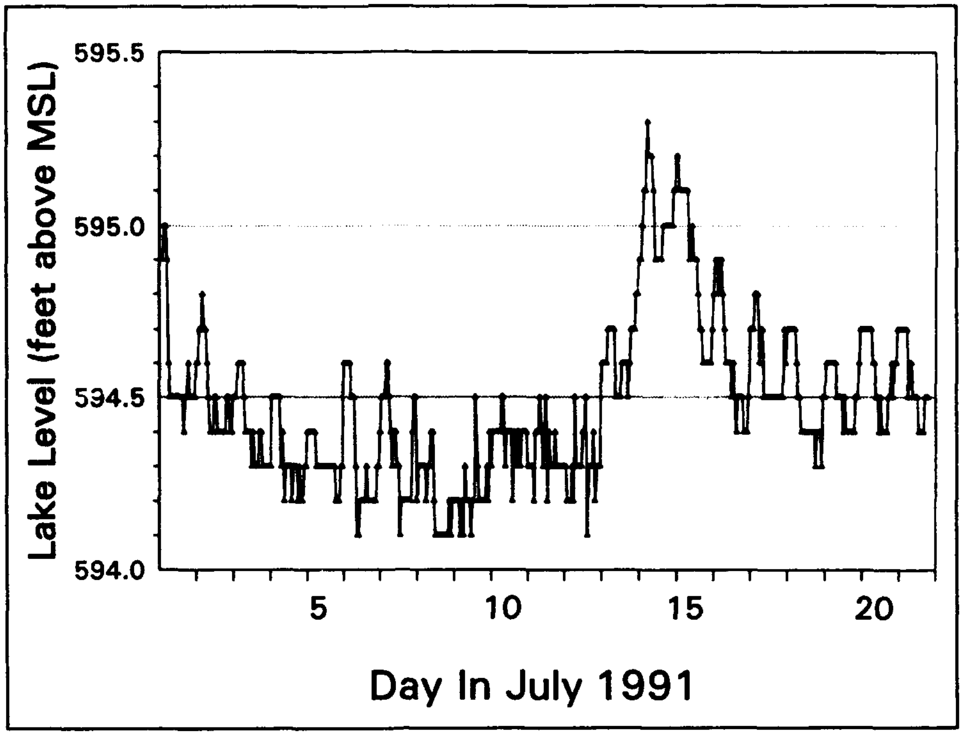

Figure 10. Water level fluctuations over the first 21 days of July 1991 (data collected at 1-hr intervals)

The apparent survival of *Justicia* at Boshart Creek (control site) was excellent in both 1991 and 1992 (75 to 100 percent, Figure 11). While the surface cover at the control site rarely exceeded 50 percent, this was primarily due to the open, less dense growth characteristic of this species and not to poor health of the transplants. The results at the two *Lyngbya* sites were variable. At the Ossa-Win-Tha site the apparent survival and surface cover of this species was comparable to that at the control site with 60 to 80 percent apparent survival and 10 to 40 percent surface cover. However, at Waterfront the apparent survival and percent surface cover were very low in both 1991 and 1992. In both years at this site the apparent survival was less than 20 percent by mid summer and remained low throughout the remainder of the growing season. The reason for the poorer survival of *Justicia* at Waterfront is unclear, although that site had a much higher level of *Lyngbya* infestation and was also more heavily impacted during the year by herbivorous turtles.

In 1991 *Saururus* survival was about 50 percent at both *Lyngbya* sites compared to more than 90 percent at the control site; surface cover at the *Lyngbya* sites never exceeded 25 percent, but was as high as 50 percent at the control site (Figure 12). In 1992 *Saururus* had poorer survival at all sites than in 1991. At the control site, the apparent survival was only 25 to 40 percent during most of the season. Apparent survival was even lower at the *Lyngbya* sites, although at least a few plants survived until the end of the growing season.

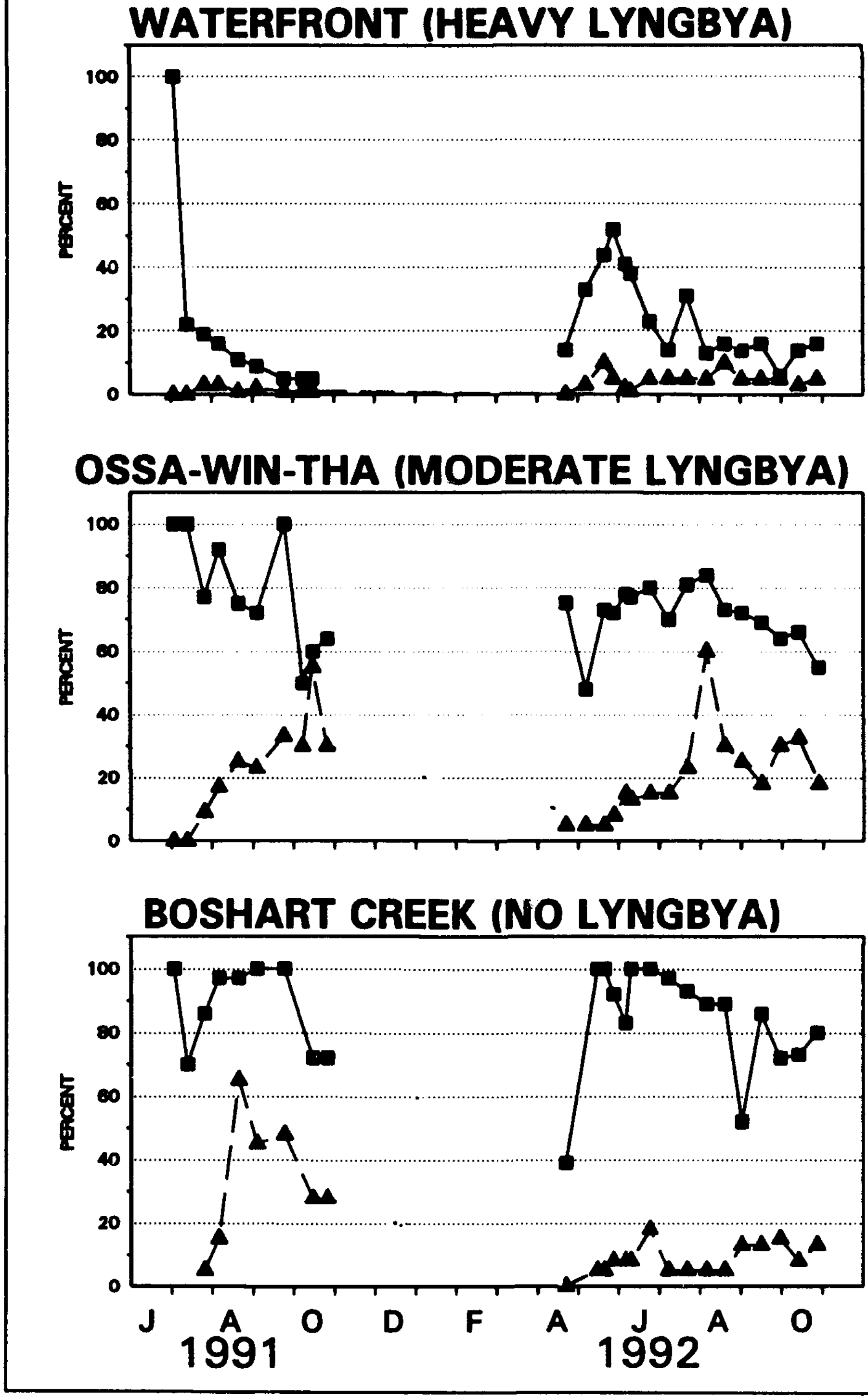

Figure 11. Percent apparent survival (squares) and percent surface coverage within plots (triangles) of *Justicia americana* at the control site (Boshart Creek) and the two *Lyngbya* sites

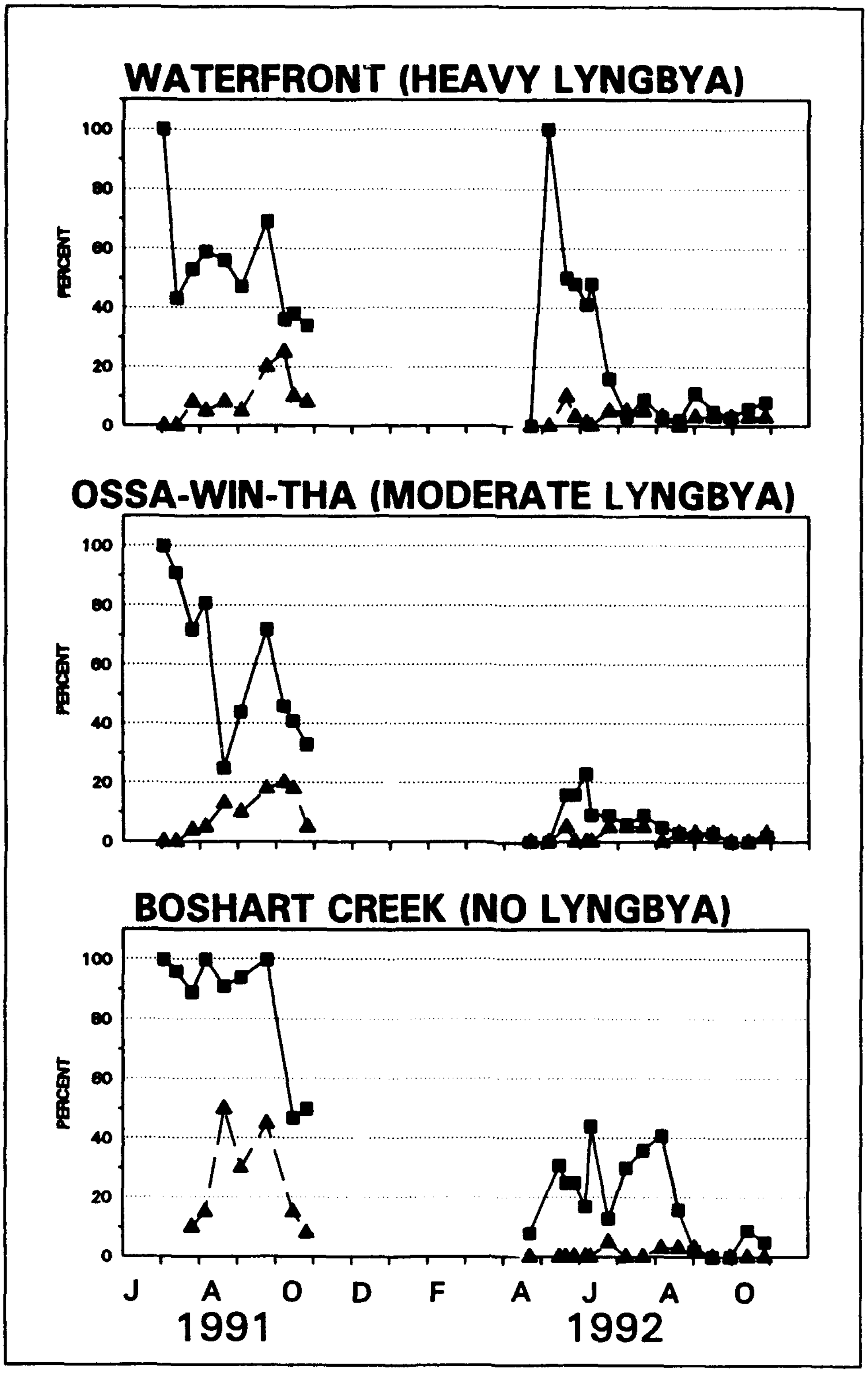

Figure 12. Percent apparent survival (squares) and percent surface coverage within plots (triangles) of *Saururus cernuus* at the control site (Boshart Creek) and the two *Lyngbya* sites

***Nelumbo*, *Potamogeton*, and *Pontederia*.** These three species showed good to excellent survival at the control and *Lyngbya* sites and are considered good candidates for long-term competition with the *Lyngbya* mats.

The first *Nelumbo* transplants of 1991 died quickly at all sites despite great care during collection and planting not to damage the growing terminal bud on the rhizome. These plots were replanted in July 1991 with seed collected in 1981 from Guntersville Reservoir by Leon Bates (TVA). The seeds had been stored in open containers at about 25 °C. Prior to planting, the seeds were scarified by soaking them in concentrated sulfuric acid for 4 to 6 hr. Once planted, these seeds promptly germinated and began to grow.

At the Boshart Creek control site, *Nelumbo* was established quite easily. Despite the initial problems with the rhizome transplants, a small, but apparently healthy, stand of *Nelumbo* was established from seed at the control site by the end of 1991 (Figure 13). In 1992 the growth of *Nelumbo* at the Boshart Creek site was particularly impressive with 100 percent apparent survival and high surface coverage within the planted plots. By the end of the 1992 season *Nelumbo* had not only covered much of the exclosure at Boshart Creek, but had spread outside the exclosure to cover an area roughly 25 by 25 m.

Nelumbo apparent survival and growth at the *Lyngbya* sites were lower than at the control site. The initial rhizome transplants at the *Lyngbya* sites died, just as seen at the control site. The sites were likewise replanted with acid-scarified seed in July 1991. While the seeds quickly germinated at all sites, the seedlings became established at the control site and at Ossa-Win-Tha, but not at Waterfront (Figure 13). In 1991 we observed numerous seedlings floating at the surface within the *Lyngbya* mat at the Waterfront site shortly after seed germination. We hypothesize that the young seedlings were uprooted from much of the sediment by the thick benthic *Lyngbya* mat which floated to the surface shortly after the seeds germinated but before the seedlings could establish roots in the sediments. In 1992 *Nelumbo* again had excellent survival at the Ossa-Win-Tha site. As at the control site, *Nelumbo* covered much of the exclosure and was beginning to grow beyond it. At Waterfront, however, *Nelumbo* was completely destroyed by herbivore damage early in the 1992 season (May, Figure 13). This site was replanted from seeds in June, but the seedlings were again consumed by herbivores. Consequently, we were not able to establish *Nelumbo* at the Waterfront site in 1992.

The only species to grow as well at the *Lyngbya* sites as at the control sites in 1991 was *Potamogeton*. The development of the *Potamogeton* was somewhat slower at the *Lyngbya* sites relative to the control site, but by the end of the growing season *Potamogeton* exhibited 100 percent apparent survival and had achieved near 90 percent surface cover at all sites (Figure 14). The long flexible stems and floating leaves of this plant were not damaged by the motion of the *Lyngbya* mat.

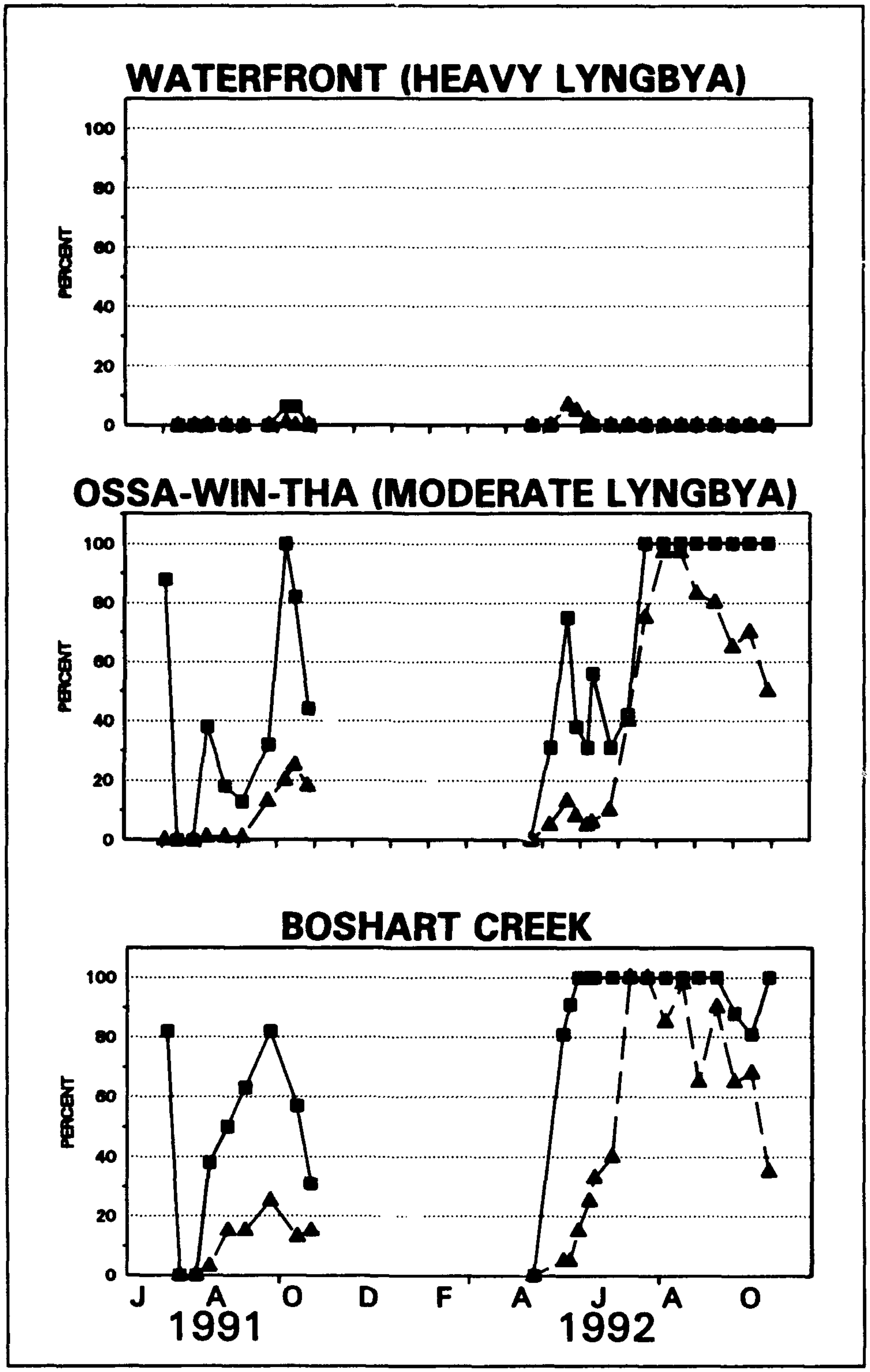

Figure 13. Percent apparent survival (squares) and percent surface coverage within plots (triangles) of *Nelumbo lutea* at the control site (Boshart Creek) and the two *Lyngbya* sites

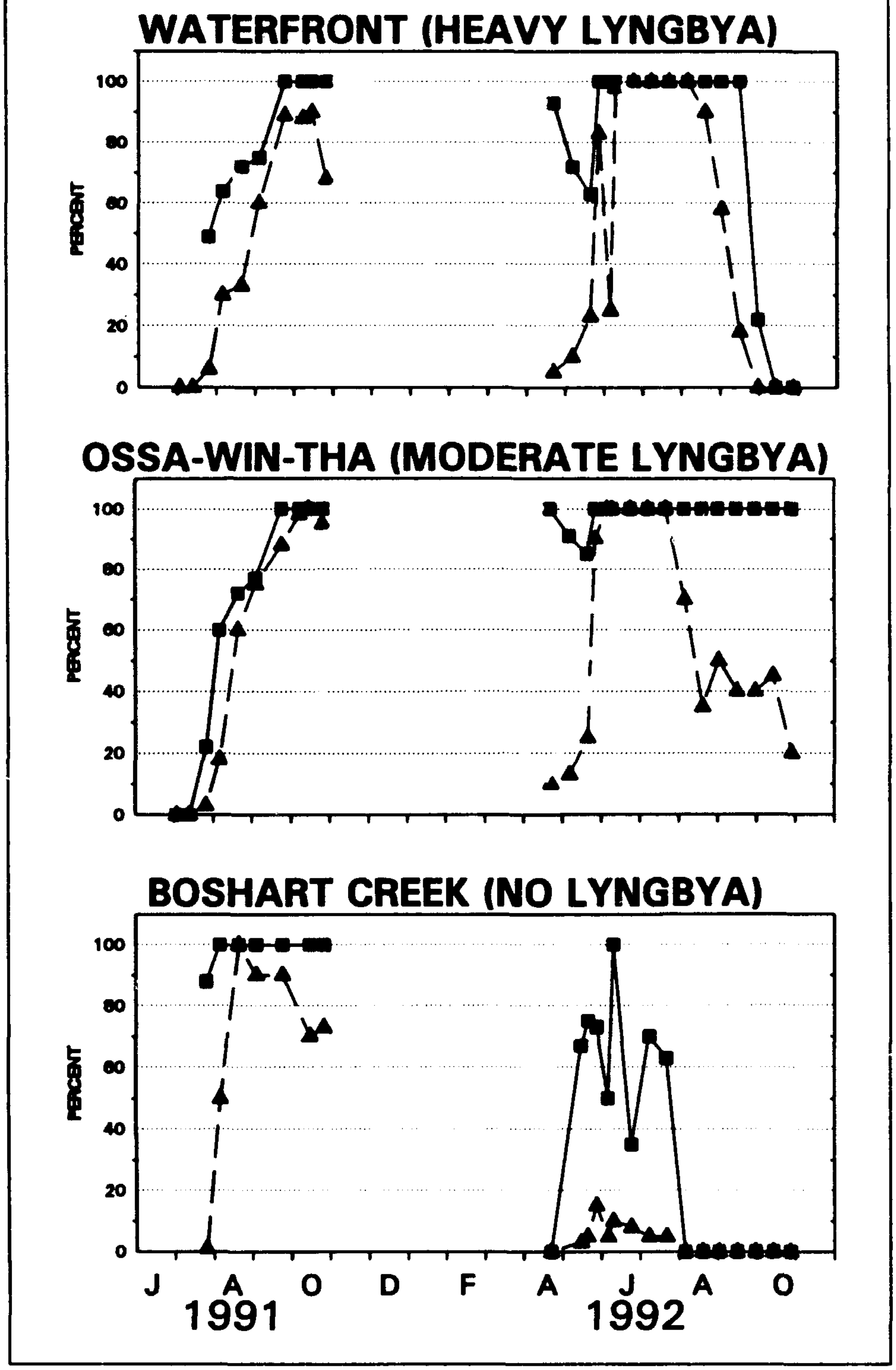

Figure 14. Percent apparent survival (squares) and percent surface coverage within plots (triangles) of *Potamogeton nodosus* planted in the deep plots at the control site (Boshart Creek) and the two *Lyngbya* sites

As in 1991, *Potamogeton* showed excellent survival at all sites in 1992. This was true of both the deeper plots which regrew from tubers produced *in situ* in the fall of 1991 (Figure 14), and of the new shallow plots established in 1992 (Figure 15). However, cover of this species within the planted plots reflected heavy herbivore pressure at all sites throughout the season. The influence of herbivores was particularly apparent at the Boshart Creek control site in 1992 where, unlike 1991, the surface cover never exceeded 30 percent (Figures 14 and 15), and evidence of turtle, duck, and insect damage was apparent throughout the growing season.

Pontederia grew extremely well at the two *Lyngbya* sites and grew better there than at the control site. While all three sites had near 100 percent survival, the surface cover and apparent vigor of the plants was higher at the *Lyngbya* sites (Figure 16). The apparent preference of this species for the *Lyngbya* sites is probably due to the sediment characteristics of the sites. The control site is mostly sand, while the *Lyngbya* sites have a 6- to 10-in. layer of highly organic "sediment" overlying the sand beneath. The October declines at the Ossa-Win-Tha and Boshart sites were due to normal winter dieback. However, the earlier crash of the *Pontederia* population at the Waterfront site was due to major disturbance by muskrats.

General Conclusions

Four of the seven species investigated were found to be unsuitable for establishment within the *Lyngbya*-infested areas of Guntersville Reservoir. *Eleocharis* and *Scirpus* were unable to survive even one growing season within the *Lyngbya*-dominated areas. The rigid, brittle shoots of these species apparently could not tolerate the movement of the *Lyngbya* mats. *Justicia* and *Saururus* were able to survive at the *Lyngbya* sites, but the apparent survival and percent cover at these sites was much lower than at the control site. These plants were always small and chlorotic at the *Lyngbya* sites, and the long-term survival of plants was in doubt. *Justicia* and *Saururus*, like *Eleocharis* and *Scirpus*, will not be used in the final phase of this research where we try to increase the plot size of plants within the *Lyngbya* areas and begin to investigate competitive interactions between the macrophytes and the *Lyngbya* mats.

Three plant species showed promise for long-term establishment and competition with the *Lyngbya* mats. *Potamogeton* and *Pontederia* were both relatively easily established at both *Lyngbya* sites and were successful in minimizing the occurrence of surface *Lyngbya* mats within the planted plots. *Nelumbo*, while never successfully established at the Waterfront site due to herbivory, grew very well at the Ossa-Win-Tha site. Since the failure of this species was apparently related to herbivory, and not an intrinsic inability to grow in the *Lyngbya* mats, it will be used in the final phase of this study.

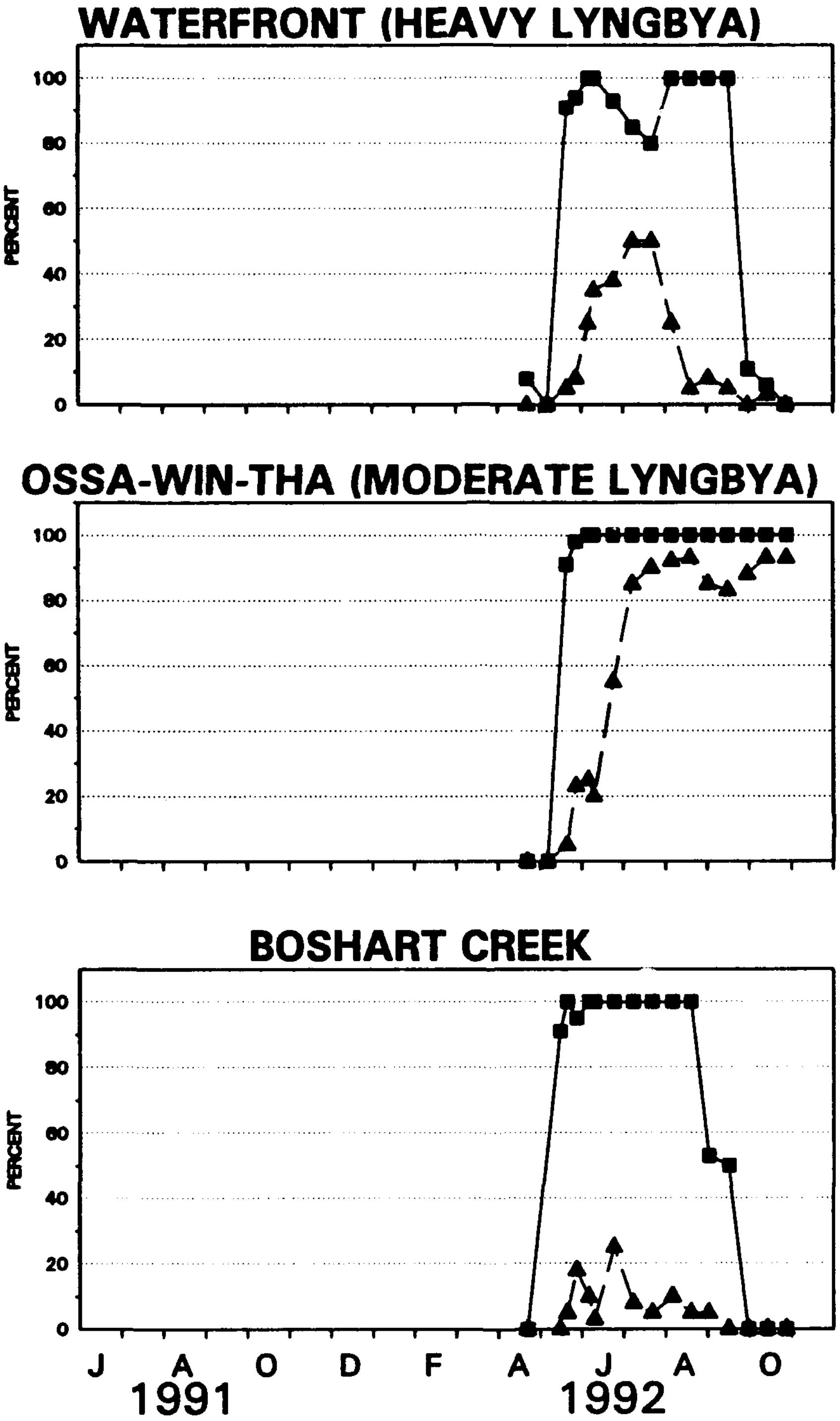

Figure 15. Percent apparent survival (squares) and percent surface coverage within plots (triangles) of *Potamogeton nodosus* planted in the shallow plots at the control site (Boshart Creek) and the two *Lyngbya* sites

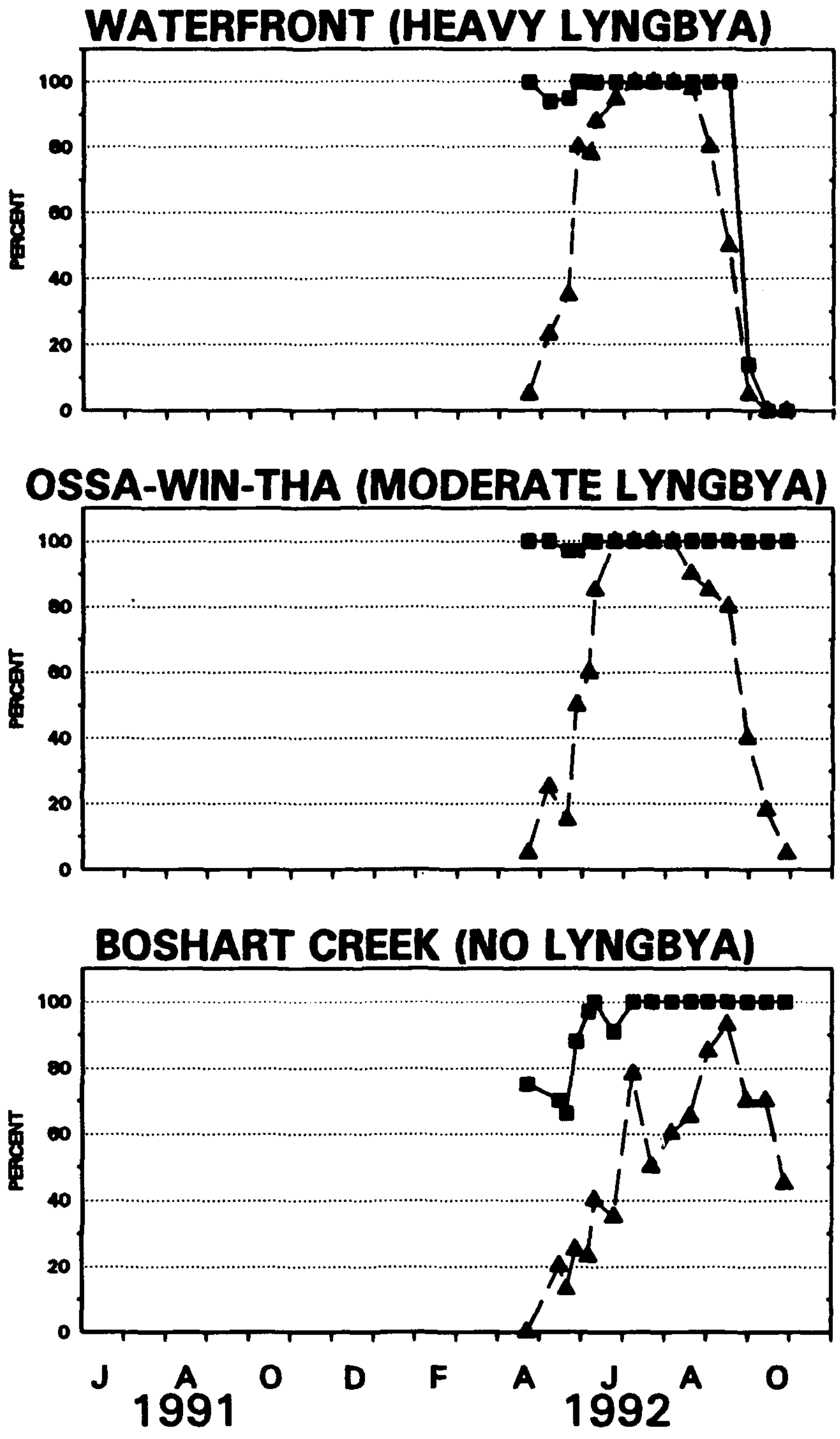

Figure 16. Percent apparent survival (squares) and percent surface coverage within plots (triangles) of *Pontederia cordata* at the control site (Boshart Creek) and the two *Lyngbya* sites

Recommendations for Future Research

During 1993 and 1994 the focus of this research will shift to understanding the dynamics of competition between *Lyngbya* and the native macrophytes for light and sediment nutrients. This will require establishment of larger (ca. 10 by 10 m) plots of *Potamogeton, Pontederia,* and *Nelumbo* at the *Lyngbya* sites. At Waterfront, the most heavily infested *Lyngbya* site, another 10- by 20-m exclosure will be constructed to serve as an unvegetated control for the planted exclosure. Special effort will be made to establish *Nelumbo* at this site.

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Appendix A
Physical and Chemical Parameters Monitored at Various Stations Within Guntersville Reservoir, Alabama (1991-1992)

Table A1
Water Quality Parameters Measured at the Chisenhall Site

Date	Depth m	Temp °C	pH	COND µS/cm	D.O. mg/ℓ	TURB ntu	Chl µg/ℓ	Secchi m	TSS	ALK	NH3-N	NO3-N	TP	SRP	Fe	Mn	Ca	Mg	Na	K
									mg/ℓ											
05/22/91	0	22.5		158	8.70															
	0.5	22.6		158	8.31															
	1.0	22.3		158	8.87															
	I					5.80	18	0.60	6	65	0.00	0.06	0.039	0.004	0.13	0.02	29.50	3.20	2.78	0.83
06/05/91	0	28.8	7.65	156	6.95															
	0.5	27.8	7.70	156	6.21															
	1.0	27.4	7.37	158	4.60															
	I					6.40	19	0.90	19	61	0.03	0.05	0.036	0.003	0.20	0.03	17.90	4.41	4.17	1.32
06/18/91	0	31.1	8.11	157	7.73															
	0.05	29.9	8.10	157	8.03															
	1.0	28.3	8.09	159	7.86															
	I					5.40	9	0.90	27	57	0.02	0.02	0.037	0.006	0.20	0.04	19.80	5.25	4.68	1.58
07/02/91	0	28.6	8.41	152	9.25															
	0.5	28.4	8.31	153	9.04															
	1.0	28.1	7.95	155	7.99															
	I					4.10	20	0.85	15	61	0.00	0.02	0.026	0.001	0.04	0.01	16.50	6.28	7.58	1.40
07/16/91	0	29.7	8.17	163	8.27															
	0.5	29.5	8.05	164	7.98															
	1.0	29.5	8.07	163	8.06															
	I					6.10	13	0.75	11	60	0.01	0.01	0.029	0.004	0.08	0.02	20.30	7.12	2.90	1.44
07/31/91	0	30.3	7.94	170	8.36															
	0.5	30.2	7.85	169	8.16															
	1.0	30.0	7.73	169	8.64															
	I					2.90			13	62	0.01	0.03	0.035	0.017	0.04	0.02	19.00	6.32	1.90	1.39
08/31/91	0	28.7		173	7.78															
	0.5	28.5		174	7.54															
	1.0	28.4		174	7.11															
	I					4.20	20		4	63	0.03	0.02	0.047	0.005	0.06	0.02	19.20	6.48	4.36	1.30
08/28/91	0	26.4	8.01	184	7.09															
	0.5	26.4	7.95	184	7.01															
	1.0	26.7	7.80	185	6.42															
	I					2.70	21	0.60	7	71	0.00	0.01	0.039	0.003	0.05	0.02	19.50	6.20	5.44	1.26

(Sheet 1 of 3)

Table A1 (Continued)

Date	Depth m	Temp °C	pH	COND µS/cm	D.O. mg/ℓ	TURB ntu	Chl µg/ℓ	Secchi m	TSS	ALK	NH3-N	NO3-N	TP	SRP	Fe	Mn	Ca	Mg	Na	K
									mg/ℓ											
09/10/91	0	26.7	8.15	180	8.03															
	0.5	26.4	7.70	184	7.00															
	1.0																			
	I					2.60	16	0.75	7	68	0.00	0.00	0.020		0.05	0.02	20.40	7.08	6.29	1.44
09/25/91	0	21.1	6.23	172	6.68															
	0.5	21.1	6.93	172	6.57															
	1.0																			
	I					3.20	16	0.60	5	70	0.04	0.08	0.035	0.002	0.05	0.05	19.50	6.08	6.60	1.43
10/07/91	0	17.5	8.00	182	8.29															
	0.5	17.5	7.97	182	8.06															
	1.0	17.2	7.82	183	7.33															
	I					0.65	18	0.75	8	58	0.09	0.05	0.028	0.002	0.04	0.02	20.70	6.82	5.70	1.48
10/22/91	0	18.4	7.66	180	7.85															
	0.5	18.4	7.71	180	7.74															
	1.0	18.4	7.72	180	7.74															
	I					5.50	16	0.75	9	60	0.22	0.11	0.021	0.002	0.04	0.02	19.90	6.28	6.14	1.52
05/05/92	0	21.3	7.49	172	8.32															
	0.5	21.2	7.60	172	8.50															
	1.0	20.9	7.90	173	9.49															
	I					0.80			8	69	0.09	0.07	0.053	0.014			23.88	5.32	7.14	1.30
05/18/92	0	27.7	7.96	180	9.14															
	0.5	27.0	8.03	178	9.28															
	1.0	25.2	8.15	179	8.00															
	I					4.90			7	67	0.02	0.24	0.039	0.007			24.50	11.42	7.16	1.36
06/01/92	0	20.1	7.27		7.67															
	0.5	20.2	7.28		7.56															
	1.0	20.2	7.29		7.34															
	I					5.90			11	61	0.04	0.13	0.050	0.000			22.80	11.04	7.23	1.17
06/15/92	0	24.3	7.48	178	9.91															
	0.05	24.2	7.49	179	9.60															
	1.0	23.4	7.22	177	8.10															
	I					4.20			12	72	0.03	0.16	0.031	0.004			25.30	10.86	3.52	0.82

(Sheet 2 of 3)

Table A1 (Concluded)

Date	Depth	Temp	pH	COND	D.O.	TURB	Chl	Secchi	TSS	ALK	NH3-N	NO3-N	TP	SRP	Fe	Mn	Ca	Mg	Na	K
	m	°C		µS/cm	mg/ℓ	ntu	µg/ℓ	m	mg/ℓ											
06/29/92	0	27.6	8.05	167	9.43															
	0.5	26.8	7.57	169	7.86															
	1.0	26.8	7.50	170	7.75															
	I					6.20			9	68	0.06	0.01	0.034	0.010			22.10	8.10	4.01	1.17
07/13/92	0	30.5	7.90	163	8.32															
	0.5	29.9	8.02	162	8.45															
	1.0	29.6	7.67	161	6.60															
	I					3.30			3	59	0.04	0.03	0.020	0.004			19.60	8.29	4.80	1.33
07/26/92	0	29.8	7.77	155	8.17															
	0.5	29.8	7.77	155	8.92															
	1.0	29.8	7.61	155	6.72															
	I					3.50			4	55	0.10	1.24	0.063	0.002			21.00	10.69	6.71	2.10
08/10/92	0	28.9	8.06	159	8.73															
	0.5	28.1	7.88	159	7.95															
	1.0	27.9	7.59	159	7.40															
	I					2.30			10	60	0.06	0.72	0.023	0.000			21.80	10.24	7.44	2.08
08/24/92	0	28.8	8.02	183	9.70															
	0.5	27.4	8.21	182	9.90															
	1.0	26.8	8.10	182	9.41															
	I					5.80			12	63	0.02	0.00	0.046	0.008			27.30	11.18	9.84	2.32
09/08/92	0	26.9	7.79	189	7.87															
	0.5	26.9	7.81	189	7.97															
	1.0	26.7	7.80	189	7.83															
	I					4.10			33	68	0.03	0.02	0.057	0.000			20.40	7.89	6.98	2.17
09/28/92	0	22.8	7.46	175	7.99															
	0.5	22.7	7.51	175	7.94															
	1.0	22.7	7.50	174	7.88															
	I					8.30			15	68	0.17	0.13	0.057	0.000			19.00	7.26	6.51	1.14
10/12/92	0	17.1	7.70	58	8.99															
	0.5	16.6	7.58	167	8.10															
	1.0	NA	NA	NA	NA															
	I					5.30			7	58	0.07	0.14	0.020	0.005			19.80	6.16	6.35	1.34
10/27/92	0	19.1	8.17	163	9.92															
	0.5	18.9	8.44	164	9.79															
	1.0	18.6	8.45	165	9.68															
	I					2.80			6	57	0.05	0.11	0.023	0.003			23.60	6.36	6.83	1.53

(Sheet 3 of 3)

Table A2
Water Quality Parameters Measured at the Boshart Creek Site

Date	Depth m	Temp °C	pH	COND µS/cm	D.O. mg/ℓ	TURB ntu	Chl µg/ℓ	Secchi m	TSS	ALK	NH3-N	NO3-N	TP	SRP	Fe	Mn	Ca	Mg	Na	K
									mg/ℓ											
05/22/91	0	24.0	7.73	157	9.73															
	0.5	24.0	7.98	158	9.22															
	I					7.20			12	63	0.00	0.05	0.031	0.003	0.16	0.01	30.70	4.75	4.08	1.16
06/05/91	0	27.8	7.83	153	7.17															
	0.5	27.9	7.83	153	7.18															
	I					9.50	16	0.60	24	58	0.06	0.08		0.001	0.15	0.02	17.90	4.54	4.53	1.40
06/18/91	0	31.8	8.06	152	8.28															
	0.5	31.7	7.79	151	8.10															
	I					6.10	3		34	54	0.08	0.02	0.025	0.001	0.22	0.02	19.80	5.43	4.66	1.42
07/02/91	0	29.1	8.47	150	9.38															
	0.5	29.0	8.39	150	8.96															
	I					7.60	13		22	55	0.00	0.02	0.044	0.001	0.04	0.02	16.50	6.31	6.59	1.45
07/16/91	0	28.7	7.89	160	7.52															
	0.5	28.6	8.04	160	7.53															
	I					6.20	4	0.75	16	57	0.00	0.01	0.020	0.004	0.04	0.01	20.30	5.98	2.64	1.56
07/31/91	0	29.3	7.71	164	7.80															
	0.5	29.4	7.88	163	7.80															
	I					4.10			11	59	0.05	0.02	0.029	0.006	0.04	0.01	19.00	6.04	1.91	1.91
08/13/91	0	28.4	7.99	170	8.06															
	0.5	28.4	8.12	170	7.98															
	I					4.50	18		5	65	0.00	0.02	0.034	0.001	0.09	0.01	19.20	6.87	4.43	1.33
08/28/91	0	28.2	8.31	179	8.64															
	0.5	28.3	8.33	179	8.58															
	I					6.50	20	0.50	7	67	0.00	0.01	0.036	0.002	0.04	0.02	19.50	7.56	5.63	1.30
09/10/91	0	27.4	8.30	181	7.81															
	0.5	27.3	8.31	182	7.58															
	I					6.20	26	0.50	9	70	0.00	0.02	0.039		0.06	0.01	20.40	7.44	7.52	1.77
09/25/91	0	22.3	7.45	174	7.44															
	0.5	22.3	7.67	174	7.32															
	I					1.81	18	0.75	10	64	0.00	0.04	0.027	0.002	0.04	0.02	19.50	6.41	7.38	1.49
10/07/91	0	19.5	8.57	180	9.18															
	0.5	19.6	8.53	180	8.94															
	I					0.96	15	1.10	9	86	0.06	0.03	0.016	0.002	0.06	0.02	20.70	7.04	6.02	1.49
10/22/91	0	20.1	8.23	179	8.70															
	0.5	20.0	8.21	179	8.68															
	I					3.50	17	0.75	6	69	0.17	0.02	0.027	0.002	0.02	0.02	19.90	6.43	6.28	1.58
05/06/92	0	21.6	7.66	160	9.09															
	0.5	21.6	7.80	160	9.84															
	I					0.46			16	61	0.08	0.00	0.032	0.011			21.36	5.60	7.53	1.31

(Continued)

Table A2 (Concluded)

Date	Depth m	Temp °C	pH	COND µS/cm	D.O. mg/ℓ	TURB ntu	Chl µg/ℓ	Secchi m	TSS	ALK	NH3-N	NO3-N	TP	SRP	Fe	Mn	Ca	Mg	Na	K
									mg/ℓ											
05/18/92	0	28.5	8.17	175	10.78															
	0.5	28.0	8.25	177	10.72															
	I					10.60			1	65	0.02	0.50	0.040	0.10			10.80	9.53	5.16	1.03
06/01/92	0	20.9	8.18	NA	10.49															
	0.5	20.8	8.19	NA	10.08															
	I					5.50			9	60	0.01	0.05	0.029	0.012			17.80	10.16	6.75	1.19
06/15/92	0	25.7	7.62	165	9.19															
	0.5	25.7	7.64	165	9.14															
	I					2.90				77	0.07	0.16	0.048	0.000			20.40	10.31	4.61	0.92
06/29/92	0	29.4	7.98	164	9.50															
	0.5	29.8	7.91	164	9.58															
	I					7.30			11	66	0.07	0.04	0.028	0.007			21.20	8.38	4.11	1.32
07/13/92	0	31.3	7.97	164	9.33															
	0.5	31.3	8.00	164	9.19															
	I					2.50			5	59	0.05	0.16	0.020	0.005			18.50	8.86	5.00	1.38
07/28/92	0	30.0	7.98	152	8.60															
	0.5	29.9	7.95	152	8.15															
	I					4.10			6	54	0.09	0.03	0.082	0.000			18.80	8.70	6.80	1.95
08/10/92	0	32.2	8.25	157	9.28															
	0.5	30.1	8.18	156	9.22															
	I					0.53			8	60	0.08	0.10	0.013	0.000			20.00	9.24	7.43	1.93
08/24/92	0	27.1	8.02	171	9.07															
	0.5	27.2	8.01	171	8.99															
	I					6.00			10	54	0.04	0.00	0.041	0.002			18.10	9.78	7.58	2.09
09/08/92	0	29.9	7.72	186	7.60															
	0.5	29.6	7.69	186	7.56															
	I					6.10			11	68	0.02	0.03	0.080	0.001			20.80	7.6	6.3	1.95
09/28/92	0	24.2	8.37	175	10.67															
	0.5	24.0	8.38	179	10.62															
	I					6.30			14	66	0.03	0.10	0.021	0.005			19.10	7.73	6.59	1.36
10/12/92	0	18.5	8.36	169	9.86															
	0.5	NA	NA	NA	NA															
	I					4.50			5	57	0.08	0.10	0.036	0.002			18.90	6.58	6.35	1.27
10/27/92	0	20.3	8.17	169	9.39															
	0.5	20.2	8.25	169	9.44															
	I					2.30			12	62	0.03	0.13	0.025	0.005			25.30	6.66	7.58	1.52

Table A3
Water Quality Parameters Measured at the Waterfront Site

Date	Depth m	Temp °C	pH	COND µS/cm	D.O. mg/ℓ	TURB ntu	Chl µg/ℓ	Secchi m	TSS	ALK	NH3-N	NO3-N	TP	SRP	Fe	Mn	Ca	Mg	Na	K
									mg/ℓ											
06/22/91	0	24.0	8.16	155	9.83															
	0.5	23.8	7.79	159	8.66															
	I					6.00	16	0.60	9	60	0.00	0.09	0.045	0.002	0.18	0.01	26.50	4.95	4.25	1.15
06/05/91	0	27.3	7.40	150	5.67															
	0.5	27.1	7.34	149	4.95															
	I					5.20	10		22	54	0.07	0.08	0.026	0.002	0.18	0.03	18.60	4.69	4.65	1.44
06/18/91	0	32.1	8.61	147	9.76															
	0.5	32.2	8.56	146	7.54															
	I					5.20	9	0.75	28	46	0.03	0.02	0.030	0.007	0.19	0.01	16.80	4.97	4.88	1.54
07/02/91	0	28.8	7.95	154	8.18															
	0.5	28.7	7.95	154	8.25															
	I					7.70	22	0.60	18	54	0.00	0.01	0.075	0.001	0.05	0.02	18.40	6.89	9.80	1.61
07/16/91	0	28.5	7.87	159	6.93															
	0.5	28.4	7.48	159	6.54															
	I					5.00	15	0.75	20	57	0.02	0.02	0.025	0.005	0.04	0.02	17.20	7.06	3.11	1.53
07/31/91	0	29.8	7.75	162	8.87															
	0.5	29.8	7.75	162	8.30															
	I					3.70			15	61	0.02	0.03	0.043	0.018	0.04	0.02	20.30	6.21	2.01	1.21
08/13/91	0	28.6	8.15	171	8.46															
	0.5	28.7	8.19	171	8.40															
	I					3.40	9		10	62	0.01	0.02	0.029	0.002	0.04	0.02	19.10	7.62	4.53	1.31
08/28/91	0	28.8	8.49	177	9.22															
	0.5	28.5	8.56	178	9.94															
	I					2.70	17	0.75	18	68	0.00	0.02	0.032	0.004	0.04	0.03	20.40	7.71	5.39	1.24
09/10/91	0	27.4	8.47	177	8.79															
	0.5	27.4	8.48	177	8.69															
	I					2.70	30	0.48	15	66	0.00	0.00	0.082		0.08	0.03	20.50	7.64	9.58	3.79
09/25/91	0	22.7	7.64	171	6.78															
	0.5	22.7	7.65	172	6.72															
	I					0.70	29	0.60		82	0.06	0.05	0.042	0.002	0.05	0.02	18.70	6.20	6.94	1.51
10/07/91	0	20.6	8.79	178	10.27															
	0.5	20.6	8.90	177	11.18															
	I					1.80	12	0.75	1	60	0.07	0.01	0.019	0.002	0.05	0.03	18.80	6.18	6.25	1.55
10/22/91	0	20.1	8.38	178	9.64															
	0.5	20.0	8.37	178	9.49															
	I					2.40	19	0.75	5	62	0.06	0.04	0.020	0.004	0.05	0.02	19.10	6.13	6.96	1.56

(Continued)

Table A3 (Concluded)

Date	Depth m	Temp °C	pH	COND µS/cm	D.O. mg/ℓ	TURB ntu	Chl µg/ℓ	Secchi m	TSS	ALK	NH3-N	NO3-N	TP	SRP	Fe	Mn	Ca	Mg	Na	K
									mg/ℓ											
05/05/92	0	22.2	8.66	156	14.16															
	0.5	21.8	8.43	157	12.03															
	I					1.43			8	57	0.05	0.13	0.042	0.012			21.30	5.34	8.85	1.30
05/18/92	0	29.3	8.77	173	13.23															
	0.5	27.8	8.78	174	14.10															
	I					5.60			6	61	0.01	0.50	0.050	0.009			14.20	10.87	4.41	0.80
06/01/92	0	21.3	8.19	NA	11.33															
	0.5	21.3	8.19	NA	11.00															
	I					5.10			8	56	0.00	0.07	0.023	0.009			19.20	11.06	7.06	1.08
06/15/92	0	26.8	8.05	165	10.50															
	0.5	26.1	8.06	165	10.48															
	I					3.10				63	0.03	0.13	0.009	0.005			19.50	10.59	4.73	0.94
06/29/92	0	29.4	8.51	161	12.40															
	0.5	29.2	8.48	163	12.12															
	I					6.50			8	63	0.06	0.05	0.038	0.006			22.80	8.28	4.75	1.93
07/13/92	0	31.7	8.23	160	10.32															
	0.5	31.4	8.21	160	10.02															
	I					2.60			10	57	0.05	0.06	0.018	0.004			4.20	5.49	4.90	1.27
07/26/92	0	29.9	8.33	152	9.64															
	0.5	30.0	8.32	152	9.53															
	I					4.00			17	53	0.17	0.05	0.076	0.001			18.80	9.43	9.05	2.41
08/10/92	0	32.4	8.29	160	11.08															
	0.5	30.3	8.66	158	11.75															
	I					0.62			7	58	0.05	0.11	0.009	0.000			20.00	9.01	8.04	1.86
08/24/92	0	27.3	8.37	180	10.65															
	0.5	27.2	8.34	181	10.05															
	I					5.80			8	62	0.06	0.02	0.048	0.006			17.80	11.06	9.45	2.26
09/08/92	0	29.8	8.03	188	9.18															
	0.5	29.3	7.93	189	9.02															
	I					2.90			8	66	0.08	0.05	0.050	0.001			19.40	8.22	7.54	2.00
09/28/92	0	24.5	8.23	177	10.40															
	0.5	24.3	8.28	176	10.64															
	I					7.30			15	64	0.04	0.08	0.047	0.002			19.30	7.84	6.92	1.30
10/12/92	0	19.3	8.50	166	10.97															
	0.5	NA	NA	NA	NA															
	I					6.90			9	57	0.04	0.14	0.039	0.004			19.00	6.47	6.92	1.28
10/27/92	0	20.4	8.55	166	10.95															
	0.5	20.4	8.56	166	10.09															
	I					3.10			12	55	0.06	0.08	0.031	0.005			21.20	6.24	7.07	1.48

Table A4
Water Quality Parameters Measured at the Ossa-Win-Tha Site

Date	Depth m	Temp °C	pH	COND µS/cm	D.O. mg/ℓ	TURB ntu	Chl µg/ℓ	Secchi m	TSS	ALK	NH3-N	NO3-N	TP	SRP	Fe	Mn	Ca	Mg	Na	K
									mg/ℓ											
06/18/91	0	31.7	8.86	141	11.46															
	0.5	31.3	8.70	140	11.41															
	I					3.60		0.60	16	51	0.07	0.03	0.031	0.001	0.19	0.02	16.30	5.52	4.85	1.54
07/02/91	0	30.0	8.22	162	9.12															
	0.5	28.9	7.56	180	7.56															
	I					4.00	16	0.50	10	57	0.00	0.01	0.040	0.002	0.03	0.01	19.30	6.60	1.27	1.41
07/16/91	0	28.2	7.18	144	6.77															
	0.5	28.2	7.10	145	6.83															
	I					8.00	6	0.60	30	48	0.03	0.02	0.019	0.006	0.06	0.02	15.50	6.92	2.95	1.51
07/31/91	0	29.8	7.75	162	8.87															
	0.5	29.8	7.75	162	8.30															
	I					6.10	8	0.25	48	55	0.00	0.08	0.064	0.021	0.04	0.05	17.20	6.45	1.83	1.18
08/13/91	0	29.3		163	7.81															
	0.5	29.2		163	8.24															
	I					3.00			10	58	0.00	0.11	0.026	0.000	0.05	0.05	11.30	7.61	4.78	1.37
08/28/91	0	28.8	8.01	172	8.14															
	0.5	28.6	7.95	172	8.33															
	I					2.60			4	67	0.02	0.10	0.022	0.004	0.04	0.05	18.70	7.80	5.55	1.07
09/10/91	0	27.5	7.78	166	8.38															
	0.5	27.5	7.84	166	8.92															
	I					4.20	15	0.50	6	56	0.01	0.04	0.019		0.06	0.02	16.30	7.09	6.55	1.47
09/25/91	0	22.1	7.22	166	5.83															
	0.5	22.2	7.24	167	6.10															
	I					1.30	4	0.50	15	58	0.12	0.11	0.027	0.002	0.07	0.06	17.70	6.21	7.06	1.66
10/07/91	0	20.5	7.84	173	8.36															
	0.5	20.5	7.75	173	8.32															
	I					4.30	8	0.33	18	57	0.09	0.16	0.029	0.002	0.07	0.02	18.50	6.32	6.24	1.60
10/22/91	0	19.1	7.42	175	6.82															
	0.5	19.2	7.39	174	6.82															
	I					5.10	5	0.50	5	60	0.08	0.22	0.023	0.004	0.08	0.02	18.60	6.66	6.82	1.59
05/05/92	0	21.3	7.45	153	9.73															
	0.5	21.3	7.41	154	9.60															
	I					1.00			8	55	0.06	0.21	0.028	0.008			20.50	5.67	8.48	1.25
05/18/92	0	29.1	8.43	169	12.03															
	0.5	26.5	8.39	168	11.69															
	I					4.30			3	59	0.01	0.35	0.033	0.009			25.40	11.55	5.03	1.15
06/01/92	0	22.3	7.36,	165	8.27															
	0.5	22.3	7.34	165	8.29															
	I					10.70			20	53	0.03	0.17	0.031	0.016			17.10	10.57	7.37	1.18

(Continued)

Table A4 (Concluded)

Date	Depth m	Temp °C	pH	COND µS/cm	D.O. mg/ℓ	TURB ntu	Chl µg/ℓ	Secchi m	TSS	ALK	NH3-N	NO3-N	TP	SRP	Fe	Mn	Ca	Mg	Na	K
									mg/ℓ											
06/15/92	0	27.4	7.25	170	7.86															
	0.5	27.1	7.24	169	7.66															
	I					4.00			12	65	0.04	0.25	0.030	0.016			20.20	11.26	4.29	0.84
06/29/92	0	29.1	7.63	156	10.39															
	0.5	NA	NA	NA	NA															
	I					7.40			7	52	0.06	0.12	0.034	0.006			18.00	7.62	3.51	1.32
07/13/92	0	31.6	8.18	151	10.18															
	0.5	31.5	8.12	151	9.91															
	I					2.70			11	50	0.05	0.10	0.011	0.001			14.20	8.19	4.70	1.28
07/26/92	0	30.2	8.07	147	10.38															
	0.5	30.0	8.09	147	10.80															
	I					3.90			6	48	0.10	0.06	0.030	0.000			4.77	4.66	7.94	2.22
08/10/92	0	32.2	8.41	153	10.33															
	0.5	32.0	8.31	154	10.22															
	I					0.43			2	54	0.03	0.13	0.007	0.000			18.70	10.14	9.01	2.14
08/24/92	0	27.1	8.41	176	10.24															
	0.5	26.8	7.94	178	6.93															
	I					3.10			1	62	0.04	0.09	0.021	0.004			19.70	10.67	8.82	2.43
09/08/92	0	29.4	8.61	181	10.44															
	0.5	28.1	7.86	187	7.51															
	I					2.10			4	64	0.02	0.03	0.020	0.000			18.30	8.22	7.14	1.88
09/28/92	0	24.4	9.15	180	13.04															
	0.5	22.9	8.23	209	10.14															
	I					3.90			5	57	0.05	0.03	0.022	0.008			21.00	6.78	8.57	1.16
10/12/92	0	19.3	9.34	156	13.45															
	0.5	NA	NA	NA	NA															
	I					3.70			1	57	0.07	0.06	0.015	0.005			18.80	6.56	6.83	1.16
10/27/92	0	20.7	9.55	153	15.99															
	0.5	18.6	8.80	158	10.13															
	I					1.60			1	53	0.03	0.02	0.009	0.003			21.60	6.16	5.72	1.03

Appendix B
Effect of a Benthic Barrier and Fertilizer Application on the Establishment and Persistence of Native Aquatic Macophytes[1]

Experimental Objective and Design

The experimental objective was to determine the efficacy of a benthic barrier and fertilizer application on the establishment and persistence of *Vallisneria americana* and *Potamogeton pectinatus* in a water body dominated by *Myriophyllum spicatum*. We wished to evaluate whether use of a benthic barrier or application of fertilizer around the plantings would increase the survival, growth, and competitive abilities of the native species (i.e. *Vallisneria* and *Potamogeton*).

The experimental design consisted of a factorial arrangement with two barrier treatments (barrier and no barrier), two fertility levels (control and fertilized sediments), and three planting treatments (*Vallisneria*, *Potamogeton*, and an unplanted control) for a total of 12 experimental treatments. Each experimental treatment was replicated 8 times for a total of 96 experimental units or subplots.

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[1] Report on experiments conducted in the North Pond at the Guntersville Reservoir Aquatic Research Facility at Murphy Hill to determine the effects of a benthic barrier and fertilizer application on the establishment of *Vallisneria americana* and *Potamogeton pectinatus* (sago pondweed) in a water body dominated by *Myriophyllum spicatum*.

Methods

One of the primary considerations for research in Guntersville Reservoir is the presence of large numbers of grass carp that were released into the reservoir. The native species we wished to evaluate (*Vallisneria americana* and *Potamogeton pectinatus*) are generally considered to be preferred food choices for these fish relative to the target nuisance species we wished to replace, *Myriophyllum spicatum*, which is one of the least-favored foods. Thus, the presence of grass carp would likely interfere with a test of competition among these species in the reservoir. For this reason, we elected to perform this research in the North Pond at Murphy Hill, a shallow pond colonized with *Myriophyllum* and located adjacent to the reservoir.

Prior to the start of the experiment in the spring of 1990, a 0.4-ha (1-acre) plot was delineated in the middle of a large monospecific stand of *Myriophyllum*. This plot was treated by TVA with a granular formulation of endothall, producing excellent control (i.e., complete kill within the plot while leaving the *Myriophyllum* intact around the periphery of the plot).

Within the treated area we laid out four 6- by 12-m plots; two plots were covered with benthic barrier material and the others were left uncovered. Within each of these plots, we established 24 1- by 1-m subplots. Each subplot was randomly assigned to one of the six possible combinations of the two fertility and three planting treatments.

For initial establishment of the plants, a planting frame was constructed which divided the subplots into 49 equal cells approximately 15 by 15 cm. Plots were initially planted during the week of 10 June 1990. Within each cell we planted a bundle of three to five *Vallisneria* plants or a set of three *Potamogeton* tubers. *Vallisneria* plants with roots and leaves were obtained from the Suwannee Laboratory in Lake City, FL. *Potamogeton* tubers were purchased from Wildlife Nurseries in Oshkosh, WI. Fertilization was achieved by inserting a house-plant fertilizer spike into the bundle of *Vallisneria* plants or in the midst of the *Potamogeton* tubers. Each fertilizer spike contained approximately 160 mg of nitrogen and 20 mg of phosphorus.

Results and Discussion

After five weeks, we returned to evaluate the growth of the plants and found that none had survived. Since no dead plants or tubers were present, we suspected that the plants had been eaten. Subsequent observations and trapping suggested that the plants had most likely been consumed by a large population of *Trachemys* turtles (pond sliders, formerly *Chrysemys*) residing in the pond. Since turtles can easily be caught in traps baited with *Vallisneria*, we constructed an exclosure of pipe and poultry wire within the experimental plot, removed the turtles from within using baited traps, and replanted only the benthic barrier portion of the experiment.

Vallisneria was replanted 26 September 1990. *Potamogeton* tubers were unavailable and were not replanted that fall. *Myriophyllum* was also beginning to re-invade the plots at that time. In the spring of 1991, *Potamogeton pectinatus* tubers were still unavailable, and we elected to replant the *Potamogeton* plots with *Potamogeton nodosus* (American pondweed) winterbuds obtained from Cedar Creek Reservoir in northwestern Alabama. Methods of planting were the same as reported for the spring 1990 plantings, except that *Potamogeton nodosus* winterbuds were substituted for *Potamogeton pectinatus* tubers.

The replantings within the exclosures initially appeared to be establishing well. The *Vallisneria* plots were visually evaluated in October 1990 and were growing vigorously. Following planting in the spring of 1991, the *Potamogeton* began vigorous growth. However, biomass of both species visually declined during the summer months, and we decided not to make the first scheduled harvest to allow more time for plant establishment. By the end of the summer 1991 very little *Vallisneria* or *Potamogeton* remained within the plots, and *Myriophyllum* was quickly becoming established within the plot.

The results obtained in the North Pond study during 1990-1991 can be attributed to several factors. First, the *Vallisneria* may have been planted too late in the season (September 1990) for it to become well established. *Potamogeton*, which was planted in the spring of 1991, was more successful in becoming established, but by that time (one year post-treatment) the *Myriophyllum* was rapidly recovering from the herbicide treatment and was invading the plot. In addition, herbivory continued in spite of the exclosure. This herbivory was attributed to turtles, which may have entered the exclosure through holes in the deteriorating fencing.

A second problem was the benthic barrier material that surrounded the plantings. The barrier tended to trap gases and billowed out due to the buoyancy of the trapped bubbles. Movement of the barrier, as a result of the water currents or escaping gases, disturbed the sediments and caused increased levels of turbidity around the plants. These suspended sediments were subsequently deposited on the leaves of the emerging plants and may have reduced growth by limiting the amount of light available to the leaves for photosynthesis. In addition, the movement of the barrier material may have physically damaged the young plants.

Another factor that may have contributed to the results is related to the composition of the pond bottom substrate. The pond was created for sediment detention associated with a large TVA construction project that was only partially completed. The pond was created by blasting rock and removing the rubble. Consequently, the pond bottom consists of fractured rock overlain with a shallow, irregular layer of loose, flocculent sediment deposited by site erosion. This thin layer of sediment may not provide firm anchorage for shallow-rooted species like *Vallisneria*. The deeper rooted *Myriophyllum* may be able to exploit fractures in the rock and anchor itself by sending roots into fissures and crevices. Although we saw no evidence of this, some of the plants may have been simply uprooted by storms. Floating plants would have drifted against the exclosure sides and could easily have been consumed by turtles on the outside of the wire mesh.

Finally, the 1- by 1-m plots may have been too small for optimal establishment of the plants. Larger plots would have been less susceptible to herbivory and might also have help minimize turbidity problems caused by the barrier material.

In an attempt to overcome the problems associated with the first two seasons, we changed the basic workplan in the North Pond for 1992. Our new objective was to simply devise a successful method for establishing populations of native plants within existing *Myriophyllum* colonies. We first removed the benthic barrier material and all of the small plots and replaced the exclosure fencing with heavier gauge wire mesh. Next, we again treated the exclosure with herbicide to eliminate the *Myriophyllum.* This herbicide treatment was applied in October 1991 so that the plantings to be made in the spring of 1992 would not be affected. Finally, we established larger plots within the exclosure. In 1992 we established eight 4- by 4-m plots each subdivided into sixteen 1- by 1-m subplots using PVC pipe. These frames were anchored to the substrate and two randomly selected 4- by 4-m plots were planted for each species. We selected three native species, *Potamogeton nodosus*, *Vallisneria americana*, and *Nelumbo lutea* (American lotus). The remaining two plots were left unplanted as controls. Plantings were made in early May 1992. No benthic barrier or fertilization treatments were made.

The first harvest of the North Pond was made on 22 June 1992. The results of the harvest showed no *Vallisneria* or *Nelumbo* biomass and very little *Potamogeton* (0.3 g dry mass$\cdot$m^{-2}). However, *Myriophyllum* was beginning to grow well with an average biomass of 18 g dry mass$\cdot$m^{-2}.

In July 1992, we made a final visual observation of the North Pond study site. At that time none of the planted native species were found within the plots, although *Myriophyllum* was growing well. Based on these observations we terminated the experimental effort at the North Pond. The high herbivore pressure within the pond and the bottom substrate characteristics (shallow sediment layer over a solid hardpan) created an environment unsuitable for establishment of native vegetation.

Appendix C

Transplant Methods for *Vallisneria americana* Populations Which Do Not Produce Winterbuds[1]

Experimental Objective

In our attempts to establish *Vallisneria* populations in Guntersville Reservoir, Alabama, we observed that the initial success of establishing this species depended on the type of propagule used: initial success was good when winterbuds (turions) were planted but was very poor with bare-root transplants. Since some of the more southern populations of *Vallisneria* do not produce winterbuds (Smart and Dorman, in press), we conducted the following study to develop a suitable transplant methodology for those plants.

The study had two objectives: first, to compare the success in establishing field populations with bare-root transplants versus peat-pot transplants and, second, to determine the optimum planting density of peat-pot transplants in the field.

Methods

The design of the first objective was a comparison of the success of the two planting methods: bare-root and peat-pot transplants. Transplants were planted at 20-cm intervals within 1.8- by 1.8-m plots for a final planting

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[1] Report on an experiment conducted at the Lewisville Aquatic Ecosystem Research Facility to determine the optimum transplant methodology for southern *Vallisneria* populations which do not produce dormant vegetative propagules.

density of 25 plants$\cdot$m^{-2}. The second experimental objective was tested with a dosage-response experiment. In this experiment peat-pot transplants were established at four planting densities. Transplants were planted within the plots on 15-, 20-, 30-, and 40-cm intervals (densities of 44.4, 25.0, 11.1, and 4.9 plants$\cdot$m^{-2}, respectively). The two experiments were conducted in a 1-acre pond at the Lewisville Aquatic Ecosystem Research Facility (LAERF) at the same time. The pond was lined with geotextile fabric to minimize the growth of endemic species. Twenty plots (1.8 by 1.8 m) were cut out of the geotextile fabric at regular intervals (1.8-m spacing) exposing the sediments beneath. The plots had an elevational difference of only about 25 cm between the deepest and shallowest plots. Four replicate plots were randomly assigned to each of the five experimental treatments (one density of bare-root transplants and four densities of peat-pot transplants). Although the geotextile fabric liner reduced the growth of the seed bank in the sediment surrounding the plots, the plots themselves contained a viable seed bank of *Chara* spores. The plots were not fenced for total protection against herbivorous turtles although fall-in traps were deployed within the pond. Over the course of the growing period, 11 herbivorous turtles were captured and removed from the pond.

The transplants were initially obtained from a native population of *Vallisneria* in Toledo Bend reservoir in east Texas. Cultures were maintained in a greenhouse at 25 °C and continuously bubbled with CO_2-enriched air. Individual plants were established in 2-in. peat pots (total sediment volume ca. 65 cc) or in 1-liter plastic pots (for bare-root transplants) containing identical sediment. Nitrogen fertilization was applied as needed to the water in the form of KNO_3 (maximum concentration of 10 mg $N \cdot \ell^{-1}$). At the time of transplanting the plants were growing vigorously and the leaves were about 50 cm in length. Peat pots containing a single *Vallisneria* plant were selected for the peat-pot treatment. Individual plants were selected from plants growing in the plastic pots for the bare-root treatment. These plants were carefully removed from the plastic pots and their roots gently rinsed to remove sediment. The leaves of transplants for both treatments were then clipped to a uniform length of 20 cm.

Transplants were planted with the aid of PVC frames fitted with nylon cord grids to achieve the proper spacing. Plants were established in the pond between 15 and 18 May 1992. The ponds had been drained so that only 30 to 50 cm of water covered the deepest plots. These plots were hand planted by persons floating over the plots on inflatable air mattresses to minimize disturbance to the area. Planting proceeded from deepest to shallowest plots as the ponds were slowly refilled. After all plots were planted, the water level in the ponds was raised to about 50 to 75 cm during the first 4 weeks and then raised again to 100 to 125 cm for the remainder of the study.

The plots were visually inspected on 10-11 June 1992, and the number of individual *Vallisneria* plants remaining in each plot was determined. This short-term (4-week) survival was used to evaluate the first study objective comparing the planting success of bare-root and peat-pot transplants. The peat-pot plots were then replanted as necessary to reestablish 100 percent of the original planting density and allowed to continue growing until 29 August

1992. At the end of that 16-week growth period a single 0.1-m^2 subplot from within each plot was harvested. The plant material from each subplot was sorted by species, dried at 60 °C, and weighed.

Results and Discussion

The survival of peat-pot and bare-root transplants was significantly different after 4 weeks of growth in the ponds (Figure C1); survival was excellent in the peat-pot plots but very poor in the bare-root plots. In fact, we observed that the survival was excellent (75 to 100 percent) within all of the peat-pot plots regardless of planting density (Table C1).

The exact reasons for the differences in survival between the peat-pot transplants and the bare-root transplants was not clear. The peat pots were buried completely beneath the sediment surface and the peat-pot and bare-root plots were visually identical from the surface. It is unclear whether the bare-root transplants died due to transplanting shock, or simply floated away due to inadequate anchorage to the sediment. The peat-pot transplants, which were transplanted with intact and completely undisturbed roots within the peat pots, would have been less likely to suffer transplant shock or float away.

These results indicate that in a "real-world" situation where herbivory and competition from plants in the seed bank are likely, transplanting *Vallisneria* with an intact root system in a peat pot is superior to bare-root transplanting. This result may explain, in part, the relatively low planting success reported by Kollar (1986, 1988)[1] who transplanted mature plants with bare roots. However, Carter and Rybicki (1985) had success within grazer exclosures with both *Vallisneria* "plugs" (intact sediment around roots) and "sprigs" (bare-rooted young plants).

The optimum plant spacing for *Vallisneria* in this experiment was one of 20 cm between individual plants (density of 25 plants·m^{-2}) (Figure C2). This plant spacing and resulting density are quite different from that advocated by Kollar (1986) who recommends planting *Vallisneria* in clumps of five individual plants on 3-ft (ca. 91-cm) centers (6.0 plants·m^{-2}). The absolute density of propagules may be more critical than the exact spacing of the plants. Carter and Rybicki (1985) speculated that when planting *Vallisneria* under suboptimal conditions (i.e. poor light, grazers, plant competition from seedbank), there may be a minimum population density required for establishment. The results of this study, in conjunction with that of Kollar (1986), suggest that this minimum population density may be between 6 and 25 plants·m^{-2}.

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[1] References cited in this appendix are located at the end of the main text.

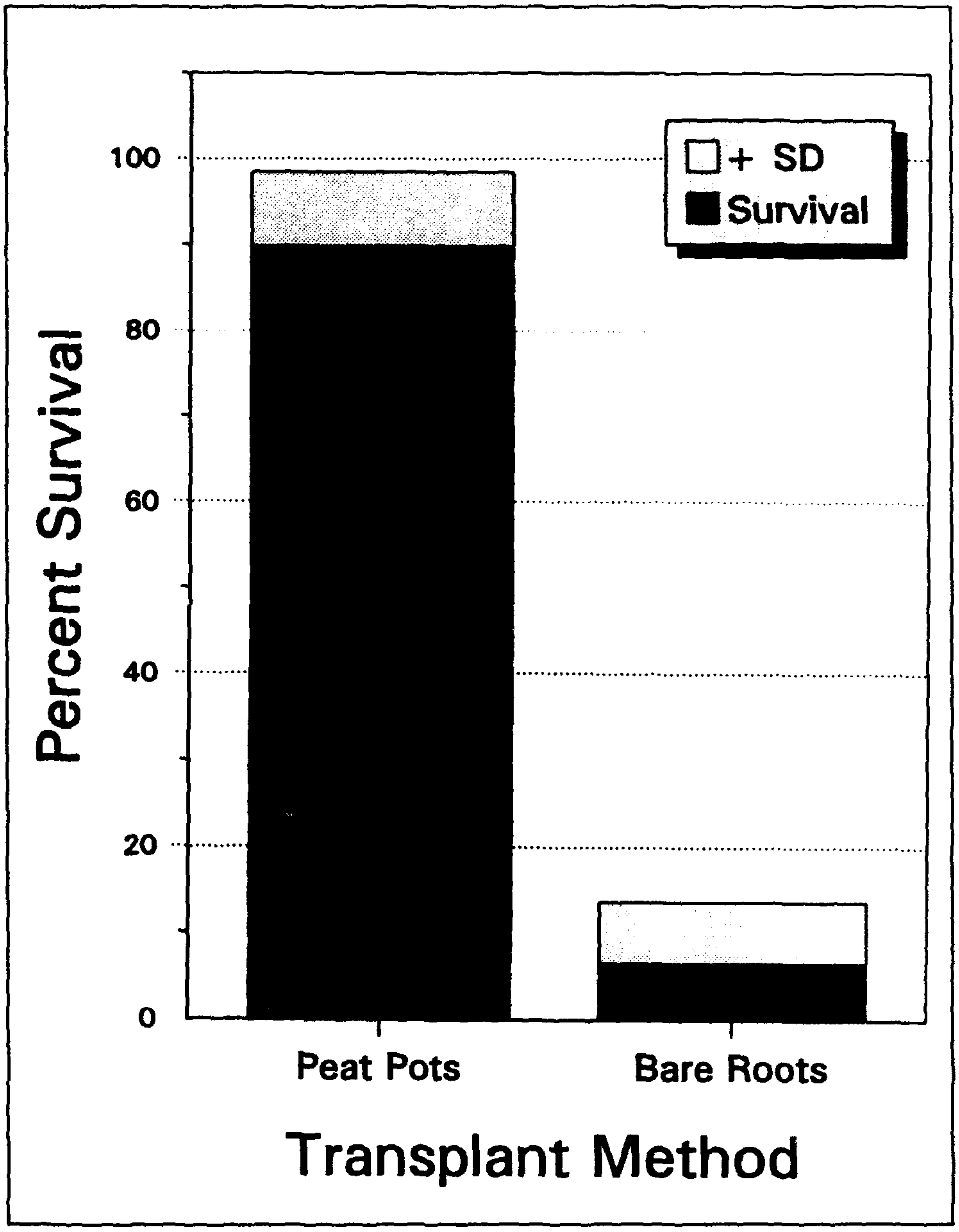

Figure C1. Average percent survival (+ SD, n = 4 for bare-root transplants and n = 16 for peat-pot transplants) of *Vallisneria* after 4 weeks in the ponds

Table C1
Survival of Peat-Pot and Bare-Root Transplants After 4 Weeks in the Field

Transplant Type	Density (plants·m^{-2})	Percent Survival (± SD)
Peat pot	44.4	89.8 ± 8.6
Peat pot	25.0	88.6 ± 6.4
Bare root	25.0	6.5 ± 7.1
Peat pot	11.1	81.9 ± 7.5
Peat pot	4.9	84.4 ± 9.4

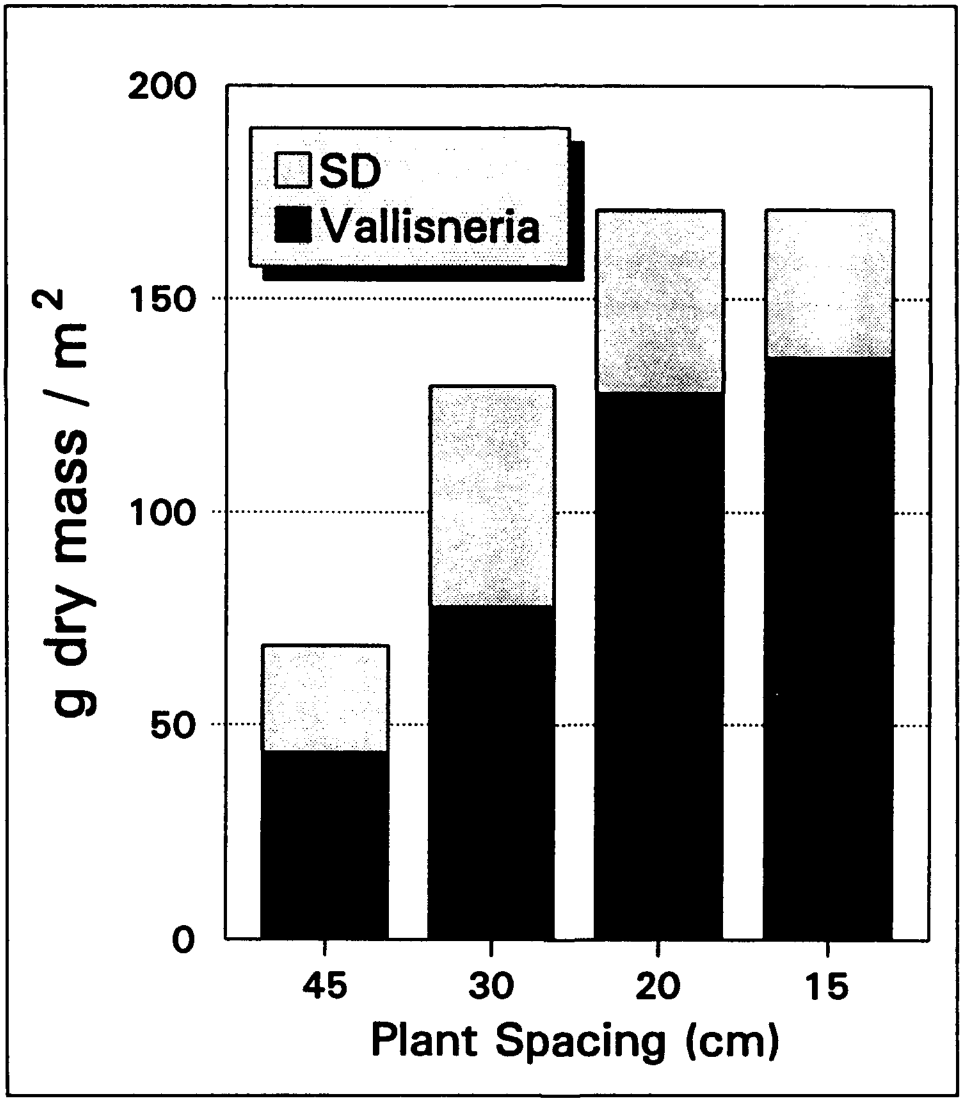

Figure C2. Average *Vallisneria* biomass (+ SD, n = 4) in plots planted under various initial planting densities after 16 weeks growth in the ponds

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13. ABSTRACT *(Maximum 200 words)*

The littoral regions of Guntersville Reservoir have a long history of nuisance infestations of *Myriophyllum spicatum* (Eurasian watermilfoil) and more recently of *Hydrilla verticillata* (hydrilla), problem species that invade recently disturbed areas. Management strategies have included water level management and chemical treatment of *Myriophyllum* and introduction of grass carp to control *Hydrilla*. Both strategies have shortcomings. Chemical treatment can be applied in specific problem-infested sites, but since the entire reservoir could never be treated, this method does not prevent, and may even promote, the re-invasion of the nuisance species. Grass carp in sufficient numbers effectively prevent re-invasion but provide limited specificity for either site or plant species, and the loss of desirable native submersed plant populations is probable. Recently, there has also been an increase in another nuisance plant, the mat-forming, blue-green alga *Lyngbya wollei*. *Lyngbya* mats result in serious, often localized, negative effects on the use of some areas. There are currently no effective chemical or biological control strategies for this organism.

A long-term solution to these problems may be the establishment of desirable native aquatic plants in areas subject to colonization by the nuisance species or in areas recently treated by conventional weed control methods. By occupying these areas, native plants may prevent, or at least delay, the regrowth of the nuisance plants.

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Efforts to establish populations of *Potamogeton nodosus* and *Vallisneria americana* in areas historically dominated by *Myriophyllum spicatum* are currently hindered by heavy herbivore pressure and a total decline of all submersed aquatic plant species in the Chisenhall embayment where this research is being conducted. While the grass carp are effectively excluded from test plots by fencing, plantings within the exclosures attract other herbivores such as turtles, muskrats, and ducks, which are capable of getting into the fenced areas. Success in establishing these two native species in Guntersville Reservoir has been low, and has come at a high price. *Potamogeton* establishment has required building fenced exclosures and then continued trapping of turtles and muskrats within the enclosed areas. *Vallisneria* establishment has been even more difficult, requiring that the individual *Vallisneria* plots within the larger exclosure be fenced as well.

Establishment of native floating-leaved and emergent species of macrophytes in *Lyngbya*-infested areas has been more successful. This research, carried out at two *Lyngbya* and one control site, has tested the suitability of seven native plant species for establishment in *Lyngbya*-infestations. Two major conclusions can be drawn. First, by comparing test plots within fenced exclosures and identical unprotected test plots, the absolute necessity of herbivore protection for establishing small populations of native macrophytes at this time is demonstrated. This result is attributed to the apparently high herbivore pressure due to the recent decline in submersed aquatic macrophytes in the reservoir. Second, only three of the seven species tested for establishment were found suitable for growth in *Lyngbya*-dominated areas. These species, *Potamogeton nodosus*, *Nelumbo lutea*, and *Pontederia cordata*, had morphological characteristics that enabled them to withstand the high degree of mechanical disturbance caused by the continuous movement of the large floating mats of *Lyngbya*. Four species were found not to be suitable. *Eleocharis quadrangulata* and *Scirpus validus* were totally destroyed by the movement of the *Lyngbya* mats. The rigid, brittle shoots of these plants were broken repeatedly by the *Lyngbya* movement. Movement of the floating mats occurred in both horizontal and vertical directions relative to the macrophyte shoots and was driven by wind and elevational changes in the reservoir. A few individuals of *Justicia americana* and *Saururus cernuus* survived in the *Lyngbya* areas, but the successful establishment of these species is doubtful.