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Evaluating the Feasibility of Planting Aquatic Plants in Shallow Lakes in the Mississippi Delta

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ABSTRACT

Planting aquatic plants is a technique used to restore native aquatic plants in lakes. However, the feasibility of using this restoration technique in shallow lakes in the Mississippi Delta has not been evaluated. We conducted two exclosure experiments to evaluate the success of planting aquatic plants in a shallow lake in the Mississippi Delta. We planted three emergent and one submersed species in experiment 1 and four submersed species in experiment 2. Each experiment contained a control treatment in which no aquatic plants were planted. We measured physico-chemical characteristics of sediment and water and monitored aquatic plants in each exclosure. No differences in mean sediment and water parameters were observed among planting treatments in either experiment. Squarestem spikerush (*Eleocharis quadrangulata* (Michx.) Roemer & J.A. Schultes) and arrowhead (*Sagittaria latifolia* Willd.) exhibited the greatest mean percentage cover and the lowest probably of extinction in experiment 1. Additionally, blunt spikerush (*Eleocharis obtusa* (Willd.) J.A. Schultes) and squarestem spikerush had the greatest mean stem density in experiment 1. Only mean percentage cover differed among planting treatments in experiment 2, and fragrant water lily (*Nymphaea odorata* Ait.) exhibited a greater mean percentage cover than the control. Our results suggest that the squarestem spikerush and fragrant water lily may be the best candidate species for aquatic plant restoration projects in shallow lakes within the Mississippi Delta.

Key words: lakes, littoral zone, restoration, aquatic plants, active planting, Mississippi.

INTRODUCTION

One past paradigm with respect to restoration of aquatic plants in lakes has centered on the removal of non-native aquatic plants with little consideration for the reestablishment of native aquatic plants (Barko et al. 1986, National Research Council 1992). Undoubtedly, removal of non-native plants will continue to be an integral component of future restoration projects, but the focus needs to shift to the establishment of native aquatic plants (Barko et al. 1986, National Research Council 1992). Planting aquatic plants is one technique used to restore aquatic plants in lakes and wetlands. Specifically, aquatic plants can be established in lakes by planting seeds, propagules (stems and tubers), or whole plants. Previous work has found that planting whole plants is the most effective method of establishing aquatic plants in lakes and wetlands (Hammer 1992, Smart et al. 2005). However, planting whole plants is a time consuming and costly procedure (Hammer 1992). Time and expense can be used most efficiently if project designers know which plant species will exhibit the greatest survival and growth before the initiation of planting.

The feasibility of planting aquatic plants in lakes and reservoirs in the southern United States has been evaluated in Alabama, Oklahoma, and Texas (Table 1). Initial studies in Alabama and Texas (Doyle and Smart 1993, Doyle et al. 1997, Smart et al. 1998) focused on the feasibility of planting submersed aquatic plants with limited efforts devoted to emergent aquatic plants (Table 1). Recent work in Oklahoma and Texas (Dick et al. 2004a, b) expanded evaluation efforts by examining the planting success of an additional eight emergent species and 11 submersed species (Table 1). All 15 aquatic plant species recommended as candidate species for restoration projects (Smart et al. 1996, Smart et al. 2005) have been evaluated at least once (Table 1). Specifically, American eelgrass (*Vallisneria americana* Michx.) and American pondweed (*Potamogeton nodosus* Poir.) were the most frequently evaluated species (Table 1). Unfortunately, a synthesis of the results of previous evaluations is lacking and limited guidance is available regarding the selection of candidate species for restoration efforts.

Many lakes in the Mississippi Delta are impacted by sediment, pesticides, and herbicides as a result of extensive agricultural land use in the region (Duda and Johnson 1984, Guedon and Thomas 2004, Miranda and Lucas 2004). The restoration of aquatic plants within these lakes may reduce turbidity and the amounts of pesticides and herbicides (Bouldin et al. 2004), and provide habitat structure and refugia for aquatic organisms (Dibble et al. 1996). However, information on the feasibility of planting aquatic plants in Mississippi lakes is lacking (Table 1), and the high turbidity levels typically found in shallow lakes in the Mississippi Delta may limit the establishment of aquatic plants. Therefore, we conducted two exclosure experiments from June to September 2002 to evaluate the success of planting aquatic plants in a shallow lake in the Mississippi Delta. Our objectives were to evaluate: (1) the success of planting three emergent species and one submersed species in portions of the littoral zone that dry out during summer low water levels (experiment 1) and (2) the success of planting four submersed species in portions of the littoral zone that remain inundated all year (experiment 2). We measured selected sediment and water parameters to assess whether differences in physical habitat

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TABLE 1. EMERGENT AND SUBMERSED PLANT SPECIES EVALUATED FOR FEASIBILITY OF PLANTING IN SOUTHERN LAKES AND RESERVOIRS, AND THE LOCATION (STATE) WHERE EVALUATIONS WERE CONDUCTED.

Emergent species	State
Bacopa monnieri (L.) Pennell	OK[4], TX[5]
Echinodorus berteroi (Spreng.) Fassett	OK[4], TX[5]
Echinodorus cordifolius (L.) Griseb.	TX[5]
Eleocharis acicularis (L.) Roemer & J.A. Schultes	OK[4], TX[5]
***Eleocharis palustris* (L.) Roemer & J.A. Schultes**	**OK[4], TX[5]**
Eleocharis quadrangulata (Michx.) Roemer & J.A. Schultes	AL[1], OK[4], TX[5]
***Justicia americana* (L.) Vahl**	**AL[1], OK[4], TX[5]**
Polygonum hydropiperoides Michx.	OK[4], TX[5]
***Pontederia cordata* L.**	**AL[1], OK[4], TX[5]**
Sagittaria graminea Michx.	OK[4], TX[5]
Sagittaria latifolia Willd.	OK[4], TX[5]
Saururus cernuus L.	AL[1], OK[4]
***Scirpus validus* Vahl**	**AL[1], OK[4], TX[5]**
Submersed species	State
***Chara vulgaris* L.**	**TX[5]**
Brasenia schreberi J.F. Gmel.	TX[5]
Ceratophyllum demersum L.	OK[4], TX[5]
***Elodea canadensis* Michx.**	**OK[4]**
***Heteranthera dubia* (Jacq.) MacM.**	**OK[4], TX[2, 3, 5]**
***Najas guadalupensis* (Spreng.) Magnus**	**TX[5]**
Nelumbo lutea Willd.	AL[1], OK[4], TX[5]
Nuphar lutea (L.) Sm.	OK[4], TX[5]
***Nymphaea odorata* Ait.**	**OK[4], TX[5]**
***Potamogeton illinoensis* Morong**	**OK[4], TX[5]**
***Potamogeton nodosus* Poir.**	**AL[1], OK[4], TX[2, 3, 5]**
***Potamogeton pectinatus* L.**	**OK[4], TX[5]**
***Potamogeton pusillus* L.**	**TX[5]**
***Vallisneria americana* Michx.**	**AL[1], OK[4], TX[2, 3, 5]**
***Zannichellia palustris* L.**	**TX[5]**

[1]Doyle and Smart 1993, [2]Doyle et al. 1997, [3]Smart et al. 1998, [4]Dick et al. 2004a, [5]Dick et al. 2004b.
Bolded species are those recommended for use in restoration projects by Smart et al. 1996 and Smart et al. 2005.

characteristics differed among planting treatments. We evaluated planting success by comparing mean percentage cover, stem density, and probability of extinction of aquatic plants among planting treatments.

METHODS

Study Site

Lake Charlie Capps is located in the west-central portion of the Mississippi Delta (lat 33°52'N, long 90°57'W) within Bolivar County, Mississippi. The Mississippi Delta is characterized by flat topography, extensive amounts of agricultural land use, and alluvial soils originating from centuries of flooding from the Mississippi River and other rivers in the region (Lohoefener and Altig 1983). Lake Charlie Capps has a surface area of 2.07 km^2 (Nazary and Henke 1986), and a mean water depth of 1.73 m. Turbidity within the lake is greater than mean values observed in other Mississippi Delta lakes (Lucas et al. 2003, Miranda and Lucas 2004). The Bolivar County Conservation League created the lake in 1963 by constructing a levee system around a cypress swamp (Avery 1982). The levee system prevents surface runoff into the lake, and hydrology is maintained by rainfall and a pump and drain system. Two groundwater pumps draw water into the lake, and two drains allow the release of water from the lake. Past aquatic plant management efforts were designed to reduce excessive amounts of coontail (*Ceratophyllum demersum* L.). In May 1996 a whole-lake application of a systemic herbicide [fluridone (1-methyl-3-phenyl-5-[-3(trifluoromethyl) phenyl]-4 (1*H*)-pyridinone)] eradicated all aquatic plants from the lake (Lucas et al. 1999). Aquatic plants were still absent from the lake at the beginning of this study.

Construction of Experimental Exclosures

Experimental exclosures were built to protect planted aquatic plants from wave action and herbivory. Each exclosure was 2 m × 2 m in size and constructed with a 2 m high plastic fence (0.64 cm mesh). Fencing material was supported with metal T-posts. Construction of exclosures began in October 2000 and was completed in June 2001. We selected four locations in the littoral zone of the lake and constructed five exclosures within each location for each experiment (total number of exclosures in each location = 10). Experiment 1 was designed to evaluate the feasibility of establishing three species of emergent plants and one submersed species in shallow areas of the littoral zone that dry out during the summer. Exclosures constructed for this experiment were placed adjacent and parallel to the shoreline, and were located within littoral zone areas that would be dry when lake levels are 0.6 to 0.7 m below the normal lake level of 2.16 m. Experiment 2 was designed to evaluate the feasibility of planting submersed aquatic plants in littoral zone areas that are inundated all year. Exclosures constructed for experiment 2 were also placed parallel to the shoreline, but were positioned further offshore than exclosures in experiment 1. Specifically, these exclosures were placed in locations that would have water depths between 0.9 to 1.1 m at the normal lake level.

Experimental Design and Planting Methods

Previous studies (Doyle and Smart 1993, Doyle et al. 1997, Smart et al. 1998, Dick et al. 2004a, 2004b) evaluating the feasibility of planting aquatic plants in lakes have not accounted for the possible influence of within lake habitat variation. Therefore, we used a randomized block design with location as the block to account for the possible influence of location (i.e., within lake habitat variation) on planting success. Our experimental treatment was type of aquatic plant planted in an exclosure and an unplanted control at each site. We randomly placed one of each planting treatment in each location (block), which results in four replicates of each treatment for experiments 1 and 2. Planting treatments in experiment 1 were: (1) unplanted control; (2) American lotus (*Nelumbo lutea* Willd.); (3) blunt spikerush (*Eleocharis obtusa* (Willd.) J.A. Schultes); (4) arrowhead (*Sagittaria latifolia* Willd.); and (5) squarestem spikerush (*Eleocharis quadrangulata* (Michx.) Roemer & J.A. Schultes). Planting treatments in experiment 2 were: (1) unplanted control; (2) watershield (*Brasenia schreberi* J.F. Gmel.); (3) fragrant water lily (*Nymphaea odorata* Ait.); (4) American lotus; and (5) American pondweed (*Potamogeton no-*

dosus Poir.). American lotus was planted in experiments 1 and 2 because there was local interest in reestablishing this aquatic plant due to its historical occurrence in the lake.

We followed planting methods recommended for aquatic plants in southern lakes and reservoirs (Smart et al. 1996, 1998). Aquatic plants used in experiments 1 and 2 were native species that we were able to obtain locally. We collected plants from field sites and transported them to temporary holding tanks, so that we could monitor them to ensure that non-native plants were not included with the collections. We selected the healthiest looking specimens, such as those with sturdy stem and leaf structure and exhibiting root growth, from the holding tanks for planting. Specimens were placed into planting pots containing a mixture of peat, topsoil, ammonium sulfate, and pea gravel. The use of planting pots helped maintain root integrity and facilitated transport from the holding tanks to the nursery area within the lake. We held plants in a nursery area prior to planting to reduce stress on the plants by allowing acclimization to the lake habitat conditions (Smart et al. 1996). Plants were planted in exclosures by first excavating a small depression in the lake sediment by hand. Plants and potting materials attached to the roots were then removed from the pots, placed into the depression, and covered with lake sediment up to the root collar. We planted 10 specimens of each species within experimental exclosures designated to receive aquatic plants in summer of 2001 and June 2002. A total of 640 plants were planted as part of this study.

Sediment Properties, Water Chemistry, and Water Depths

We measured selected physicochemical properties of lake sediments and water within each exclosure in both experiments so we could determine if potential differences in plant growth and establishment among planting treatments could be attributed to selected physical habitat characteristics. Sediment samples were collected in October 2000 after the locations of all 40 exclosures were delineated. Three sediment samples were taken from each exclosure. Sediment samples were placed in sealed plastic bags and transported to the laboratory. Sediment samples were oven dried at 30.6°C, ground, and passed through a sieve (250 micron) in preparation for analyses. Sediment pH was measured with a pH meter on a 1:1 mixture (by weight) of sediment and distilled water. Calcium, magnesium, potassium, and sodium were measured using the ammonium acetate extraction method (Carter 1993), and phosphorus was measured with the Mehlich III extraction method (Carter 1993). Extractable nitrogen and carbon were measured with an organic elemental analyzer.

We used a multiparameter meter to measure pH, dissolved oxygen, temperature, turbidity, and conductivity of the water *in situ* within each of the 40 exclosures. Water depths in each exclosure were measured with a meter stick. We measured water chemistry and depths concurrently with assessments of aquatic plants. Specifically, water chemistry and water depths were measured eight times from June to September 2002.

Aquatic Plants

Monitoring of aquatic plants began after transplants were planted within experimental exclosures in June 2002. We measured aquatic plants eight times from June to September 2002. Plant growth was assessed by measuring percentage cover and stem density of aquatic plants in experimental exclosures. A 1 m^2 quadrat divided into 0.1 m^2 grids with string was used for estimating percentage cover and stem density. The quadrat was placed in each of the four 1 m^2 sections within the exclosure, and we identified the plants and enumerated the number of grids containing plants. Percentage cover is the percent of total surface area within the exclosure containing plants. Additionally, we randomly selected twelve 0.1 m^2 grids for measurements of stem density. We identified the plants and counted the number of stems in each randomly selected grid.

We used presence and absence information from each sampling period to calculate the probability of extinction for each of planted species within experimental exclosures (Gotelli and Taylor 1999). The probability of extinction (PE) provides a measure of the persistence of planted aquatic plants within the exclosures. The index is calculated as follows:

> PE = number of times an exclosure was occupied in sampling period (t) but was unoccupied the following sampling period (t+1)/total number of times the exclosure was occupied in sampling period (t)

This index is expressed in percentages and scores range from 0 to 1. For example, a score of 0.2 indicates that there is a 20% probability that an aquatic plant will not survive the sampling season. Aquatic plants having the least probability of extinction scores are those exhibiting the greatest persistence in the exclosures during the study period.

Statistical Analyses

Prior to statistical testing we pooled data from the eight sampling trips by calculating the means of all response variables except probability of extinction for each planting treatment in experiments 1 and 2. The probability of extinction index summarizes presence and absence information from all sampling trips and pooling the data was not necessary. Percentage cover and probability of extinction were arcsine transformed to meet the assumptions of analysis of variance (ANOVA) (Zar 1984). We conducted a two factor randomized block design ANOVA coupled with the Tukey test to assess differences in mean sediment properties, water chemistry, water depths, percentage cover, stem density, and probability of extinction among planting treatments in experiment 1 and experiment 2. Two factor randomized block design ANOVAs were conducted with Statistix (Analytical Software 1999), and a significance level of $p < 0.05$ was used for all statistical tests.

RESULTS

Sediment Properties, Water Chemistry, and Water Depths

Sediment properties among planting treatments were similar in experiments 1 and 2 (Table 2). No differences in mean pH ($f_{4, 12} = 0.26$, $p = 0.90$), magnesium ($f_{4, 12} = 1.04$, $p = 0.43$), potassium ($f_{4, 12} = 0.77$, $p = 0.56$), calcium ($f_{4, 12} = 0.20$, $p = 0.94$), sodium ($f_{4, 12} = 0.07$, $p = 0.99$), phosphorus ($f_{4, 12}$ =

TABLE 2. MEANS (STANDARD ERRORS) OF SEDIMENT PROPERTIES AMONG PLANTING TREATMENTS IN EXPERIMENT 1 AND EXPERIMENT 2 IN LAKE CHARLIE CAPPS, MISSISSIPPI, 2000. ABBREVIATIONS ARE: ALO—AMERICAN LOTUS; BSR—BLUNT SPIKERUSH; ARH—ARROWHEAD; SSR—SQUARESTEM SPIKERUSH; WSH—WATERSHIELD; FWL—FRAGRANT WATER LILY; APW—AMERICAN PONDWEED.

Experiment 1	Control	ALO	BSR	ARH	SSR
pH	8.1 (0.13)	8.1 (0.11)	8.1 (0.12)	8.1 (0.14)	7.9 (0.21)
Magnesium (ppm)	2480.1 (120.67)	2561.4 (149.89)	2620.0 (129.97)	2517.8 (120.95)	2394.5 (133.55)
Potassium (ppm)	390.2 (13.95)	404.4(14.85)	422.0 (26.86)	375.6 (16.25)	403.3 (21.89)
Calcium (ppm)	6021.4 (444.00)	5881.0 (461.25)	5655.5 (280.73)	5655.0 (268.93)	5785.1 (122.42)
Sodium (ppm)	78.8 (4.88)	80.1 (2.39)	79.2 (4.17)	78.0 (4.57)	80.2 (2.83)
Phosphorus (ppm)	2.7 (0.44)	3.1 (0.69)	3.2 (0.64)	2.9 (0.57)	3.5 (0.44)
Total Nitrogen (%)	0.1 (0.00)	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)	0.1 (0.00)
Carbon (%)	0.9 (0.05)	1.4 (0.18)	1.1 (0.12)	1.1 (0.13)	0.9 (0.06)
Experiment 2	Control	WSH	FWL	ALO	APW
pH	8.0 (0.10)	7.9 (0.12)	8.1 (0.10)	8.0 (0.12)	8.1 (0.20)
Magnesium (ppm)	2408.0 (87.94)	2414.9 (57.88)	2486.5 (94.17)	2463.9 (159.59)	2374.9 (27.01)
Potassium (ppm)	367.9 (16.68)	368.7 (20.99)	381.6 (25.23)	360.9 (31.02)	368.7 (32.14)
Calcium (ppm)	5497.7 (140.70)	5339.9 (94.99)	5877.1 (249.31)	5638.1 (215.22)	5533.1 (271.79)
Sodium (ppm)	69.4 (1.85)	68.5 (3.65)	69.2 (4.35)	67.5 (6.28)	69.2 (4.62)
Phosphorus (ppm)	3.1 (0.71)	2.7 (0.66)	3.5 (0.75)	2.5 (0.62)	2.7 (0.81)
Total Nitrogen (%)	0.1 (0.01)	0.1 (0.20)	0.1 (0.01)	0.1 (0.10)	0.1 (0.02)
Carbon (%)	1.2 (0.18)	1.7 (0.39)	1.1 (0.10)	1.5 (0.18)	1.5 (0.33)

1.59, $p = 0.24$), total nitrogen ($f_{4, 12} = 0.98$, $p = 0.46$), and carbon ($f_{4, 12} = 2.44$, $p = 0.10$) were observed among the five planting treatments in experiment 1 (Table 2). Similarly, no differences in mean pH ($f_{4, 12} = 1.40$, $p = 0.29$), magnesium ($f_{4, 12} = 0.38$, $p = 0.82$), potassium ($f_{4, 12} = 0.11$, $p = 0.98$), calcium ($f_{4, 12} = 0.86$, $p = 0.52$), sodium ($f_{4, 12} = 0.05$, $p = 0.99$), phosphorus ($f_{4, 12} = 1.78$, $p = 0.20$), total nitrogen ($f_{4, 12} = 3.08$, $p = 0.06$), and carbon ($f_{4, 12} = 2.87$, $p = 0.07$) were observed among planting treatments in experiment 2 (Table 2).

Water chemistry and water depths among planting treatments were similar in experiments 1 and 2 (Table 3). No differences in mean pH ($f_{4, 12} = 0.72$, $p = 0.60$), dissolved oxygen ($f_{4, 12} = 2.07$, $p = 0.15$), water temperature ($f_{4, 12} = 0.07$, $p = 0.99$), turbidity ($f_{4, 12} = 1.3$, $p = 0.33$), conductivity ($f_{4, 12} = 1.08$, $p = 0.41$), and water depth ($f_{4, 12} = 0.14$, $p = 0.96$) were observed among planting treatments in experiment 1 (Table 3). Additionally, no differences in mean pH ($f_{4, 12} = 1.44$, $p = 0.28$), dissolved oxygen ($f_{4, 12} = 1.29$, $p = 0.33$), water temperature ($f_{4, 12} = 1.13$, $p = 0.39$), turbidity ($f_{4, 12} = 0.50$, $p = 0.74$), conductivity ($f_{4, 12} = 1.62$, $p = 0.23$), and water depth ($f_{4, 12} = 0.49$, $p = 0.74$) were observed among planting treatments in experiment 2 (Table 3).

Aquatic Plants

Mean percentage cover, stem density, and the probability of extinction differed among planting treatments in experiment 1 (Figure 1). Arrowhead and squarestem spikerush exhibited a greater mean percentage cover ($f_{4, 12} = 14.43$, $p < 0.001$) than the control (Figure 1). The blunt spikerush and the squarestem spikerush exhibited a greater mean stem density ($f_{4, 12} = 8.71$, $p = 0.002$) than the control (Figure 1).

TABLE 3. MEANS (STANDARD ERRORS) OF WATER CHEMISTRY VARIABLES AND WATER DEPTH AMONG PLANTING TREATMENTS IN EXPERIMENT 1 AND EXPERIMENT 2 IN LAKE CHARLIE CAPPS, MISSISSIPPI, 2002. ABBREVIATIONS ARE: ALO—AMERICAN LOTUS; BSR—BLUNT SPIKERUSH; ARH—ARROWHEAD; SSR—SQUARESTEM SPIKERUSH; WSH—WATERSHIELD; FWL—FRAGRANT WATER LILY; APW—AMERICAN PONDWEED.

Experiment 1	Control	ALO	BSR	ARH	SSR
pH	8.4 (0.10)	8.5 (0.07)	8.5 (0.10)	8.5 (0.09)	8.5 (0.09)
Dissolved oxygen (mg/L)	6.2 (0.49)	6.3 (0.45)	6.3 (0.46)	6.4 (0.50)	6.5 (0.47)
Water temperature (°C)	31.4 (0.40)	31.4 (0.45)	31.4 (0.42)	31.4 (0.46)	31.4 (0.44)
Turbidity (NTU)	49.6 (9.52)	43.0 (5.40)	41.3 (6.01)	46.7 (5.23)	52.1 (8.86)
Conductivity (µhos/sec)	305.0 (2.01)	304.4 (2.40)	304.7 (1.99)	302.5 (2.16)	300.1 (1.72)
Water depth (m)	0.1 (0.04)	0.1 (0.05)	0.1 (0.05)	0.1 (0.05)	0.1 (0.05)
Experiment 2	Control	WSH	FWL	ALO	APW
pH	8.4 (0.09)	8.3 (0.09)	8.3 (0.10)	8.4 (0.07)	8.4 (0.10)
Dissolved oxygen (mg/L)	5.8 (0.48)	6.0 (0.52)	5.8 (0.55)	6.1 (0.52)	6.0 (0.54)
Water temperature (°C)	30.5 (0.40)	30.7 (0.45)	30.6 (0.41)	30.7 (0.41)	30.7 (0.47)
Turbidity (NTU)	38.9 (2.83)	35.3 (3.08)	40.6 (7.21)	38.7 (7.00)	39.9 (6.75)
Conductivity (µhos/sec)	309.4 (2.97)	309.4 (1.30)	310.4 (2.15)	310.7 (2.32)	307.1 (3.88)
Water depth (m)	0.5 (0.04)	0.5 (0.03)	0.5 (0.04)	0.5 (0.08)	0.5 (0.04)

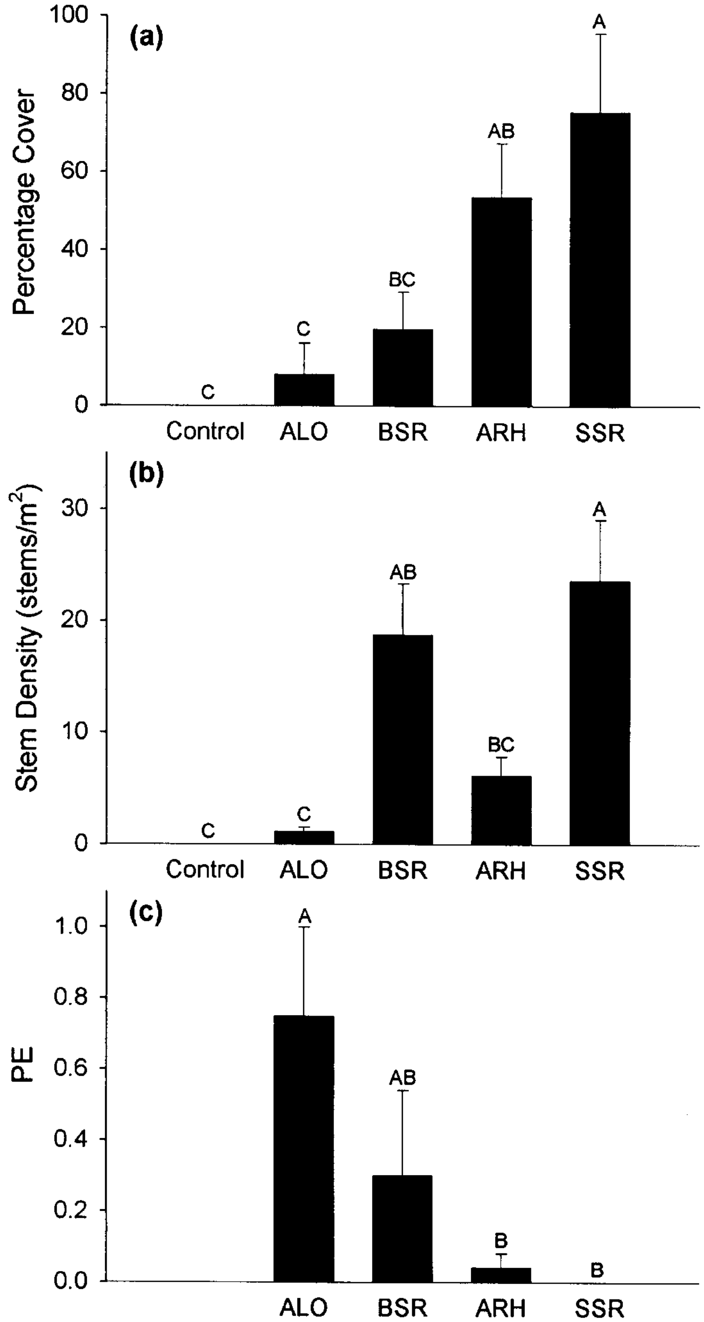

Figure 1. Means and standard error of percentage cover (a), stem density (b), and probability of extinction (PE) (c) among planting treatments in experiment 1 in Lake Charlie Capps, Mississippi, 2002. Different letters above the bars indicate significant difference ($p < 0.05$) in means among planting treatments. Abbreviations are: ALO—American lotus; BSR—blunt spikerush; ARH—arrowhead; SSR—squarestem spikerush.

Arrowhead and squarestem spikerush also exhibited the least probability of extinction ($f_{3, 12} = 5.08$, $p = 0.03$), and are most likely to persist for the duration of the monitoring period (Figure 1). Additionally, none of the four species that were planted as part of experiment 1 grew in the control exclosures during this study (Figure 1).

Mean percentage cover differed among planting treatments in experiment 2 (Figure 2). Mean percentage cover of fragrant water lily was greater ($f_{4, 12} = 7.20$, $p = 0.003$) than the control (Figure 2). No differences in mean stem density ($f_{4, 12} = 2.17$, $p = 0.14$) and probability of extinction ($f_{3, 12} = 3.76$, $p = 0.05$) among planting treatments were observed (Figure 2). Furthermore, none of the four species planted as part of experiment 2 grew in the control exclosures during this study (Figure 2).

DISCUSSION

Sediment Properties, Water Chemistry, and Water Depths

The establishment and growth of aquatic plants is influenced by sediment chemistry, water chemistry, and water depths (Barko et al. 1986, Hammer 1992). Observed values of sediment and water properties in Lake Charlie Capps are within the range of values observed in other shallow lakes in the Mississippi Delta (Cooper et al. 1982, Cooper 1987, Miranda et al. 2001). Additionally, mean water depths observed in both experiments (Table 3) were similar to recommended water depths for planting emergent and submersed plant species in the southern United States (Smart et al. 2005). Differences in sediment properties, water chemistry, and water depths among planting treatments in experiments 1 and 2 were not observed (Tables 2 and 3). Therefore, we infer that observed differences in percentage cover, stem density, and probability of extinction of aquatic plants among planting treatments in Lake Charlie Capps were not influenced by the measured physico-chemical characteristics.

Aquatic Plants

Our success with planting squarestem spikerush is consistent with research conducted in Guntersville Reservoir (Alabama), Arcadia Lake (Oklahoma), and Cooper Lake (Texas) (Doyle and Smart 1993, Dick et al. 2004a, 2004b). Doyle and Smart (1993) successfully established squarestem spikerush within an exclosure at water depths of 0.5 m in Guntersville Reservoir. Transplants of squarestem spikerush were also successfully established in exclosures having water depths between 0 and 0.3 m in Arcadia Lake and Cooper Lake (Dick et al. 2004a, 2004b). Our results in conjunction with those of previous assessments (Doyle and Smart 1993, Dick et al. 2004a, 2004b) suggest the squarestem spikerush would be the most viable candidate for planting within water depths <0.5 m in shallow Mississippi Delta lakes and a suitable candidate for other lake restoration projects in the southern United States.

Our results also suggested that arrowhead and blunt spikerush may be a secondary candidate species for planting in water depths <0.5 m within shallow Mississippi Delta lakes. Our successful results with planting arrowhead are concurrent with results from Arcadia Lake (Dick et al. 2004a), but not Cooper Lake (Dick et al. 2004b). Arrowhead was successfully established in shallow water areas with and without exclosures in Arcadia Lake (Dick et al. 2004a). Conversely, arrowhead exhibited poor recovery from drought conditions and did not spread beyond the exclosures in Cooper Lake (Dick et al. 2004b). Water levels in Cooper Lake were main-

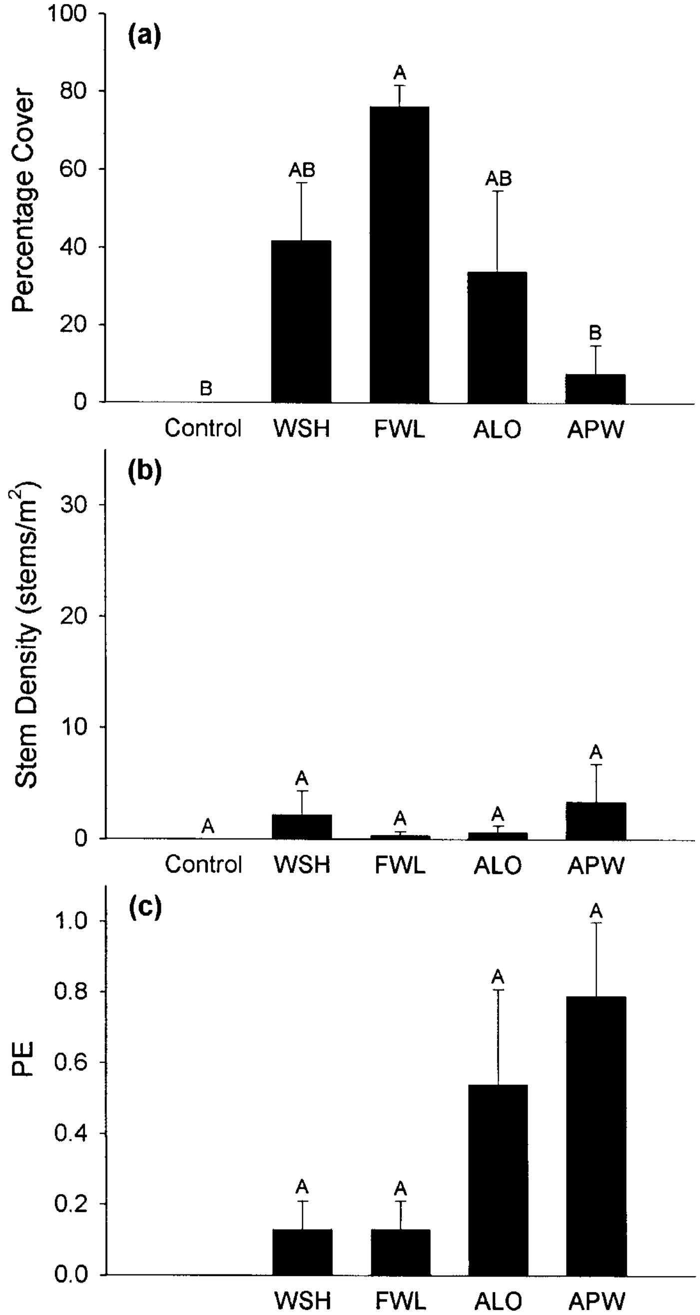

Figure 2. Means and standard error of percentage cover (a), stem density (b), and probability of extinction (PE) (c) among planting treatments in experiment 2 in Lake Charlie Capps, Mississippi, 2002. Different letters above the bars indicate significant difference ($p < 0.05$) in means among planting treatments. Abbreviations are: WSH—watershield; FWL—fragrant water lily; ALO—American lotus; APW—American pondweed.

tained 1.2 m below the normal water level for one year during the study, which may have contributed to the poor planting success of arrowhead. Additionally, our study is the first to examine the feasibility of planting blunt spikerush in southern lakes (Table 1), and more research is needed to evaluate its suitability for use in lake restoration projects.

Our results from experiment 2 suggest that fragrant water lily is the most viable species for planting in water depths of 0.5 m in shallow Mississippi Delta lakes. Our successful results with planting fragrant water lily are consistent with the results of previous studies in Arcadia Lake (Dick et al. 2004a) and Cooper Lake (Dick et al. 2004b). Transplants of fragrant water lily were successfully established after planting within protective exclosures having water depths between 0.3 and 0.9 m in both lakes (Dick et al. 2004a, 2004b). However, fragrant water lily exhibited poor tolerance to low water levels and dessication in these lakes (Dick et al. 2004a, 2004b). These results suggest the possibility that poor survival of fragrant water lily transplants may occur if plants are subjected to low water levels following planting.

Watershield exhibited reduced percentage cover compared with the fragrant water lily, but exhibited similar probability of extinction scores (i.e., persistence) (Figure 2). The similarity in probability of extinction suggested that watershield might be a potential secondary candidate species to consider for use in restoration projects in shallow Mississippi Delta lakes. However, watershield exhibited poor survival in Cooper Lake and was eliminated from consideration as a candidate species after the first year of the study (Dick et al. 2004b). These mixed results suggest that more research is needed before recommending the use of watershield in lake restoration projects.

Poor survival of American lotus transplants was observed in Guntersville Reservoir, Arcadia Lake, and Cooper Lake (Doyle and Smart 1993, Dick et al. 2004a, 2004b). Doyle and Smart (1993) were not able to establish American lotus within an exclosure having water depths of 0.7 m in Guntersville Reservoir. Additionally, survival of transplanted American lotus was reduced further in exclosures containing floating mats of blue-green algae (Doyle and Smart 1993). Poor survival of American lotus transplants was observed after planting within exclosures at water depths between 0.3 and 0.9 m in Arcadia Lake (Dick et al. 2004a) and Cooper Lake (Dick et al. 2004b). We also had poor success with transplanting American lotus, as percentage cover and stem density in experiments 1 and 2 did not differ from the unplanted controls (Figures 1 and 2). Conversely, Doyle and Smart (1993) successfully established American lotus in an exclosure within Guntersville Reservoir using acid scarified seed. Future planting efforts of American lotus in the southern United States should explore the use of acid scarified seeds and other planting methods instead of planting whole plants.

The poor success with planting American pondweed observed in our study is not in agreement with the results of previous work conducted in Guntersville Reservoir, Arcadia Lake, and Cooper Lake (Doyle and Smart 1993, Doyle et al. 1997, Smart et al. 1998, Dick et al. 2004a, b). American pondweed is one of the more frequently evaluated aquatic plants (Table 1). The floating leaves of American pondweed enable it to establish in shallow turbid waters, and it is thought to be more tolerant to herbivory than other submersed species (Smart et al. 2005). American pondweed has been successfully established in protected exclosures with water depths between 0.6 and 1.3 m (Doyle and Smart 1993, Doyle et al. 1997, Smart et al. 1998, Dick et al. 2004a, 2004b). Additionally, Dick et al. (2004a) planted seven submersed species in Arcadia Lake, and the greatest planting success occurred with American pondweed (Dick et al. 2004a). The poor survival observed in our study may be due to the planting methodology. Previous studies (Doyle et al. 1997, Dick et al. 2004a, 2004b) evaluated the success of American pondweed planted within planting pots (peat and plastic), while we removed plants from the pot prior to planting within the lake. Doyle and Smart (1993) observed greater survival of peat pot planted American eelgrass compared to the survival of bare-rooted specimens. The success of planting American pondweed may also be improved if transplants are planted within planting pots rather than planting bare-rooted specimens.

Shallow lakes in the Mississippi Delta, such as Lake Charlie Capps, are often the most impacted and in the greatest need of restoration (Miranda and Lucas 2004). Overall, our results suggest that it is feasible to establish native aquatic plants within shallow Mississippi Delta lakes despite the high turbidity levels characteristic of these lakes. Our results also suggest that the squarestem spikerush and fragrant water lily will be the best candidate species to plant in shallow lakes in the Mississippi Delta. Additionally, our results suggest that planting will be necessary to successfully establish these two species because they did not grow in the unplanted controls (Figures 1 and 2). Notably, our results are representative of the growth and establishment expected of these aquatic plants within exclosures that protect plants from herbivory and within lakes that experience either no herbivory or low levels of herbivory. Providing newly established plants protection from herbivores is an essential component of lake restoration projects attempting to reestablish aquatic plants (Smart et al. 1996). Lake Charlie Capps and many other lakes in the Mississippi Delta contain common carp (*Cyprinus carpio* L.) and grass carp (*Ctenopharyngodon idella* Valenciennes), and removal of these non-native fishes will also assist with the restoration of native aquatic plants (Fernandez et al. 1998). Future research is needed to evaluate whether the large-scale coverage of aquatic plants through the establishment of protected founder colonies is feasible in shallow lakes in the Mississippi Delta that experience excessive levels of herbivory.

Shallow lakes are important ecologically and sociologically worldwide, and information that contributes to the refinement of restoration efforts in these aquatic habitats is needed (Perrow et al. 1997). The reestablishment and conservation of aquatic plants within shallow lakes is a vital component for successful restoration of shallow lakes (van Nes et al. 2002). Past research in eutrophic shallow lakes in Europe has examined the effectiveness of using biomanipulation (i.e., removal of zooplanktivorous fish) for the restoration of aquatic plants (Moss 1990, Strand 1999). However, information on the effectiveness of planting aquatic plants in shallow lakes outside of United States is limited (but see Qiu et al. 2001 and Lauridsen et al. 2003). The aquatic plants that we identified as the best candidate species (squarestem spikerush and fragrant water lily) for Mississippi Delta lakes are also native to parts of Canada, the northeastern United States, and central America (Flora of North America Editorial Committee 1993). Therefore, our results also provide guidance for lake managers and restoration practitioners in these areas attempting to restore aquatic plants in shallow lakes.

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