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Response of Littoral Fishes in Upper Lake Marion, South Carolina Following Hydrilla Control by Triploid Grass Carp

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ABSTRACT

A seven-year study in upper Lake Marion, South Carolina evaluated the response of fishes to hydrilla (*Hydrilla verticillata* (L. f.) Royle) removal by triploid grass carp (*Ctenopharyngodon idella* Valenciennes). A boat-mounted electroshocker was used to quantify relative abundance and species composition of fishes at 10 permanent locations distributed throughout the upper lake. A total of 16,306 fish representing 64 species were collected. The taxonomically dominant family was Centrarchidae and the numerically dominant family was Clupeidae. There were significant differences in catch between years with high and low hydrilla coverage. Littoral fishes, especially Centrarchidae, increased as hydrilla decreased from a maximum of 4,700 ha (approximately 50% of the surface area) to less than 100 ha by 1994. Mean lengths of most littoral species were similar during the study. Despite substantial declines in hydrilla, other forms of cover persisted during the study providing an intermediate level of structural complexity. Consequently, grass carp effectively controlled hydrilla but did not create any detectable negative effects on the littoral fish assemblage during the study.

Key words: plant coverage, electroshocking, largemouth bass, multi-year.

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INTRODUCTION

Hydrilla became established in upper Lake Marion during the early 1980's (de Koslowski 1994) and by 1988 had colonized over 4,000 ha. In 1989, triploid grass carp were stocked into upper Lake Marion to control hydrilla. By 1994, almost 600,000 fish had been released into the Santee Cooper system (Lakes Marion, Moultrie, and the connecting canal). With an annual mortality of approximately 20%, the 1994 density of triploid grass carp in the Santee Cooper system was estimated at 17 fish per vegetated ha (Morrow et al. 1997). Extensive surface coverage of hydrilla persisted through 1991, began to decline in 1992, and was reduced to less than 60 ha in upper Lake Marion by 1994 (S. de Kozlowski, South Carolina Department of Natural Resources, personal communication).

Triploid grass carp have also been found to be an effective biocontrol technique in other water bodies (Allen and Wattendorf 1987, Wattendorf and Anderson 1987). However, achieving appropriate densities of grass carp can be difficult, and stocking results can vary from no control to total elimination of vegetation (Sutton 1977, Leslie et al. 1987, Santha et al. 1991, Kirk 1992). Adverse impacts on fish communities, particularly sport fishes, are commonly cited as an environmental concern (Fedorenko and Fraser 1978, Gasaway 1978, Ware and Gasaway 1978, Bain 1993). Angling is an important recreational activity in the Santee Cooper system (Sample 1990) as well as in most vegetated water bodies. Largemouth bass (*Micropterus salmoides* Lacepède) anglers prefer to fish around aquatic vegetation, particularly in areas devoid of any other cover (Wilde et al. 1992, Maceina and Reeves 1996). Consequently, any control activities, particularly using grass carp, are controversial because of potential negative effects on angling.

We sampled fish in upper Lake Marion for seven years to evaluate effects of decreasing hydrilla coverage on fish abundance. Unlike unvegetated water bodies colonized by exotic plants, upper Lake Marion had substantial amounts of standing timber and native aquatic plants prior to the establishment of hydrilla. Electroshocking was used to determine relative abundance of littoral fishes from 1988 when hydrilla dominated most of the littoral zone, to 1994 when hydrilla was virtually eliminated. Relative abundance of fish species, including largemouth bass, were compared among years to determine long-term response of the fish community to large-scale changes in vegetation coverage.

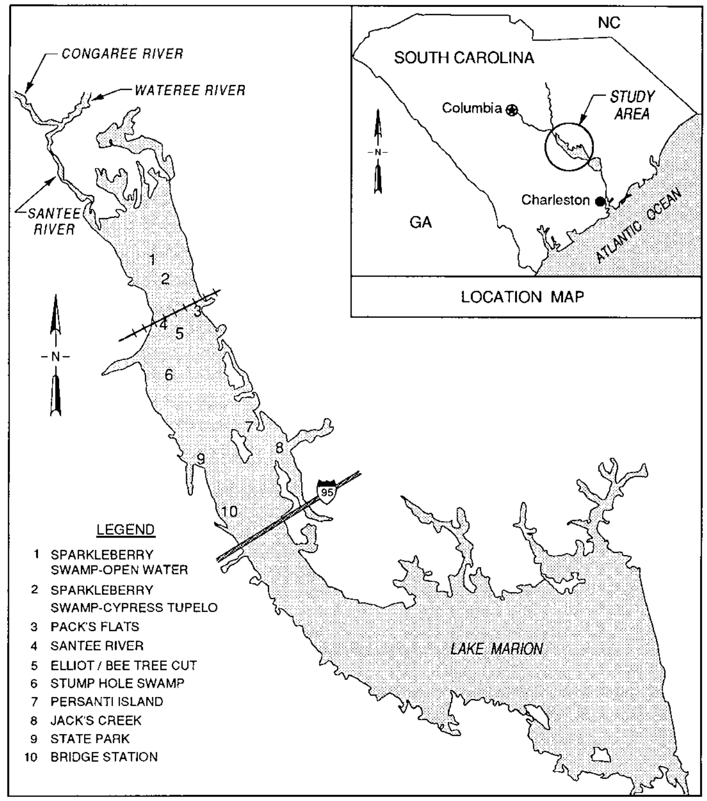

Figure 1. Location of electroshocking sampling stations in upper Lake Marion, South Carolina.

MATERIALS AND METHODS

The 70,000 ha Santee Cooper system was created in 1941 for hydropower and flood control. The study site, upper Lake Marion, is approximately 10,000 ha located from the confluence of the Wateree and Congaree Rivers downstream to the Interstate 95 bridge (Figure 1). This portion of the lake is mostly shallow (<2 m deep) with substantial amounts of standing timber and has historically supported abundant native aquatic vegetation. During the study, the dominant submersed aquatic vegetation was hydrilla but other aquatic species included Brazilian elodea (*Egeria densa* Planch.), coontail (*Ceratophyllum demersum* L.), slender naiad (*Najas minor* All.), pondweed (*Potamogeton* spp.), and water primrose (*Ludwigia* spp.). Coverage of submersed vegetation visible from the surface was estimated yearly (except for 1989) from either aerial photography or maps prepared from overflights. Ground truth surveys were conducted to verify maps. The estimated coverage for 1988, 1990, 1991, 1992, 1993, and 1994 was 4,170 4,800, 4,700, 1,580, 323, and 60 ha, respectively (S. de Kozlowski, South Carolina Department of Natural Resources, personal communication). Coverage for 1989 was interpolated using 1988 and 1990 estimates.

Permanent sites were distributed throughout upper Lake Marion to represent the different levels of hydrilla coverage (Figure 1). Sites 1 and 2 were located at the extreme upper end of the lake, called Sparkleberry Swamp; surface coverage of hydrilla was moderate. Site 3 was located on the main stem of the Santee River near a railroad trestle and had the least amount of plants. The remaining sites had extensive hydrilla coverage prior to elimination by grass carp. Site 4 was situated between Pack's and Elliott's flats; Site 5 was located at Elliott/Bee cut; and site 6 was located in Stump Hole Swamp where herbicides had been used to control hydrilla. Sites 7 and 8, Persanti Island and Jack's Creek, were added in 1989 and sites 9 and 10 found near the State Park and Interstate 95 bridge, were added in 1990. Sampling locations within each site remained the same throughout the study.

A boat-mounted electroshocker using pulsed, direct current of approximately 400 v at 3 to 6 amps was used to collect fish. Each site was sampled for 15 min on each sampling date and two dippers attempted to retrieve all fish. Except in 1988, each site was repeatedly sampled during the plant growing season (April through November) resulting in the following sample size: 1988 = 5, 1989 = 16, 1990 = 45, 1991 = 40, 1992 = 10, 1993 = 20, 1994 = 40. Electroshocking usually occurred in boat lanes adjacent to plant beds or in sub-surface vegetated zones; dense mats of vegetation were avoided because of a lower dipping efficiency in these habitats. All stunned fish were identified, counted, measured for total length, and released.

Because electroshocking is a sampling technique for shallow waters, littoral species are more vulnerable than pelagic species (Reynolds 1983). Thus, catch-per-unit-effort (CPUE, 15 min shocking) was statistically analyzed for the following taxa: all species combined, all littoral species combined, and individual littoral species commonly collected during the study (>0.8% of total number collected); individual pelagic species were excluded. Catch-per-unit-effort was log transformed to adjust for heterogeneity of variances. After log transformation, normality was verified using the Shapiro-Wilk statistic (SAS 1985).

Catch-per-unit-effort was compared between high (>4,000 ha, 1989-1990) and low (<500 ha, 1993-1994) hydrilla coverage using a repeated-measures analysis of variance. This procedure was selected because observations at fixed stations within each time period were not independent (Maceina et al. 1994). In addition to similar sample sizes, time periods represented pretreatment and posttreatment conditions relative to vegetation control by grass carp. The transition years of 1991-1992 were excluded to increase the likelihood that 1989-1990 and 1993-1994 were independent samples. Mean lengths of the 10 most common species were similarly tested. Statistical significance was set at $P < 0.1$ because of high variability associated with electroshocking data and the patchy distribution of fishes in aquatic plants.

RESULTS

We collected 16,306 fish representing 64 species in 176, 15-min electroshocking samples (Table 1). The taxonomically dominant family was Centrarchidae, comprising 15 species and accounting for 22% of the total number of fish collected. The numerically dominant family was Clupeidae, comprising five species and accounting for 37% of the total number of fish collected. Other common families included Cyprinidae and Catostomidae. Dominant species (≥4%), in decreasing order of abundance, were: threadfin shad (*Dorosoma petenense* Günther), golden shiner (*Notemigonus crysocleucas* Mitchill), gizzard shad (*Dorosoma cepedianum* Lesuer), largemouth bass, bluegill (*Lepomis macrochirus* Rafinesque), eastern silvery minnow (*Hybognathus regius* Girard), blueback herring (*Alosa aestivalis* Mitchill), redear sunfish (*Lepomis microlophus* Günter), and inland silverside (*Menidia beryllina* Cope).

Number of species collected during high and low hydrilla coverage was similar (51 and 50 species, respectively). However, mean catch of all species combined significantly increased during low hydrilla coverage (Table 2). Littoral fishes showed similar results. Frequently collected littoral species (>0.8% of total catch) that increased significantly after hydrilla declined included bowfin (*Amia calva* Linnaeus), golden shiner, lake chubsucker (*Erimyzon sucetta* Lacepède), bluegill, redear sunfish, largemouth bass, and yellow perch (*Perca flavescens* Mitchill). Mean catch of coastal shiner (*Notropis petersoni* Fowler) and black-spotted sunfish (*Lepomis punctatus* Valenciennes) also increased significantly during low hydrilla coverage, but to a lesser degree. There was no significant difference in mean catch of chain pickerel (*Esox niger* Lesueur) between the two time periods.

Of the ten frequently collected littoral species, total length of coastal and golden shiners were significantly higher during low hydrilla coverage (Figure 2). However, mean total length (± SD) of largemouth bass was significantly higher during high hydrilla coverage (207 mm ± 130), compared to low coverage (180 mm ± 137). There were no significant differences in total length for the remaining seven littoral species.

DISCUSSION

Effects of large-scale control of submersed aquatic plants on fishes are limited to a few conflicting studies (Dibble et al. 1996). Bailey (1978) suggested that variables such as weather,

TABLE 1. FISHES COLLECTED AT UPPER LAKE MARION, SOUTH CAROLINA FROM 1988-1994 USING A BOAT-MOUNTED ELECTROSHOCKER. TOTAL NUMBER COLLECTED AND HABITAT GUILD ARE INDICATED (L = LITTORAL, L/P = LITTORAL/PELAGIC, P = PELAGIC). ONLY LITTORAL (L AND L/P) SPECIES REPRESENTING MORE THAN 0.8% OF TOTAL NUMBER COLLECTED (>16 INDIVIDUALS), EXCLUDING GRASS CARP, WERE INCLUDED IN STATISTICAL ANALYSIS.

Family and Species	Total Number Collected	Habitat Guild
Lepisosteidae		
Longnose gar (*Lepisosceus osseus* Linnaeus)	173	P
Amiidae		
Bowfin (*Amia calva* Linnaeus)	235	L
Anguillidae		
American eel (*Anguilla rostrata* Lesueur)	3	L/P
Clupeidae		
Blueback herring (*Alosa aestivalis* Mitchill)	771	P
Hickory shad (*A. mediocris* Mitchill)	3	P
American shad (*A.sapidissima* Wilson)	260	P
Gizzard shad (*Dorosoma cepedianum* Lesuer)	1718	P
Threadfin shad (*D. petenense* Günther)	3333	P
Cyprinidae		
Grass carp (*Ctenopharyngodon idella* Valenciennes)	25	L/P
Whitefin shiner (*Cyprinella nivea* Cope)	18	L
Common carp (*Cyprinus carpio* Linnaeus)	51	P
Eastern silvery minnow (*Hybognathus regius* Girard)	964	P
Golden shiner (*Notemigonus crysoleucas* Mitchill)	1828	L/P
Ironcolor shiner (*Notropis chalybaeus* Cope)	3	L
Spottail shiner (*N. hudsonius* Clinton)	9	L
Taillight shiner (*N. maculatus* Hay)	73	L/P
Coastal shiner (*N. petersoni* Fowler)	367	L
Fathead minnow (*Pimephales promelas* Rafinesque)	1	L
Creek chub (*Semotilus atromaculatus* Mitchill)	3	L/P
Catostomidae		
White sucker (*Catostomus commersoni* Lacepède)	2	P
Creek chubsucker (*Erimyzon oblongus* Mitchill)	3	L
Lake chubsucker (*E. sucetta* Lacepède)	412	L
Highfin carpsucker (*Carpiodes velifer* Rafinesque)	2	P
Smallmouth buffalo (*Ictiobus bubalus* Rafinesque)	1	P
Spotted sucker (*Minytrema melanops* Rafinesque)	276	P
Ictaluridae		
Yellow bullhead (*Ameiurus melas* Lesueur)	1	L/P
Brown bullhead (*A. nebulosus* Lesueur)	10	L
Blue catfish (*Ictalurus furcatus* Lesueur)	17	P
Channel catfish (*I. punctatus* Rafinesque)	12	P
Flathead catfish (*Pylodictis olivaris* Rafinesque)	5	L/P
Esocidae		
Redfin pickerel (*Esox americanus americanus* Gmelin)	5	L
Chain pickerel (*E. niger* Lesueur)	150	L
Umbridae		
Eastern mudminnow (*Umbra pygmaea* DeKay)	3	L
Aphredoderidae		
Pirate perch (*Aphredoderus sayanus* Gilliams)	15	L
Belonidae		
Atlantic needlefish (*Strongylura marina* Walbaum)	2	P
Cyprinodontidae		
Golden topminnow (*Fundulus chrysotus* Günter)	60	L
Lined topminnow (*F. lineolatus* Agassiz)	1	L
Poeciliidae		
Eastern mosquitofish (*Gambusia holbrooki* Girard)	296	L
Least killifish (*Heterandria formosa* Agassiz)	7	L
Atherinidae		
Brook silverside (*Labidesthes sicculus* Cope)	129	P
Inland silverside (*Menidia beryllina* Cope)	606	P
Percichthyidae		
White perch (*Morone americana* Gmelin)	399	P
White bass (*M. chrysops* Rafinesque)	10	P
Striped bass (*M. saxatilis* Walbaum)	30	P
Centrarchidae		
Flier (*Centrarchus macropterus* Lacepède)	9	L
Blackbanded sunfish (*Enneacanthus chaetodon* Baird)	50	L

TABLE 1. FISHES COLLECTED AT UPPER LAKE MARION, SOUTH CAROLINA FROM 1988-1994 USING A BOAT-MOUNTED ELECTROSHOCKER. TOTAL NUMBER COLLECTED AND HABITAT GUILD ARE INDICATED (L = LITTORAL, L/P = LITTORAL/PELAGIC, P = PELAGIC). ONLY LITTORAL (L AND L/P) SPECIES REPRESENTING MORE THAN 0.8% OF TOTAL NUMBER COLLECTED (>16 INDIVIDUALS), EXCLUDING GRASS CARP, WERE INCLUDED IN STATISTICAL ANALYSIS.

Family and Species	Total Number Collected	Habitat Guild
Bluespotted sunfish (*E. gloriosus* Holbrook)	44	L
Banded sunfish (*E. obesus* Girard)	7	L
Redbreast sunfish (*Lepomis auritus* Linnaeus)	10	L
Green sunfish (*L. cyanellus* Rafinesque)	2	L
Pumpkinseed (*L. gibbosus* Linnaeus)	20	L
Warmouth (*L. gulosus* Cuvier)	88	L
Bluegill (*L. macrochirus* Rafinesque)	1167	L
Dollar sunfish (*L. marginatus* Holbrook)	17	L
Redear sunfish (*L. microlophus* Günter)	783	L
Black-spotted sunfish (*L. punctatus* Valenciennes)	154	L
Largemouth bass (*M. salmoides* Lacepède)	1224	L
White crappie (*Pomoxis annularis* Rafinesque)	3	L/P
Black crappie (*P. nigromaculatus* Lesueur)	46	L/P
Percidae		
Tessellated darter (*Etheostoma olmstedi* Storer)	7	L
Swamp darter (*E. fusiforme* Girard)	3	L
Sawcheek darter (*E. serrifer* (Hubbs and Cannon)	2	L
Yellow perch (*Perca flavescens* Mitchill)	346	L
Mugilidae		
Striped mullet (*Mugil cephalus* Linnaeus)	32	P
Total:	16306	

water level fluctuation, trophic status, and fishing pressure contribute to uncertainty in predicting the response of fishes to declining vegetation. Water body size can also influence fish-plant interactions. The importance of aquatic macrophytes to the overall functioning of lakes decreases proportionately as lakes get larger and deeper (Hoyer and Canfield 1996) suggesting that fish-plant interactions are more difficult to predict in larger water bodies and comparative studies are likely to result in different patterns of species abundance.

Grass carp stocked into Lake Conroe, TX, which encompasses 8,100 ha, completely eliminated hydrilla resulting in a numerical increase of pelagic species and a decline in some littoral species (Noble 1986, Bettoli et al. 1993). Bailey (1978) and Shireman et al. (1985) detected no changes or conflicting patterns of species abundance as vegetation declined in larger impoundments in Arkansas and Florida, respectively. Unlike most of these lakes, which lacked substantial structure prior to infestation of exotic plants, moderate amounts of submersed structure remained in upper lake Marion and thus, we suggest, contributed to an increase in abundance of littoral fishes.

Moderate densities of vegetation, which reportedly range from 10 to 40% coverage of the surface area, provide spatial complexity that promote fish diversity and is optimal for sport fish production (Hestand and Carter 1978, Crowder and Cooper 1979a, 1979b, Wiley et al. 1984). Most sunfishes, including largemouth bass, bluegill, redear sunfish, and black-spotted sunfish, are structurally-oriented so their abundance is often positively correlated with vegetation coverage (Ware and Gasaway 1978, Borawa et al. 1979, Forester and Lawrence 1978, Noble 1986, Durocher et al. 1984, Wiley et al. 1984, Moxley and Langford 1985, Klussman et al. 1988, Scott 1993). Consequently, phytophilic sunfishes decrease in abundance after removal of vegetation (Bettoli et al. 1993, Ware and Gassaway 1978) but this response was not observed in our study. Although grass carp reduced surface coverage of hydrilla in upper Lake Marion from approximately 50% to less than 10%, abundant structure in the form of standing timber, sub-surface submersed vegetation, and floating and emergent species near the shoreline remained (S. de Kozlowski, South Carolina Department of Natural Resources, personal communication). Thus, the underwater landscape of upper Lake Marion was shifted from monospecific stands of hydrilla to intermediate levels of structural complexity.

Dense hydrilla contributes to stunted populations (Colle and Shireman 1980), but intermediate levels of structural complexity allow juvenile sunfish to forage in vegetated regions on soft-bodied organisms (Mittelbach 1981) and

TABLE 2. MEAN NUMBER (± SD)OF FISH PER 15 MINUTES OF ELECTROSHOCKING COLLECTED IN UPPER LAKE MARION, SOUTH CAROLINA, 1988-1994. PROBABILITIES (P) INDICATE SIGNIFICANCE BETWEEN HIGH (1989-1990) AND LOW (1993-1994) HYDRILLA COVERAGE USING REPEATED-MEASURES ANALYSIS OF VARIANCE. VEGETATION COVERAGE IS THE AERIAL AMOUNT OF SUBMERSED AQUATIC VEGETATION DETERMINED DURING SEPTEMBER OR OCTOBER OF EACH YEAR.

		1988	1989	1990	1991	1992	1993	1994
Taxa	P	N = 5	16	45	40	10	20	40
All species	<0.01	61.2 ± 39.3	124.2 ± 184.3	66.4 ± 99.2	40.4 ± 40.0	38.8 ± 22.0	109.1 ± 52.2	170.8 ± 126.2
Littoral guild	<0.01	25.0 ± 27.0	30.0 ± 28.9	28.7 ± 40.0	25.9 ± 25.8	18.5 ± 15.5	65.7 ± 40.5	73.8 ± 61.6
Bowfin	<0.01	3.2 ± 3.6	0.7 ± 1.0	0.7 ± 1.0	0.8 ± 1.4	0.2 ± 0.4	2.1 ± 2.7	2.5 ± 3.0
Golden shiner	<0.01	7.2 ± 15.5	3.7 ± 7.4	9.2 ± 20.5	3.2 ± 7.0	1.8 ± 4.1	9.4 ± 15.1	24.6 ± 40.7
Coastal shiner	0.07	0.6 ± 1.3	0.4 ± 1.3	2.3 ± 7.3	0.7 ± 2.4	0.8 ± 1.3	2.6 ± 6.0	4.2 ± 11.9
Lake chubsucker	<0.01	0.2 ± 0.4	0.2 ± 0.5	3.3 ± 17.0	2.0 ± 4.5	1.0 ± 1.6	2.2 ± 4.0	3.1 ± 4.9
Chain pickerel	0.25	0.4 ± 0.9	0.8 ± 1.2	1.0 ± 1.5	0.8 ± 1.8	0.1 ± 0.3	0.9 ± 1.5	1.0 ± 2.6
Bluegill	<0.01	3.2 ± 2.5	4.5 ± 5.0	2.8 ± 4.1	5.8 ± 8.4	4.1 ± 7.3	15.8 ± 17.6	9.4 ± 13.2
Redear sunfish	<0.01	3.6 ± 5.4	1.6 ± 2.3	1.4 ± 1.9	3.0 ± 5.2	1.6 ± 0.5	8.6 ± 5.1	9.5 ± 9.9
Black-spotted sunfish	0.01	0	0.3 ± 0.8	0.6 ± 1.5	0.8 ± 3.1	2.2 ± 5.0	2.0 ± 3.3	0.7 ± 1.4
Largemouth bass	<0.01	5.6 ± 3.4	2.4 ± 2.4	4.4 ± 5.3	4.3 ± 3.4	3.6 ± 3.0	15.8 ± 12.7	11.0 ± 10.0
Yellow perch	<0.01	0.6 ± 0.5	4.8 ± 17.7	0.3 ± 0.9	0.9 ± 3.0	1.5 ± 1.8	1.9 ± 2.4	4.2 ± 7.5
Vegetation Coverage, ha		4170	4385	4800	4700	1580	323	60

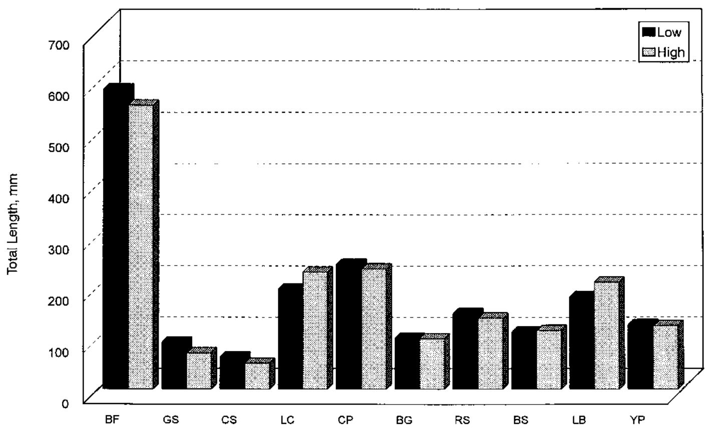

Figure 2. Mean lengths of commonly collected (>0.8% of the total catch) littoral fishes during low (1989 to 1990) and high (1993 to 1994) coverage of hydrilla in upper Lake Marion. Abbreviations for species on the x-axis are: BF = bowfin, GS = golden shiner, CS = coastal shiner, LC = lake chubsucker, CP = chain pickerel, BG = bluegill, RS = redear sunfish, BS = black-spotted sunfish, LB = largemouth bass, and YP = yellow perch.

adults to feed in open water on zooplankton (Mittelbach 1988). Although growth is a temporary response to the surrounding environment, most littoral fishes frequently collected in our study showed minimal changes in average lengths during high and low hydrilla coverage suggesting that foraging efficiency was not substantially altered. An exception was largemouth bass whose total length was statistically lower after hydrilla coverage declined, but differences between the two time periods differed by only 20 mm.

Use of grass carp to control a noxious aquatic plant in Lake Marion appeared to have minimal, if any, negative effects on the fish assemblage during the seven-year study period. However, composition of the fish assemblage will continue to respond to changes in the abundance of hydrilla depending on the level of control by grass carp. If other forms of structure remain in the upper lake, it is unlikely that a major decline of littoral fish populations will occur as found in other studies where grass carp have completely eliminated submersed aquatic plants.

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