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AQUATIC MACROPHYTES IN REELFOOT LAKE AFTER THE RELEASE OF GRASS CARP

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ABSTRACT--Aquatic macrophytes in Reelfoot Lake were monitored following a 1983-1984 winter release of 30,700 grass carp, *Ctenopharyngodon idella* (Val.). The herbivorous fish were stocked for control of *Potamogeton crispus* L. (curlyleaf pondweed) and *Ceratophyllum demersum* L. (coontail). Macrophytes were monitored by measurements of biomass and, for *P. crispus*, turion densities. Coverage of vegetation was estimated by aerial and surface surveys. Submersed macrophytes declined during the 3 years that followed fish stocking until, by late 1986, the previously-vegetated major basins were open. Certain floating species also declined during this rapid-growth period of the fish. Submersed and floating macrophytes increased during 1987 through 1990. Annual restocking from 1988 through 1991 culminated in the release of 79,402 additional fish. In certain locations, weeds gradually attained near former levels of density and coverage, but recolonization was less in most zones and absent in some. Other than by grass carp, weed reestablishment likely was negatively influenced by the maintenance of greater average water depths after a partial lake drawdown in 1985. Heavy blooms of filamentous green algae retarded the growth of submersed weeds in several parts of the lake during 1989 through 1991, but the algae also appeared to reduce weed consumption by grass carp. In 1991, *P. crispus* grew widespread in scattered populations, and *C. demersum* formed dense beds in numerous areas. During 1992, both coverage and density of *P. crispus* attained or exceeded pre-grass carp levels in many sections of the lake. During the present study, little or no reduction of macrophytes occurred within numerous small sub-basins and sloughs that are less accessible to grass carp.

Two vascular macrophytes, *Potamogeton crispus* L. (curlyleaf pondweed) and *Ceratophyllum demersum* L. (coontail), were codominant submersed weeds in Reelfoot Lake in 1983 (Henson, 1990*b*). The former species interfered with spring fishing and boating while the latter restricted access during the summer and fall.

In mid-winter 1983-1984, the Tennessee Wildlife Resources Agency (TWRA) stocked the lake with 30,700 herbivorous grass carp, *Ctenopharyngodon idella* (Val.), for submersed-weed control. The diploid fish, 20 to 25 cm in length, were released at the three locations indicated by R1 in Fig. 1 (Tennessee Wildlife Resources Agency, pers. comm.).

Hydrophytes were extensively surface-surveyed during 1983 (Henson, 1990*a*), but limited quantitative data prior to stocking of grass carp are available. An aerial remote sensing study of Basin III (Fig. 1) in 1983 found coverage by *C. demersum* to be 61.3 ha (Denton and Dobbins, 1984), which was approximately 13.2% of the basin's total area. This August survey could not map the summer-dormant *P. crispus* and did not identify *C. demersum* growing with *Nuphar luteum* subsp. *macrophyllum* (Small) Beal. (spatterdock) or beneath floating *Lemna*, *Spirodela*, and *Wolffia* (duckweeds and watermeals). Thus, the initial grass carp stocking-rate per unit area of submersed vegetation is not precisely known. Based upon boat surveys in 1983 and planimetry of the vegetated basins, an estimate of the initial stocking rate was 40 to 50 fish/vegetated ha of *P. crispus*.

The present study was initiated to monitor aquatic macrophytes following the initial introduction of grass carp and to develop guidelines for restocking. Notes on the progress of this project have been published (Sliger and Henson, 1987; Johnson et al., 1988).

MATERIALS AND METHODS

Submersed and surface-floating macrophytes were monitored by annual comparisons of total biomass (including portions within the hydrosoil) at selected lake sites. Additional estimates of *P. crispus* were obtained by measuring densities of its vegetative propagule. The summer-dormant vegetative propagule of *P. crispus* is termed turion in the present study. Coverage of aquatic macrophytes was monitored by high-altitude aerial infrared photography, low-altitude true-color 35-mm photography, and surface boat surveys.

Biomass and Turion Data Collection--In March 1984, prior to seasonal aquatic weed growth, seven experimental study sites (Fig. 1, sites 1 to 7) were selected where abundant submersed vegetation had grown the previous year. Two control sites (8 and 9, Fig. 1) were established in 1985, one within a slough and another in an isolated small basin. Both control sites were remote from fish-release locations. Control site 8 was abandoned after 1987 because its submersed weeds were mostly eliminated by heavy siltation and mats of filamentous algae. Site 9 was used mainly for turion-density comparisons. Each study site consisted of a circular area 50 m in diameter. Because of the dissected nature of Reelfoot Lake and the typically variable coverage of aquatic vegetation, each site was treated as a separate plant community.

Study sites were usually sampled twice each year, near the end of the spring growth period of *P. crispus* and again during or following breakup of the pondweed. A nested sampling technique, similar to that described by Raschke and Rusanowski (1984), was used at each site. Four collections were made at evenly-spaced intervals along each of two transects across the site to provide a total of eight samples. Repeat

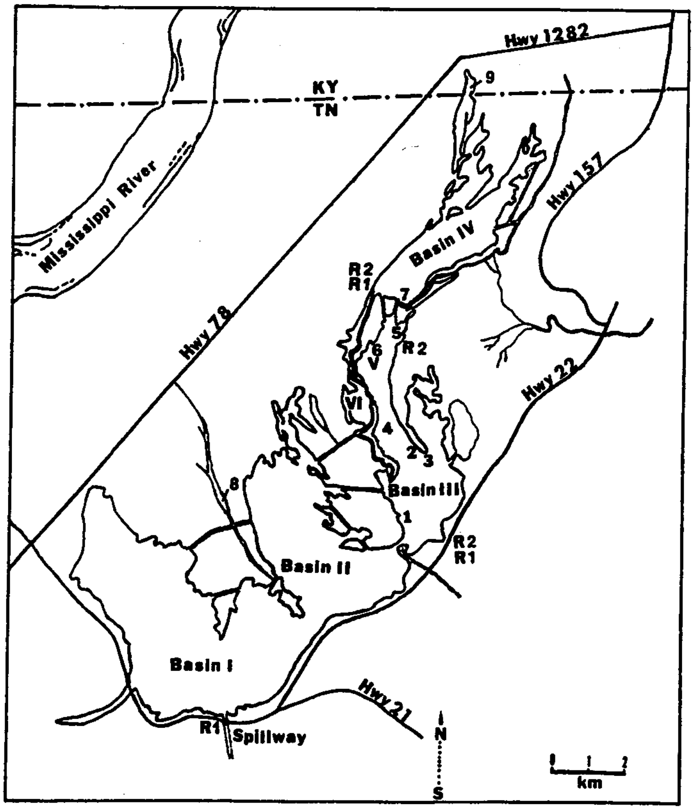

FIG. 1. Outline map of Reelfoot Lake. Major basins and subbasins are designated by Roman numerals. Study sites are numbered 1 to 9 (controls = 8 and 9). Grass carp release locations: R1 = winter 1984; R2 = November 1988.

sampling within a given year was randomized by varying the direction of transects.

Initially, biomass was harvested with a cylindrical sampler (Unni, 1976) that we found difficult to use in this lake. The Reelfoot Sampler (Sliger et al., 1990), designed and built in June 1984, was used for the remainder of the study.

Each sample was a quantitative collection of vegetation from a vertical, 0.25-m^2 water column that included hydrosol to a depth of 0.25 m. Harvested vegetation included submersed and seasonally emergent species and consisted of leaves, stems, roots, rhizomes, tubers, and other propagules that were retained by the sampler screen. It was impractical to separate the various species within samples due to fragmentation of the specimens, but the relative abundance of each species was recorded. Following collection, samples were immediately washed with lake water and placed in plastic bags for transport to the laboratory where they were dried on screened racks in the ambient air of a sun-heated attic.

Mean biomass was usually determined from eight samples. Sampling was occasionally limited at site 3, due to combined shallow water and dense seasonally-emergent vegetation. Those samples, from any site, that consisted almost exclusively of sediment-anchored, seasonally emergent macrophytes were excluded from this analysis of submersed and surface-floating plant biomass.

In late spring of each year from 1984 through 1988, an estimate of the average density (number per square meter) of turions was obtained for each site. *Potamogeton crispus* is not known to reproduce from seeds in Reelfoot Lake (Henson, 1990*b*). Therefore, asexual-propagule estimates were expected to allow prediction of the next year's relative abundance of the pondweed and, thus, serve as indicators for the need to restock grass carp. Luther (1983) suggested the use of turions for estimating overwintering biomass of rooted submersed macrophytes. Turions were included with total biomass in the present study.

Data were statistically analyzed with ABSTAT™ (AndersonBell, Parker, Colorado) software. For each site, data were compared with the previous year's data by using a oneway analysis of variance. The range of sample measurements at a site was sometimes large due to nonuniform coverage of vegetation.

Aerial and Surface Surveys--Aquatic vegetation was mapped each year from 1984 through 1986, from aerial color-infrared photographs (Fauss, 1987; Henson, 1990*c*). Flights were flown in late August 1984, early September 1985, and early September 1986.

True-color film, with low-altitude photography, is more effective than color-infrared film for delineating submersed macrophytes (Andrews et al., 1984; Breedlove and Dennis, 1984). The original mapping objectives included emergent vegetation (Henson, 1990*c*), which precluded the use of true-color film. Low-altitude (305 m) photography with true-color 35-mm film began in 1989 and has continued annually in late May or June.

Macrophytes were surface-surveyed by boat from early spring through late fall of each year. Ground-truthing allowed estimates of heavily vegetated zones where species fingerprints could not be resolved from aerial photographs alone.

RESULTS AND DISCUSSION

Initial Decreases of Aquatic Macrophytes--Surface surveys and aerial photography indicated that submersed weeds gradually declined in coverage and density within the major vegetated basins during 1984 (Table 1). Although both *C. demersum* and *P. crispus* were well represented in the spring biomass samples, *C. demersum* declined throughout the season.

Potamogeton spp. have been ranked above *C. demersum* as preferred food by grass carp (Sutton and Vandiver, 1986); our observation that *P. crispus* seemed to be consumed in preference to *C. demersum* is in agreement. However, in Reelfoot Lake, *C. demersum* is the primary submersed-food species for grass carp following the late-spring breakup of *P. crispus*.

Widespread feeding by fish was observed in beds of submersed weeds during 1984 through 1986, with less activity noted thereafter. The fish often surfaced or leaped from the water as boats moved through shallow feeding areas. A feeding pattern that we noted while surface surveying was similar to that observed by Martyn et al. (1986) with remote sensing. Open pockets appeared within dense beds of submersed macrophytes prior to complete removal of the vegetation.

TABLE 1. Hectares of Reelfoot Lake covered by *Ceratophyllum demersum* (1983 through 1986), as determined by aerial color-infrared imagry.

Type of coverage	1983[1]	1984[2]	1985[2]	1986[2]
C. demersum	61.3	42.53	1.31	2.25
C. demersum with *Nelumbo lutea*		2.58		

[1] Data from Denton and Dobbins (1984); August survey of Basin III (Fig. 1) only.

[2] Data adapted from Fauss (1987); all major basins surveyed each year in late summer; ground-truthing by J. W. Henson

During 1985 and continuing through 1986, most previously weed-clogged sections of the major basins were open to boating and fishing. Tables 2 and 3 illustrate the general decline of weed biomass from 1984 through 1986. Turions of *P. crispus* were reduced by 85 to 100% during this period (Table 4). Coverage of *C. demersum*, within the main body of the lake, had been reduced by >95% from 1984 levels (Table 1). Samples collected in 1985 and 1986 were mostly devoid of *C. demersum*, except at site 3 where the species persisted until fall 1986. In addition to submersed species, site 3 also supported dense stands of seasonal emergents.

Potamogeton crispus, still prevalent at some sites in 1985, had declined precipitously by 1986 (Tables 2 and 4). Schooling grass carp removed vegetation from one area before shifting to another (Martyn et al., 1986). The decline of *C. demersum* in 1984, together with reduced fish grazing as water temperatures fell below 20°C (Osborne et al., 1982), may have favored growth of *P. crispus* in the late fall of that year and in early spring of 1985. During the late spring and early summer of 1985, a drawdown lowered the lake by about 0.8 m (Johnson et al., 1988) before it was terminated on July 9. The shallower waters should have fostered submersed macrophyte growth (Henson, 1990*b*) throughout much of the 1985 season.

During the period of 1984 through 1986, other submersed macrophytes also decreased in areas where grass carp were known to have fed. The species included *Elodea nuttallii* (Planch.) St. John (elodea), *Potamogeton pusillus* L. (small pondweed), *Cabomba caroliniana* L. (fanwort), and *Utricularia biflora* Lam. (humped bladderwort). These reductions were not expressed in biomass samples, but less-abundant plant species seldom are adequately sampled (Nichols, 1984).

Potamogeton pectinatus L. (sago pondweed) usually grows at a few locations within Basin II (Fig. 1), somewhat removed from other submersed species. This pondweed was rare in 1984 and could have been consumed by fish moving upstream (Nixon and Miller, 1978; Stocker and Hagstrom, 1986) from a release site near the spillway (R1 in Fig. 1). Yet, in 1985, *P. pectinatus* grew luxuriantly and widespread in the shallower waters of Basin II when other submersed vegetation was much reduced in other parts of the lake. The seasonal abundance and distribution of *P. pectinatus* has been less, but variable, since 1985 (Henson, 1990*b*). Annual growth of *P. pectinatus* may have been more influenced by variations in light penetration during critical growth stages (Van Dijk and Van Vierssen, 1991) than by the grass carp. Photon flux densities vary with water depth and with changes in silt and plankton turbidity-levels.

Submersed macrophytes were never appreciably reduced in most of the very shallow, less-accessible basins and sloughs. Based upon surface observations, abundance, accessibility, and palatability of food species appeared to influence movements and feeding of the initially-stocked grass carp in Reelfoot Lake. However, movement behavior of grass carp within this lake has not been studied. The initial vegetation-declines

TABLE 2. May biomass[1] (grams per square meter, dry weight) of submersed and floating macrophytes, 1984 through 1990.

Site no.	1984[2]	1985	1986	1987	1988	1989	1990
1	153.4 (2)	69.6* (7)	4.1	91.1	316.9 (7)	520.0	231.2
2	135.3	57.6	4.3*	149.5	194.7	254.5*	191.2*
3		187.0	19.6 (6)	121.9	192.6	246.6*	262.4*
4		1.6	0.0	36.9*	0.0*	0.0*	0.0*
5	204.2	2.1 (7)	0.2	205.8	345.2*	330.2*	
6		3.9	0.0	174.9	282.2	266.8*	
7		0.9	0.0*	0.1*	0.0*	0.0*	0.0*
8[3]		155.0 (7)	122.1*	43.6			

[1] Each value is the mean of eight samples, except where noted by a number in parentheses.

[2] Cylindrical sampler was used; all other samples were taken with the Reelfoot Sampler.

[3] Control.

*Value is not significantly different ($P > 0.05$, oneway analysis of variance) from the preceding year.

TABLE 3. June biomass[1] (grams per square meter, dry weight) of submersed and floating macrophytes, 1984 through 1987.

Site no.	1984	1985	1986	1987
1	145.3	27.9	0.0	36.9
2		0.0	0.0*	30.0
3	294.6 (6)		10.8 (2)	4.5* (3)
4	32.4	0.0	0.0*	14.2
5	330.8	0.0	0.0*	38.2
6	118.8	0.0	0.0*	61.1
7	28.5	0.0	0.0*	0.0*
8[2]			103.0	24.7
9[2]			110.5	181.6*

[1] Each value is the mean of eight samples, except where noted by a number in parentheses.

[2] Controls.

*Value is not significantly different ($P > 0.05$, oneway analysis of variance) from the preceeding year.

TABLE 4. Density[1] (number per square meter) of *Potamogeton crispus*turions in late spring, 1984 through 1988.

Site no.	1984	1985	1986	1987	1988[2]
1	169.0	279.5*	40.5	288.0	772.5
2	262.0	81.5	4.5	387.5	502.3* (7)
3	71.0	76.0*	5.0	75.5	108.0*
4	495.5	25.5	0.0	127.0	
5	524.0	19.0	0.0	327.0	850.5
6	451.0	89.5	0.0	332.5	825.0
7	437.0	18.0	0.0	0.0*	
8[3]		199.5	133.0*	45.5	
9[3]		151.5 (7)	208.0*	304.0*	

[1] Each value is the mean of eight samples, except where noted by a number in parentheses.

[2] Vegetation was absent at sites 4 and 7.

[3] Controls.

*Value is not significantly different ($P > 0.05$, oneway analysis of variance) fromthe preceding year.

occurred in more readily accessible areas, often near release sites. Later, submersed macrophytes were reduced in certain shallower zones that supported both anchored seasonal emergents and submersed species. The abnormally low water levels of 1985, due to the partial lake drawdown, may have curbed movements of grass carp into certain areas.

By fall 1986, *Limnobium spongia* (Bosc.) Steud. (frog's-bit) and *Ludwigia peploides* (HBK.) Raven (creeping water primrose) had declined to the extent that they were rarely observed within the major basins. Site 3, which had been completely covered with these floating types in previous years, was free of them. Throughout this study, the smaller duckweeds and watermeals (*Lemna*, *Spirodela*, and *Wolffia*) were abundant and widespread in most vegetated lake areas.

Grass carp do not readily consume sediment-anchored, seasonally emergent macrophytes such as *Nelumbo lutea* (Willd.) Pers. (American lotus), *N. luteum*, and *Polygonum* spp. These plants are of lower selective preference (Prowse, 1971; Sutton and Vandiver, 1986), and fish have difficulty in taking petioles or emersed leaves into the pharynx, end first (Bailey, 1975). With the number of grass carp that were initially released, little or no reduction of these species was expected, and none was evident.

Subsequent Increases of Aquatic Macrophytes--Potamogeton crispus sharply increased in spring 1987 (Tables 2 and 4) and, in some zones during 1988, attained densities near those prior to stocking of grass carp. Less dense stands occurred in numerous areas where none grew in 1986. The spring biomass measurements of 1987 and 1988 were low in *C. demersum*, but the species increased over the lake throughout the summer and fall of each year. *Potamogeton pusillus* and other minor submersed species also increased during this period.

Biomass and turion quantitative determinations are equally effective for the estimation of *P. crispus*. Except when vegetation is sparse, either measurement can be utilized for prediction of the next year's relative abundance of the species. The 1987 increase of *P. crispus* was not predicted from the previous year's data (Tables 2 and 4), but sampling accuracy decreases when biomass is in low density (Nichols, 1984), and *P. crispus* exhibits high reproductive potential from very few propagules (Yeo, 1966). Turions can be measured anytime during the dormancy period. At specific study sites, no significant differences were found between turion densities of October 1988 and those of the previous May.

Competition between *C. demersum* and the summer-dormant *P. crispus* occurs during the spring and late fall. For best estimates of *C. demersum*, sampling probably should occur in late summer or early fall. However, in Reelfoot Lake, weed-management with grass carp that is directed toward *P. crispus* is expected to exert a measure of control over *C. demersum*. In most parts of the lake, dispersal of *C. demersum*, *P. crispus*, and other species occurs by drifting plants or fragments (often with attached turions). This can result in rapid recolonization of previously depleted zones. Plant material often accumulates against other vegetation, submersed logs or stumps, creating spotty but sometimes locally dense stands. Propagules of various species are shifted about in shallow waters as soft sediments are disturbed by turbulence from outboard motors or wind-driven water currents. Boat dispersal likely is significant for most submersed macrophytes within Reelfoot Lake; several of the less common species grow near heavily-used boat ramps.

The thinning of aquatic weeds often allows encroachment of other species into vacated areas (Cooke et al., 1986). At some sites, we observed gradual increases in spatial coverage by *N. luteum* as submersed vegetation declined. Wide annual fluctuations of *N. lutea* are typical in Reelfoot Lake (Henson, 1990*c*).

Grass Carp Restocking--Studies have shown that grass carp lower food intake to a maintenance-level diet as mature size is attained (Osborne and Sassic, 1981). Other factors that contribute to resurgence of aquatic weeds after the initial control period include loss of fish by natural mortality, commercial fishing, emigration, and spillways (Bailey, 1975). Reelfoot Lake lost fish from all of the preceding. We are aware of few literature reports regarding the restocking of grass carp in lakes. A study by Mitzner (1978) suggested restocking each fifth year following the initial introduction.

The 1987 increase of *P. crispus* suggested the need for additional grass carp in continued weed management. However, plans to restock in winter 1987-1988 were not realized because of fish-supply problems. This allowed relatively unchecked weed growth during the next season. Restocking began in November 1988 when TWRA released 21,320 diploid fish, 13 to 20 cm in length, at the R2 locations designated in Fig. 1.

Since 1988, grass carp have been released, annually, in the following numbers: 1989 (November), 5,000; 1990 (July through August), 25,652; 1991 (October through December), 27,430 (Tennessee Wildlife Resources Agency, pers. comm.). All of the latter releases were diploid fish, except for one load of 6,188 triploids. Most fish were 15 to 20 cm in length, but 20,200 fish released in December 1991 averaged only 7.6 cm in length. Release locations were in Basins III and V, identical to or near two R2 sites in Fig. 1.

Aquatic Macrophytes, 1989 Through 1992--Submersed macrophytes had recolonized most previously cleared areas by 1989 and 1990 and certain zones supported populations that approached or exceeded levels in 1983 and 1984. Both *P. crispus* and *C. demersum* were abundant and widespread, but stand densities of each were variable. During this period, submersed plants did not recolonize some locations that previously were heavily vegetated (e.g., sites 4 and 7, Fig. 1). Restocked grass carp thinned existing stands of vegetation and grazed young plants before they could reach maturity. Weed reestablishment also was influenced by the higher water levels that were maintained after 1985. Greater water depths tend to reduce both the abundance and the distribution of aquatic macrophytes in Reelfoot Lake (Henson, 1990*b*, 1990*c*).

Each spring and early summer of 1989, 1990, and 1991, filamentous green algae extensively blanketed submersed macrophytes in major vegetated parts of Basin III (Fig. 1) and elsewhere in the mid-section of the lake. Heavy blooms of filamentous green algae had not previously occurred in these sections during the present study. The algae were mainly *Oedogonium*, but *Spirogyra* and other genera also were present. The algae slowed macrophyte growth and possibly reduced consumption by grass carp. *Potamogeton crispus*, weighted with algal mats, often failed to reach the water surface prior to normal fragmentation in late spring. *Ceratophyllum demersum* was less affected and increased density and coverage each year following the summer demise of algal blooms. Fish consumption of algae or algal-covered macrophytes was not apparent during any year. Algal reduction of submersed plants was reported in the 1960s (see Henson, 1990*b*) and has been significant at site 8 since 1987. Throughout the present study, filamentous algae grew on macrophytes in a small basin (VI of Fig. 1); schooling grass carp were observed here, but submersed weeds were never cleared from the area.

Literature reports indicate that filamentous algae are among the less-preferred foods of grass carp. Factors that influence preference include size and age of fish (Michewicz et al., 1972; Sutton and Vandiver, 1986), mucilaginous nature of the algal species (Prowse, 1971), and availability of other food plants.

Basin V (Fig. 1) and nearby lake sections were again relatively free of submersed weeds by 1991. Weed populations also were lower in most parts of Basin III, especially adjacent to fish-release sites. Where present, *P. crispus* usually grew in scattered clumps or as individual plants, sometimes within dense beds of *C. demersum*. Stands of *C. demersum* thickened and expanded throughout the summer and fall of 1991. Locally-dense stands of *C. caroliniana* appeared in the northern part of Basin III, where other submersed species were less prevalent. In the fall of 1991, *L. sponga* grew more abundantly here than at any other time during the present study.

Potamogeton crispus grew prolifically during the spring of 1992. Both coverage and density of the pondweed probably exceeded pre-grass carp levels in Basin III and in certain eastern sections of Basin II. Experimental site 4, essentially free of weeds since 1984, was recolonized in 1992. Basin V and other adjacent zones, however, remained relatively free of submersed vegetation. Filamentous algal blooms were sparse during the spring of 1992, occurring mainly in the southwestern section of Basin III.

Hydrocotyle ranunculoides L.f. (water pennywort), believed to have been a recent introduction into Reelfoot Lake (Henson, 1990*a*, 1990*c*), has spread rapidly. It now grows along persistent marsh borders throughout much of the lake mid-section.

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