Use of Grass Carp in Two Florida Lakes, 1975 to 1994

by
Douglas E. Colle[1] *and Jerome V. Shireman*[1]

Introduction

The multirecreational usage of water bodies is continually increasing throughout the country. As user groups become more diverse in their recreational pursuits, which include sailing, windsurfing, water-skiing, swimming, and boating, their requests for aquatic macrophyte control are steadily increasing. This increased demand coupled with the introduction of the exotic aquatic macrophyte hydrilla (*Hydrilla verticillata*) into the United States has generated considerable interest in the development of biological plant controls to alleviate the continued usage of aquatic herbicides.

The grass carp (*Ctenopharyngodon idella*) was first introduced into the United States for plant control in Arkansas and Alabama in 1963 (Guillory and Gasaway 1978). The use of grass carp for vegetation control has been extremely controversial. The two major concerns have been fear of reproduction and the potential negative impact that total aquatic macrophyte elimination might have upon aquatic systems. The reproduction issue has been addressed with the commercial production of sterile grass carp (Allen and Wattendorf 1987). Long-term (>10 years) submersed vegetation elimination has been documented for grass carp (Leslie et al. 1987). The removal of vegetation has resulted in increased total phosphorous, total nitrogen, chlorophyll *a* values, and turbidity and a decrease in Secchi disk transparency (Leslie, Nall, and Van Dyke 1983; Shireman and Hoyer 1986). The majority of reported fisheries investigations have had 1 to 2 years of background data and from 2 to 4 years of results after submersed vegetation removal by grass carp (Ware and Gasaway 1976; Bailey 1978; Shireman and Hoyer 1986; Klussmann et al. 1988). This report summarizes 14 years of research in two Florida lakes using grass carp for aquatic macrophyte control.

Study Sites

Lake Baldwin is an 80-ha urban lake located within the United States Naval Training Center in Orlando, Orange County, Florida. The lake has a maximum depth of 7.8 m and a mean depth of 4.4 m. Water tupelo (*Nyssa aquatica*) occupies 35 percent of the shoreline extending out to a depth of 0.75 m. Hydrilla has been the dominant submersed plant in Lake Baldwin since 1971, covering as much as 80 percent of the lake bottom; other submersed macrophytes are southern naiad (*Najas quadalupensis*) and eel-grass (*Vallisneria americana*). Cattail (*Typha latifolia*), maidencane (*Panicum hemitomon*), and torpedograss (*Panicum repens*) are present along the shoreline.

Lake Pearl is a 24-ha, urban lake located in Orange County, Florida. Urban development was present on 40 percent of Lake Pearl's shoreline in 1978; by 1990, most of the shoreline was developed. The lake has a maximum depth of 7.0 m and a mean depth of 2.5 m. Hydrilla was first documented in Lake Pearl in 1977, and by 1978, it covered 95 percent of the lake bottom. Surface coverage of native rooted aquatic vegetation at project initiation was approximately 10 percent; 5 percent in a 12-m shoreline band of nutgrass (*Sceleria* sp.) and 5 percent consisting of interspersed beds of spatterdock (*Nuphar luteum*) and fragrant water lily (*Nymphaea odorata*). Small communities of cattail, torpedo grass, and pickerelweed (*Pontederia cordata*) totaled less than 1-percent surface coverage. Bladderwort

[1] Department of Fisheries and Aquatic Sciences, University of Florida, Gainesville, FL.

(*Utricularia subulata* and *U. inflata*) covered 14 percent of the lake surface area in association with the hydrilla community.

Methods

Lake Baldwin submersed vegetation was treated with aquatic herbicides from 1971 to 1978; but after 1978, no aquatic herbicides were applied to the lake. Diploid grass carp were initially stocked in April 1975 with 4,999 (63/hectare) fish (mean length 144-mm total length (TL)). By 1977, hydrilla covered 35 percent of the lake bottom; therefore, a selective rotenone treatment was conducted in October 1977 to obtain a grass carp population estimate (Colle et al. 1978). Only 264 (3/hectare) grass carp (169 to 434, 95-percent confidence intervals) remained from the initial stock. The lake was restocked during the summer of 1978 with an additional 1,865 (23/hectare) larger grass carp (>304-mm TL) to reduce the likelihood of predation by largemouth bass (Shireman, Colle, and Canfield 1978).

Fifty percent of Lake Pearl submersed vegetation was treated with aquatic herbicides from March 1980 through February 1982; herbicides have not been applied since 1982. The lake was stocked with diploid grass carp (>300-mm TL) in July 1980 (143 fish), July 1981 (284 fish), December 1981 (300 fish), and March 1982 (300 fish) for a total of 1,027 grass carp (43/hectare).

A recording fathometer was used to determine the percent of bottom coverage and percent of the lake volume containing submersed vegetation (PVI). Water samples were collected 0.5 m below the surface at midlake stations. Water quality analysis was conducted by the University of Florida utilizing standard methods (American Public Health Association 1992) for chlorophyll *a*. Total nitrogen concentrations were determined using Nelson and Sommers' (1975) modified Kjeldahl technique. Total phosphorous concentrations were analyzed by Murphy and Riley's (1962) procedures with a persulfate digestion (Menzel and Corwin 1965). Secchi disk transparency was measured using a standard black and white Secchi disk.

Annual fall fish population estimates were conducted in Lakes Baldwin and Pearl with block-nets (0.08 ha) and rotenone following procedures outlined by Shireman, Colle, and Durant (1981); a minimum of three nets were set in all study years. Estimates of the Florida largemouth bass (*Micropterus salmoides floridanus*) population in Lake Pearl were calculated from electrofishing samples with Chapman's modification of the Schnabel method; confidence intervals were determined from Ricker (1975). Estimates were determined for subadult (151 to 250-mm TL), adult (>250-mm TL), and large female (>500-mm TL) largemouth bass. All fish were weighed, measured, and tagged with numbered Floy FD-68BC tags. Growth allowances were made from the tag data to prevent recruitment bias during the estimate period (4 to 8 months). Adult (≥160-mm TL) bluegill (*Lepomis macrochirus*) and redear sunfish populations were estimated in 1987 with Chapman's adjusted Peterson estimate; confidence intervals were determined from Ricker (1975). Fish were collected with electrofishing gear, and a pelvic fin was clipped for an identifiable mark.

Results

Aquatic vegetation

The 1975 grass carp stock had no impact upon hydrilla coverage in Lake Baldwin (Table 1). During 1977, the mean individual biomass of grass carp was 12.23 kg, with a standing stock estimate of three fish and 40.36 kg/hectare (Colle et al. 1978). However, the second grass carp stocking in 1978 resulted in hydrilla elimination by June of 1980. The plant has not been collected in Lake Baldwin as of April 1994 (Table 1). Grass carp averaged 9.17 kg during June 1980, with an estimated standing stock of 26 fish/hectare and 235 kg/hectare (Shireman and Maceina 1981). Eel-grass, southern naiad, maidencane, torpedograss, cattail, and

Table 1
Water Quality Parameters, Percent Submersed Vegetation Coverage and PVI for Lake Baldwin, Florida

Year	Percent Cover	PVI	Secchi Depth m	Total Phosphorus mg/m^4	Total Nitrogen mg/m^4	Chlorophyll *a* mg/m^4
1977	35	–	3.1	17.5	465	5.9
1978	69	37	5.0	11.3	870	1.0
1979	57	19	1.5	45.7	832	26.1
1980	11	1	1.5	33.9	628	16.2
1981	0	0	1.3	33.5	694	24.7
1982	0	0	1.6	21.5	526	14.1
1983	0	0	1.8	23.9	462	10.6
1984	0	0	1.6	32.3	561	14.8
1985	0	0	1.5	19.0	445	9.0
1986	0	0	1.5	21.0	573	15.9
1987	0	0	1.4	27.5	635	19.1
1988	0	0	1.3	22.8	577	24.5
1989	0	0	1.6	15.3	270	13.5
1990	0	0	1.6	24.6	687	13.2
1993	0	0	1.3	19.0	726	20.3
1994	0	0	1.5	27.3	395	15.2

all other aquatic macrophytes were consumed by the winter of 1982, and regrowth has not occurred for any submersed macrophytes as of April 1994. During 1993, both cattail and panic grass communities began to revegetate along the lake shoreline. The blue-green alga (*Lyngbya* sp., averaging <15 cm high) covered 23 percent of the lake bottom in water depths to 3.5 m from 1985 through 1990. However, vegetation transects in 1993 and 1994 indicated only trace amounts of *Lyngbya* sp. within the lake. Lake Baldwin grass carp mean weights declined to 6.16 kg after 1985. Periodic food habits analysis showed grass carp were consuming filamentous algae and detritus after macrophyte elimination. Although not collected, grass carp were visually sighted in 1994 electrofishing samples in Lake Baldwin.

Lake Pearl received 50-percent areal treatments of aquatic herbicides from March 1980 through February 1982, coupled with grass carp stockings in an attempt to control hydrilla without totally eliminating all submersed macrophytes. The initial hypothesis was that grass carp would select hydrilla regrowth in the herbicided region; however, herbicide applications were required at approximately 2-month intervals until February 1982. This treatment schedule was comparable with other lakes in Orange County, Florida, where only aquatic herbicides were utilized for aquatic plant management. By August 1982, all submersed vegetation was eliminated, and no submersed macrophyte regrowth had occurred by April 1994 (Table 2). During the summer of 1982, when macrophytes were eliminated, grass carp averaged 4.57 kg; assuming a 62-percent survival rate (based on results from Shireman and Hoyer 1986), the standing stock estimate would be 27 fish/hectare and 123 kg/hectare. All emergent vegetation was consumed by the fall of 1983, and as of April 1994, the only shoreline vegetation was giant cutgrass (*Zizaniopsis miliacea*). The only aquatic vegetation still present is the spatterdock and fragrant water lily communities, which had 3-percent areal coverage as of April 1994.

Water quality

Complete removal of submersed vegetation produced significant long-term changes in certain water quality values in both study lakes, but the trophic status of the lakes did not change (Tables 1-2). Chlorophyll *a* values increased in both lakes after vegetation removal and have remained higher as the systems shifted from macrophytic- to phytophytic-dominated lakes. Lake Pearl chlorophyll *a* values were negatively correlated to both percent submersed-vegetation coverage ($p < 0.05$, $r = -0.66$) and PVI ($p < 0.05$, $r = -0.68$) and positively correlated with year ($p < 0.01$,

Table 2
Water Quality Parameters, Percent Submersed Vegetation Coverage and PVI for Lake Pearl, Florida

Year	Percent Cover	PVI	Secchi Depth m	Total Phosphorus mg/m^4	Total Nitrogen mg/m^4	Chlorophyll *a* mg/m^4
1978	89	63	–	–	–	–
1979	89	63	2.2	–	–	9
1980	93	64	2.2	20.2	783	4
1981	90	54	2.2	20.3	578	13
1982	35	17	0.8	21.8	703	24
1983	0	0	1.2	28.8	881	13
1984	0	0	1.0	24.5	862	17
1985	0	0	1.0	28.5	923	23
1986	0	0	0.9	33.2	892	20
1987	0	0	0.9	32.4	949	25
1988	0	0	0.9	36.5	695	24
1989	0	0	0.9	28.2	820	25
1990	0	0	1.0	32.1	897	44
1994	0	0	1.0	27.4	–	23

$r = +0.72$). Lake Baldwin chlorophyll *a* values were not significantly correlated to vegetation coverage, PVI, or year. Concurrently, Secchi disk transparency was reduced at least 50 percent in both lakes with increased algal biomass as measured by chlorophyll *a* concentrations. Secchi disk transparencies were positively correlated with plant coverage and PVI and negatively correlated with year in both systems (Baldwin: $p < 0.01$, percent cover 0.76, PVI 0.87, year $p < 0.05$, $r = -0.51$; Pearl: $p < 0.01$, percent cover 0.93, PVI 0.95, year -0.68). Total nitrogen values in Lake Baldwin were positively correlated with both percent cover ($p < 0.5$, $r = 0.57$) and PVI ($p < 0.05$, $r = 0.64$) and not significantly correlated to year. Lake Pearl total nitrogen was negatively correlated to both percent cover ($p < 0.05$, $r = -0.67$) and PVI ($p < 0.05$, $r = -0.62$) and not significantly correlated with year. Lake Baldwin total phosphorous values were not correlated to either percent plant cover, PVI, or year. Total phosphorous levels in Lake Pearl were negatively correlated to both percent cover ($p < 0.01$, $r = -0.78$) and PVI ($p < 0.01$, $r = -0.76$) and positively correlated with year ($p < 0.01$, $r = 0.82$).

Fish populations

Total number and biomass of fish in Lake Baldwin were not significantly correlated to percent macrophyte coverage, PVI, or year. Mean number of fish per hectare in Lake Baldwin were equivalent during the vegetated and nonvegetated years (Table 3). Total kilograms per hectare were also equivalent when submersed vegetation was present and when Lake Baldwin was devoid of submersed macrophytes. Estimates of total number of fish per hectare in Lake Pearl were positively correlated with plant coverage and PVI and negatively correlated with year (Table 4). Mean number of fish per hectare when Lake Pearl had submersed vegetation was greater than in the nonvegetated years (Table 5). Biomass estimates in Lake Pearl were positively correlated to percent plant coverage and PVI, but were not significantly correlated with year. Mean biomass estimates during years with submersed vegetation were greater than in years when Lake Pearl had no submersed plants (Table 5).

The elimination of submersed vegetation in Lakes Baldwin and Pearl resulted in significant population declines in both systems for the following species: lake chubsucker (*Erimyzon sucetta*), golden shiners (*Notemigonus crysoleucas*), and warmouth (*Lepomis gulosus*). The loss of submersed vegetation in Lake Pearl resulted in the elimination or reduction in the populations to levels below detection for chain pickerel (*Esox niger*), redfin pickerel (*Esox americanus*), taillight shiner (*Notropis maculatus*), golden topminnow (*Fundulus chrysotus*), bluespotted sunfish (*Enneacanthus gloriosus*), and Everglades pygmy sunfish

Table 3
Annual Fish Population Standing Crop Estimates (number and kilograms per hectare) from Block-net and Rotenone Samples in Lake Baldwin, Florida

Year	Total		Bluegill (<160-mmTL)		Bluegill (≥160-mmTL)		Redear (<160-mmTL)		Redear (≥160-mmTL)		Largemouth Bass (<240-mmTL)		Largemouth Bass (≥240-mmTL)	
	Number	Kilograms	Number	Kilograms	Number	Kilograms	Number	Kilograms	Number	Kilograms	Number	Kilograms	Number	Kilograms
1977	16,223	141	6,134	23.0	74	2.9	1,170	7.4	31	3.3	386	3.6	14	4.5
1978	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1979	8,049	199	4,532	48.7	9	0.6	942	16.0	47	5.5	33	0.3	35	6.4
1980	11,028	54	2,849	2.1	1	0.1	5	0.1	1	0.1	0	0	25	38.1
1981	35,950	102	2,104	12.8	8	0.5	6	0.1	7	0.5	52	0.2	11	7.1
1982	12,924	75	7,357	17.2	115	12.8	91	0.2	139	7.6	8	0.1	20	4.1
1983	5,497	28	418	0.7	24	0.6	122	0.8	31	3.3	4	0.8	22	7.8
1984	9,497	69	1,912	4.9	156	12.4	659	7.7	53	3.7	123	0.6	21	3.6
1985	13,675	206	5,512	73.7	172	11.9	1,019	21.9	136	11.6	135	3.1	32	5.1
1986	14,390	143	4,670	74.5	152	11.6	576	16.5	81	8.9	137	1.7	30	6.1
1987	—	—	—	—	174[a]	13.1[a]	—	—	156[a]	15.9[a]	—	—	19	8.2
1988	7,104	79	4,467	37.1	22	1.0	358	6.7	8	10.7	92	0.3	10	2.4
1989	8,371	101	3,799	42.6	33	2.6	167	3.4	35	2.8	48	0.4	27	20.9
1977-1980[b]	11,767 (2,388)	131 (42)	4,505 (948)	24.6 (13.5)	28 (23)	1.2 (0.9)	706 (356)	7.8 (4.8)	26 (13)	2.9 (1.6)	140 (124)	1.3 (1.1)	25 (6)	16.3 (10.9)
1981-1989[b]	12,108 (3,286)	91 (19)	3,780 (788)	32.9 (10.3)	95 (24)	7.4 (2.0)	375 (124)	(7.7) (2.9)	72 (20)	7.2 (1.7)	75 (19)	0.9 (0.4)	21 (3)	7.3 (1.8)

[a] Mark-recapture estimates.
[b] Mean of annual means and (standard error).

Table 4
Plant Coverage, PVI, and Year Correlation Coefficients for Standing Crops per Hectare of Fish Population Estimates in Lake Pearl, Florida

Species	Plant Coverage		PVI		Year	
	p<	r	p<	r	p<	r
Total number	0.01	0.75	0.01	0.78	0.05	-0.61
Total kilograms	0.05	0.70	0.05	0.71	—	—
Bluegill <160, kg	0.01	0.73	0.01	0.71	—	—
Redear ≥160, number	0.05	-0.63	0.05	-0.62	0.01	0.74
Redear >160, kg	0.05	-0.65	0.05	-0.63	0.01	0.80
Largemouth bass <160, number	0.05	0.69	0.05	0.66	0.05	-0.57
Largemouth bass ≥250, number	0.05	0.62	0.05	0.55	0.05	-0.67

Table 5
Annual Fish Population Standing Crop Estimates (number and kilograms per hectare) from Block-net and Rotenone Samples in Lake Pearl, Florida

Year	Total		Bluegill (<160-mmTL)		Bluegill (≥160-mmTL)		Redear (<160-mmTL)		Redear (≥160-mmTL)		Largemouth Bass (<160-mmTL)
	Number	Kilograms	Number	Kilograms	Number	Kilograms	Number	Kilograms	Number	Kilograms	Number
1978	33,868	130	2,645	25.2	41	2.8	342	2.2	8	0.2	97
1979	10,862	254	2,815	68.8	248	21.2	188	4.4	9	0.2	97
1980	30,617	118	22,427	44.0	17	1.5	858	3.5	8	0.1	68
1981	19,547	183	10,638	84.6	86	6.4	541	6.7	3	0.1	217
1982	1,584	63	884	11.7	10	0.9	86	2.9	35	2.4	4
1983	7,852	41	5,944	10.5	54	4.5	752	1.5	4	0.1	44
1984	8,044	45	5,697	15.7	42	4.3	626	3.0	18	2.7	36
1985	5,979	89	3,856	17.3	5	0.5	347	5.1	179	22.3	58
1986	8,924	58	6,322	31.2	22	3.0	129	1.6	205	29.5	49
1987	—	—	—	—	—	—	—	—	—	—	—
1988	9,472	123	1,981	16.7	51	5.1	1,132	3.0	92	14.0	5
1989	8,051	118	3,062	22.8	184	25.0	278	2.0	145	25.0	10
1978-1982[a]	19,295 (6,022)	150 (32)	7,881 (4,007)	46.9 (13.5)	80 (43)	6.5 (3.8)	403 (137)	3.9 (0.8)	13 (6)	0.6 (0.5)	97 (35)
1983-1989[a]	8,053 (487)	79 (15)	4,477 (723)	19.0 (2.9)	60 (26)	7.1 (3.7)	544 (150)	2.7 (0.6)	107 (34)	15.6 (4.6)	34 (9)

[a] Mean of annual means and (standard error).

(*Elassoma evergladei*). Gizzard shad (*Dorosoma cepedianum*) and threadfin shad (*Dorosoma petenense*) abundance increased significantly in Lake Pearl with the elimination of submersed vegetation. The Lake Baldwin threadfin shad population also increased significantly after the loss of submersed macrophytes.

Subadult bluegill (<160-mm TL) number and kilogram/hectare estimates in Lake Baldwin were not significantly correlated to percent plant coverage, PVI, or year. Lake Baldwin subadult bluegill standing crop estimates were equivalent in both vegetated and nonvegetated years (Table 3). Adult bluegill (≥160-mm TL) were not significantly correlated to percent plant coverage, PVI, or year. Although mean standing crop estimates of adult bluegill in Lake Baldwin were lower during vegetated years than in nonvegetated years, the 95-percent confidence intervals overlapped. Subadult bluegill number/hectare in Lake Pearl were not significantly correlated to plant coverage, PVI, or year. However, kilogram/hectare estimates were positively correlated to percent plant coverage and PVI, but were not significantly correlated with year (Table 4). Adult bluegill standing crop estimates were not significantly correlated with plant coverage, PVI or year in Lake Pearl. Both number/hectare and kilograms/hectare estimates of adult bluegill were equivalent for both vegetated and nonvegetated years in Lake Pearl (Table 5).

Subadult (<160-mm TL) and adult (≥160-mm TL) redear sunfish standing crop estimates in Lake Baldwin were not significantly correlated to plant coverage, PVI, or year. Subadult redear sunfish numbers/hectare and kilograms/hectare estimates were equivalent in Lake Baldwin during vegetated and nonvegetated years (Table 3). Adult redear sunfish standing crop estimates were also equivalent in vegetated and nonvegetated years. Subadult redear sunfish populations in Lake Pearl were not significantly correlated with plant coverage, PVI, or year. Standing crop estimates for subadult redear sunfish in Lake Pearl were equivalent in vegetated and nonvegetated years (Table 5). Adult redear sunfish in Lake Pearl were negatively correlated with plant coverage and PVI and positively correlated with year. Lake Pearl adult redear sunfish populations were significantly higher in nonvegetated years than vegetated years.

Subadult (<240-mm TL) and adult (≥240-mm TL) largemouth bass populations in Lake Baldwin were not significantly correlated to percent plant coverage, PVI, or year. Subadult standing crop estimates were equivalent during vegetated and nonvegetated years (Table 3). Adult largemouth bass populations were not significantly different during years with and years without submersed plants. Young-of-year largemouth bass numbers/hectare (<160-mm TL) in Lake Pearl were positively correlated with plant coverage and PVI and negatively correlated with year (Table 4). Annual standing crop estimates for young-of-year largemouth bass were greater during years with submersed vegetation except 1982 when only four fish/hectare were collected; however, all submersed vegetation had been consumed by June 1982, and block-net and rotenone sampling was not conducted until October (Table 5).

Mark-recapture estimates for largemouth bass (151- to 250-mm TL) in Lake Pearl were not correlated with percent plant cover, PVI, or year. Population estimates of subadult bass peaked from 1981 to 1983, with equivalent annual estimates before and after this period (Table 6). Subadult largemouth bass numbers were not significantly correlated to the previous year's standing crop of young-of-year largemouth bass. Adult largemouth bass (≥250-mm TL) numbers were positively correlated with plant coverage and PVI and negatively correlated to year; however, biomass estimates were not significantly correlated (Table 4). Annual estimates of adult bass were larger during vegetated years, but 95-percent confidence intervals overlapped during almost all study years (Table 6). The mean of means of the annual estimates from 1979 to 1983 was 49 fish/hectare (90-percent confidence intervals: 39 to 59); while during the nonvegetated years (1984-1989), the mean of means was 25 fish/hectare (90-percent confidence intervals:

15 to 36). Annual mark-recapture estimates for largemouth ≥500-mm TL, which represents the population of fish that are at least 4 years old and primarily female, were not correlated with plant coverage, PVI, or year. Confidence intervals overlapped during all study years except 1981 when the annual estimate was greater than most study years (Table 6).

Annual growth rates of Lake Pearl largemouth bass were estimated from Floy tag data. Largemouth bass <350-mm TL had significantly faster growth rates during nonvegetated years (Table 7). However, the growth rates of largemouth bass ≥350-mm TL were equivalent during both vegetated and nonvegetated periods. Young-of-year largemouth bass in both Lakes Pearl and Baldwin had first year growth averaging 150-mm TL during years when submersed vegetation was present. After macrophyte removal, first year growth averaged 210-mm TL in both lakes. Largemouth bass in Lake Pearl averaged 28 months to reach 250-mm TL during vegetated years. After all submersed vegetation was eliminated, largemouth bass grew to 250-mm TL in 18 months.

Discussion

Grass carp were successfully used for long-term elimination of both hydrilla and other submersed aquatic macrophytes in Lakes Baldwin and Pearl. Other urban Florida lakes (Lakes Bell (32 ha), Clear (64 ha), Holden (102 ha), Killarney (96 ha) and Wales (132 ha)) stocked with grass carp in the 1970s to control hydrilla have also been devoid of all submersed macrophytes since plant removal occurred (Leslie, Nall, and Van Dyke 1983; Leslie et al. 1987; and authors' personal observations). Plant species eliminated in the Florida lakes were bladderwort, common cattail, coontail, eel-grass, hydrilla, maidencane, pickerelweed, and torpedograss. Aquatic macrophytes still present in these systems include spatterdock, fragrant water lily, sawgrass, and elephant-ear (*Colocasia esculenta*). Complete removal of submersed macrophytes in these Florida lakes resulted in similar changes in water quality parameters that occurred in Lakes Baldwin and Pearl: increases in nutrient-related variables of total phosphorous, total nitrogen, chlorophyll *a*, and increased turbidity or a decrease in Secchi transparency (Leslie, Nall, and Van Dyke 1983; Leslie et al. 1987).

Complete removal of submersed plants from Lake Pearl caused significant reductions in total fish standing crop estimates and the elimination or reduction to levels below detection of six fish species. Lake Baldwin total standing crop estimates were not impacted by plant removal. Centrarchid populations, except for warmouth, were not adversely affected by the total removal of submersed macrophytes. Clupeid species in both lakes increased significantly with submersed plant removal. Utilization of grass carp for vegetation control in systems containing fish species that are protected or of special concern (Johnson 1987) or species known to require submersed macrophytes within their life cycles should be exercised with caution because long-term macrophyte removal may occur.

The actual duration of submersed vegetation control with grass carp has not been verified; fish are still present and controlling aquatic macrophytes in Florida's lakes stocked in the 1970s. Grass carp removal techniques by both State and Federal agencies and universities in Florida utilizing haul seines, gill nets, trammel nets, trap nets, electrofishing, and 0.1 rotenone treatments have not proven successful in reducing stocks to levels that resulted in submersed macrophyte regrowth in systems >20 ha. Therefore, utilization of grass carp for submersed vegetation control should be viewed as a long-term management decision; control will occur for a minimum of 15 years in lakes with surface water temperatures over 20 °C for at least 7 months of the year.

Table 6
Annual Mark-Recapture Estimates and 95-Percent Confidence Intervals for Florida Largemouth Bass in Lake Pearl, Florida

Total Length, mm	Year	Number/Hectare (kg/hectare)		
		Lower Bound	Estimate	Upper Bound
151 to 250	1980	14 (3.3)	26 (3.5)	52 (12.1)
	1981	41 (8.6)	86 (8.5)	199 (41.6)
	1982	39 (8.5)	96 (10.9)	241 (52.5)
	1983	48 (7.9)	69 (11.4)	103 (17.0)
	1984	13 (2.1)	21 (3.4)	36 (5.9)
	1985	10 (1.4)	22 (3.1)	56 (7.8
	1986	12 (1.6)	22 (3.0)	45 (6.0)
	1987	25 (1.7)	38 (5.4)	60 (8.5)
	1989	4 (0.5)	7 (0.8)	15 (1.7)
>250	1979	19 (8.9)	37 (17.4)	78 (36.7)
	1980	38 (15.9)	55 (23.1)	83 (34.8)
	1981	40 (23.7)	63 (37.4)	102 (60.5)
	1982	28 (25.3)	49 (44.40)	91 (82.4)
	1983	26 (18.5)	42 (30.0)	72 (51.3)
	1984	30 (12.2)	47 (19.1)	79 (32.1)
	1985	13 (8.8)	21 (14.2)	35 (23.7)
	1986	18 (14.3)	27 (21.5)	42 (33.4)
	1987	21 (13.1)	30 (18.8)	43 (26.9)
	1989	12 (7.2)	16 (9.6)	22 (13.1)
≥500	1979	0.5 (1.7)	1.3 (4.2)	3.3 (10.4)
	1980	0.8 (2.5)	2.3 (6.8)	5.7 (16.8)
	1981	1.5 (3.6)	5.0 (12.0)	9.1 (21.8)
	1982	1.1 (2.9)	2.4 (6.1)	5.4 (14.0)
	1983	0.5 (1.1)	1.1 (2.8)	2.7 (7.0)
	1984	0.3 (0.8)	0.8 (2.0)	2.0 (4.9)
	1985	0.3 (1.0)	0.9 (2.5)	2.1 (6.2)
	1986	1.0 (2.9)	3.4 (9.5)	6.1 (17.2)
	1987	0.2 (0.6)	0.6 (1.7)	1.5 (4.2)
	1989	0.3 (0.6)	0.8 (2.0)	1.5 (3.5)

Table 7
Mean Daily Growth Rates for Floy-Tagged Florida Largemouth Bass from Lake Pearl, Florida, 1979-1989

Total Length mm	Year	Sample Size		Growth	
		mm/day	gm/day	mm/day (mean ± 2SE)	gm/day (mean ± 2SE)
151 to 250	1979-1982	80	71	0.13 ± 0.02	0.24 ± 0.05
	1983-1986	177	169	0.22 ± 0.02	0.43 ± 0.04
	1987-1989	33	30	0.26 ± 0.08	0.60 ± 0.20
251 to 350	1979-1982	111	98	0.10 ± 0.02	0.40 ± 0.08
	1983-1986	210	194	0.16 ± 0.02	0.65 ± 0.10
	1987-1989	58	50	0.13 ± 0.02	0.59 ± 0.14
>350	1979-1982	37	31	0.10 ± 0.03	1.21 ± 0.56
	1983-1986	46	39	0.14 ± 0.04	1.48 ± 0.46
	1987-1989	33	29	0.08 ± 0.02	0.94 ± 0.24

References

Allen, S. K., and Wattendorf, R. J. (1987). "Triploid grass carp: Status and management implications," *Fisheries* 12(4),20-24.

American Public Health Association, American Water Works Association and Water Pollution Control Federation. (1992). *Standard methods for the examination of water and wastewater.* 18th ed., Washington, DC.

Bailey, W. M. (1978). "A comparison of fish populations before and after extensive grass carp stocking," *Transactions of the American Fisheries Society* 107, 181-206.

Colle, D. E., Shireman, J. V., Gasaway, R. D., Stetler, R. L., and Haller, W. T. (1978). "Utilization of selective removal of grass carp from an 80-hectare Florida lake to obtain a population estimate," *Transactions of the American Fisheries Society* 107, 724-729.

Guillory, V., and Gasaway, R. D. (1978). "Zoogeography of the grass carp," *Transactions of the American Fisheries Society* 197, 105-112.

Johnson, J. E. (1987). "Protected fishes of the United States and Canada," American Fisheries Society, Bethesda, MD.

Klussmann, W. G., Noble, R. L., Martyn, R. D., Clark, W. J., Betsill, R. K., Bettoli, P. W., Cichra, M. F., and Campbell, J. M. (1988). "Control of aquatic macrophytes by grass carp in Lake Conroe, Texas, and the effects on the reservoir ecosystem," Final Report, Texas Agricultural Experiment Station, Texas A & M University, College Station, TX.

Leslie, A. J., Jr., Nall, L. E., and Van Dyke, J. M. (1983). "Effects of vegetation control by grass carp on selected water-quality variables in four Florida lakes," *Transactions of the American Fisheries Society* 112, 777-787.

Leslie, A. J., Jr., Van Dyke, J. M., Hestand, R. S., III, and Thompson, B. Z. (1987). "Management of aquatic plants in multi-use lakes with grass carp," *Lake and Reservoir Management* 3, 266-276.

Menzel, D. W., and Corwin, N. (1965). "The measurement of total phosphorous in seawater based on the liberation of organically bound fractions by persulfate oxidation," *Limnology and Oceanography* 10, 280-282.

Murphy, J., and Riley, J. P. (1962). "A modified single solution method for the determination of phosphate in natural waters," *Analytica Chemica Acta* 27, 31-36.

Nelson, D. W., and Sommers, L. E. (1975). "Determination of total nitrogen in natural waters," *Journal of Environmental Quality* 4, 465-468.

Ricker, W. E. (1975). "Computation and interpretation of biological statistics of fish populations," Fisheries Research Board of Canada Bulletin 191.

Shireman, J. V., Colle, D. E., and Canfield, D. E., Jr. (1978), "Efficacy and cost of aquatic weed control in small ponds," *Water Resources Bulletin* 22, 43-48.

Shireman, J. V., Colle, D. E., and DuRant, D. F. (1981). "Efficiency of rotenone sampling with large and small block-nets in vegetated and open water habitats," *Transactions of the American Fisheries Society* 110, 77-80.

Shireman, J. V., and Hoyer, M. V. (1986). "Assessment of grass carp for weed management in an 80-hectare Florida lake." *Fish Culture in Fisheries Management.* R. H. Stroud, ed., American Fisheries Society, Bethesda, MD, 469-474.

Shireman, J. V., and Maceina. (1981). "The utilization of grass carp *Ctenopharyngodon idella* Val., for hydrilla control in Lake Baldwin, Florida," *Journal of Fish Biology* 19, 629-636.

Ware, F. J., and Gasaway, R. D. (1976). "Effects of grass carp on native fish populations in two Florida lakes." *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 30, 324-335.