J. Aquat. Plant Manage. 22: 87-95

The Effects of the Grass Carp on the Aquatic Macrophytes of Four Florida Lakes

JESS M. VAN DYKE, A. J. LESLIE, JR., AND L. E. NALL[1]

ABSTRACT

Grass carp (*Ctenopharyngodon idella* (Val.)) stocked at 50/ha eliminated hydrilla (*Hydrilla verticillata* Royle) from established line transects in three central Florida lakes. The hydrilla has remained absent for six years in these lakes and is possibly eradicated. The only remaining vegetation is growing in very shallow water, woody plants, or unpalatable species such as spatterdock (*Nuphar luteum* (L.) Smith and Smitz). The number of plant species on the transects was reduced by half. Grass carp (61/ha) eliminated Illinois pondweed (*Potamogeton illinoenis* Morong) two years after initial stocking in a north Florida reservoir and greatly reduced Eurasian watermilfoil (*Myriophyllum spicatum* L.) three years after stocking. The control of watermilfoil lasted three years, and the pondweed remains absent, eight years after stocking the grass carp. The number of plant species in the reservoir was reduced by half.

Key words: Hydrilla, Eurasian watermilfoil, Illinois pondweed, line transects, biocontrol.

INTRODUCTION

Florida's fresh water resources are as varied as they are important. The immense value of these waters stems from their utilization for recreation, industry, agriculture, transportation, wildlife and as potable water supplies. The management of these vast resources is particularly complex due to the fact that most water bodies are multipurpose, providing for instance, not only wildlife habitat but industrial and agricultural uses. Perhaps the most perplexing aspect of water resource management is the control of problem growths of aquatic plants. Infestations of aquatic plants exist in many water bodies throughout the state due to nutrient enrichment and introduction of foreign plant species. Two of the most problematic of these exotic macrophytes are hydrilla (*Hydrilla verticillata* Royle) and Eurasian watermilfoil (*Myriophyllum spicatum* L.). Both of these plants have a broad habitat tolerance and are able to form dense submersed stands. In 1979, 15,185 ha of hydrilla and 865 ha of Eurasian watermilfoil were found in 375,671 ha and 27,345 ha of public water bodies 40 ha or greater in size, respectively.[2]

This study, which began in 1974, and continues at this writing, relates the effects of the grass carp, *Ctenopharyngodon idella* (Val.) on the aquatic plant communities in four Florida lakes.[3,4] The purpose of this paper is to describe and evaluate the changes in the aquatic flora as a result of grass carp feeding activities.

LITERATURE REVIEW

The grass carp, a large Asian cyprinid, was introduced into the United States in 1963 as an experimental control agent for aquatic vegetation (29). This species is herbivorous at lengths greater than 3.0 cm (18), and generally, grass carp prefer soft submersed and floating vegetation to hard or

[1]Florida Department of Natural Resources, Bureau of Aquatic Plant Research and Control, 3900 Commonwealth Boulevard, Tallahassee, Florida 32303.

[2]Tarver, D. P., J. A. Rodgers and M. J. Mahler. 1979. The 1979 Aquatic Flora of Florida Survey Report. Florida Department of Natural Resources. 56 pp.

[3]Miley, W. W. II, A. J. Leslie, Jr., and J. M. Van Dyke. 1979. The effects of the grass carp (*Ctenopharyngodon idella* Val.) on vegetation and water quality in three central Florida lakes. Final Report, Florida Department of Natural Resources. 119 pp.

[4]Kobylinski, G. J., W. W. Miley, II, J. M. Van Dyke and A. J. Leslie, Jr. 1980. The effects of the grass carp (*Ctenopharyngodon idella* Val.) on vegetation, water quality, zooplankton and macroinvertebrates of Deer Point Lake, Bay County, Florida. Final Report, Florida Department of Natural Resources. 114 pp.

fibrous plants, but larger fish can eat a wider range of plants (28, 32, 35). Selectivity in younger fish is determined by the morphological structure of a particular plant and the development of the mouth apparatus (14).

Prowse (27) found that grass carp ate duckweeds (*Lemna* and *Spirodela*) freely and, although coarse sedges were not eaten, the fish grazed on the new growth of these plants. In Japanese reservoirs, Tsuchiya (37) reported that grass carp ate common coontail (*Ceratophyllum demersum* L.), Eurasian watermilfoil, hydrilla, curly leaf pondweed (*Potamogeton crispus* L.), water chestnut (*Trapa natans* L.), giant reed (*Phragmites australis* (Cav.) Trin. ex Steud.), wild rice (*Zizania latifolia* Turcz), bulrush (*Scirpus fluviatilis* A. Gray) and sharpscale mannagrass (*Glyceria acutiflora* Torr). Tan (36) and Blackburn and Sutton (8) found that hydrilla was an excellent food for grass carp. In India, Alikunhi and Sukumaran (4) reported excellent control of musk grass (*Chara* sp.), variable leaf pondweed (*Potamogeton diversifolius* Raf.), slender spikerush *Eleocharis acicularis* R. and S.) and the green algae *Rhizoclonium* sp. Singh et al. (30) found that grass carp did not consume floating heart (*Nymphoides cristatum* and *N. indica*) in India. Opuszynski (24, 25) reviewed Easter European publications and reported that grass carp readily consume common eloder (*Elodea canadensis* Michx.), common coontail, sago pondweed (*Potamogeton pectinatus* L.) and Eurasian watermilfoil. Opuszynski found that musk grass was readily consumed and that giant reed was eaten where the leaves were near the water but *Nuphar* sp. remained. Based on a review of the literature and their own studies in England, Alabaster and Stott (2) showed that grass carp prefer common elodea, coontail and sago pondweed to cattails (*Typha* spp.) and milfoil (*Myriophyllum* sp.) with rushes (*Juncus* spp.), sedges (*Carex* spp.) and spatterdock (*Nuphar luteum* (L.) Sibth. and Smith) rated lowest. Similar results were reported by Fowler and Robson (15), but they stated that Eurasian watermilfoil was reluctantly or not at all eaten. In Holland, von Zon (39) found that grass carp ate common coontail, *Elodea nuttallii,* and duckweeds (*Lemna* spp.), but *Utricularia* and *Ranunculus* were infrequently eaten. Edwards (12) indicated that although common elodea is highly selected in New Zealand, African elodea (*Largarosiphon major* Ridley), common coontail and Brazilian elodea (*Egeria densa* Planch) were not preferred. In Arkansas, grass carp stocked at 1693 per hectare eliminated southern naiad (*Najas guadalupensis* (Spreng.) Magnus), variable-leaf pondweed, Brazilian elodea, musk grass, giant duckweed (*Spirodela* sp.), bladderwort (*Utricularia biflora* Lam.), slender spikerush, tapegrass (*Vallisneria americana* Michx.), and *Pithophora* sp. in two to three weeks, did not eat for two weeks and then eliminated alligatorweed (*Alternanthera philoxeroides* (Mart.) Griesb.), parrot's feather (*Myriophyllum brasiliense* Camb.), Eurasian watermilfoil and waterhyacinths (*Eichhornia crassipes* (Mart.) Solms) in two weeks (5, 6). The order of preference in studies in Arkansas was similar to that of Alabaster and Stott (2) with Eurasian watermilfoil, tapegrass, waterhyacinths, parrot's feather, and alligatorweed rated least preferred (5). Baker et al. (7) and Alikunhi and Sukumaran (4) also reported that large grass carp were able to consume waterhyacinth. Bailey[5] reported that *Pithophora* sp., musk grass, *Nitella* sp., *Spirogyra* sp., *Utricularia* sp., common coontail, *Najas* sp., *Potamogeton* sp. and *Myriophyllum* sp. are routinely controlled using 247 to 1235 grass per hectare in Arkansas farm ponds. In Illinois, grass carp reduced filamentous algae (mainly *Oscillatoria* sp.) in plastic-lined pools faster than macrophytes but did not eliminate the algal species (9). In this study, leafy pondweed (*Potamogeton foliosus* Raf.), small pondweed (*P. pusillus* (L.) Fernald), slender naiad (*Najas flexilis* (Willd.) Rostk and Schmidt) and spring naiad (*N. gracillima* (A. Br.) Morong) were eliminated while common coontail abundance increased. Mitzner (23) reported that after 3 years, grass carp in Red Haw Lake, Iowa, had nearly eliminated *Potamogeton* sp. and *Najas* sp. and that the initially scarce *Elodea* sp. increased while common coontail never became a problem. Colle et al. (10), using naturally vegetated ponds in Florida, found Illinois pondweed (*P. illinoensis* Morong) was not important in the gut of grass carp until they reached 174 mm, then was highly selected. Coastal arrowhead (*Sagittaria graminaea* Michx.) was highly selected by fish less than 124 mm. Hestand and Carter (17) reported that grass carp stocked into plastic-lined pools in Florida, in which the macrophytes had been planted and allowed to establish for one year, eliminated southern naiad and musk grass in 130 days, common coontail in 20 days, hydrilla in 205 days and Eurasian watermilfoil in 265 days. Tapegrass was the only plant left at the end of the study. Osborne[6] planted Florida stormwater retention ponds with common cattail, pickerelweed (*Pontederia lanceolata* Nutt), elephant-ear (*Colocasia esculentum* (L.) Schott.), torpedograss (*Panicum repens* L.), pennywort (*Hydrocotyl umbellata* L.), fragrant water lily (*Nymphaea odorata* Aiton), spatterdock, tapegrass and Brazilian elodea and stocked 66.7 to 629.8 grass carp per hectare. When the ponds were dewatered the pickerelweed and Brazilian elodea were gone, the torpedograss and tapegrass were severely cropped and the spatterdock, fragrant water lily and pennywort were untouched. The filamentous algae present was eaten only when the submersed macrophytes were gone. Studies in four small Florida lakes showed the following trends (16). Alligatorweed was not affected, but a substantial reduction in fanwort (*Cabomba caroliniana* Gray) and eastern bladderwort (*Utricularia biflora* Lam.) occurred in Madison pond. Suwannee pond did not have an aquatic plant problem but grass carp eliminated slender spikerush and umbrella grass (*Fuirena simplex* Vahl.). However, maidencane (*Panicum hemitomon* Schult.) was not affected. In Pasco Pond, *Eleocharis vivipara* (eliminated), purple bladderwort (*U. purpurea* Walt.; reduced 99%), and umbrella grass (eliminated) were the first to show effects then watershield (*Brasenia schreberi* Gmelin) was eliminated. When these species were gone, notable declines in floating heart (*Nymphoides aquatica* (Gmel.) O. Ktze), spatterdock and fragrant water lily became ap-

[5]Bailey W. M. 1975. Operational experiences with the white amur in weed control programs. Arkansas Game and Fish Commission. 16 pp.

[6]Osborne, J. A. 1978. Management of emergent and submergent vegetation in stormwater retention ponds using grass carp. Final Report to the Florida Department of Natural Resources by the University of Central Florida, Orlando, Florida.

parent. In Broward pond, a limestone borrowpit, hydrilla and southern naiad were eliminated, waterhyssop (*Bacopa monnieri* (L.) Penell) and pennywort increased in shallow areas, cattail increased, but evidence of grass carp feeding on this species was seen by the end of the study.

Grass carp feeding rates on aquatic vegetation are strongly dependent on the age and size of the fish, ambient temperatures and species of plants present (19, 21, 24, 26, 28, 34). Growth rates ranged from 2.8 g/day in Siberia to 11.7 g/day in Malacca, Indonesia and 13.5 g/day in Florida (8, 19). Osborne (26) has recently shown that the amount of vegetation eaten per fish is much less for large grass carp (14 kg) compared with smaller fish (2.5 and 6.5 kg). Tsuchiya (37) reported that 100 grass carp (200 g in weight) per hectare were needed for plant control while only fifty-750 g fish and thirty-2 kg fish per hectare were required in reservoirs in Japan. Apparently, the consumption of plant matter per fish increases with the size of grass carp until a weight of about 2.5 kg is attained, after which consumption declines as the fish grow larger. Kuronuma and Nakamura (22) recommended 30 grass carp per hectare (35 kg/ha) for aquatic plant control in Japan. Alikunhi and Sukumaran (4) achieved plant "control" in four to eight weeks at 49 to 99 grass carp per hectare (25 to 40 cm in length) in India. In Arkansas, 8.6 to 55.1 grass carp per hectare are used to eliminate submersed plants in three years in lakes and reservoirs. Opuszynski (24) found that 32.5 grass carp per hectare (250 to 1000 g in weight) removed all vegetation except spatterdock in the heated water of Polish power plants. Good results in the first year after stocking were reported for temperate zones using 250 to 400 g grass carp at 150 to 250 kg per hectare (40). In most cases cited above, the term "control" was used to indicate elimination of submersed aquatic plant species.

METHODS

The aquatic plants in Lakes Bell (34 ha) and Clear (64 ha) in Pasco county and Lake Holden (102 ha) in Orange county were systematically monitored quarterly from September 1974 to September 1978 and yearly in September after 1978 using the line transect method (11). Deer Point Lake (1900 ha) in Bay county was monitored quarterly from September 1974 to September 1980 and yearly in September after 1980 using the line transect method (11). Transects were established in areas where plant communities were typical of the lake. The presence and identification of vegetation was recorded at 1.5 m intervals on a nylon rope stretched between two fixed points at each station. The data were tabulated as percent frequency of occurrence by species. Because more than one species of plant may occupy a single transect point, total percent of transect points with vegetation is not equal to the sum for the individual species.

In tables 2 to 5, only those species which had a frequency of occurrence on line transects of at least 1% or occurred in more than 50% of the samples are included. Species with an occurrence of less than 1% could be ephemeral and thus it would be difficult to say the grass carp affected them. In general, although some of the occurrences for species included in the table are low, the results on the transects followed very closely the qualitative whole-lake surveys done and were documented photographically.

Lakes Bell, Clear, and Holden were stocked in October 1974 with 50 grass carp per hectare (Table 1). In Deer Point Lake, predators were removed from small, fenced-off coves for use as grass carp grow out areas. Grow out areas were stocked with 43 grass carp per hectare of total lake area in fall 1975. The fences were taken down in April 1976 and the grass carp thus were released into the lake. Eighteen grass carp per hectare were added to Deer Point Lake betweent 1976 and 1978 because of fears of high predation on some of the smaller 1975 fish. Total grass carp stocked in this reservoir was 61 per hectare by 1978.

Aerial photography showed about one-half of Lake Bell contained stands of hydrilla reaching the surface in November 1974.[7] This species occupied 86.8% of the initial transect points (September 1974). The second most common submersed species, big floating bladderwort (*Utricularia inflata* Walt.), was scarce relative to hydrilla, occupying only 6.3% of the transect points in September 1974. Marginal plants were diverse (eight species) but each occupied less than 4.5% of the initial transect points. Salvinia (*Salvinia rotundifolia* Wield.) and *Pithophora* sp. occupied 5.8 and 3.4% of the initial transect points, respectively.

Clear Lake contained mixed stands of hydrilla and common coontail reaching the surface from depths of 4.5 m and occupying over one-third of the lake based on aerial photographs in January 1974. These two species occupied 74.6% and 23.1% of the initial transect points conducted in September 1974. The shoreline was dominated by torpedograss and waterhyacinth occupying 11.5 and 11.3% of the initial transect points, respectively.

Lake Holden, a highly developed urban lake, had a relatively limited flora due to alteration of most of the shoreline to create beaches and seawalls. More than one-third of this lake contained hydrilla growing to the surface in November 1974 based on aerial photography. Hydrilla occupied 82.4% of the transect points in September 1974. The next most common species on the initial transects was *Pithophora* sp. (10.8%). The marginal plant community

[7]Vause, G. M. and T. C. Davis. 1977. Remote sensing and automated data processing methods for monitoring noxious aquatic vegetation. NASA-FDNR project 21-73 (Phase II). 67 pp.

TABLE 1. NUMBER, AVERAGE SIZE AND DATES GRASS CARP WERE STOCKED INTO LAKES BELL, CLEAR, HOLDEN, AND DEER POINT.

Lake	Hectares	Grass Carp		
		Number	Avg. Size (g)	Date Stocked
Bell	34	1,780	227	Oct. 1974
Clear	64	3,180	227	Oct. 1974
Holden	102	5,080	227	Oct. 1974
Deer Point	1,900	82,436	10 to 500	Fall 1975
		13,169	400	Fall, Winter 1976-77
		11,829	363	Spring, Summer 1977
		10,615	350	Summer, Fall 1978
Deer Point total		118,049		

was dominated by maidencane and common cattail at an initial frequency of occurrence of 7.1 and 6.2% respectively.

Unlike Lakes Bell, Clear and Holden, which are closed systems, Deer Point Lake is a reservoir fed by Bear Creek, Bayou George, Econfina Creek and Big Cedar Creek. Aerial photography showed that more than one-third of Deer Point Lake contained mixed stands of Eurasian watermilfoil and Illinois pondweed reaching the surface in November 1974. These two species hampered lake utilization and frequently fouled the potable water intake from Panama City, FL. This relatively undeveloped north Florida reservoir contained a diverse emersed and submersed aquatic flora with rather extensive marsh areas around the embayed creeks. Plant transects averaged 15 species during the first year (Table 5). The frequency of occurrence of the two dominant plant species, Eurasian watermilfoil and Illinois pondweed averaged 45.6% and 29.1% respectively for the first year. The next most abundant species was watershield (3.6%), followed by fragrant water lily (2.6%), eastern bladderwort (2.5%), foxtail (*Myriophyllum pinnatum* (Walt.) BSP; 2.3%), and common arrowhead (*Sagittaria lancifolia* L.; 2.0%).

RESULTS

The vegetation on transects in Lake Bell decreased by 94% between 1974 and 1977 (Table 2), and the plant community had not changed significantly (from 1977) as of September 1982. Hydrilla, which had an average frequency of occurrence of 83.9% in the first year was eliminated from the transects by December 1976. Southern naiad was eliminated by March 1975 and has remained absent. The second most abundant submersed plant, big floating bladderwort (initial frequency of occurrence 6.3%) was reduced 68% by the second year and was absent from the transects from December 1976 to September 1982. Maidencane increased 76% (from 1.7% to 3.0% frequency of occurrence) in year two, but was reduced and has remained at a frequency of occurrence of 0.5% or less. Torpedograss was reduced 58% (from 4.3% to 1.8% frequency of occurrence) by year three, but in year four increased to 2.6% frequency of occurrence. Pickerelweed was reduced 46% (from 2.1% to 0.8% frequency of occurrence) by year three and eliminated by September 1980. Pennywort (1.4% frequency of occurrence) was eliminated from the transects in year three. This species reappeared on the transects in year four (at a frequency of occurrence of 0.7%) and was present as of September 1982. Salvinia was reduced 93% (from 3.0% to 0.2% frequency of occurrence) by year three and has remained confined to very shallow water. Slender spikerush was eliminated from the transects in year four. The filamentous alga *Pithophora* sp. was eliminated by year five. Only sawgrass (*Cladium jamaicense* Crantz.) and fragrant water lily appeared relatively unaffected. The average number of species on the tarnsects was reduced 50% by September 1978.

The aquatic vegetation on transects in Clear Lake was reduced 94% by year three and had not recovered as of September 1982 (Table 3). Hydrilla, which had an average frequency of occurrence of 74.8% in year one was reduced 53% in year two and eliminated from the transects in December 1976. The frequency of occurrence of common coontail was little changed by year two (18.6 and 16.6% for years one and two respectively) but was reduced 96% in year three and eliminated by December 1976. Azolla, common duckweed, salvinia and bog mat (*Wolfiella floridana* (Smith) Thompson) were all eliminated during the second year. Sawgrass was apparently little affected from 1974 to 1982, the frequency of occurrence fluctuated between 0.6 and 0.3%. Water primrose (*Ludwigia octovalis* (Jacq.) Raven) increased from a frequency of occurrence of 0.1% in the first two years to an average of 0.5% for the rest of the study. Maidencane was reduced 58% (from 3.6% to 1.5% frequency of occurrence) by year three but was not eliminated from the transects until September 1981. Torpedograss was reduced 84% (from 8.6% to 1.4% frequency of occurrence) by year three and eliminated by September 1978. Pickerelweed was not eliminated until September

TABLE 2. AVERAGE PERCENT FREQUENCY OF OCCURRENCE OF AQUATIC PLANT SPECIES IN LAKE BELL BASED ON QUARTERLY LINE TRANSECT DATA FROM SEPTEMBER 1974 TO SEPTEMBER 1978 AND YEARLY IN SEPTEMBER BEGINNING 1978. SPECIES WHICH HAD AN OCCURRENCE OF LESS THAN 1% OR OCCURRED LESS THAN 50% OF THE SAMPLE TIMES ARE OMITTED FROM THE TABLE.[1]

Species	1974-1975	1975-1976	1976-1977	1977-1978	SEPT 1978	SEPT 1979	SEPT 1980	SEPT 1981	SEPT 1982
Cladium jamaicense	0.2	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.5
Eleocharis acicularis	0.9	0.2	0.3	0	0	0	0	0	0
Hydrilla verticillata	83.9	30.6	0.2	0	0	0	0	0	0
Hydrocotyle umbellata	1.4	0.2	0	0.7	0.3	1.0	0.8	0.5	1.0
Ludwigia octovalis	1.0	0.7	0	0.5	0.8	0.3	0	1.8	0.8
Nymphaea odorata	1.8	1.3	1.7	2.1	1.9	0.5	0	2.1	1.0
Panicum hemitomon	1.7	3.0	1.0	0	0	0.3	0	0	0.5
P. repens	4.3	3.2	1.8	2.6	2.9	3.7	2.4	3.1	1.6
Pontederia lanceolata	2.1	1.9	0.8	0.6	0.8	0.3	0	0	0
Pithophora sp.	1.4	1.0	0.3	0.1	0	0	0	0	0
Salvinia rotundifolia	3.0	2.3	0.2	0.7	0	0.3	0	0	0.8
Typha latifolia	1.2	0.9	0.2	0.2	0	0	0	0	0
Utricularia inflata	2.8	0.9	0.1	0	0	0	0	0	0
% Points Vegetated	88.0	37.2	4.8	5.5	6.0	4.5	3.9	5.2	4.2
total Number of Species	19	15	14	9	6	9	3	8	8

[1]Species found at one time or another but not included in the table: *Bacopa caroliniana, Cyperus* sp., *Lemna minor, Limnobium spongia, Najas guadalupensis, Nymphoides aquatica, Rhyncospora* sp., *Sagittaria lancifolia, S. subulata,* and *Scirpus validus.*

1980. The filamentous algae *Pithophora* sp. and *Spirogyra* sp. were both eliminated from the transects in the first two years. Common cattail increased from a frequency of occurrence of 0.1% in year one to 1.0% in years two and three, by years four and five cattails were reduced 67% over the level of the previous two years, and then eliminated from the transects by September 1979. The number of species on the transects was reduced from an average of nine in the first year to two by September 1982. Much of the 91% reduction (from 9.9% to 0.9% frequency of occurrence) in waterhyacinths by year three must be attributed to annual herbicide treatment by the Florida Game and Freshwater Fish Commission. After these treatments were discontinued in 1977, waterhyacinth increased 111% (in year four versus year three) then decreased 74% by year six and were absent (probably due to grass carp feeding, see 4, 5, 6, 7) from the transects from September 1980 to 1982.

The most rapid change in the plant community occurred in Lake Holden following a herbicide treatment of 13% of the lake that took place in spring 1975 (Table 4). Hydrilla was reduced 85% on the March and June 1975 transects (13.0% frequency of occurrence) versus the September and December 1974 transects (84.4% frequency of occurrence), and was entirely absent from all subsequent transects. The aquatic vegetation on transects was reduced 80% in year two versus year one and has not recovered, although a large increase (2.0% frequency of occurrence) in alligatorweed was found in September 1982. Waterhyacinths expanded from a frequency of occurrence of 0.1% in the first year to 2.2% in year two and then decreased to 0.6% in year three (a 73% reduction over year two). This species has remained at a relatively constant level over the last six years. Common cattail, initially the second most abundant species, decreased over 62% in year three versus years one and two (2.2% versus 5.9% and 6.2% frequency of occurrence), and was eliminated from the transects by September 1979) some regrowth was evident beginning September 1981). Maidencane was reduced 92% (from 4.8% to 0.4% frequency of occurrence) by year three and was absent from the transects five of the last six years. Torpedograss was reduced 84% (from 2.5% to 0.4% frequency of occurrence) by year three and remained absent from the transects after September 1978. The alga *Pithophora* sp., initially the second most abundant submersed species, was eliminated by year three. Tapegrass (frequency of occurrence 1.4% in year one) was eliminated from the transects by year three. The average number of species on the transects was reduced over 50% for years two to eight versus year one, a possible reversal of this trend started in September 1981.

The aquatic vegetation on transects in Deer Point Lake was reduced 66% by year five and 97% by year six, but had begun to recover following a drawdown in year seven (Table 5). Eurasian watermilfoil, the most common species on the transects and the primary target plants, had a frequency of occurrence of 45.6% for year one. Although essentially unchanged at 45.0% for year four, the frequency of occurrence declined to 16.9% (a 63% reduction) by year five and to 1.1% by year six. A large increase (frequency of occurrence 21.1%) in Eurasian watermilfoil was found in September 1982 after a drawdown was conducted from December 5, 1980 to February 2, 1981. The secondary target species, Illinois pondweed, declined 62% (from 29.1% to 11.0% frequency of occurrence) by year three and was eliminated from transects by year six. Watershield declined 83% (from 3.6% to 0.7% frequency of occurrence) in year two and was eliminated from the transects by year six. Slender spikerush increased from a frequency of occurrence of 0.3% to 0.6% over the first three years, decreased to 0.2% in years four and five, and was subsequently eliminated from the transects in year six. Ludwigia decreased 83% (from 1.2% to 0.2% frequency of occurrence) by year two and was eliminated from the transects by year three. Foxtail was reduced 74% (from 2.3% to 0.6% frequency of occurrence) by year three and eliiminated from the transects by year six. Fragrant water lily increased from a frequency of occurrence of 2.6% in the first year to 4.0% by year three and then declined to 0.5% by year six. Torpedograss increased from 0.0% in year one to 1.0% by years three and four. This grass declined to 0.6% in year five and fluctuated slightly thereafter. Pickerelweed and

TABLE 3. AVERAGE PERCENT FREQUENCY OF OCCURRENCE OF AQUATIC PLANT SPECIES IN CLEAR LAKE BASED ON QUARTERLY LINE TRANSECT DATA FROM SEPTEMBER 1974 TO SEPTEMBER 1978 AND YEARLY IN SEPTEMBER BEGINNING 1978. SPECIES WHICH HAD AN OCCURRENCE OF LESS THAN 1% OR OCCURRED LESS THAN 50% OF THE SAMPLE TIMES ARE OMITTED FROM THE TABLE.[1]

Species	1974-1975	1975-1976	1976-1977	1977-1978	SEPT 1978	SEPT 1979	SEPT 1980	SEPT 1981	SEPT 1982
Ceratophyllum demersum	18.6	16.6	0.7	0	0	0	0	0	0
Cladium jamaicense	0.6	0.4	0.6	0.3	0.5	0.5	0.3	0.3	0.3
Eichhornia crassipes	9.9	2.2	0.9	1.9	0.8	0.5	0	0	0
Hydrilla verticillata	74.8	21.8	0.1	0	0	0	0	0	0
Lemna minor	1.2	0.6	0	0	0	0	0	0	0
Ludwigia octovalis	0.1	0.1	0.4	0.7	0.3	0.5	0.5	0.5	0.8
Panicum hemitomon	3.6	3.1	1.5	1.5	1.1	1.1	0.3	0	0
P. repens	8.6	6.2	1.4	0.1	0	0	0	0	0
Pontederia lanceolata	0.2	0.2	0.1	0.1	0.5	0.3	0	0	0
Typha latifolia	0.1	1.0	1.0	0.3	0.3	0	0	0	0
% Points Vegetated	89.2	40.5	5.2	3.2	2.0	1.6	1.1	0.5	1.1
total Number of Species	15	13	9	7	6	5	3	3	2

[1]Species found at one time or another but not included in the table: *Azolla* sp., *Cyperus* sp., *Pithophora* sp., *Salvinia rotundifolia, Spirogyra* sp., and *Wolfiella floridana.*

TABLE 4. AVERAGE PERCENT FREQUENCY OF OCCURRENCE OF AQUATIC PLANT SPECIES IN LAKE HOLDEN BASED ON QUARTERLY LINE TRANSECT DATA FROM SEPTEMBER 1974 TO SEPTEMBER 1978 AND YEARLY IN SEPTEMBER BEGINNING 1978. SPECIES WHICH HAD AN OCCURRENC OF LESS THAN 1% OR OCCURRED LESS THAN 50% OF THE SAMPLE TIMES ARE OMITTED FROM THE TABLE.[1]

Species	1974-1975	1975-1976	1976-1977	1977-1978	SEPT 1978	SEPT 1979	SEPT 1980	SEPT 1981	SEPT 1982
Alternanthera philoxeroides	0.1	0	0	0	0	0	0	0.3	2.0
Eichhornia crassipes	0.1	2.2	0.6	0.8	1.2	0.9	0.6	0.9	0.9
Eleocharis acicularis	1.0	0	0	0	0	0	0	0	0
Hydrilla verticillata	48.7	0	0	0	0	0	0	0	0
Ludwigia octovalis	0.8	0	0.2	0.6	0.6	0.6	0	1.5	0.9
Panicum hemitomon	4.8	3.3	0.4	0	0	0.3	0	1.5	0
P. repens	2.5	1.6	0.4	0.2	0.3	0	0	0	0
Pithophora sp.	2.7	1.4	0	0	0	0	0	0	0
Typha latifolia	5.9	6.2	2.2	1.1	0.6	0	0	0.3	0.3
Vallisneria americana	1.4	0.5	0	0	0	0	0	0	0
% Points Vegetated	59.2	12.0	3.5	2.0	3.0	1.2	0.6	1.7	3.2
total Number of Species	13	7	5	4	4	3	1	6	7

[1]Species found at one time or another but not included in the table: *Bacopa caroliniana, Ceratophyllum demersum, Cyperus* sp., *Hydrocotyle umbellata, Ludwigia leptocarpa, Polygonium* sp., and *Salvinia rotundifolia.*

common arrowhead displayed similar trends, a 57% and 90% reduction (from 0.7% and 2.0% to 0.3% and 0.2% frequency of occurrence) by year four, respectively. Common cattail (initial frequency of occurrence 0.4%) was eliminated from the transects in years three and four, increased to 0.3% in year five and then declined to 0.1% or less for the next three years. Eastern bladderwort decreased an average of 84% in years two and three, increased to surpass year one (2.6% frequency of occurrence versus 2.5%) in year four and was then eliminated from the transects by year six. Tapegrass (initial frequency of occurrence 0.7%) was eliminated from the transects in year two but after the drawdown had reestablished at a frequency of occurrence of 4.2% four years later. The average number of species on the transects was reduced from fifteen to seven by year four.

DISCUSSION

The results of feeding activities of the grass carp in these four lakes over the course of this study have demonstrated this fish to be a voracious herbivore and an effective biological control agent of aquatic plants. The average frequency of occurrence for plant species classed as submersed, floating and emersed declined 83%, 61% and 75% respectively, in four years for all lakes combined. By September 1981, submersed and floating species had an average frequency of occurrence of only 2% and 17%, respectively, of that of the first year, while emersed species in general experienced no further reduction after four years. Although it was commonly believed that grass carp would not affect emersed species (28), all emersed species except sawgrass, *Cyperus* sp., water primrose, and alligatorweed were re-

TABLE 5. AVERAGE PERCENT FREQUENCY OF OCCURRENCE OF AQUATIC PLANT SPECIES IN DEER POINT LAKE BASED ON QUARTERLY LINE TRANSECT DATA FROM SEPTEMBER 1974 TO SEPTEMBER 1980 AND YEARLY IN SEPTEMBER BEGINNING 1980. SPECIES WHICH HAD AN OCCURRENCE OF LESS THAN 1% OR OCCURRED LESS THAN 50% OF THE SAMPLE TIMES ARE OMITTED FROM THE TABLE.[1]

Species	1974-1975	1975-1976	1976-1977	1977-1978	1978-1979	1979-1980	SEPT 1980	SEPT 1981	SEPT 1982
Brasenia schreberi	3.6	0.6	0.7	0.1	0.1	0	0	0	0
Cladium jamaicense	0.1	0.2	0.4	0.4	0.5	0.2	0.1	0.1	0.3
Eleocharis baldwinii	0.3	0.5	0.6	0.2	0.2	0	0	0	0
Ludwigia leptocarpa	1.2	0.2	0	0	0	0	0	0	0
Myriophyllum pinnatum	2.3	0.2	0.6	0.3	0.2	0	0	0	0
M. spicatum	45.6	27.1	30.6	45.0	16.8	1.1	5.8	3.1	21.1
Nymphaea odorata	2.6	2.9	4.0	3.7	3.0	0.5	0.6	0.3	0.6
Panicum repens	0	0.3	1.0	1.0	0.6	0.4	0.6	0.4	0.6
Pontederia lanceolata	0.7	1.0	0.8	0.3	0.1	0	0.1	0	0
Potamogeton illinoensis	29.1	20.9	11.0	0.4	0.1	0	0	0	0
Sagittaria lancifolia	2.0	1.7	2.2	0.2	0.2	0.1	0	0.1	0
Typha latifolia	0.4	0.1	0	0	0.3	0.1	0	0.1	0
Utricularia foliosa	1.0	0	0	0	0	0	0	0	0
U. biflora	2.5	0.3	0.4	2.6	0.2	0	0	0	0
Vallisneria americana	0.7	0.5	0	0	0	0	0	0	4.2
% points vegtated	61.0	43.4	40.0	49.0	20.8	2.0	6.9	4.1	26.3
total Number of Species	21	15	13	11	12	6	5	8	5

[1]Species found at one time or another but not included in the table: *Ceratophyllum demersum, Cyperus* sp., *Hydrocotyl umbellata, Lycopus americanus, Najas guadalupensis, Nitella* sp., *Panicum hemitomon, Saccrolepsis striata,* and *Scirpus validus.*

duced by September 1981. After two years, only 6% of the transect points in Lakes Bell, Clear and Holden were vegetated. Similar conditions were found in Deer Point Lake after five years. Qualitative surveys of Lakes Bell, Clear and Holden revealed no submersed species of plants after two years; however, submersed vegetation was never completely eliminated in Deer Point Lake.

Much of the differences in the impacts on the plant communities in the three Central Florida hydrilla lakes versus Deer Point Lake are probably due to a cooler climate, lower initial stocking rate and a target plant of low grass carp feeding selectivity (Eurasian watermilfoil) for the latter. In Lakes Bell and Clear, the effect of the grass carp on most species of aquatic plants was minimal until the hydrilla frequency of occurrence was reduced 50% or more. In Lake Holden, feeding on non-target plants occurred sooner probably because the hydrilla reduction was aided by a chemical treatment. In Deer Point Lake, the opposite occurred, most plant species were substantially reduced before a reduction in Eurasian watermilfoil could be demonstrated. Furthermore, the average number of plant species on the transects was reduced by half before any reduction in Eurasian watermilfoil was noted. The reduction of this species was probably due to the supplementary stockings of grass carp. Illinois pondweed and pondweeds in general have been found to be more preferred by grass carp than Eurasian watermilfoil (1, 3, 13, 20, 22, 31). The selective feeding of the grass carp during this study can be seen by comparing the abundance of Eurasian watermilfoil and Illinois pondweed through time on Deer Point Lake (Figure 1). In the first half of the study a gradual decline of both species was apparent despite the large seasonal fluctuations. After the Illinois pondweed was reduced about 60% in year three, the frequency of occurrence of Eurasian watermilfoil increased, approaching that of year one in abundance. A less dramatic, but similar trend can be seen for common coontail versus hydrilla in Clear Lake (Figure 1). The Eurasian watermilfoil increase may be in response to the elimination of Illinois pondweed. As Krummrich[8] predicted, the Illinois pondweed was "selected out" of the milfoil-pondweed community by the grass carp. Food selectivity by the grass carp may result in an expansion in the distribution of non-preferred target plants. This phenomenon was initially temporary in Deer Point Lake, Eurasian watermilfoil declined to only 3.1% by September 1981. However, Eurasian watermilfoil expanded greatly by September 1982. Other workers have found that the use of grass carp at below optimal stocking rates to control non-preferred plants could produce undesirable results if the desirable plants are more palatable than the targets. Edwards (12) also expressed fears that unpalatable more troublesome species might spread to fill the space left by the removal of palatable species. Such an occurrence has happened in Deer Point Lake, especially after the 1981 drawdown. Vinogradov and Zolotova (38) noted the disappearance of some plants and an increase in mainly "poisonous plants" and "hygrophytic weeds" due to the

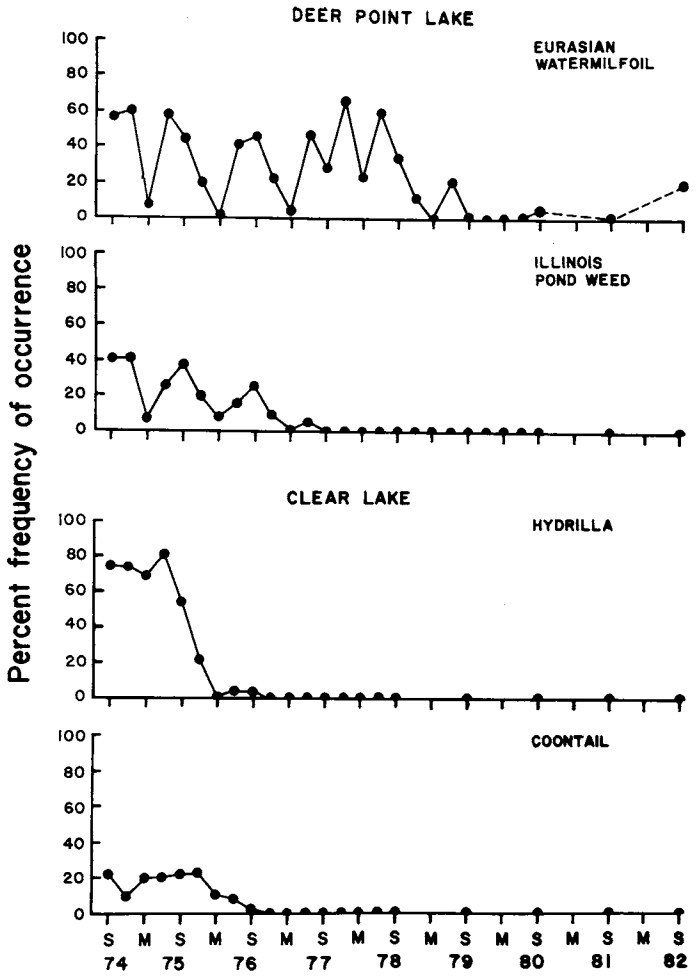

Figure 1. Percent frequency of occurrence of Eurasian watermilfoil and Illinois pondweed on transects in Deer Point Lake and, hydrilla and common coontail on transects in Clear Lake.

selective consumption of plants by grass carp. Dutch workers have found that stocking at sub-optimal rates allowed the rejected plants to grow vigorously (40). Fowler and Robson (15) found that grass carp reduced an initially diverse plant community to one with a few unpalatable species (mainly Eurasian watermilfoil) and that the initially solved plant problems reoccurred until lack of food forced the grass carp to consume the less palatable species.

Grass carp completely eliminated all submersed plants and greatly reduced most other plants in the three central Florida lakes, and effected a 93% reduction in all aquatic plants in Deer Point Lake before the drawdown. Bailey[9] stated that grass carp do not strip lakes of all cover, but leave upright emersed grasses, reeds and lilies. The only plants remaining in Lakes Bell, Clear and Holden are either in very shallow water (probably inaccessible to 10 kg grass carp), are woody plants such as water primrose (however, the leaves of this plant near the water have been stripped in Clear Lake) or are unpalatable species such as spatterdock and sawgrass. Earlier, Bailey had described similar condi-

[8]Krummrich, J. T. 1975. Deer Point Lake studies. Florida Game and Fresh Water Fish Commission. 14 pp.

[9]Bailey, W. M. 1972. Arkansas' evaluation of the desirability of introducing the white amur (*Ctenopharyngodon idella* Val.) for control of aquatic weeds. Arkansas Game and Fish Commission. 59 pp.

tions in Lake Greenlee two years after grass carp were stocked at 22 fish/ha. The only plant material left after removal of the common coontail and smartweed was woody roots, a few leaves of willow, grass roots, and rotting logs and stumps. Apparently, the number of grass carp necessary to "control" a submersed target plant will lead to a substantial reduction in the marginal plant community. Stott and Robson (33), Stott (32) and Fowler and Robson (15) have come to similar conclusions. Presently, there is no hydrilla in the three central Florida lakes and it possibly has been eradicated. In Deer Point Lake, Eurasian watermilfoil is still present, although it was substantially reduced in the main body of the reservoir before the drawdown. The persistence of this species indicates that a major reinfestation of the reservoir will occur as the grass carp become larger (consume less vegetation per fish, 26), and as the stocking rate is decreased through natural mortality, escapement over the spillway, and by drawdown. Future studies on the reservoir should determine if as the aquatic flora recovers, the remaining grass carp will selectively browse plants such as Illinois pondweed, tapegrass, and southern naiad, and thus allow Eurasian watermilfoil a considerable competitive advantage.

These data show grass carp are quite effective in controlling aquatic plants it prefers, but will control non-preferred species only after a considerable reduction in non-target species. Also, following control of preferred species, considerable reductions may be expected for non-target species. Future studies should be directed to delineate strategies to avoid or reduce the damage on non-target species, which are generally marginals which prevent erosion and provide protection and spawning areas for fishes.

ACKNOWLEDGEMENTS

The authors are sincerely grateful to the following people for their assistance in this project: Woody Miley, Danny Riley, Jo McIntosh, Gerry Kobylinski, Rue Hestand, Dr. Duane Meeter, Jeffrey Shardt and Elsa Leslie. The authors would also like to thank Dr. Bill Haller for his patience and suggestions. Don Schmitz drafted Figure 1 and provided valuable crticisms of the manuscript. The project was a cooperative effort between the Department of Natural Resources and the Florida Game and Fresh Water Fish Commission.

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