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# Evaluation of macrophyte control in 38 Florida lakes using triploid grass carp

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## ABSTRACT

Florida's large number of shallow lakes, warm climate and long growing season have contributed to the development of excessive growths of aquatic macrophytes that have seriously interfered with many water use activities. The introduction of exotic aquatic macrophyte species such as hydrilla (*Hydrilla verticillata*) have added significantly to aquatic plant problems in Florida lakes. The use of grass carp (*Ctenopharyngodon idella*) can be an effective and economical control for aquatic vegetation such as hydrilla. Early stocking rates (24 to 74 grass carp per hectare of lake area) resulted in grass carp consumption rates that vastly exceeded the growth rates of the aquatic plants and often resulted in the total loss of all submersed vegetation. This study looked at 38 Florida lakes that had been stocked with grass carp for 3 to 10 years with stocking rates ranging from < 1 to 59 grass carp per hectare of lake and 1 to 207 grass carp per hectare of vegetation to determine the long term effects of grass carp on aquatic macrophyte communities. The median PAC (percent area coverage) value of aquatic macrophytes for the study lakes after they were stocked with grass carp was 14% and the median PVI (percent volume infested) value of aquatic macrophytes was 2%. Only lakes stocked with less than 25 to 30 fish per hectare of vegetation tended to have higher than median PAC and PVI values. When grass carp are stocked at levels of > 25 to 30 fish per hectare of vegetation the complete control of aquatic vegetation can be achieved, with the exception of a few species of plants that grass carp have extreme difficulty consuming. If the management goal for a lake is to control some of the problem aquatic plants while maintaining a small population of predominately unpalatable aquatic plants, grass carp can be stocked at approximately 25 to 30 fish per hectare of vegetation.

*Key words*: *Ctenopharyngodon idella*, biological control, aquatic plant control, lake management.

## INTRODUCTION

Florida's large number of shallow lakes, warm climate and long growing season have contributed to the development of excessive growths of aquatic macrophytes that have seriously interfered with many water use activities. The introduction of exotic aquatic macrophyte species such as hydrilla (*Hydrilla verticillata*) have added significantly to aquatic plant problems in Florida lakes (Florida Department of Environmental Protection, 1982-1997). Consequently, when aquatic plants reach nuisance levels, some form of aquatic plant management is implemented.

The primary techniques used to control aquatic vegetation include herbicide applications, mechanical harvesting and biological control (Hoyer and Canfield 1997). These techniques have positive and negative attributes depending on the management objectives of the aquatic plant control program. For example, herbicides can be used to quickly and selectively control some types of aquatic weeds in specific areas, but they can be expensive and short-lived requiring repeat applications. Additionally, the public sometimes perceives chemicals as "toxins" in the environment that may harm non-target animals or even humans. Mechanical controls using specialized machines have the advantages of immediate weed control, no water use restrictions following plant removal, and selective control in small areas (i.e., boat ramps, docks, etc.). However, mechanical control is more expensive due to high maintenance and repair costs to the machinery, rapid regrowth of plants, and mechanical harvesting may not be practical for controlling large areas of nuisance weeds.

Biological control can be effective, economical, and eliminate concerns over the use of chemicals. Biological control with insects and pathogens have had some successes. For example, the alligator weed flea beetle (*Agasicles hygrophila*), imported from South America, was introduced for biocontrol in 1964, and has since effectively controlled alligator weed (*Alternanthera philoxeroides*) in Florida (Riemer 1984). However, no insects have been found to effectively control hydrilla and some of the other problem aquatic weeds in Florida.

Experimental work on the feasibility of using grass carp (*Ctenopharyngodon idella*) for weed control in Florida demonstrated that diploid grass carp effectively eliminated not only hydrilla and other target weed species but also almost all other submersed macrophytes (Opuszynski and Shireman 1995). The following experimental lakes were stocked with at least 24 grass carp per hectare of lake area, successfully eliminating hydrilla and all other submersed aquatic vegetation (Canfield et al. 1983, Small et al. 1985, Leslie et al. 1987): Lake Baldwin (24 fish/ ha), Clear (62 fish/ ha), Fairview (30 fish/ ha), Orienta (44 fish/ ha), and lakes Bell, Clear and Holden (all stocked with 50 fish/ ha). Data from these lakes led to the use of grass carp as the primary biological control agent in Florida's waters.

After successful experimental work with diploid grass carp, there were fears that these fish may be capable of reproduction in native Florida rivers (Conner et al. 1980; Leslie

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et al. 1982). The concern over potential grass carp reproduction led to the development of sterile fish produced using temperature or pressure to shock the fertilized eggs to produce an extra set of chromosomes (Cassani and Caton 1986). This process produces triploid grass carp that are sterile. Florida Game and Fresh Water Fish Commission (FGFC) studies compared the vegetation consumption rates of diploid verses triploid grass carp and found them to have similar aquatic weed control capabilities (Bob Wattendorf, FGFC, personal communication). Triploid grass carp are now used in Florida waters to control nuisance vegetation without fear of developing a reproducing population of grass carp.

Early stocking rates (24 to 74 grass carp per hectare of lake) resulted in grass carp consumption rates that vastly exceeded the growth rates of the aquatic plants and caused the total loss of all submersed vegetation. The elimination of all submersed vegetation led to the conclusion that stocking grass carp in high enough numbers to have an effect, would result in complete elimination of all aquatic plants. In addition, grass carp are known to survive for 15 or more years and cannot be effectively removed from a system once they are introduced (Opuszynski and Shireman 1995). This information has created many debates concerning the use of grass carp to control aquatic plants.

The total eradication of aquatic macrophytes in a lake may not always be the desired result of a lake management plan. Aquatic plant species are often valued for their aesthetic value and benefit to wildlife such as the ring-necked duck (Hoyer and Canfield 1994). Aquatic macrophytes are also believed by some lake managers to be important for sustaining sportfish populations (Wiley et al. 1984; Durocher et al. 1984). The elimination of macrophytes may also result in increased phytoplankton populations with a subsequent decrease in water transparency (Canfield et al. 1983). Thus, there is significant concern over the ability of grass carp to remove all submersed aquatic vegetation from lake systems.

Current strategies for using triploid grass carp include initial herbicide treatments followed with low stocking rates (< 10 fish/hectare of lake), in an attempt to control nuisance weeds while maintaining some desirable plants (Cassani 1996). Information concerning the use of grass carp to control weeds without detrimentally affecting desirable plants in lakes is lacking. Lake Conway, a 737-ha lake located in Orange County, Florida, is one of the few lakes where grass carp have been stocked with the objective of maintaining desirable submersed aquatic plants while controlling hydrilla (Nall and Schardt 1978; Leslie et al. 1994). Lake Conway was stocked with approximately 10 grass carp per hectare of lake or about 20 grass carp per hectare of vegetation in 1977 and they have successfully controlled hydrilla while maintaining a diverse community of aquatic plants in the lake, including submersed plants.

In recent years, low stocking rates of grass carp have been used in many lakes, with the objective of controlling problem plants while maintaining some macrophytes (Cassani 1996). Many of these lakes were also treated with herbicides to decrease the biomass of aquatic vegetation before the grass carp were stocked (Jaggers 1994; Eggeman 1994). Unfortunately, there have been few studies evaluating the long-term efficacy of this management technique. Debates have again erupted over whether low stocking rates can be used to control problem levels of plants while leaving some. The objective of this study was to determine impacts of grass carp stocking rates, ranging from < 1 to 60 fish per hectare of lake area and 1 to 208 fish per hectare of vegetation, on aquatic macrophyte communities in a wide range of Florida lakes.

## MATERIALS AND METHODS

### Study Lakes

The Florida Fish and Wildlife Conservation Commission (formerly Florida Game and Fresh Water Fish Commission) is charged with permitting the use of triploid grass carp in Florida. They maintain a list of lakes that have been stocked and record the stocking rates, dates of stocking, species of problem macrophyte that was to be controlled and the area of the lake covered with the problem plant. From this list, 38 lakes were selected that had been stocked with triploid grass carp from 3 to 10 years (Table 1, Figure 1). The grass carp stocking rates of these 38 lakes ranged from < 1 to 60 grass carp per hectare of lake and 1 to 208 grass carp per hectare of vegetation. Twenty lakes were stocked with less than 25 fish per hectare of vegetation. The stocked fish were all greater than 250 mm total length to help them avoid large predatory fish inhabiting most Florida lakes.

The percent area covered (PAC) with aquatic vegetation was visually estimated by Florida Fish and Wildlife Conservation biologists at the time the grass carp were stocked. Following an integrated approach to aquatic plant management, the majority of the lakes were treated with some level of herbicides prior to stocking the grass carp to decrease the initial biomass of aquatic vegetation. The primary problem plant was hydrilla which infested 27 lakes with 7 to 100 percent area covered with vegetation. Triploid grass carp were also stocked to control *Najas guadalupensis*, filamentous algae, *Cabomba caroliniana*, *Ceratophyllum demersum*, *Myriophyllum heterophyllum* and *Mayaca fluviatilis* (Table 1).

### Field Procedures

Chlorophyll *a*, lake morphology, and aquatic macrophyte data, 3 to 10 years after the grass carp were stocked, were available for 13 of the lakes (Canfield and Hoyer 1992; Florida LAKEWATCH 1997). Water chemistry, lake morphology, and aquatic macrophyte data for the remaining 25 lakes were collected between May and August, 1994. Water samples were collected from one to three open water stations on one date. Water was collected just below the surface (0.5 m) in 1.0-L acid-cleaned, triple-rinsed Nalgene bottles. Water samples were placed on ice and returned to the laboratory for analysis.

Water was filtered through Gelman type A-E glass fiber filters for chlorophyll *a* determination. Chlorophyll *a* concentrations (µg/L) were determined by using the method of Yentsch and Menzel (1963) and the equations of Parsons and Strickland (1963).

Measured chlorophyll *a* values are often not good indicators of lake trophic status when large amounts of aquatic macrophytes are present (Canfield et al. 1984). An adjusted chlorophyll *a* value (µg/L) was calculated by modifying the

TABLE 1. SURFACE AREA (IN HECTARES), TROPHIC STATUS (AS ADJUSTED CHLOROPHYLL A LEVELS BASED ON FORSBERG AND RYDING (1980) TROPHIC STATE CRITERIA), NUMBER OF GRASS CARP STOCKED PER HECTARE OF LAKE, NUMBER OF GRASS CARP STOCKED PER HECTARE OF VEGETATION, PRIMARY WEED SPECIES FOR WHICH GRASS CARP WERE STOCKED, PAC (PERCENT AREA COVERAGE) OF TARGET WEED BEFORE GRASS CARP WERE STOCKED, PAC THREE OR MORE YEARS AFTER GRASS CARP WERE STOCKED, AND THE NUMBER OF YEARS BETWEEN GRASS CARP STOCKING AND THE REEXAMINATION OF THE 38 FLORIDA LAKES USED IN THIS STUDY.

| Lake | County | Surface area (ha) | Trophic status | Carp/ha of lake | Carp/ha of vegetation | Primary weed problem | PAC before carp | PAC after carp | Years stocked |
|---|---|---|---|---|---|---|---|---|---|
| Ashby[1] | Volusia | 417 | Eutrophic | 1.7 | 8.5 | *Hydrilla verticillata* | 20 | 34 | 3 |
| Bryant[1] | Marion | 311 | Eutrophic | 2.2 | 6.7 | *Hydrilla verticillata* | 33 | 14 | 7 |
| Cay Dee[1] | Orange | 5 | Eutrophic | 19.8 | 21.8 | *Najas guadalupensis* | 91 | 12 | 3 |
| Concord[1] | Orange | 29 | Eutrophic | 4.2 | 38.2 | *Hydrilla verticillata* | 11 | 2 | 6 |
| Diane | Leon | 26 | Mesotrophic | 15.2 | 28.1 | *Myriophyllum heterophyllum* | 54 | 24 | 6 |
| Eaton[1] | Marion | 124 | Hypereutrophic | 1.9 | 3.2 | *Hydrilla verticillata* | 59 | 74 | 3 |
| Egypt[1] | Hillsborough | 27 | Eutrophic | 20.7 | 62.7 | *Hydrilla verticillata* | 33 | 10 | 4 |
| Fairview | Orange | 172 | Eutrophic | 9.3 | 12.1 | *Hydrilla verticillata* | 77 | 6 | 8 |
| Fish[1] | Osceola | 90 | Eutrophic | 9.9 | 9.9 | *Hydrilla verticillata* | 100 | 16 | 6 |
| Harris[1] | Lake | 5582 | Hypereutrophic | 0.1 | 1.4 | *Hydrilla verticillata* | 7 | 34 | 6 |
| Highland | Orange | 13 | Eutrophic | 10.8 | 60.0 | *Hydrilla verticillata* | 18 | 6 | 6 |
| Hollingsworth | Polk | 160 | Hypereutrophic | 8.5 | 11.2 | *Hydrilla verticillata* | 76 | 34 | 9 |
| Hunter[1] | Polk | 41 | Hypereutrophic | 10.7 | 10.7 | *Hydrilla verticillata* | 100 | 1 | 3 |
| Iola | Pasco | 43 | Mesotrophic | 38.8 | 129.3 | *Hydrilla verticillata* | 30 | 0 | 9 |
| Island | Marion | 55 | Mesotrophic | 7.2 | 18.0 | *Mayaca fluviatilis* | 40 | 0 | 4 |
| Ivanhoe[1] | Orange | 53 | Eutrophic | 3.9 | 26.0 | *Hydrilla verticillata* | 15 | 14 | 6 |
| John's[1] | Orange | 979 | Eutrophic | 8.5 | 19.8 | *Hydrilla verticillata* | 43 | 22 | 6 |
| Keene | Hillsborough | 20 | Eutrophic | 21.7 | 54.3 | *Ceratophyllum demersum* | 40 | 0 | 8 |
| Kerr[1] | Marion | 1146 | Mesotrophic | 4.9 | 14.0 | *Hydrilla verticillata* | 35 | 12 | 7 |
| Koon[1] | Lafayette | 51 | Eutrophic | 59.2 | 61.7 | *Cabomba caroliniana* | 96 | 62 | 9 |
| Lawne[1] | Orange | 63 | Hypereutrophic | 10.1 | 22.4 | *Hydrilla verticillata* | 45 | 4 | 6 |
| Linsey[1] | Hernando | 56 | Eutrophic | 4.3 | 11.9 | *Cabomba caroliniana* | 36 | 100 | 6 |
| Live Oak[1] | Osceola | 152 | Eutrophic | 10.1 | 11.6 | *Hydrilla verticillata* | 87 | 18 | 7 |
| Mariana[1] | Polk | 202 | Eutrophic | 5.9 | 29.5 | *Hydrilla verticillata* | 20 | 30 | 5 |
| Milldam | Marion | 85 | Mesotrophic | 6.8 | 9.7 | *Hydrilla verticillata* | 70 | 6 | 7 |
| Miona | Sumter | 169 | Eutrophic | 47.0 | 47.0 | *Hydrilla verticillata* | 100 | 16 | 8 |
| Mirror | Polk | 7 | Hypereutrophic | 39.5 | 207.9 | *Hydrilla verticillata* | 19 | 0 | 8 |
| Okahumpka[1] | Sumter | 271 | Hypereutrophic | 16.2 | 16.2 | *Hydrilla verticillata* | 75 | 100 | 8 |
| Padgett | Pasco | 81 | Eutrophic | 9.9 | 10.4 | *Hydrilla verticillata* | 95 | 8 | 6 |
| Pineloch | Orange | 24 | Eutrophic | 49.4 | 49.4 | *Hydrilla verticillata* | 100 | 2 | 10 |
| Rabamba[1] | Orange | 2 | Eutrophic | 26.1 | 26.1 | *Najas guadalupensis* | 100 | 6 | 4 |
| Saddleback N. | Hillsborough | 13 | Eutrophic | 6.0 | 6.4 | *filamentous algae* | 94 | 48 | 7 |
| Tallavana[1] | Gadsden | 67 | Hypereutrophic | 4.0 | 26.7 | *Najas guadalupensis* | 15 | 36 | 3 |
| Van Ness | Citrus | 2 | Eutrophic | 19.8 | 19.8 | *Najas guadalupensis* | 100 | 82 | 4 |
| Watertown[1] | Columbia | 20 | Eutrophic | 30.4 | 30.4 | *filamentous algae* | 100 | 7 | 3 |
| Waunatta[1] | Orange | 28 | Oligotrophic | 17.6 | 50.3 | *Hydrilla verticillata* | 35 | 2 | 7 |
| Willis[1] | Orange | 52 | Eutrophic | 3.8 | 6.3 | *Hydrilla verticillata* | 60 | 52 | 5 |
| Yale[1] | Lake | 1636 | Eutrophic | 6.5 | 26.0 | *Hydrilla verticillata* | 25 | 44 | 7 |

[1]Lakes with some form of herbicide treatment prior to stocking of grass carp.

methods of Canfield et al. (1983). The total wet weight of plants in the lake (kg) was calculated by multiplying lake surface area ($m^2$) by PAC (percent area coverage of macrophytes) and multiplying the product by the biomass of submersed plants (kg wet weight $m^{-2}$). The dry weight (kg) of plant material was calculated by multiplying the wet weight of plant material (kg) by 0.08, a factor that represents the average percent dry weight of submersed plants (Canfield and Hoyer 1992), and then converting to grams. The potential phosphorus concentration (mg $m^{-3}$) was calculated by multiplying dry weight (g) by 1.41 mg TP $g^{-1}$ dry weight, a number that represents the mean phosphorus (mg) content of dried plant material measured in 750 samples from 60 Florida lakes (University of Florida, unpublished data), and then dividing by lake volume ($m^3$). From the potential phosphorus concentration, a predicted chlorophyll *a* concentration was determined from the total phosphorus and chlorophyll *a* relationship reported by Brown (1997) for 209 Florida lakes. Adjusted chlorophyll *a* concentrations were then calculated by adding each lake's measured chlorophyll *a* concentration to the predicted chlorophyll *a* concentration.

Aquatic macrophytes were sampled at each lake once in the summer. Ten transects were run completely across each lake with a boat-mounted Raytheon DE-719 recording fathometer for calculating PAC, percent volume infested with aquatic vegetation (PVI), and lake mean depth following the procedures described by Maceina and Shireman (1980). It should be noted that PAC and PVI values include all aquatic macrophyte types including emergent, floating-leaved and submersed plants. Lake surface area was obtained from the Gazetteer of Florida Lakes (Shafer et al. 1986) or the Florida LAKEWATCH program (Florida LAKEWATCH 1997).

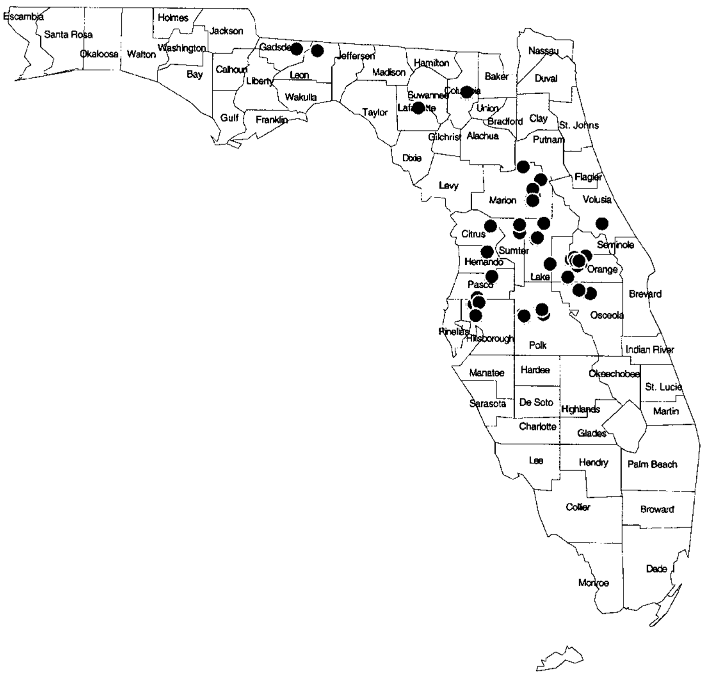


Figure 1. Map of Florida with locations of the 38 study lakes.

The above-ground standing crop of emergent, floating-leaved, and submersed vegetation was measured along ten uniformly placed transects around each lake. Plant species found along a transect were recorded. At each transect, divers cut the above-ground portions of aquatic macrophytes that were inside a plastic square (0.25 $m^2$) which was randomly thrown once in each plant zone. Vegetation was placed into nylon mesh bags, spun to remove excess water, and weighed to the nearest 0.10 kg. Average standing crop ($kg/m^2$) for each vegetation zone was calculated by averaging 10 samples from each zone. The combined width (m) of the floating-leaved and emergent zones was also measured at each transect and then averaged for each lake. This information was used to calculate the total wet plant biomass (kg) of each lake.

## RESULTS AND DISCUSSION

The 38 Florida lakes in this study ranged in size from 2 to 5580 ha with mean depths ranging from 0.5 to 5.9 m (Tables 1 and 2). The measured chlorophyll *a* concentrations in these lakes ranged from 1 to 202 μg/L, with a mean of 22 μg/L (Table 2). Adjusted chlorophyll *a* concentrations, which consider the algal biomass that would be present without aquatic macrophytes (Canfield et al. 1983), ranged from 2 to 208 μg/L with a higher mean of 30 μg/L. Using the lake classification system of Forsburg and Ryding (1980) and the adjusted chlorophyll *a* concentrations, these 38 Florida lakes range from oligotrophic to hypereutrophic (Table 1). However, over 80% of the lakes were classified as eutrophic or hypereutrophic suggesting that these lakes are highly productive lakes. The fact that most of these 38 lakes have aquatic macrophyte problems and they are eutrophic is consistent with observations that problem levels of aquatic vegetation rarely occur in nutrient poor oligotrophic or mesotrophic lakes (Hoyer and Canfield 1997). It should be noted, however, that the vast majority of aquatic macrophyte problems in this data set are caused by non-native plant species (primarily hydrilla, Table 1).

Table 2. Minimum value, maximum value, mean value and standard deviation of 14 variables for 38 Florida lakes stocked with grass carp.

| Variable | Minimum | Maximum | Mean | Std Dev |
|---|---|---|---|---|
| Surface area (acres) | 5.0 | 13788 | 797.8 | 2322 |
| Surface area (ha) | 2.0 | 5580 | 322.9 | 939.8 |
| Mean depth (m) | 0.5 | 5.9 | 2.7 | 1.3 |
| Measured chlorophyll *a* (μg/L) | 1 | 202 | 22 | 35 |
| Adjusted chlorophyll *a* (μg/L) | 2 | 208 | 30 | 37 |
| PAC before stocking | 7 | 100 | 57 | 33 |
| PAC after stocking | 0 | 100 | 24 | 28 |
| PVI after stocking | 0 | 67 | 9 | 18 |
| Emergent biomass ($kg/m^2$) | 0.0 | 6.9 | 2.2 | 1.9 |
| Floating leaved biomass ($kg/m^2$) | 0.0 | 3.9 | 1.0 | 1.1 |
| Submersed biomass ($kg/m^2$) | 0.0 | 11.6 | 2.2 | 2.8 |
| Grass carp/ha of lake | 0.1 | 59.2 | 15.1 | 14.6 |
| Grass carp/ha of vegetation | 1.4 | 207.9 | 31.7 | 38.1 |
| Number of years stocked | 3 | 10 | 6 | 2 |

The following seven aquatic plant species were designated as problem plants in theses 38 Florida lakes: *Hydrilla verticillata* (27 lakes), *Najas guadalupensis* (4 lakes), *Mayaca fluviatilis* (1 lake), *Cabomba caroliniana* (2 lakes), *Myriophyllum heterophyllum* (1 lake), filamentous algae (2 lakes), and *Ceratophyllum demersum* (1 lake) (Table 1). The percent of the lake surface area covered with aquatic macrophytes (PAC) in these lakes, before grass carp were stocked, ranged from 7 to 100%, averaging 57% (Tables 1 and 2). The length of time after grass carp were stocked until aquatic macrophyte abundance was again examined ranged from 3 to 10 years, averaging 6 years (Tables 1 and 2). The PAC in the 38 lakes, after grass carp were stocked, ranged from 0 to 100%, averaging only 24%. The percentage volume infested with aquatic macrophytes (PVI), after grass carp were stocked, ranged from 0 to 67%, averaging 9%. The emergent, floating leaved and submersed plant biomass in the study lakes, after grass carp were stocked, averaged 2.2, 1.0, and 2.2 kg wet wt/$m^2$.

The median PAC value for the study lakes, which includes emergent, floating leaved, and submersed aquatic plants, after they were stocked with grass carp was 14% (Figure 2A). The ability of some lakes to maintain a PAC of 14% or greater in the presence of grass carp suggests that under some circumstances grass carp will not eliminate all aquatic macrophytes from a lake. PVI is a measure more closely associated with aquatic macrophyte biomass than PAC and is usually a close measure of submersed aquatic macrophyte abundance. The low median PVI value of 2% (Figure 2B) suggest that grass carp had a significant impact on submersed aquatic vegetation in these lakes. However, several lakes maintained PVI values greater than 10%, again suggesting that some lakes can maintain abundant aquatic macrophytes in the presence of grass carp.

There is a wide range of years between the stocking of grass carp and the reexamination of the aquatic macrophyte abundance in these 38 Florida lakes (3 to 10 years, Table 1). Potentially, lakes stocked for only a few years may be the ones

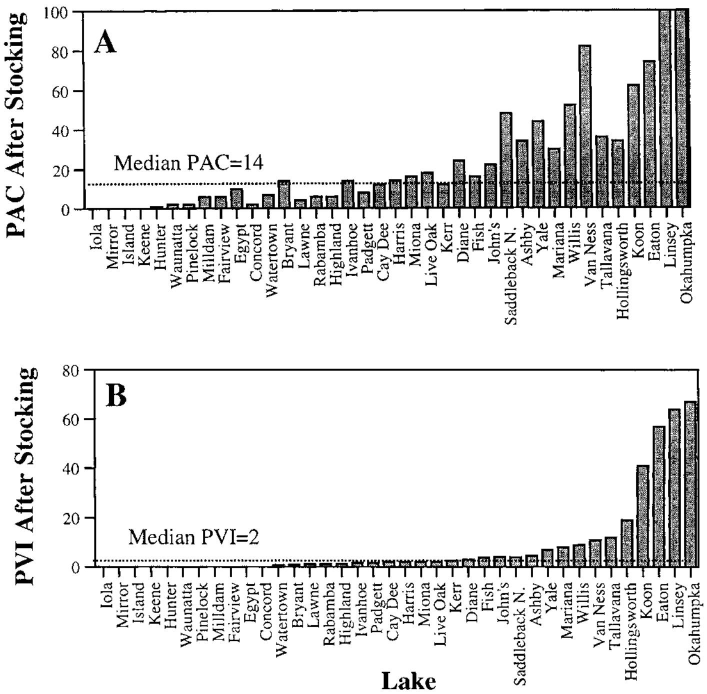


Figure 2. PAC (percent area coverage, A) and PVI (percent volume infested, B) of 38 Florida lakes after stocking with grass carp for 3 or more years. Dashed lines represents median value for all lakes.

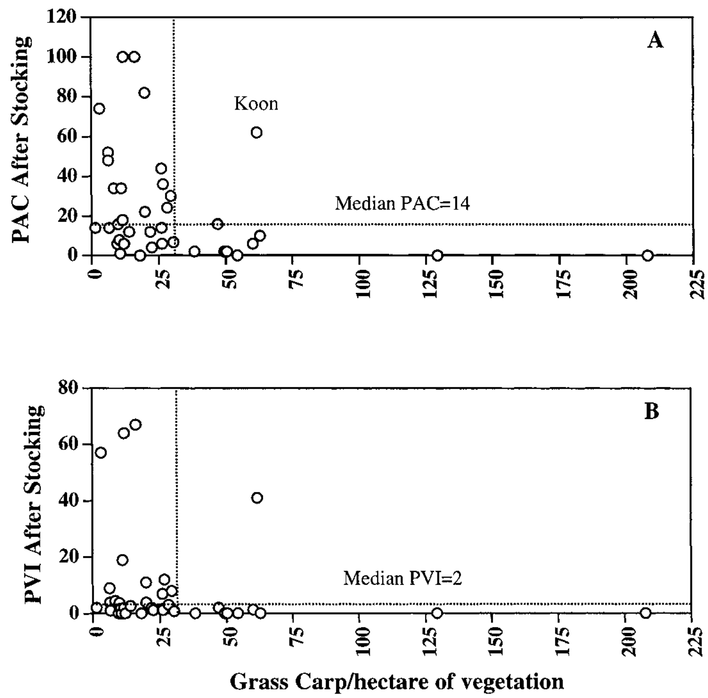


Figure 3. PAC (percent area coverage, A) and PVI (percent volume infested, B) for 38 Florida lakes after stocking with grass carp for 3 or more years, compared with the number or grass carp (accounting for 20% mortality) per hectare of vegetation.

maintaining high PAC and PVI values, while those stocked for longer periods are the ones with low PAC and PVI values. This depends on the assumption that it takes several years before grass carp can control the biomass and production of aquatic macrophytes. However, there is no relation between the PAC and PVI in lakes after grass carp have been stocked and the number of years the grass carp have been in the lake (Table 1). Thus, it appears that low and high aquatic macrophyte abundances can be present in lakes stocked with grass carp from 3 to 10 years.

There was also a wide range of grass carp stocking rates used in these 38 Florida lakes (0.1 to 59.2 grass carp/ha of lake, and 1.4 to 208 grass carp/ha of vegetation, Table 2). Potentially, lakes stocked with low rates were the ones maintaining high PAC and PVI values, while those with high stocking rates maintained low PAC and PVI values. Indeed, only lakes stocked with less than about 25 to 30 grass carp/ha of vegetation tended to have higher than median PAC and PVI values and those lakes stocked with more than about 25 to 30 grass carp/ha of vegetation tended to have less than median PAC and PVI values (Figure 3). Koon lake was a noticeable outlier to this relation, maintaining both PAC and PVI values greater than the median for all lakes and still having more than 30 grass carp/ha of vegetation (Figure 3).

One of the major difficulties in the use of grass carp is determining the mortality rate of the grass carp after stocking (Opuszynski and Shireman 1995; Cassani 1996). High mortality of grass carp after initial stocking has been documented. For example, Lake Baldwin (80 ha) was stocked with over 60 fingerling diploid grass carp per hectare of lake to control hydrilla (Colle et al. 1978). No control was achieved, however, because an estimated 94% of the stocked grass carp died. The high mortality rate was apparently due to largemouth bass (*Micropterus salmoides*) predation (Shireman et al. 1978). Handling stress, water chemistry changes, and temperature changes are some additional causes of mortality that could affect grass carp after they are stocked into a lake (Opuszynski and Shireman, 1995; Cassani 1996). Thus, grass carp in Koon could have experience high mortality after being stocked, explaining why this lakes appear to be an outlier in Figure 3.

Examining the abundance of aquatic vegetation in lakes after grass carp have been stocked only reveals what remains in a lake and not what changes have occurred in the lake. Therefore, to examine the impact grass carp had on the aquatic vegetation in the 38 study lakes, the percentage change in PAC (%PAC difference) was calculated using the following equation:

$$\% \text{ PAC difference} = ((\text{PAC after} - \text{PAC before})/\text{PAC before}) \times 100$$

where PAC before is the percentage area covered with aquatic vegetation before grass carp were stocked and PAC after is the percentage area covered with aquatic vegetation after grass carp were stocked.

There is a strong hyperbolic relationship between % PAC difference and the number of grass carp stocked per hectare of vegetation (Figure 4), with a break point around 25 to 30 grass carp/ha of vegetation. Similar to Figure 3, many lakes stocked with less than 25 to 30 grass carp/ha of vegetation appear to have no reduction or even an increase in aquatic vegetation, and those stocked with more 25 to 30 grass carp/

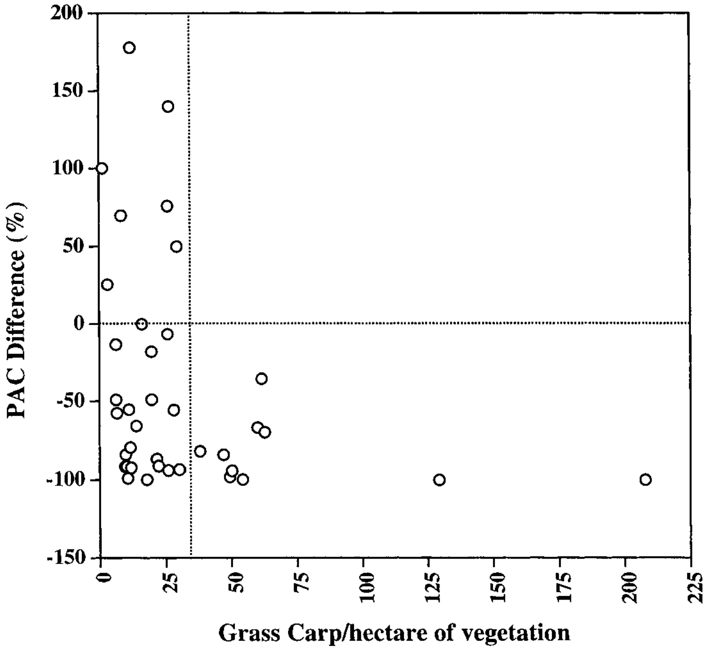


Figure 4. PAC difference (PAC difference =[(PAC after - PAC before)/ PAC before] x 100) compared with the number of grass carp (accounting for 20% mortality) per hectare of vegetation.

ha of vegetation had dramatic decreases in aquatic vegetation approaching PAC's of 0%. Thus, it appears that if grass carp are stocked in sufficient numbers (> 25 to 30 grass carp/ha of vegetation), where the consumption rate of the grass carp exceeds the growth rate of aquatic plants, there will be control of aquatic vegetation. If grass carp are stocked at < 25 to 30 grass carp/ha of vegetation, their effect on the abundance of aquatic vegetation is unpredictable.

Examples of lakes stocked with less than 25 grass carp per hectare of vegetation while maintaining abundant aquatic vegetation include; John's (PAC = 22, PVI = 4), Willis (PAC = 52, PVI = 9), Saddleback (PAC = 48, PVI = 4), and Ashby (PAC = 34, PVI = 4.5). These lakes tended to have higher than average PAC values and low PVI values suggesting that submersed plants may have been impacted while emergent and floating leaved plant may not have been impacted. Indeed, the dominant types of aquatic vegetation in these lakes were not submersed. The aquatic plant species with the highest frequency of occurrence in these lakes were emergent and floating leaved vegetation including *Panicum repens, Fuirena scirpoidea,* Typha spp., *Nuphar luteum, Ludwigia octovalis, Taxodium distichum, Pontederia cordata,* and *Polygonum hydropiperoides.* Thus, while it appears that grass carp stocked at less than 25 to 30 grass carp/ha of vegetation have little impact on the PAC of a lake, they may be having an impact on the species composition by selectively consuming desirable submersed aquatic vegetation.

Many emergent and floating-leaved plants are not considered palatable to grass carp because they have fibrous or woody tissue (Van Dyke et al. 1984). The vegetation most preferred by grass carp are soft and succulent submersed plants, but even the preferences for the same plant may differ depending on the age of the plant. Young plants are soft and tender, while older plants tend to become more fibrous (Opuszynski and Shireman 1995). Therefore, the selective feeding of grass carp pushes the remaining species of aquatic plants in a lake toward less palatable emergent and floating leaved plant species.

Examples of lakes stocked with greater than 30 grass carp per hectare of vegetation while maintaining almost no aquatic vegetation include; Keene (PAC < 1, PVI < 1), Rabamba (PAC = 6, PVI < 1), Watertown (PAC = 6.7, PVI < 0.8), Iola (PAC = 0, PVI < 0.01), and Mirror (PAC < 0.01, PVI < 1). These lakes tended to have extremely low PAC values and almost nonexistent PVI values after grass carp. The remaining dominant aquatic plants in these five lakes included: *Typha* spp., *Ludwigia octovalis, Myrica ceriferia, Scirpus californicus,* and *Nuphar luteum.* These are emergent and floating-leaved plants that are considered to be extremely difficult for grass carp to consume (Van Dyke et al. 1984).

## Management Implications

Aquatic plant management is a difficult task requiring a strict definition of goals and evaluations of methods to reach the defined goals. When grass carp are stocked at >25 to 30 grass carp/ha of vegetation where the grass carp consumption rate exceeds the growth rate of aquatic plants in a lake (approximately > 10 to 15 grass carp/hectare of water), then the complete control of aquatic vegetation can be achieved, with the exception of a few species of plants that grass carp have difficulty consuming (e.g., *Typha* spp., and *Ludwigia octovalis*). If complete control of aquatic vegetation in a lake is compatible with the stated management goals for that lake, then grass carp stocked at more than 25 to 30 grass carp/ha of vegetation is an excellent choice of an aquatic plant control technique.

Stocking grass carp per area of vegetation is the current approach used by most aquatic plant managers. However, if the complete control of aquatic vegetation is the management objective for a lake then it may not be necessary to assess how much aquatic vegetation needs to be controlled. Table 1 suggests that stocking grass carp > 10 to 15 grass carp/ha of lake will yield a grass carp density sufficient for complete control of all but the most unpalatable plant species. It is much more difficult, however, to selectively control only a small portion of aquatic vegetation with grass carp.

If the management goal for a lake is to control some of the problem aquatic plants while maintaining a small population of aquatic plants, grass carp can be stocked at approximately 25 to 30 grass carp per hectare of vegetation. When stocked at this rate, grass carp consume much of the submersed vegetation while leaving predominantly unpalatable aquatic plants. Thus, there appears to be a narrow "window of opportunity" to obtain control of nuisance levels of submersed vegetation while maintaining some predominately unpalatable submersed, floating-leaved and emergent vegetation. It is difficult, however, to achieve a stocking rate of 25 to 30 grass carp/ha of vegetation because of varying mortality rates of grass carp. There are also problems with other factors impacting aquatic plants (e.g., winter die-back, decreases in water transparency caused by increased color, turbidity or phytoplankton abundance, and large decreases in lake surface area due to drought) that may allow grass carp consumption rates to exceed the growth rate of aquatic plants, again yielding complete elimination of submersed aquatic vegetation.

When grass carp are stocked at low levels (< 25 to 30 grass carp/ha of vegetation), growth rates of aquatic macrophytes are often greater than the consumption rates of grass carp and little control may be achieved. Aquatic plants may even continue to expand. Thus, low stocking rates of grass carp may not meet a management goal of decreasing aquatic macrophyte abundance. There is, however, some indication that these low levels may impact aquatic plant species composition because of their selective feeding. Therefore, if the management goal is to shift the aquatic macrophyte species composition from palatable to unpalatable aquatic macrophytes, low level stocking of grass carp may be appropriate.

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