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THE WATER QUALITY AND FISHERY OF LAKE BALDWIN, FLORIDA: 4 YEARS AFTER MACROPHYTE REMOVAL BY GRASS CARP

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ABSTRACT

Grass carp (*Ctenopharyngodon idella*) were used to manage submersed macrophytes in Lake Baldwin, Fla. Two years after stocking, grass carp eliminated all submersed macrophytes. Four years after the elimination of submersed macrophytes, increases in total phosphorus and chlorophyll *a* concentrations and decreases in Secchi disk transparencies have been measured. Following introduction of the grass carp, lake water quality showed major changes before macrophytes were reduced below nuisance levels. Lake Baldwin continues to support a good sport fishery 4 years after the loss of macrophytic vegetation. Use of grass carp at Lake Baldwin is an economical and environmentally sound management technique for the stated management objectives. Where compatible with management objectives, use of grass carp is recommended.

INTRODUCTION

Changes have occurred in the water quality and fishery of Lake Baldwin, Fla., 4 years after the elimination of aquatic macrophytes by grass carp (*Ctenopharyngodon idella*). Aquatic macrophytes have long been regarded as an integral component of lake ecosystems (Frohne 1938; Wetzel and Hough, 1973; Shireman et al. 1982). Excessive growths of native and non-native aquatic macrophytes (such as *Hydrilla verticillata*), however, can seriously interfere with many water use activities. Consequently, some form of aquatic plant management is needed when aquatic weeds reach nuisance proportions.

Grass carp have proven to be a cost-effective biological management agent (Shireman, 1982; Shireman and Smith, 1983). Grass carp, however, can eliminate nearly all aquatic macrophytes. Use of grass carp in the United States has met considerable opposition because of fears that the elimination of aquatic macrophytes will have an adverse environmental impact. Specific concerns include increased nutrient concentrations, excessive growths of phytoplankton and filamentous algae, reduced water clarity, loss of fish habitat for feeding and spawning, and reduced harvestable sportfish (numbers/ha and kg/ha) populations. Most of these concerns are based on short-term research projects (Ware and Gasaway, 1978). The long-term impact of macrophyte removal by grass carp, however, has not been extensively studied (Bailey, 1978; Leslie et al. 1983).

STUDY AREA

Lake Baldwin is an 80 ha eutrophic lake (28° 34′ N, 80° 19′ W) located at the U.S. Naval Training Center in Orlando, Fla. The lake has a maximum depth of 7.7. m and a mean depth of 4.4 m. The lake is used primarily for swimming, boating, and fishing. Hydrilla, a non-native aquatic plant, became the dominant submersed aquatic macrophyte after 1971. Hydrilla colonized approximately 80 percent of the lake by late 1978. Colonization created a severe problem, limiting fishing and resulting in a ban on water skiing and swimming. Between 1971 and 1975, hydrilla management used the pelletized herbicide HYDOUT (Mono (N, N-dimethylalkalamine) salt of endothal). Lake Baldwin was treated with 40,000, 21,000, and 26,000 kg of HYDOUT in 1972, 1973, and 1974, respectively, at a cost exceeding $100,000 (Shireman, 1982). Herbicide treatments, however, controlled hydrilla only temporarily.

In April 1975, 4,999 fingerling grass carp (cost $1,999) were stocked into the lake in conjunction with a 14,000 kg HYDOUT treatment in an attempt to reduce hydrilla. This introduction of grass carp, however, was unsuccessful. Weed control was not achieved because 94 percent of the grass carp died (Colle et al. 1978). The high mortality rate was apparently due to largemouth bass predation (Shireman et al. 1978). An additional 1,800 grass carp (cost $8,499; Shireman, 1982) over 304 mm total length (size required to avoid largemouth bass predation) were stocked during the summer and fall of 1978. Grass carp eliminated submersed macrophytes from Lake Baldwin by June 1980 (Canfield et al. 1983a). Filamentous algae (primarily *Lyngbya* sp.) temporarily became common along the shoreline (Shireman and Maceina, 1981), but grass carp consumed these plants by late 1980 leaving only the original, small (<3 percent coverage) clumps of cattails (*Typha latifolia*), panicums (*Panicum hemitomon* and *P. repens*), and water hyacinths (*Eichhornia crassipes*) along the shoreline (Canfield et al. 1983a). These aquatic macrophytes were eliminated by late 1982. No appreciable growths of aquatic macrophytes have occurred in Lake Baldwin since June 1980.

RESULTS

Water Quality

Macrophyte coverage, the percentage of the lake's total volume infested by aquatic macrophytes (PVI), and water quality have been measured in Lake Baldwin since 1977. The experimental methods are described in Canfield et al. (1983a). Mean annual macrophyte coverage (69 percent) and PVI (37 percent) were highest in 1978 (Table 1). Macrophyte coverage by the end of the 1978 growing season had expanded to approximately 80 percent and PVI was 41 percent. During this period of high macrophyte abundance, total phosphorus concentrations averaged 11 mg/m^3, Secchi disk transparencies averaged 5.0 m (maximum 6.0 m), and chlorophyll *a* concentrations were estimated to be less than 3 mg/m^3 (Table 1). Only the presence of large amounts of aquatic macrophytes (156 g dry wt/m^2) and the mean annual total nitrogen concentration (870 mg/m^3) indicated the lake was eutrophic rather than oligotrophic as suggested by the commonly measured trophic state parameters of total phosphorus, chlorophyll *a*, and Secchi disk transparency (Canfield et al. 1983b).

Macrophyte abundance began to decline soon after the second grass carp introduction in late 1978. The concentrations of total alkalinity, calcium, magnesium, potassium, total phosphorus, and chlorophyll *a* (maximum 35 mg/m^3) showed large increases in conjunction with a sharp reduction in Secchi disk transparency (<2.0 m) shortly after the macrophyte decline began (Canfield et al. 1983a). All major changes in water quality occurred prior to the complete elimination of aquatic macrophytes, but before macrophyte abundance was reduced below nuisance (<10 percent PVI) levels (Canfield et al. 1983a). Elevated chemical concentrations and reduced Secchi disk transparencies were measured until late 1981 (Canfield et al.

Table 1.—Annual mean water quality, macrophyte abundance (PVI is the percentage of the lake's total volume infested with aquatic macrophytes), and rainfall data between 1977 and June 1984 at Lake Baldwin, Fla.

Parameter	Year							
	1977	1978	1979	1980	1981	1982	1983	1984
Total phosphorus (mg/m^3)	17.5	11.3	45.7	33.9	33.5	21.5	23.9	32.3
Chlorophyll *a* (mg/m^3)	5.9	0.5[1]	26.1	16.2	24.7	14.1	10.6	14.8
Secchi depth (m)	3.1	5.0	1.5	1.5	1.3	1.6	1.8	1.6
Total nitrogen (mg/m^3)	465	870	832	628	694	526	462	561
Calcium hardness (mg/l as $CaCO_3$)	•	•	86	85	95	81	17	16
Total hardness (mg/l as $CaCO_3$)	•	•	106	106	118	98	31	29
Total alkalinity (mg/l as $CaCO_3$)	70	59	85	100	109	91	22	17
Specific conductance (μS/cm^2 at 25°C)	233	230	220	262	281	213	100	92
Macrophytes:								
% coverage	35	69	57	11	0	0	0	0
% PVI	•	37	19	1	0	0	0	0
Yearly rainfall[2] (cm)	96.8	128.5	127.5	104.6	119.6	131.1	141.0	•
Rain departure from normal[2] (cm)	−33.2	−1.6	−2.5	−25.4	−10.4	+1.0	+19.5	•

[1]Because chlorophyll was not measured in this year it was estimated with Secchi depth and the Secchi–chlorophyll *a* relation of Canfield and Hodgson (1983).
[2]Data from nearest rain gage of U.S. Department of Commerce National Oceanic and Atmospheric Administration Environmental Data Services.

1983a). In the following year, mean annual calcium hardness, total hardness, total alkalinity, specific conductance, total phosphorus, total nitrogen, and chlorophyll *a* concentrations began to decline and Secchi disk transparencies increased slightly (Table 1).

The findings at Lake Baldwin are in general agreement with other investigations using grass carp in macrophyte-dominated lakes (Leslie et al. 1983). Our interpretation of the effect of grass carp on water quality in macrophyte-dominated lakes, however, differs somewhat from earlier interpretations. The long-term Lake Baldwin study clearly shows that other factors such as the abundance of aquatic macrophytes relative to lake volume and lake hydrology must be considered before specific changes in the limnology of a lake can be attributed solely to the action of grass carp. For example, use of grass carp in various parts of the United States has been restricted or forbidden (for example Florida) because various studies have suggested that grass carp can increase lake eutrophication and cause changes in the trophic status (Opuszynski, 1972, 1979). This conclusion has been based on the fact that total phosphorus and chlorophyll *a* concentrations are generally lower and Secchi disk transparency is generally higher prior to the loss of macrophytes (as seen in Lake Baldwin). Large errors in trophic state assessment, however, can occur when these classical indicators of lake trophic states are used to assess the trophic status of macrophyte-dominated lakes (Canfield et al. 1983b). Although total phosphorus, chlorophyll *a*, and Secchi disk values measured at Lake Baldwin in 1978 were suggestive of an oligotrophic lake, macrophyte abundance (156 g dry wt/m^2) clearly indicated that the lake was eutrophic. Thus, the elimination of aquatic macrophytes by grass carp did not change the trophic status of Lake Baldwin from oligotrophic to eutrophic. Grass carp did, however, convert the lake to a phytoplankton dominated system where the classical trophic parameters are more useful for assessing lake trophic status (Canfield et al. 1983b).

Mean annual total phosphorus and chlorophyll *a* concentrations were generally higher and Secchi disk transparencies were lower in 1979, 1980, and 1981 than in 1982, 1983, and 1984 (Table 1). These higher concentrations suggest that a slight eutrophication of Lake Baldwin occurred as grass carp removed the aquatic macrophytes and released the plant nutrients back into the lake water. The apparent trophic state upsurge, however, lasted only a little over a year after macrophytes were eliminated. The hydraulic flushing rate of Lake Baldwin is estimated to be 1.2 years. Rainfall in the Orlando, Florida area has increased since aquatic macrophytes were virtually eliminated in June of 1980 (Table 1). Nutrients that may have been released from the aquatic macrophytes via the feeding activities of grass carp appear to have been flushed from the system or lost by sedimentation. Major declines in calcium hardness, total hardness, total alkalinity, and specific conductance (even though grass carp were present) also suggest that changes in lake hydrology are having an effect on lake water quality (Table 1). It is concluded from the Lake Baldwin data that the grass carp have little long-term effect on lake eutrophication. The trophic status of a lake and its overall water chemistry appears to be determined largely by chemical loading rates, lake hydrology, and sedimentary losses (Canfield and Bachmann, 1981).

Although the elimination of aquatic macrophytes from Lake Baldwin by grass carp has not altered the trophic status of the lake or caused any long-term eutrophication, increased chlorophyll *a* concentrations and reduced Secchi disk transparencies could be interpreted as a degradation of water quality. At present, the increased phytoplankton densities have not impaired any recreational uses of Lake Baldwin. It has been argued that if some other method had been used to manage the aquatic macrophytes so that a small littoral zone had been left to assimilate nutrients, chlorophyll *a* levels and Secchi disk transparencies could be improved. Major water quality changes in Lake Baldwin occurred before macrophyte abundance was reduced below nuisance (<10 percent PVI) levels. For other lakes, the presence of small amounts of macrophytes (<10 percent PVI) generally has little effect on overall lake chlorophyll *a* concentrations and Secchi disk transparencies (Canfield et al. 1984). Thus, not using grass carp for the sole purpose of leaving a small littoral zone would appear to have little effect on whole-lake chlorophyll *a* concentrations and Secchi disk transparencies.

Fish

The potential impact of grass carp on native fish populations is a major environmental concern. Some studies have suggested that grass carp have no predictable impact (Bailey, 1978), whereas other studies suggest a deleterious impact (Ware and Gasaway, 1978). Blocknet sampling in the fall of 1977 and from 1979 to 1983 was conducted to determine fish abundance and population structure. In 1977, blocknets were used in conjunction with a selective whole-lake rotenone treatment used to estimate the grass carp population (Colle et al. 1978). Two 0.4 ha and two 0.08 ha blocknets were set in areas colonized by hydrilla. Water depths ranged from 2 to 3 m. In 1979, most of the lake still had hydrilla. Three 0.08 ha blocknets (2–3 m deep) were set in the littoral area.

During 1980–83, three limnetic and three littoral 0.08 ha blocknets were used to sample open-water and littoral fish populations. Blocknet areas were treated with 2.0 mg/l rotenone (5 percent active ingredient, Noxfish). Fish killed inside the nets were collected for 3 consecutive days. Fish were identified to species and separated into 40 mm total length (TL) size groups, counted, and weighed. All data on the number of fish per hectare and the weight (kg) of fish per hectare were reported on a whole-lake basis adjusting for the area of littoral and open water regions during each year.

Relative weight (Wr) of largemouth bass captured between 1977 and June 1984 were determined using a method modified from Wege and Anderson (1978). Wr was calculated as follows:

$$Wr = \frac{Wt}{Ws} \times 100 \qquad (1)$$

where Wt is the individual fish's weight (g) and Ws is the calculated weight for that fish's length (mm) based on weight-length relationships determined for different size groups of largemouth bass collected at Lake Baldwin. Largemouth bass with a Wr greater than 100 are defined as being in better than average condition.

The major predator and sportfish in Lake Baldwin is the largemouth bass. Mean Wr is either equivalent or higher in years without large amounts of vegetation (1980–84) for all size groups of largemouth bass (Table 2). This is similar to findings of Bailey (1978) and Colle and Shireman (1980) who reported that condition factors of bluegill, redear sunfish, and largemouth bass are negatively impacted by large amounts of aquatic macrophytes. This is probably due to reduced predation success because of the increased environmental complexity caused by macrophyte structure (Heck and Thoman, 1981; Savino and Stein, 1982).

The total standing crop (kg/ha) of largemouth bass in Lake Baldwin has averaged about three times higher in years without vegetation (1980–83) than in years with large amounts of vegetation (1977 and 1979) (Table 3). During abundant macrophyte years, greater numbers and biomass of small and intermediate sized largemouth bass existed while during macrophyte-free years there were generally greater numbers and biomass of harvestable largemouth bass (Table 3). Although the stock of young of the year largemouth bass was generally greater in years with large amounts of macrophytes (1977 and 1979), recruitment into harvestable size classes has generally been better in macrophyte-free years (Table 3).

Total fish number (9,200 to 36,000 fish/ha) and standing crop (39 to 217 kg/ha) have fluctuated greatly as determined by blocknet sampling (Table 4). The total stock and biomass of fish does not appear to be related to macrophyte abundance. The total stock of harvestable fish has also varied greatly (Table 4). The total standing crop (kg/ha) of harvestable fish in Lake Baldwin, however, has been greater in years without macrophytes (Table 4).

Management Implication

At the present time, there are three basic approaches for managing aquatic weed problems in lakes where significant reductions in nutrient inputs cannot be made: (1) mechanical harvesting and removal of aquatic plants, (2) herbicide treatments, and (3) the stocking of grass carp (biological control). These approaches may be integrated. However, each approach has its own environmental impact. Mechanical harvesting and herbicide treatments generally require repeated application. A major drawback to these treatments is that they are very expensive (Shireman, 1982). Grass carp provide long-term, cost-effective management for submersed aquatic weeds if they are stocked at a size large enough to avoid predation and in sufficient numbers to consume the aquatic plants.

Table 2.—Annual mean Relative Weight (Wr) of largemouth bass by total length (TL) group caught with electrofishing gear between 1977 and June 1984 in Lake Baldwin, Fla. Numbers in parentheses are the sample size.

Largemouth bass Size groups (mm TL)	Year 1977	1978	1980	1981	1982	1983	1984
<150	97	98	99	102	106	97	108
	(111)	(77)	(36)	(45)	(108)	(13)	(10)
150 to 250	97	93	97	103	99	99	108
	(155)	(142)	(89)	(142)	(111)	(70)	(63)
>250[1]	99	94	103	106	101	99	110
	(170)	(128)	(188)	(455)	(342)	(132)	(83)

[1]harvestable

Table 3.—Largemouth bass stock by total length (TL) group (number/ha) and standing crop (kg/ha) in Lake Baldwin, Fla. Standing crop numbers are in parentheses.

Largemouth bass Size group (mm TL)	Year 1977	1979	1980	1981	1982	1983
<161	318	58	0	105	33	3
	(2.8)	(0.5)	(0.0)	(0.5)	(0.5)	(0.02)
160 to 241	75	37	0	0	8	3
	(4.5)	(2.6)	(0.0)	(0.5)	(0.7)	(0.3)
>240[1]	8	21	24	26	19	38
	(3.3)	(4.3)	(44)	(25)	(9.0)	(22)
Total	401	116	24	131	60	44
	(11)	(7)	(44)	(26)	(10)	(23)

[1]harvestable

Table 4.—Fish population parameters for Lake Baldwin, Fla. Total harvestable fish include largemouth bass and ictalurids greater than 240 mm total length (TL), and black crappie, bluegill, and redear sunfish greater than 160 mm TL.

Parameter	Year 1977	1979	1980	1981	1982	1983
Total fish:						
numbers/ha	17,000	9,200	11,000	36,000	21,000	11,000
kg/ha	163	217	53	172	173	39
Total harvestable fish:						
numbers/ha	81	83	24	64	327	66
kg/ha	12	8.8	44	33	54	28

Using grass carp, however, will result in the removal of all submersed aquatic macrophytes unless some of the grass carp are removed.

Complete removal of aquatic macrophytes by grass carp in Lake Baldwin caused no long-term negative impact on either the water quality or fishery. Major water quality changes occurred prior to the complete loss of macrophytic vegetation and before macrophyte abundance was reduced below nuisance (<10 percent PVI) levels. Thus, maintaining a littoral macrophytic fringe would not substantially improve water quality. The total number of largemouth bass in Lake Baldwin was reduced after macrophyte removal, but the remaining fish are now in better condition and more of them are of harvestable size. The survival of small largemouth bass was generally reduced after vegetation removal, but the growth and recruitment of these fish, as well as other sportfish, has increased. Even after submersed macrophytes have been eliminated and emergent vegetation reduced, the lake continues to sustain a sport fishery for largemouth bass, bluegill, black crappie, and redear sunfish. Lake Baldwin supports almost three times the standing crop (kg/ha) of harvestable largemouth bass and five times the total harvestable fish biomass that it did during years when macrophyte abundance was high.

Prior to selecting an approach or approaches for managing a lake aquatic weed problem, management objectives must be clearly stated for the waterbody. Not all water uses are compatible, and it is not always possible to optimize lake conditions for each use. Some sort of prioritization of uses must be made. Management objectives, however, must also be realistic. Many shallow lakes in fertile areas are very productive and no reasonable amount of management will make them oligotrophic. For example, Lake Baldwin is used for general recreation (boating, water skiing, swimming, and fishing) and the management consensus was that all submersed vegetation should be removed. The use of grass carp proved to be an economical, environmentally sound management technique for the stated management goals. Although there have been limnological and fishery changes associated with the use of grass carp, overall recreational use of the lake has increased. The changes both in water quality and fish populations have generally been within limits considered satisfactory by the major user groups and would have occurred regardless of the type of control methods used. Changes occur primarily because of the removal of vegetation not because of the removal method (Brooker and Edwards, 1975).

Grass carp are the only aquatic weed management approach available that can provide a low cost, effective, long-term management solution. Grass carp must be stocked at a size large enough not to be preyed upon by predators. In Florida, largemouth bass prey heavily upon grass carp less than 300 mm TL. Stocking rate depends upon the density of aquatic weeds present. In this study a stocking rate of approximately 25 grass carp/ha controlled hydrilla within 2 years. If a slower rate of control were acceptable, a lower stocking rate could be used (15–20 fish/ha). It might be possible to use lower stocking rates with lower plant density, but a stocking rate of 20 fish/ha will control hydrilla in Florida in most situations. Grass carp did not reproduce in Lake Baldwin, nor did they switch their food habits once vegetation was removed. They also pose no threat either real or potential, to human health. Where compatible with management objectives, we recommend use of this fish.

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