LIMNOLOGICAL AND ECOLOGICAL EFFECTS OF GRASS CARP IN PONDS

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ABSTRACT

The feeding activity of grass carp (Ctenopharyngodon idella) *significantly reduced the final biomass of submerged plants in Missouri ponds. Water quality was improved; total alkalinity and pH were sustained at levels more suitable for productivity. Nocturnal oxygen depletion was less severe, and noxious phytoplankton blooms did not develop in ponds stocked with grass carp. Grass carp had no significant effect on abundance of glass shrimp* (Palaemonetes kadiakensis); *bluegills* (Lepomis macrochirus) *had a much greater negative effect. In six of eight ponds with grass carp the densities of fathead minnows* (Pimephales promelas) *were greater than in any control pond. Young bluegills were significantly more abundant in ponds with grass carp. Bluegill growth was negatively correlated with bluegill density, but not with grass carp biomass. Average total apparent fish production was 270% greater in ponds with grass carp than in control ponds.*

The grass carp (*Ctenopharyngodon idella*) has been promoted as an ideal biological control agent for rooted aquatic plants, Nair (1968) cited numerous references attesting to its effectiveness. The grass carp has also been condemned as a serious potential threat to native fishes and their habitat (Pelzman 1971). Relatively few experiments have been conducted to determine the effects of grass carp on limnological and ecological conditions in ponds. The objectives of the present study were to evaluate the effects of grass carp on (1) aquatic plant abundance; (2) water quality, i.e., dissolved oxygen, pH, alkalinity, turbidity, and photosynthetic pigment; (3) benthos biomass; and (4) the production of selected organisms, i.e., the omnivorous glass shrimp (*Palaemonetes kadiakensis*), the detritus-eating fathead minnow (*Pimephales promelas*), and the carnivorous bluegill (*Lepomis macrochirus*).

The project was stimulated by local and national problems in weed control. The experimental ponds at the Fish-Pesticide Research Laboratory, Columbia, Missouri, are difficult to use for aquatic research because excessive growth of submerged rooted plants periodically causes high pH, oxygen depletion, and hinders sampling (Houf 1974). In many lakes and reservoirs in the United States, aquatic vegetation impedes recreational activities such as fishing, boating, water skiing, and swimming. Excessive cover provided by submerged plants can reduce the effectiveness of largemouth bass (*Micropterus salmoides*) as a predator and contribute to overpopulation of bluegills (Bennett 1962, Swingle and Smith 1942). Rooted plants and filamentous algae may be used less efficiently than phytoplankton in aquatic food chains and thus limit available fish foods and decrease the annual production of sport fishes (Summers 1963, Bennett 1962).

MATERIALS AND METHODS

Duplicate ponds were stocked with various combinations of fathead minnows, glass shrimp, adult bluegills and grass carp (Table 1). The study ponds were of two approximate sizes; 0.03 ha (ponds 1-8) and 0.07 ha (ponds 9-14). Maximum depth was about 1.5 m. Ponds 13 and 14 were used to determine the effects of doubling grass carp density. Dense stands of aquatic vegetation were present in all ponds. Bushy pond weed (*Najas guadalupensis*) and muskgrass (*Chara* sp.) were the most abundant plants. Other plants present in some ponds were cattail (*Typha* sp), arrowhead (*Sagittaria* sp.), smartweed

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[1] Reference to trade names does not imply Government endorsement of commercial products.

(*Polygonum* sp.), water hysop (*Bacopa rotundifolia*), sedge (*Carex* sp.), spiderush (*Eleocharis* sp.), and Eurasian water milfoil (*Myriophyllum spicatum*).

Table 1. Surface area of study ponds and initial stock number and biomass (kg).

Pond no.	*Pond area (ha)*	*Glass shrimp (no.)*	*Fathead minnow*		*Bluegill*		*Grass carp*	
			No.	*Wgt.*	*No.*	*Wgt.*	*No.*	*Wgt.*
1	0.028	480	100	0.21	51	4.18	3	2.02
2	0.033	480	100	0.16	—	—	—	—
3	0.034	480	100	0.17	—	—	—	—
4	0.039	480	100	0.20	—	—	3	1.81
5	0.031	480	100	0.21	51	3.90	—	—
6	0.038	480	100	0.17	52	3.97	3	1.11
7	0.043	480	100	0.20	—	—	3	1.52
8	0.039	480	100	0.18	58	3.83	—	—
9	0.060	—	250	0.46	130	10.60	—	—
10	0.074	—	250	0.43	134	10.16	—	—
11	0.085	—	250	0.45	126	10.20	8	3.81
12	0.075	—	250	0.43	115	10.06	8	4.26
13	0.069	—	250	0.47	91	9.18	16	7.53
14	0.083	—	250	0.45	91	8.66	16	8.73

Two-year-old grass carp weighing 370-673 g each were stocked in the 0.03 ha ponds on 14 May 1973, and in the 0.07 ha ponds on 21 May. Adult bluegills (weight 82-224 g) were stocked on 5-8 June; fathead minnows (49-74 mm total length) on 11 June and glass shrimp (10-25 mm) on 17 May and 12 and 20 June.

Surface water samples were collected near the area of maximum depth just after dawn on 4 days; 31 June, 13 and 27 August, and 28 September, 1973. The pH was measured with a Fisher[1] Accumet model 210 pH meter. Alkalinity was determined by the potentiometric titration method (American Public Health Association 1971). Turbidity was measured with a Hach turbidimeter (Model 2100). Total photosynthetic pigment (chlorophyll and phaeophytin) was measured with a Bausch and Lomb Spectronic 20 at 663 and 750 mμ (Golterman 1970). Dissolved oxygen and temperature profiles were measured with a Yellow Springs Instrument temperature—oxygen meter (Model 54) near the area of maximum depth. Plant biomass (live drained weight) was estimated by uniform hauls of a plant hook 30 cm in diameter.

An Ekman dredge mounted on a pole was used to sample benthic organisms. Samples were preserved and stained in rose bengal-formalin solution (Lackey and May 1971), washed through a combination benthic sample washer and sorting trough (Houf 1974), and sorted by the sugar flotation method described by Anderson (1959). Only biomass of benthos (g/m^2) is discussed. Populations of shrimp were estimated from triplicate 1 m^2 samples before the ponds were drained (Nielsen 1974). Populations of fish were measured when ponds were drained in October 1973.

Statistical significance was determined by the Student's *t* distribution, at the 0.05 confidence level.

RESULTS

Plant Growth

On September 27, ponds with grass carp contained significantly less submerged aquatic vegetation (mean biomass, 309 g/m^2) than did ponds without grass carp (1071 g/m^2; Fig. 1). Five of six control ponds, but only one (Pond 6) of eight ponds with grass carp had a macrophyte biomass greater than 1 kg/m^2. Rooted submerged vegetation was completely eliminated in four of eight grass carp ponds—two ponds stocked at the "regular" density of grass carp (7 and 12) and both ponds (13 and 14) with the double density (Table 2).

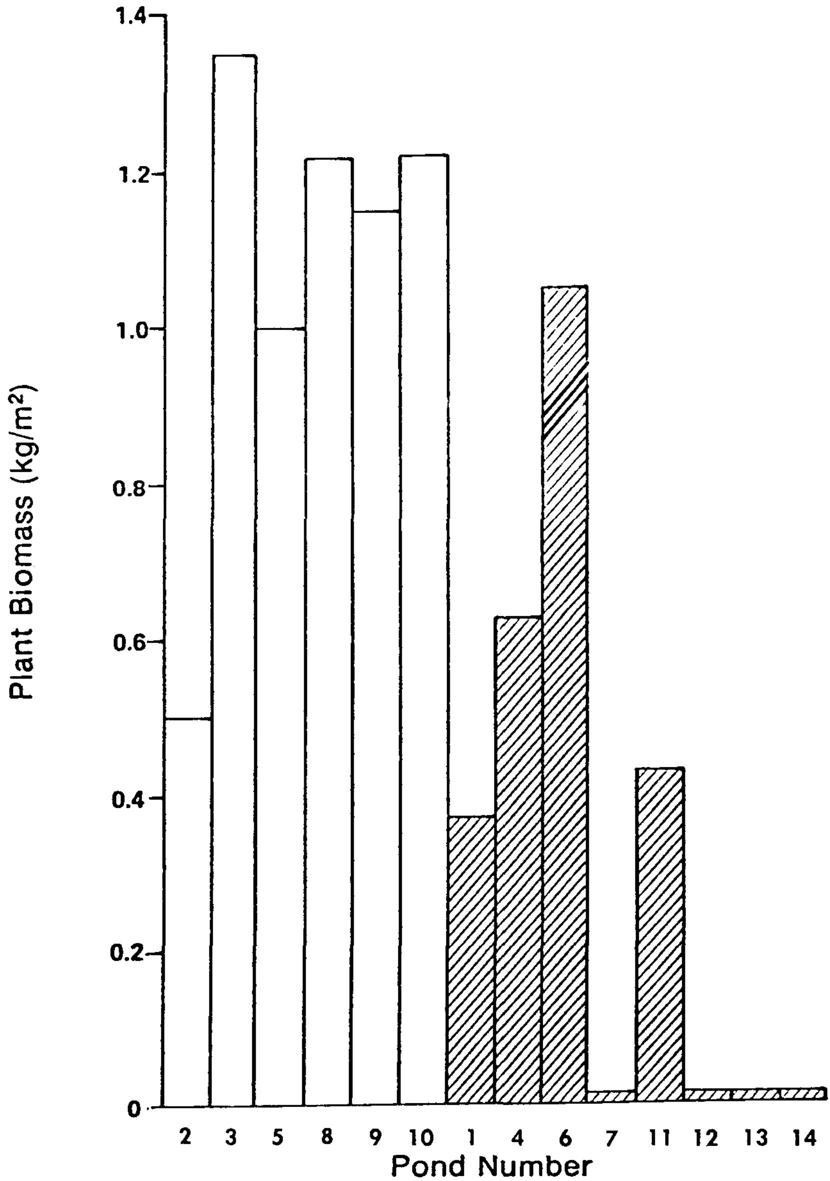

Figure 1. Final plant biomass of study ponds. Open bars are control ponds; hatched bars are grass carp ponds.

Table 2. Grass carp stocking density, growth, condition (K_{TL}), and apparent production as related to final vegetation biomass.

Pond no.	Stocking density no./ha	Final plant biomass g/m²	Average length (mm) Initial	Final	Increment	Average weight (g) Initial	Final	Increment	Condition factor (K_{TL})	Apparent production (kg/ha)
1	106	368	409	699	290	673	4323	3650	1.26	388
4	78	631	391	666	275	605	3593	2988	1.21	231
6	78	1044	330	637	307	370	3638	3268	1.40	256
7	70	0	355	638	283	507	3130	2623	1.21	183
11	94	429	359	618	259	476	3613	3137	1.53	294
12	107	0	373	518	145	533	1549	1016	1.08	109
13	233	0	357	451	94	471	1190	719	1.08	167
14	193	0	376	546	150	546	1767	1221	1.08	193

Water Quality

Photosynthesis by aquatic plants removes free CO_2 from the water which raises the pH and may lower the alkalinity. On all sampling dates except 28 September, the pH was significantly lower and total alkalinity was significantly higher in ponds with grass carp than in ponds without them (Fig. 2). Average pH of ponds without grass carp exceeded 10.0 in late August and four of six ponds (3, 5, 9, and 10) had a pH of 10.35 or higher. Bluegills have survived pH as high as 10.35, but adverse physiological reactions occurred (Trama 1954).

Dissolved oxygen concentrations were measured at the surface and at 0.5 m and 1.0 m depths before sunrise on four days (Fig. 2). Oxygen depletion was more severe in control ponds without grass carp, than in ponds with grass carp. Average oxygen concentrations at 0.5 m was 7.0 ppm or more in grass carp ponds for all sample dates. In control ponds during August, mean dissolved oxygen was 4.0 ppm or less at 0.5 m. On 23 August, the dissolved oxygen concentration in control pond 8 did not exceed 5 ppm at the surface or 1 ppm at 0.5 m depth. Highest levels of oxygen supersaturation were observed at the surface of the 0.07 ha ponds without grass carp.

Introduction of grass carp in other waters has resulted in algal blooms (Alikunki and Sukumaran 1964, Prouse 1969); however Terrell (1975) observed that nutrients released by grass carp feeding are in the sediments and may not be available to plankton. No algal bloom was seen in any of the ponds during the study. Control ponds had lower ranges in values of both photosynthetic pigment and turbidity, but total pigment concentration did not differ significantly between grass carp and control ponds on either of two sampling dates (Fig. 4). In general, turbidity in the study ponds was correlated with the amount of photosynthetic pigment. The average turbidity of the ponds remained nearly constant (Fig. 5). Turbidity of grass carp ponds did not differ significantly from control ponds except on 13 August.

Invertebrates

Glass shrimp, freshwater decapod crustaceans that attain a maximum length of 38 mm, are eaten by bluegills (Nielsen 1974). Density of shrimp was variable, but mean density of ponds with and without grass carp was almost identical; 147 and 146/m², respectively (Fig. 6). The presence of bluegills appears to have a depressing effect on the number of shrimp. The biomass of benthic organisms was variable. Grass carp had no significant effect on benthic biomass. There may appear to be a negative relationship between grass carp biomass and benthic biomass (Fig. 7), but the two ponds (1 and 11) with the highest grass carp biomass had submerged vegetation remaining. A high density pond (13), void of vegetation, had the greatest benthic biomass in grass carp ponds. It is improbable that an intermediate density of large grass carp with an abundant supply of vegetation would have a greater depressing effect on benthos than a high density of grass carp in a pond void of vegetation. There was no apparent correlation between bluegill biomass and biomass of benthic organisms.

Fish Production

Nearly all grass carp stocked were recovered when the ponds were drained; unaccountable losses amounted to only two fish from a high-density 0.07-ha pond (14). Growth of some of the fish was considered phenomenal; maximum weight at the end of the study was 5.1 kg. Average growth and apparent production—i.e. final biomass less

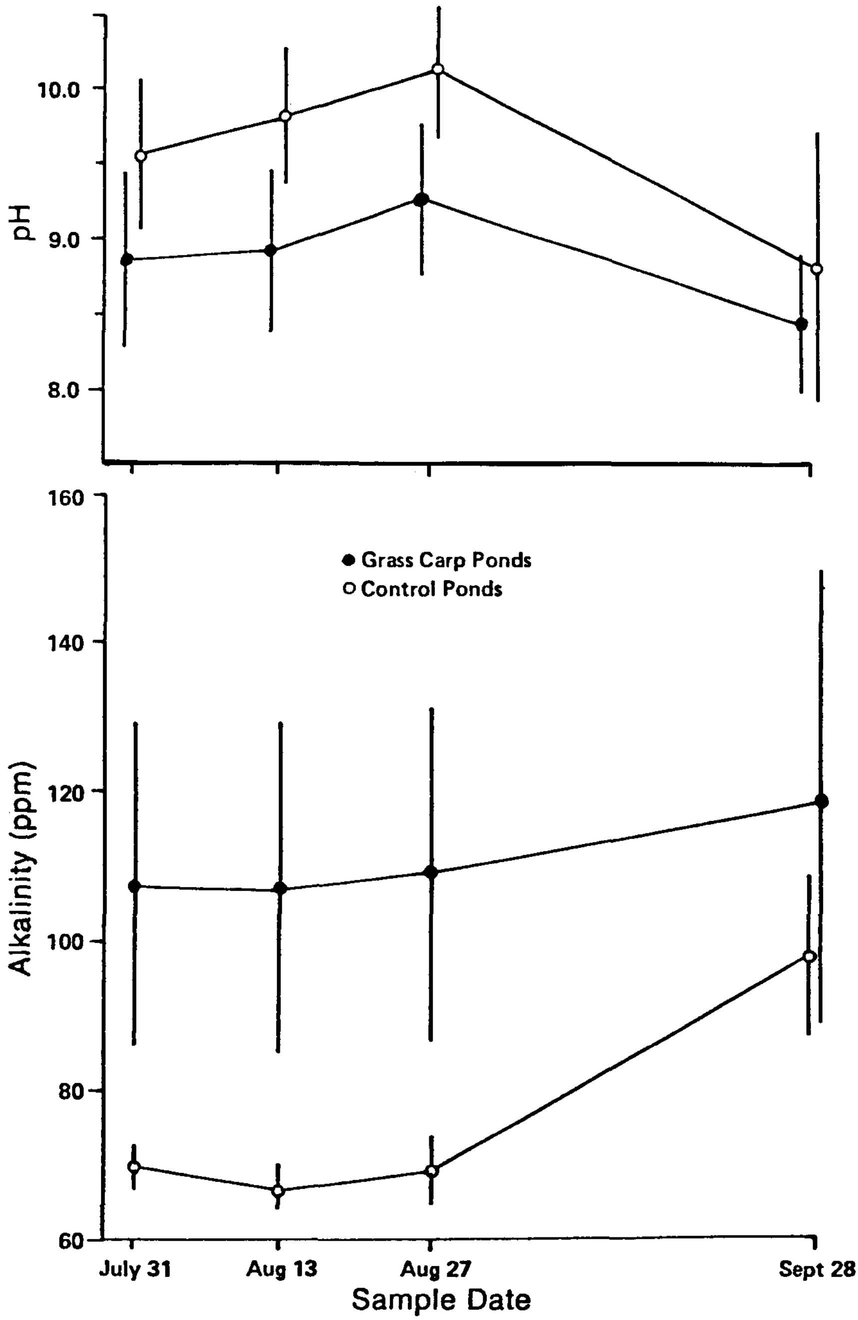

Figure 2. Average pH and total alkalinity in study ponds with and without grass carp. Ranges equal ± one standard deviation.

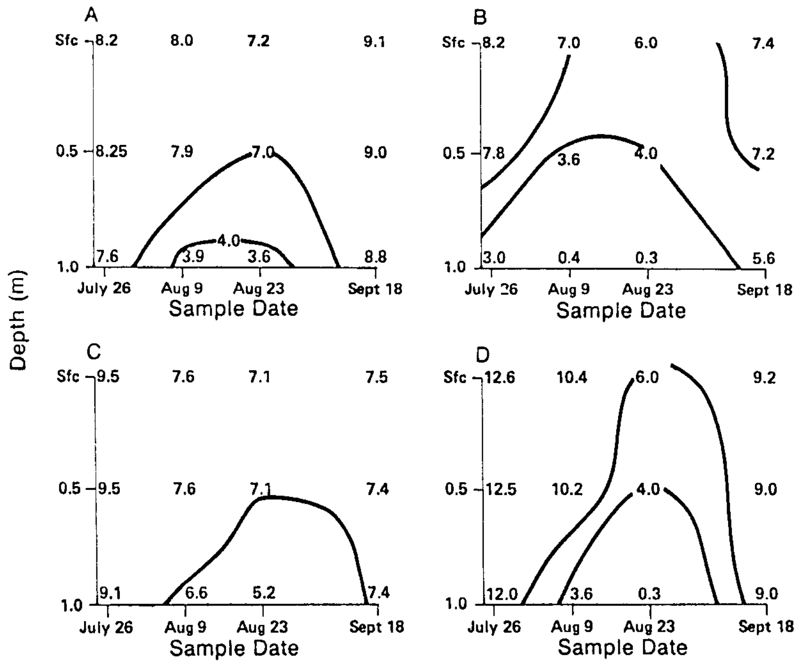

Figure 3. Average dissolved oxygen profiles in experimental ponds. Sections A and B are 0.03 ha ponds; Sections C and D are 0.07 ha ponds. Sections B and D are control ponds; Sections A and C are ponds with grass carp. Lines are isopleths of 4.0 and 7.0 ppm dissolved oxygen.

biomass of survivors at the time of stocking—were significantly lower in the four ponds where vegetation was eliminated than in the four ponds where plants remained (Table 2). The coefficient of condition (K_{TL}) of grass carp in ponds was also significantly lower without vegetation than in ponds with vegetation. Terrell and Fox (1975) reported that in the absence of vegetation in ponds, grass carp lost weight.

The highest density of fathead minnows in a control pond was 133,700/ha; higher densities were observed in six of eight ponds with grass carp (Fig. 8). Fathead minnows were most abundant in ponds from which grass carp had eliminated all submerged plants (ponds 7, 12, 13, and 14). Density of fathead minnows was highest when vegetation was eliminated at the "regular" grass carp stocking density (ponds 7 and 12). Removal of vegetation by grass carp appears to have a positive effect on the reproduction of fathead minnows; this effect may be due to improved pH or dissolved oxygen conditions. Apparent production of fathead minnows did not differ significantly in ponds with and without grass carp; average values were 150 and 63 kg/ha respectively (Fig. 8).

Survival of adult bluegills to the end of the study was quite variable—5.4 to 61.5% (Table 3). Some mortality was observed shortly after stocking. Due to the low survival of adult bluegills in control pond 8, growth and condition data were not included in the analysis.

Adult bluegill growth varied among ponds but could not be correlated with any measured factor other than bluegill density. Mean weight increment was inversely related to adult bluegill abundance; slope = 0.071, Y-axis intercept = 74.5, r = 0.55. From this relationship, an adjusted adult bluegill growth was computed. There was no correlation between grass carp biomass and adjusted adult bluegill growth (Fig. 9). Average length

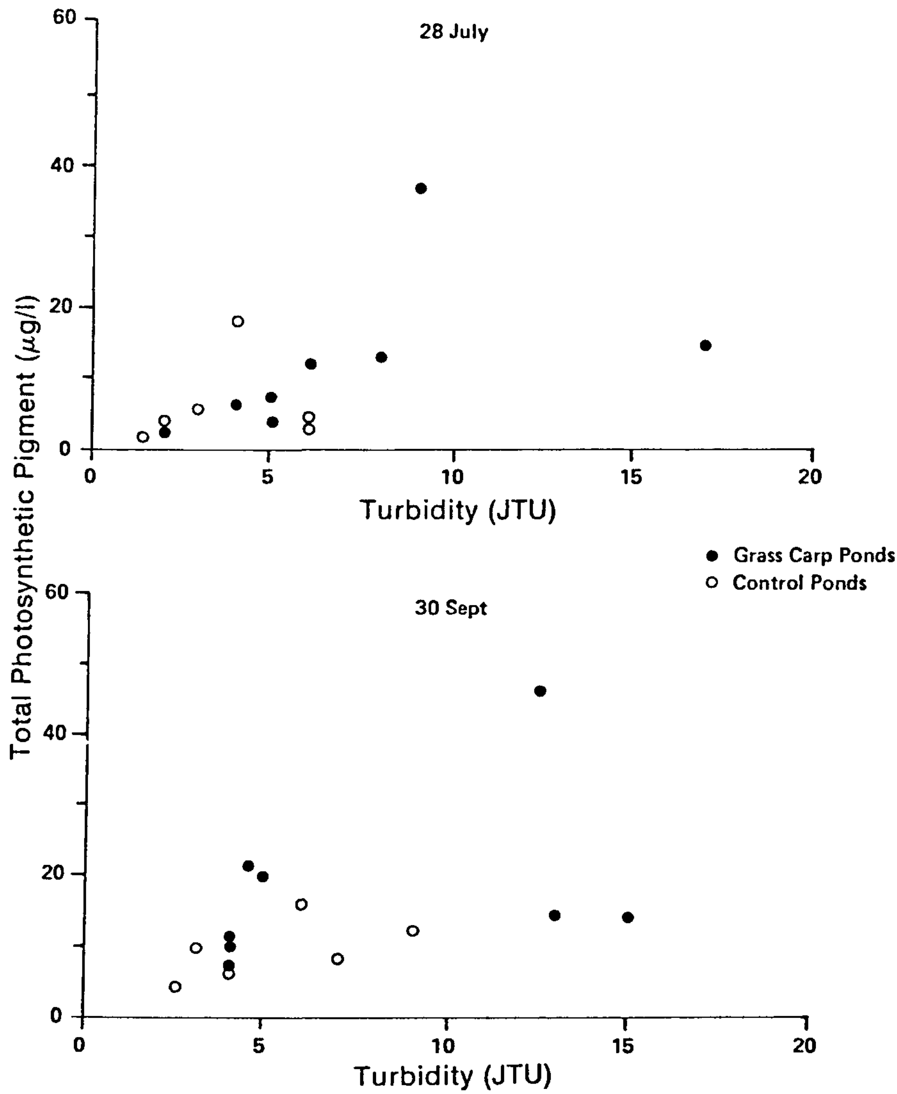

Figure 4. Total chlorophyll and phaeophytin as a function of turbidity. Open symbols are for ponds without grass carp, closed symbols are for ponds with grass carp.

increments of adult bluegills in ponds containing grass carp were not significantly different from that in control ponds.

Young bluegills were significantly more abundant in ponds containing grass carp (Fig. 10). Density of young bluegills was higher in four of six grass carp ponds (6, 12, 13, and 14) than any of the control ponds. Three of the four ponds (12, 13, and 14) had no submerged vegetation at the end of the study. Bluegill nest depressions were observed in the 0.07 ha

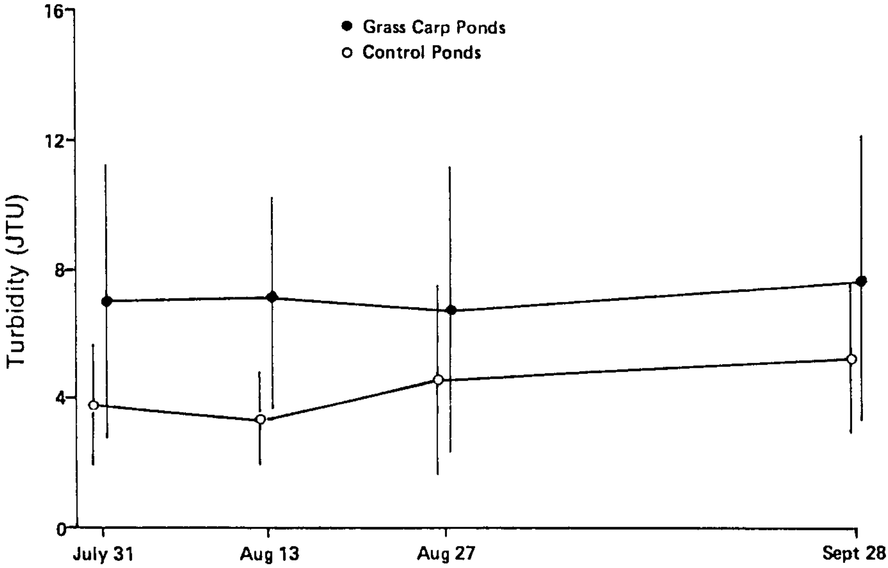

Figure 5. Average turbidity of study ponds on sample dates.

grass carp ponds at the time of draining at a depth of 0.5 m. No beds were observed in ponds without grass carp. Heavy plant growth may have had a direct adverse effect on nesting activity (Swingle and Smith 1942), or an indirect adverse effect caused by oxygen depletion.

Final biomass of young bluegills was not significantly affected by the presence of grass carp (Fig. 10). The growth of survivors from the June hatch in ponds without grass carp was adequate to compensate for the relatively low density.

Nikolskii and Verigin (1968) reported that herbivorous fish have increased the fish production of ponds by 50 to 100%. In our study ponds the addition of grass carp increased the mean total fish production by 270% (Fig. 11), supporting a statement by Cure (1970): "The grass carp makes profitable a trophic level little or even non-utilized by the native species, changing it into useful production (fish meat) of good quality and increasing the fish crop per hectare."

DISCUSSION, CONCLUSIONS, AND SPECULATIONS

One concern expressed about the introduction of grass carp to aquatic ecosystems is the fertilization effect on phytoplankton from the green manure of macerated and poorly digested plants. However, the growth of phytoplankton was not excessive in any of our experimental ponds. Possibly grass carp feces become part of the sediments and do not appreciably add to the available nutrient level in open water. Rooted plants may thrive on nutrients from the substrate. Conditions conducive for the luxurious growth of submerged plants may not necessarily favor the growth of noxious algae blooms. The level of phytoplankton as measured by chlorophyll concentration in lakes has been correlated with the rate of phosphorous input (Bachman and Jones 1974). In pond fertilization programs, algal blooms are encouraged and sustained by periodic addition of nutrients before rooted plants become established (Swingle 1965). Noxious algae blooms in lakes may be supported by the addition of allochthonous nutrients rather than the cycling of nutrients within the ecosystem.

Another concern expressed about the introduction of grass carp in aquatic ecosystems is their possible consumption of aquatic invertebrates, in competition for food with native

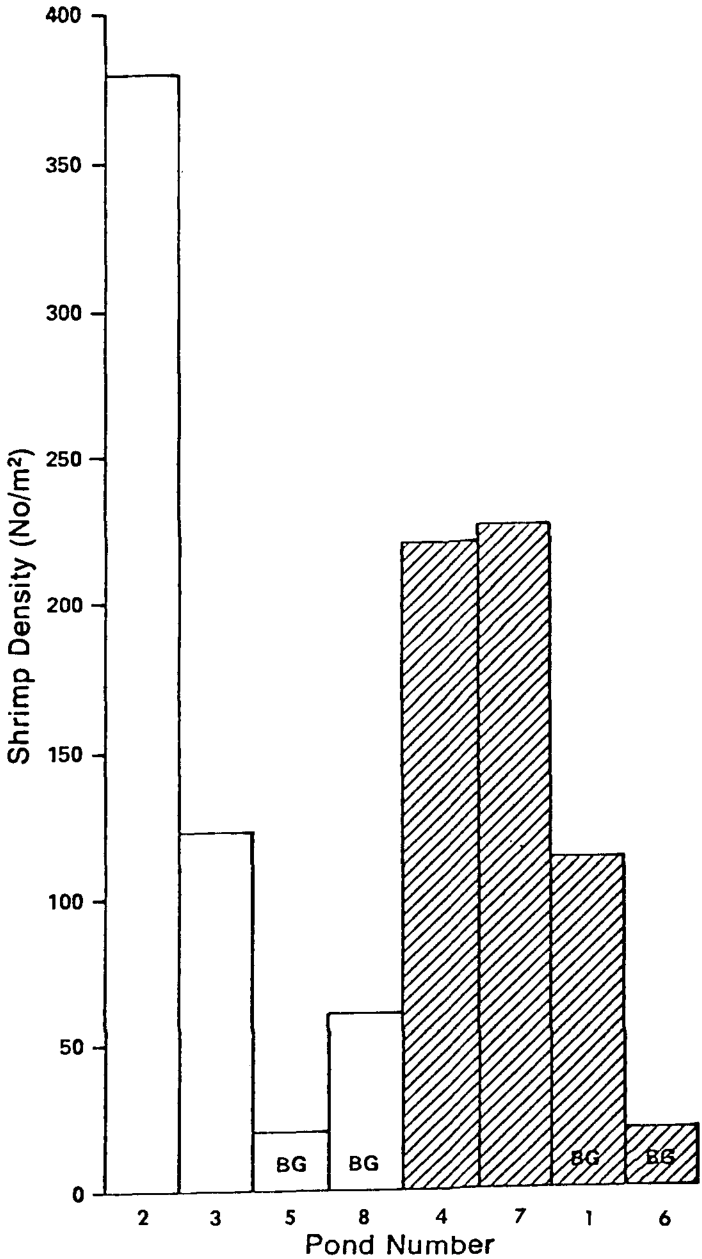

Figure 6. Final glass shrimp densities. Open bars are control ponds; hatched bars are grass carp ponds. Ponds 1, 5, 6, and 8 contained bluegills.

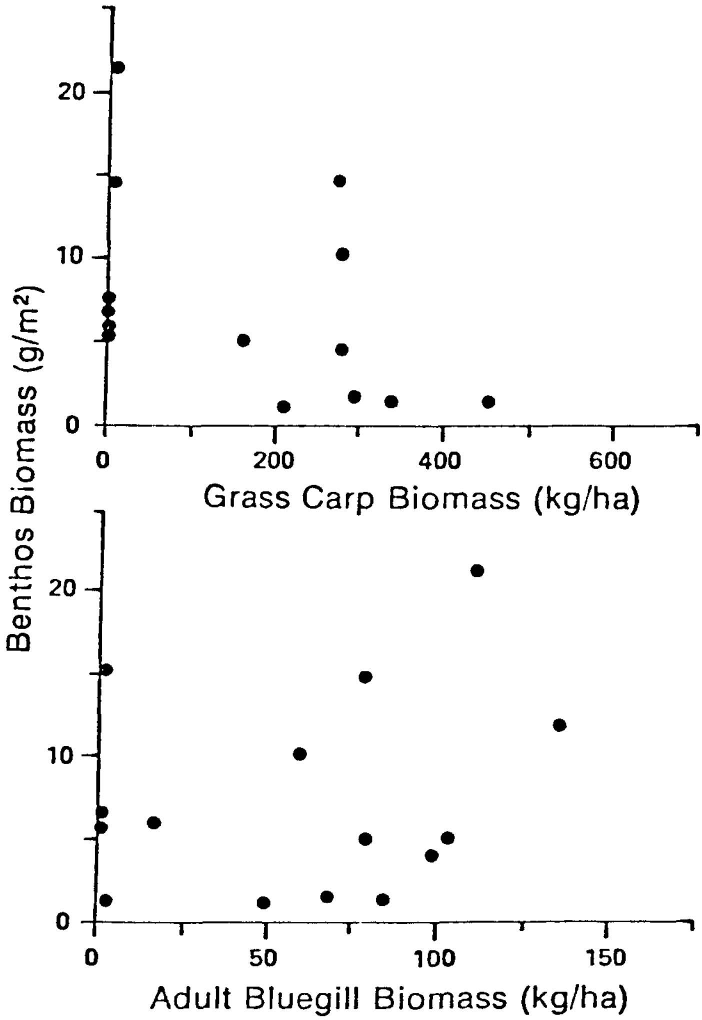

Figure 7. Benthos biomass in the study ponds in September as a function of grass carp biomass and adult bluegill biomass.

fishes. The results of this study indicate that when the supply of submerged plants is diminished, the growth and condition of grass carp suffer. At the reported stocking densities, intraspecific competition among bluegills influences their growth more than interspecific competition with grass carp. The concept that grass carp compete with or feed on young fish of other species has developed primarily from the results of feeding experiments with small grass carp in aquaria. The results of our study indicate that a concern for competition or predation on young fish may be unfounded when grass carp are larger than 0.5 kg and when the standing crop is less than 300 kg/ha. Bluegills appear to have a much greater impact on aquatic invertebrates, such as glass shrimp, than do grass carp. The addition of grass carp may enhance the production of fathead minnows,

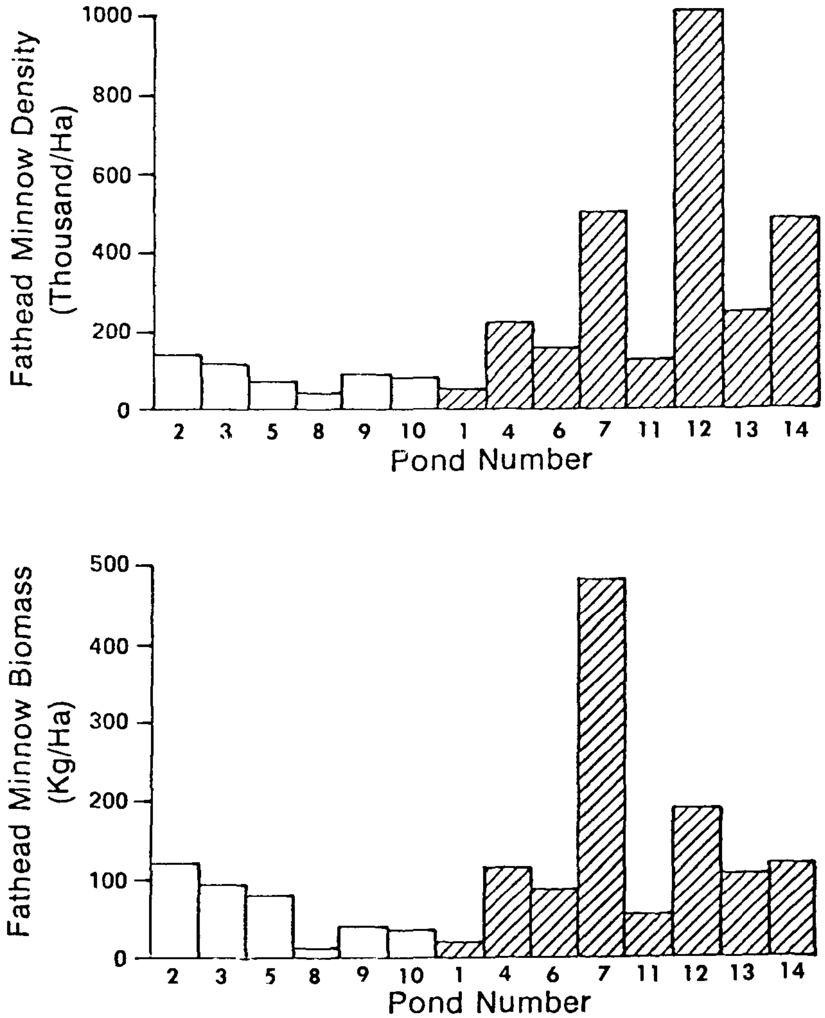

Figure 8. Final fathead minnow density and biomass in study ponds. Open bars are control ponds; hatched bars are grass carp ponds.

bluegills, and other fishes with similar reproduction and food habits. Grass carp feces could logically increase the production of detritus feeders. Reduction of vegetation and cover for bluegills might increase their availability as prey for largemouth bass. If these interpretations are valid, the introduction of grass carp could increase the production of sport fishes and more than double total fish biomass in ponds.

There should be a great economic and ecological advantage in the use of grass carp for the regulation of excessive plant growth. Treatments with herbicides may cost from $35 to more than $1000 per acre per year. Most owners of weedy ponds do not elect to undertake this management practice on a sustained basis. Besides economic cost, herbicides may have ecological costs; if they are applied incorrectly, acute oxygen depletion may result in

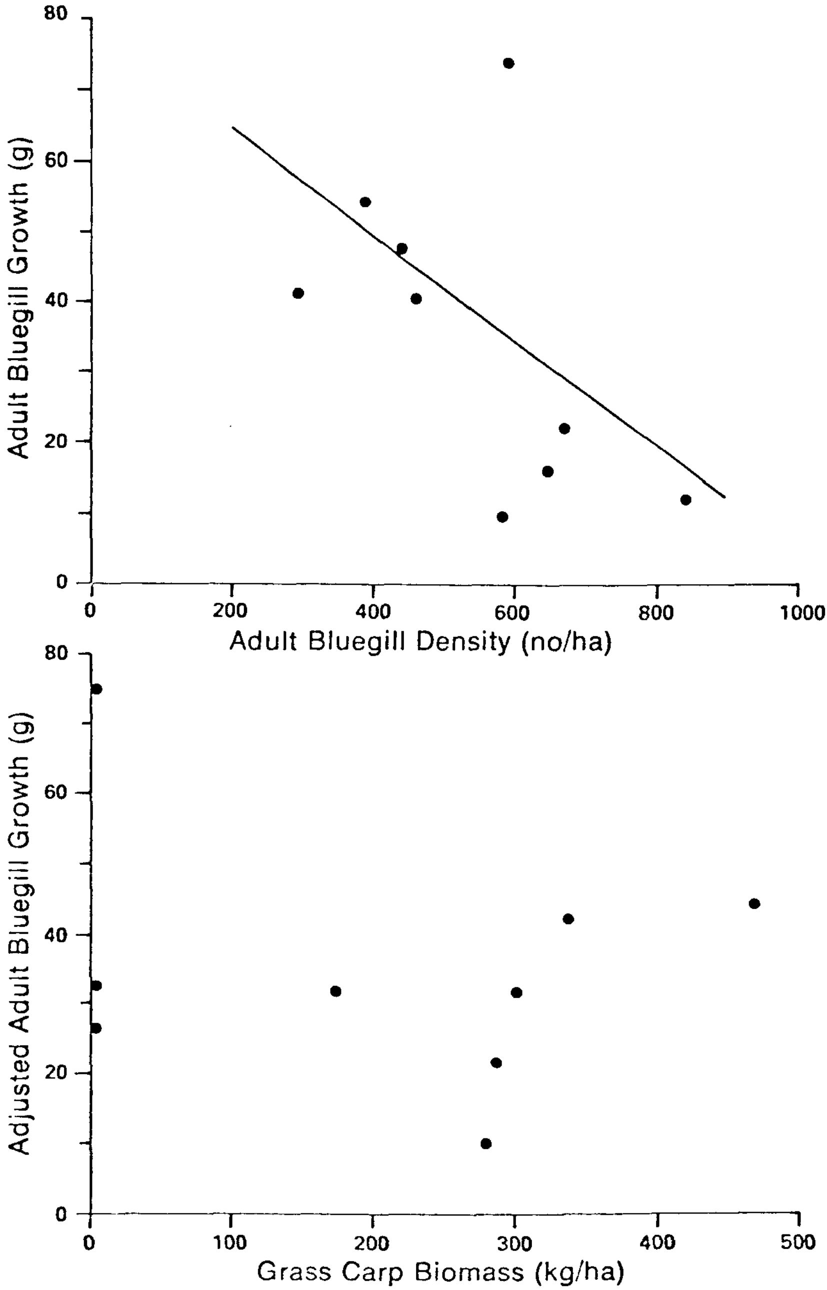

Figure 9. Adult bluegill growth as a function of adult bluegill density and grass carp biomass.

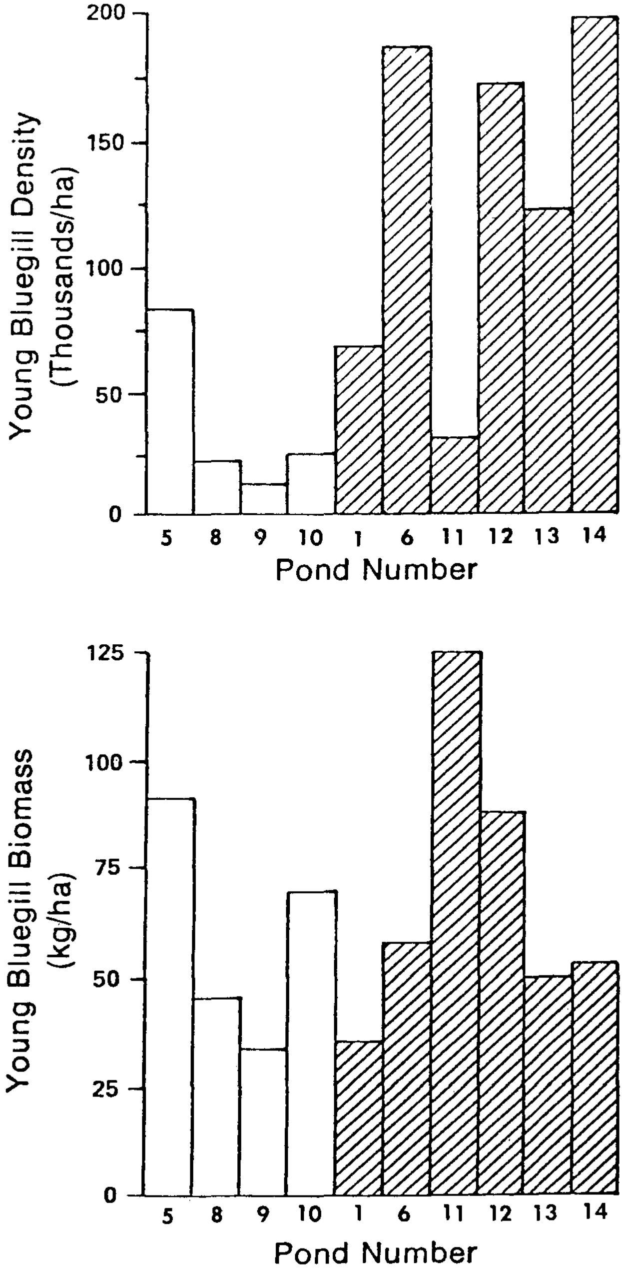

Figure 10. Young bluegill density and biomass in the study ponds. Open bars represent control ponds; hatched bars are grass carp ponds.

Table 3. Survival and biomass increment of adult bluegills.

Pond no.	Initial stocking Number	Initial stocking Density (no./ha)	Final recovery Number	Final recovery Density (no./ha)	Survival (%)	Biomass increment of survivors (kg/ha)
1*	51	1809	11	390	21.6	21.4
5	52	1705	18	590	34.6	43.0
6*	52	1358	12	313	23.1	12.3
8	56	1447	3	78	5.4	—
9	130	2156	40	663	30.8	12.3
10	134	1813	35	474	26.1	17.8
11*	126	1475	38	445	30.2	21.6
12*	115	1537	63	842	54.8	9.7
13*	91	1323	40	581	44.0	5.5
14*	91	1099	56	676	61.2	15.7

* Ponds with grass carp.

fish kills. If a herbicide is too effective, primary production may be reduced to a level that has an adverse effect on fish production. Grass carp stocked at an appropriate density should be able to reduce the level of excess plant growth to a point closer to optimum. Because of the longevity and hardiness of grass carp, the benefits of one introduction may persist for at least 5 years with relatively low economic cost and a low probability of ecological cost.

The grass carp offers advantages for research and hatchery work. The ponds at the Fish-Pesticide Research Laboratory appear to be closer to a "normal" aquatic ecosystem when grass carp are present. The reduction of vegetation facilitates sampling for fish, benthos, and zooplankton. Weithman (1975) reported that the presence of two large grass carp per 0.2-ha pond facilitated seining; in six ponds seined at monthly intervals, the average first haul collected 85% of the fish in the pond. Additional research is needed on grass carp for use in management and research situations. Guidelines to define optimum qualitative and quantitative characteristics of submerged aquatic plants and optimum stocking size and density of grass carp needed to be established. Submerged vegetation was completely eliminated at both the low and high densities in the present study (70 and 233/ha) but persisted in some ponds in which grass carp were stocked at intermediate densities. Number stocked should be related to the quality and quantity of plants and the degree of control desired. The area of the lake bottom covered by plants, or their biomass, rather than total area of an impoundment or lake, may be one key to predicting an appropriate number of grass carp to stock. The potential growth of the fish, and their plant consumption in future years should be considered. Since two large fish essentially eliminated most weeds in the 0.2-ha ponds studied by Weithman (1975), one fish per pond may be the proper number of grass carp to stock in small weedy ponds in Missouri. The size of grass carp stocked is also important. Fish should be large enough to feed on plants and avoid predation by largemouth bass, but not so large that the cost of raising them is high.

These short-term studies need to be followed by long-term evaluations. What are expected weed consumption, growth, and survival values of grass carp in ponds and reservoirs? What factors influence the probability of emigration or angler harvest from various bodies of water? What other management considerations are involved when grass carp are introduced. Inasmuch as a reduction in excessive plant growth may increase angler effort and bass vulnerability to angling, will it be necessary to establish more restrictive regulations on bass harvest in these waters to maintain a satisfactory balance in the fish populations? Adequate evaluation in a variety of impoundments and lakes will be necessary in order to effectively use the potential benefits of the grass carp.

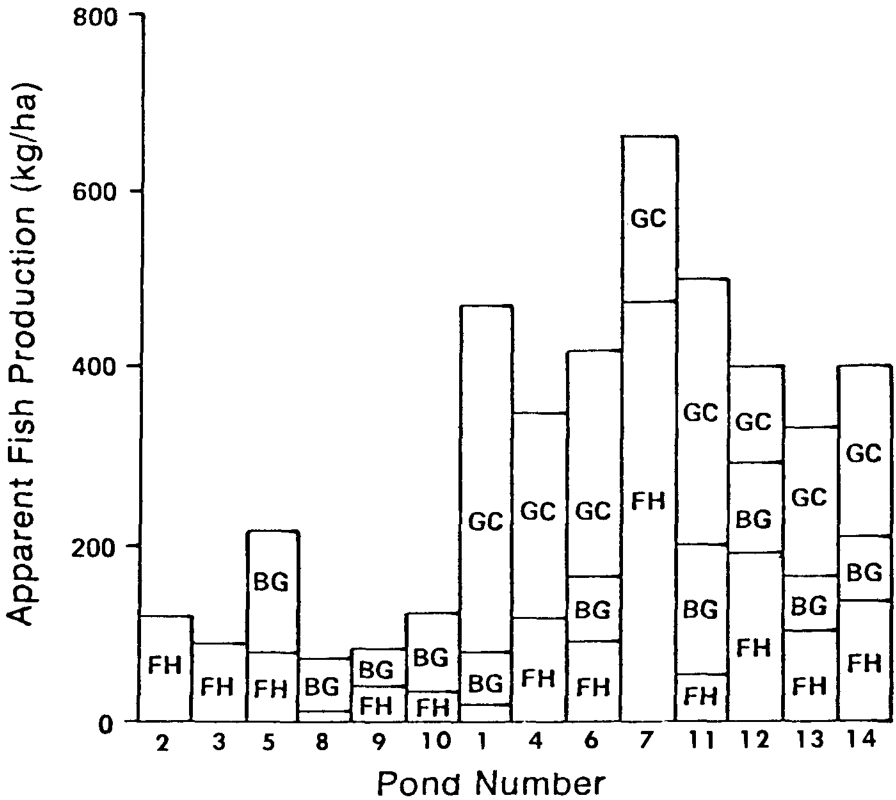

Figure 11. Total apparent fish production of the study ponds; FH denotes fathead minnows; BG, bluegills; and GC, grass carp.

Even though stocking of grass carp may improve environmental conditions in small impoundments with an overgrowth of submerged aquatic plants, their introduction should be controlled in public and private waters. Their impact on stream systems is difficult to predict. Stocking in the near future might be best allowed by permit and only in drainage basins of rivers where grass carp are already present.

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