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THESIS

ABILITY OF GRASS CARP
(*CTENOPHARYNGODON IDELLA*) TO CONTROL AQUATIC
MACROPHYTES IN FISH CULTURE PONDS IN COLORADO

Submitted by

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In partial fulfillment of the requirements

for the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Fall, 1980

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George,

I am sure that you will be hearing from the Blairs about grass carp. Keep in mind as you read this thesis that we were trying to eliminate aquatic vegetation, not reduce it.

Steve Flickinger

____

Wm J McConnell
____

Stephen A. Flickinger
____

Adviser

ABSTRACT OF THESIS

ABILITY OF GRASS CARP (*CTENOPHARYNGODON IDELLA*) TO CONTROL AQUATIC MACROPHYTES IN FISH CULTURE PONDS IN COLORADO

Grass carp were stocked at different densities into ponds during the summers of 1978 and 1979 to determine their usefulness for aquatic vegetation control under Colorado conditions. Grass carp fed effectively on aquatic vegetation from mid-June to mid-September in Colorado. Several stocking densities were found to be effective: a 375 kg/ha density of grass carp consumed a 60 cm stand of *Chara kieneri* by mid-July; a 125 kg/ha density of grass carp consumed a 66 cm stand of *Zannichellia palustris* by mid-July; and a 50 kg/ha density of grass carp stocked into a pond with no vegetation prevented the growth of any aquatic macrophytes. These stocking densities were achieved with grass carp weighing 0.43-0.67 kg apiece.

.95 - 1.47 LB.

1.18 LB - 6 LB

Grass carp grew from an average of 0.54 kg to 2.72 kg apiece in 26 weeks (12 g/day), but stunted easily in ponds with no available vegetation and did not feed on abundant populations of fathead minnows (*Pimephales promelas*) and aquatic insects (Odonata, Ephemeroptera, and Hemiptera).

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INTRODUCTION

Chemical control of aquatic vegetation is costly and often detrimental to the chemical balance of the surrounding water (Sills 1970). The grass carp (*Ctenopharyngodon idella*) has been listed as the fish with the greatest potential as an aquatic weed control agent by Sills (1970) and Avault et al. (1968). The grass carp is native to large rivers of eastern China and Siberia, and it has been introduced widely in central Asia, Europe, Russia, and India as a food fish and biological agent for aquatic weed control. Some of the factors that make the grass carp a highly regarded weed control agent are: the grass carp is an herbivore (Terrell and Fox 1974), it is unaggressive with other fish (Bailey 1978), it can consume more than its body weight per day in wet weight of vegetation (Cross 1969), it has a potential size of 50 kg (Nikolskii 1956), it has the ability to withstand water temperatures from near 0 C to over 34 C (Stevenson 1965), and is incapable of natural reproduction in ponds (Greenfield 1973).

Fry feed on zooplankton and phytoplankton. They gradually change to a diet of macrophytes after the fish reach 3 cm (Nikolskii 1956). Examination of stomach contents of fish captured in ponds and reservoirs reveals over 99% aquatic macrophytes (Kilgen and Smitherman 1971, Terrell and Fox 1974). The authors concluded that the small amount of animal material found in the gut was due to insects and mollusks attached to the plants eaten. Fingerling grass carp feed readily on filamentous algae until they reach 1.4 kg or more. Adult grass carp have a definite food selectivity and prefer soft submerged vegetation (Alabaster and Stott 1967). However, after eating all available soft vegetation the grass carp will begin eating more fibrous vegetation. Food selectivity depends mostly on age, size, and availability. However, grass carp feed less selectively at higher temperatures (Stroganov 1963). Plants are chewed off near the pond bottom, rather than being pulled up (Bailey 1975). The morphology of mouth and teeth restricts the grass carp's food. The pharyngeal teeth with serrated edges and horny pad show its adaptation for mascerating aquatic vegetation. The mouth is small and terminal which is not effective for rooting. The grass carp has no effect on water turbidity (Terrell and Terrell 1975), or water quality (Mitzner 1978).

Grass carp do not compete with native fishes for food. Grass carp have been used for many years in Arkansas state fish hatcheries and have not been detrimental, nor have they adversely affected fish production in lake and reservoir sport fisheries (Bailey 1978).

Grass carp can consume more than their body weight per day in vegetation because 30% to 40% of the ingested food is passed through the digestive tract (Stroganov 1963). Grass carp cannot digest cellulose (Fischer 1972).

Growth rate depends primarily on availability of aquatic vegetation and water temperature. In the absence of weeds grass carp grew to 15 cm in 2 years while grass carp with sufficient vegetation present grew to 60 cm in 1 year (Bailey 1972). Terrell and Terrell (1975) found in the absence of aquatic macrophytes grass carp lost weight, and did not eat animal matter. Under favorable conditions, female grass carp grew from

2 g to 5.9 kg in less than 1.5 years (Hickling 1967). This species can live 14 years or more (Gorbach 1966). Feeding slows considerably below a water temperature of 14 C and intensive feeding occurs at 20 C (Opuszynski 1968).

Spawning requirements are restrictive because the eggs of grass carp are semibuoyant and require a current of 0.5 to 3.5 m per s to remain suspended for 24 to 30 hr until they hatch (Gidumal 1958). Therefore, grass carp will not reproduce naturally in lakes and ponds due to lack of adequate flowing water. Stanley et al. (1978) have predicted that some spawning may occur in the Mississippi River, but the survival of grass carp fingerlings would be very low, and the chance of an undesirable environmental impact even less likely.

The grass carp is sensitive to nearby noise and vibration. Grass carp in small ponds do not eat and control aquatic macrophytes as well as grass carp in larger ponds in the wild. Sutton (1974) found that a stocking density of up to 320 kg/ha was needed to control vegetation in an experimental 0.1 ha pond while Drda (1973) showed that a stocking density of 68 kg/ha was sufficient in a 2 ha pond in the wild.

Stocking densities reported in the literature range from 11 kg/ha in Indiana (Lembi et al. 1978) to 1140 kg/ha in India (Singh et al. 1969). These stocking rates differ because the rates depend upon the species of aquatic macrophytes, temperature of the water, length of time desired for control or elimination of aquatic weeds, and amount of noise and vibration from the surrounding environment. The most common stocking densities of grass carp used to achieve control of aquatic vegetation are 100 kg/ha in warm climates (Bailey 1978, Mitzner 1978) and 250 kg/ha in cold climates (Jahnichen et al. 1973, Stott 1978).

One hundred percent removal of aquatic vegetation is desirable in a fish culture operation, because of harvesting problems created by vegetation. A moderate amount of aquatic vegetation is desirable in a sport fishery, because either a sparse or dense amount of vegetation will lower fish production (Crowder and Cooper 1979).

Objectives

The primary objective of this study was to determine the live weight of grass carp necessary for complete removal of the aquatic vegetation in a given area.

Secondary objectives were to calculate grass carp wet weight gain from the dry weight of aquatic macrophytes eaten, to determine grass carp mortalities, the effect of grass carp on fish and invertebrates, harvesting methods for grass carp, the effect of water temperatures on grass carp feeding, and the effect of different densities of grass carp on vegetation.

STUDY AREA

This study was conducted in fish culture ponds at the Colorado State University (C.S.U.) Foothills Campus, Larimer County, Colorado (elevation 1,519 meters), and at the Colorado Division of Wildlife Wray fish hatchery, Yuma County, Colorado (elevation 1,072 meters).

Nine different earthen ponds were used at the C.S.U. Foothills Campus. Seven ponds were 0.04 ha and two ponds were 0.1 ha. The ponds were filled with well water and allowed to grow dense stands of aquatic macrophytes in the spring of 1978 and 1979. The ponds had been heavily fertilized in previous fish rearing activities and had a history of dense stands of primarily *Chara kieneri*, with some *Potamogetan pectinatus*, *Zannichellia palustris*, *Spirogyra* sp., and *Cladophora* sp.

Six different earthen ponds were used at the Wray hatchery. These ponds varied in size from 0.28 ha to 0.44 ha. The ponds were filled with spring water and stocked with grass carp. The ponds had a history of dense stands of primarily *C. kieneri*, with some *P. pectinatus*, *Z. palustris*, *Cladophora* sp., and *Elodea canadensis*.

HIGH DENSITY OF GRASS CARP IN VEGETATED PONDS

High densities of grass carp were used because grass carp were reported to feed slowly upon the heavier, tougher species of aquatic macrophytes, and to feed slowly in cold water temperatures. Colorado has colder water temperatures than the southern states where previous grass carp experiments had been tried, and the primary aquatic plant available for grass carp for food at the C.S.U. ponds was *C. kieneri* which grew dense stands and felt crusty due to calcium deposits.

Materials and Methods

Grass carp for this trial were brought in by truck from Arkansas in November, 1977. These grass carp were held in 0.1 ha ponds (which were soon devoid of vegetation) all winter under ice cover at densities of 960 to 1480 kg/ha at the C.S.U. Foothills Campus.

The 0.04 ha ponds were filled in April, 1978, to an average depth of 1.6 m. Grass carp were stocked into the ponds on 5 July 1978, when the ponds had attained substantial quantities of aquatic macrophytes. Seven ponds were stocked with three different densities of grass carp. Three ponds were stocked with 15 kg of grass carp (375 kg/ha) apiece, another two ponds were each stocked with 40 kg of grass carp (1000 kg/ha), and the remaining two ponds were each stocked with 65 kg of grass carp (1625 kg/ha).

The initial and final standing crops of vegetation were determined by exclosures and mapping. The exclosures were made by nailing 13 mm mesh hardware cloth onto four sides of a wooden frame. The two open ends of the exclosure were each 1 m^2 and the height was 1.8 m. Two exclosures extending from the bottom to above the water surface were placed in each pond to document what would have happened without grass carp. Paired vegetation samples were taken to compare the ungrazed vegetation to the grazed vegetation. A random sample was taken inside the exclosure. A paired sample was taken outside of the exlcosure 1 m from the inside sample on an axis parallel to the shoreline on the side of the exclosure nearest the inside sample. To prevent sampling the same area twice, each location of each sample was recorded. The samples were collected on 5 July 1978, and 22 July 1978. A tube with a cross sectional area of 0.1 m^2 was dropped from above the water surface onto the aquatic macrophytes. The vegetation was removed by using a modified hoe. The modified hoe was a three-pronged hoe with a piece of 3.2 mm mesh hardware cloth cut to fit over the three prongs and secured with baling wire. The vegetation samples were dried at 105 C for 24 hours and weighed. The standing crop of vegetation in the pond was calculated by multiplying the dry weight per 0.1 m^2 of the vegetation sample taken outside of the exclosure times the total surface area of the vegetation in the pond. The total surface area of the vegetation was measured by hand with a tape measure. The actual width and length of the total aquatic vegetation present were measured.

Plant species were hand sampled for identification and the various groupings were mapped from visual observations on land and from aerial photographs.

The grass carp wet weight gain was determined by weighing the grass carp at the time of final harvest and subtracting the wet weight at the time of initial stocking. The weight of any mortality was added. The total amount of wet weight gain of grass carp was compared to the estimate of the dry weight of vegetation eaten.

The temperature of the water was recorded on thermographs and was averaged for all ponds.

Results

Grass carp (averaging 0.43 kg apiece) stocked into ponds with dense stands of primarily *Chara kieneri*, with some *Potamogeton pectinatus*, *Zannichellia palustris*, and *Eleocharis acicularis* consumed all aquatic vegetation within 12 days (Table 1). The average water temperature from 5 July 1978, to 17 July 1978, was 22.5 C with an average daily fluctuation of 4.7 C.

All three stocking densities (375 kg/ha, 1000 kg/ha, and 1625 kg/ha) produced results much sooner than expected. Grass carp grew an average of 76 g/week by eating an average of 32% of their body weight per day in dry weight of vegetation (169% of their body weight per day in wet weight of vegetation (Table 1). Food conversion on the basis of dry weight of vegetation eaten to wet weight gain of grass carp was 13.4 to 1 (conversion of wet weight of vegetation eaten to wet weight gain of grass carp was 71 to 1).

Three exclosures out of 14 were devoid of vegetation. Those three cages each had sufficient areas cleared of silt under the bottom edges of the cages to allow grass carp to swim into the cages and feed upon the vegetation. After this discovery, exclosures were hammered into the pond bottoms in future trials.

Table 1. Results of high density of garss carp in vegetated ponds for 12 days with grass carp averaging 0.43 kg each when stocked.

Grass carp density (kg/ha)	Dry wt of vegetation (kg/ha)		Grass carp wt gain	% of wet body wt/day of vegetation eaten		Conversion	
	initial	final	(g/day)	dry wt	wet wt	dry wt[a]	wet wt[b]
375	1822	0	9.4	40.5	214	20.3	107
375	1490	0	13.7	33.1	175	10.6	56
375	1345	0	12.9	29.9	158	10.0	53
1000	2787	0	7.3	23.2	122	14.1	74
1000	1205	0	10.2	30.0	159	12.0	63
1625	2562	0	10.5	39.3	207	16.8	89
1625	1790	0	11.4	27.6	147	10.2	54

[a]Dry weight conversions were calculated by dividing the dry weight of vegetation eaten by wet weight gain of grass carp.

[b]Wet weight conversions were calculated by dividing the wet weight of vegetation eaten by wet weight of grass carp.

MEDIUM DENSITY OF GRASS CARP IN VEGETATED PONDS IN FALL

Medium densities of grass carp were used in the fall trial due to the fast results from the high density trial during the summer of 1978.

Materials and Methods

The grass carp used for this trial were from the same group brought in November, 1977, from Arkansas. After the high density trial was concluded in July, 1978, the C.S.U. Foothills Campus ponds were drained and refilled to an average depth of 1.6 m. The ponds attained a dense stand of vegetation by 16 September 1978, and the ponds were stocked with grass carp. Six ponds were stocked with three different densities of grass carp. Two ponds were each stocked with 5 kg of grass carp (125 kg/ha), another two ponds were each stocked with 10 kg of grass carp (250 kg/ha), and the remaining two ponds were each stocked with 15 kg of grass carp (375 kg/ha).

Exclosures, thermographs, hand sampling, and aerial photographs were used as in the previous high density trial.

On 30 September 1978, measurements were taken on the standing crops of aquatic macrophytes. Grass carp were removed from the ponds, counted, and weighed.

Results

Grass carp (averaging 0.6 kg apiece) stocked into ponds with dense stands of primarily *C. kieneri*, with some *P. pectinatus*, *Z. palustris*, and *E. acicularis* removed 7%, 16%, and 29% of the vegetation with stocking densities of 125 kg/ha, 250 kg/ha, and 375 kg/ha, respectively in 14 days (Table 2). The average water temperature from 16 September 1978, to 30 September 1978, was 12.3 C with an average daily fluctuation of 3.5 C.

The stocking densities did not have the same effect upon the vegetation as the earlier high density trial in 1978, because lower densities and colder water temperatures were used in this later trial. Grass carp grew an average of 34 g/week by eating an average of 10% of their body weight per day in dry weight of vegetation (52% of their body weight per day in wet weight of vegetation) (Table 2). Food conversion on the basis of dry weight of vegetation eaten to wet weight gain of grass carp was 12.2 to 1 (conversion of wet weight of vegetation eaten to wet weight gain of grass carp was 65 to 1). In comparison with the data from the previous high density trial, the grass carp ate 70% less vegetation (wet weight) when the average water temperature dropped from 22.5 C to 12.3 C. However, the grass carp consumed a significant quantity of vegetation at a water temperature of 12.3 C.

Table 2. Results of medium density of grass carp in vegetated ponds in the fall for 14 days with grass carp averaging 0.6 kg each when stocked.

Grass carp density (kg/ha)	Dry wt of vegetation (kg/ha)		% of initial vegetation eaten	Grass carp wt gain (g/day)	% of wet body wt/day of vegetation eaten		Conversion	
	initial	final			dry wt	wet wt	dry wt[a]	wet wt[b]
125	1502	1397	6.9	4.5	6.0	32	8.4	45
125	2255	2085	7.5	4.5	9.7	52	13.6	73
250	2630	2327	11.5	3.8	8.6	46	13.4	72
250	1845	1487	19.4	4.6	10.2	54	13.0	69
375	2140	1365	36.2	6.8	14.8	79	13.4	72
375	2230	1725	22.6	4.9	9.6	51	11.2	60

[a]Dry weight conversions were calculated by dividing the dry weight of vegetation eaten by wet weight gain of grass carp.

[b]Wet weight conversions were calculated by dividing the wet weight of vegetation eaten by wet weight gain of grass carp.

MEDIUM DENSITY OF GRASS CARP IN VEGETATED PONDS IN SUMMER

Medium densities of grass carp were used to determine the lowest quantity of grass carp necessary to achieve vegetation removal by the end of summer.

Materials and Methods

The grass carp used for this trial were from the original Arkansas group. Eight 0.04 ha ponds at the C.S.U. Foothills campus were stocked with four different densities of grass carp. The stockings took place on 21 May 1979, after the ponds had been drained, refilled to an average depth of 0.72 m, and had attained substantial crops of aquatic vegetation. Two ponds were each stocked with 5 kg of grass carp (125 kg/ha), another two ponds were each stocked with 10 kg of grass carp (250 kg/ha), and the remaining two ponds were each stocked with 20 kg of grass carp (500 kg/ha). These densities (125 kg/ha, 250 kg/ha, 375 kg/ha, 500 kg/ha) were generally lower than the densities used during the summer of 1978 high density trial (375 kg/ha, 1000 kg/ha, and 1625 kg/ha).

Exclosures were used in the same manner as in previous trials except that only one exclosure was placed in each pond, because it was determined that enough vegetation samples could be taken from one exclosure for the length of the trial. Vegetation was sampled and measured at one week intervals. Thermographs, hand sampling, mapping, and aerial photographs were used in the same manner as previous trials.

Results

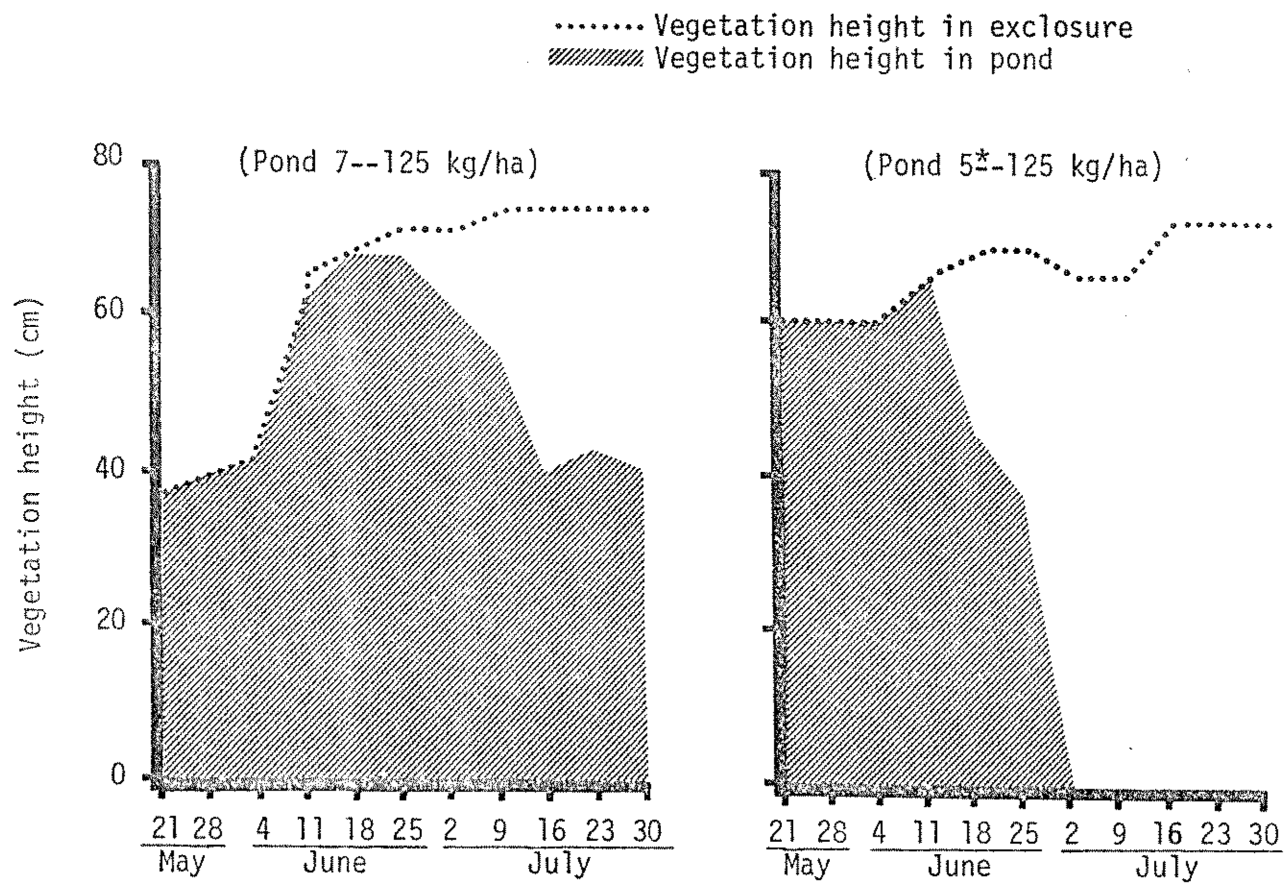
Grass carp (averaging 0.63 kg apiece) were stocked into ponds with dense standing crops of 100% *C. kieneri* initially averaging 35 cm in height, except for pond number five which consisted of 100% *Z. palustris*, initially averaging 61 cm in height.

From the point of peak vegetation height, after 10 weeks (21 May 1979 to 30 July 1979) the grass carp removed an average of 45%, 36%, 100%, and 93% of the aquatic macrophytes with stocking densities of 125 kg/ha, 250 kg/ha, 375 kg/ha, and 500 kg/ha, respectively. Those figures did not include pond five, because pond five contained less initial quantity of vegetation than the other ponds (Appendix Table A). However, pond five was stocked with grass carp at 125 kg/ha and 100% of the aquatic macrophytes were removed after six weeks.

The trial started 21 May 1979, and ended 30 July 1979. The grass carp did not appear to feed until 11 June to 18 June. Before 11 June, the vegetation grew as fast outside the exclosure as it did inside the exclosure (Figure 1). The average daily water temperature on 11 June 1979, was 18.3 C with a daily fluctuation of 6.6 C (Appendix Table C).

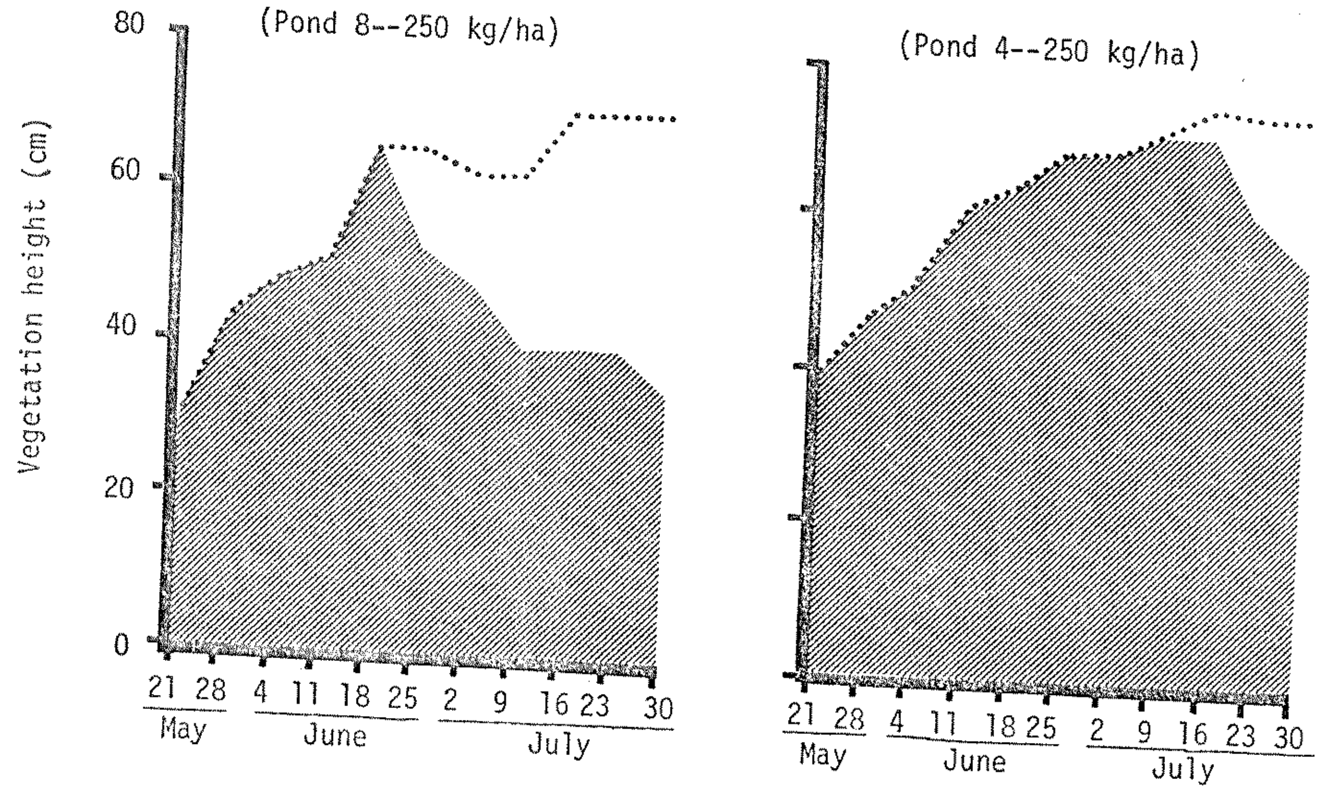
Grass carp at a stocking density of 125 kg/ha consumed a stand of *Z. palustris* 66 cm in height in 21 days (starting 11 June 1979); the same stocking density of grass carp reduced a stand of *C. kieneri* 69 cm in height by only 41% in 21 days (starting 11 June 1979). The slower feeding rate by grass carp on *C. kieneri* versus *Z. palustris* was expected, because *C. kieneri* has 5.2 times as much dry mass per unit height as *Z. palustris*.

Figure 1 shows that grass carp at stocking dnesities up to 500 kg/ha had no effect on vegetation height until 11 June to 18 June.



*Pond 5 contained *Z. palustris* while all other ponds contained *C. kieneri*.

Figure 1. Results of medium density of grass carp in vegetated ponds containing submerged plants in summer.



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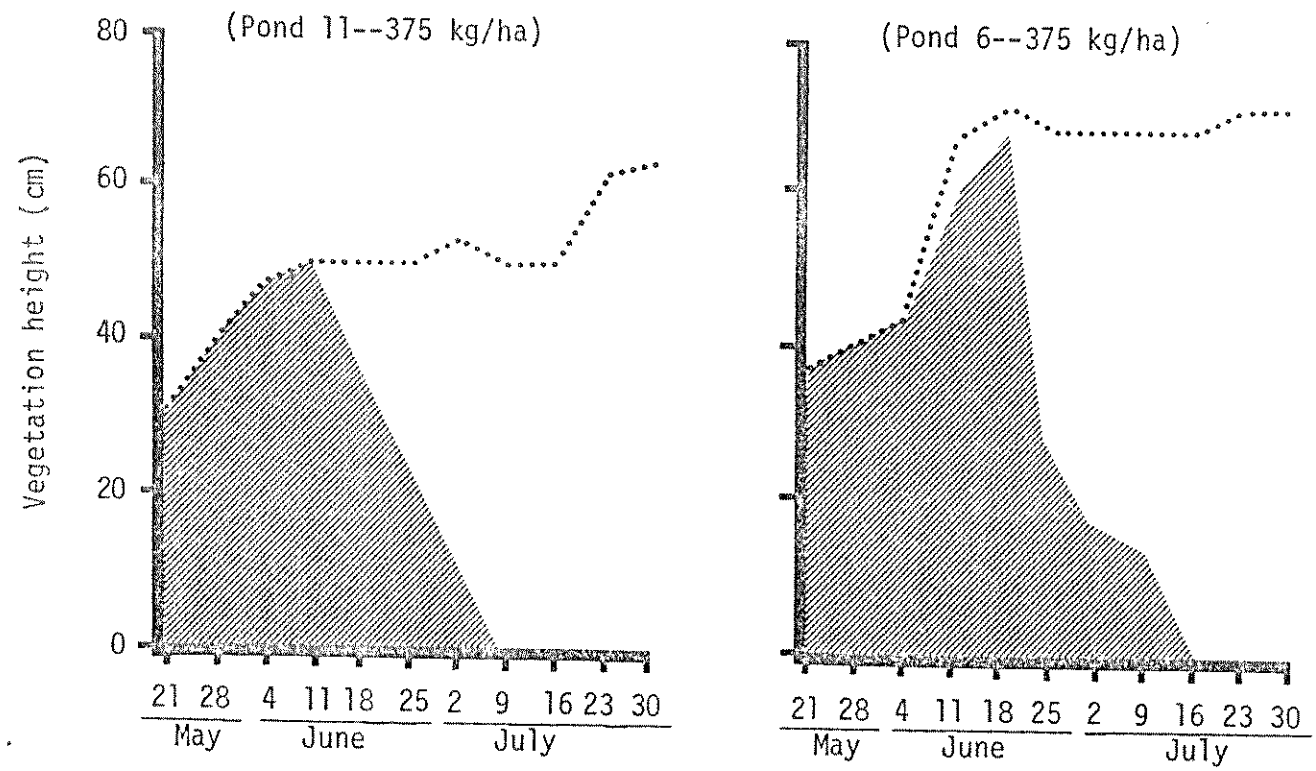

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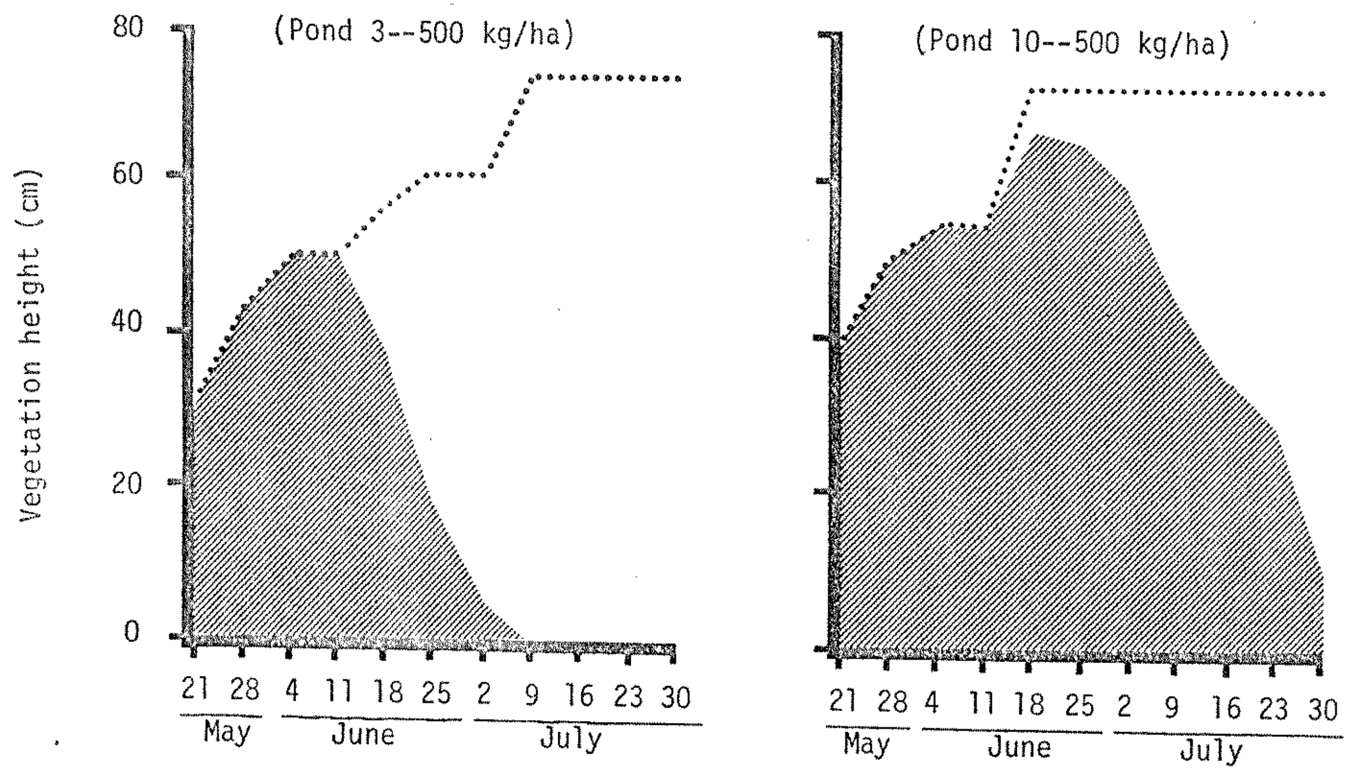


Figure 1. Continued.

Between 11 June to 9 July the heights of *C. kieneri* and *Z. palustris* quickly dropped. Figure 2 shows that the percent coverage of the ponds by algae mats quickly increased between 11 June to 9 July. However, by 9 July the percent coverage by algae mats was rapidly decreasing.

The trial ended 30 July when some of the grass carp died. The deterioration of their livers indicated a toxicity problem. The C.S.U. physical plant had sprayed a week earlier with Banvil-D mixed with 2,4-D along the sides of the ponds to kill thistles. Grass carp have low lethal limits to some chemicals (Henderson 1973). The herbicide could have accumulated in the algae mats that the grass carp were feeding on to create high concentrations of herbicide in the fish.

Most of the graphs in Figures 1 and 2 have declining slopes. The grass carp probably would have eliminated the remaining macrophytes in the ponds if they could have continued to feed through August 1979.

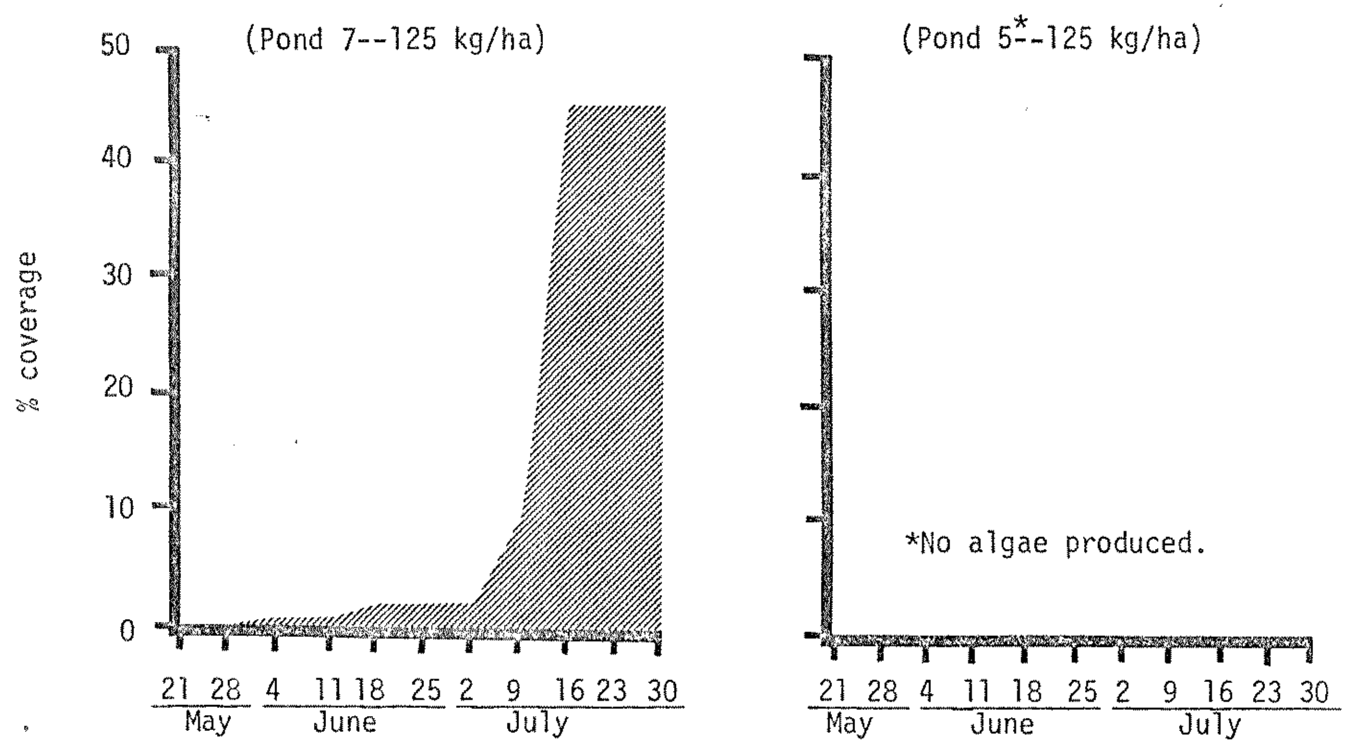
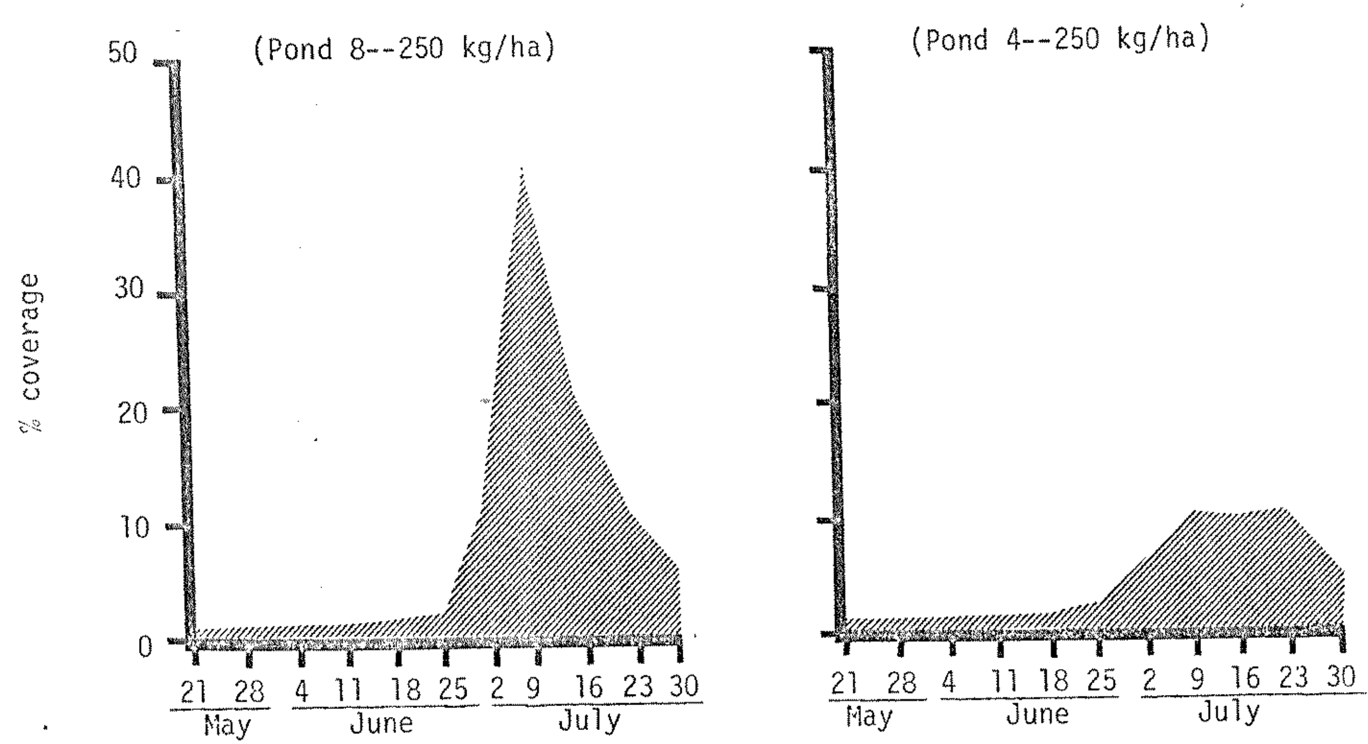


Figure 2. Results of medium density of grass carp on floating filamentous algae (*Cladophora* sp.) in same vegetated ponds in Figure 1.



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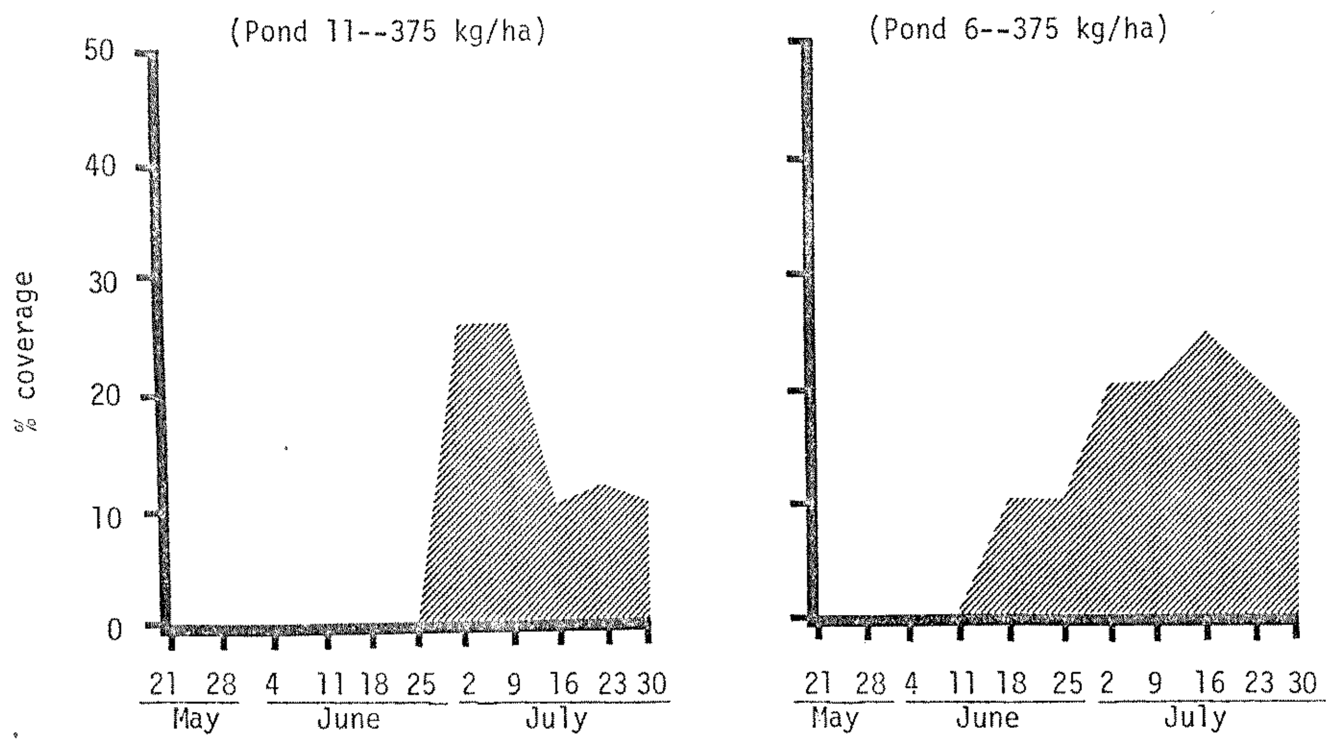

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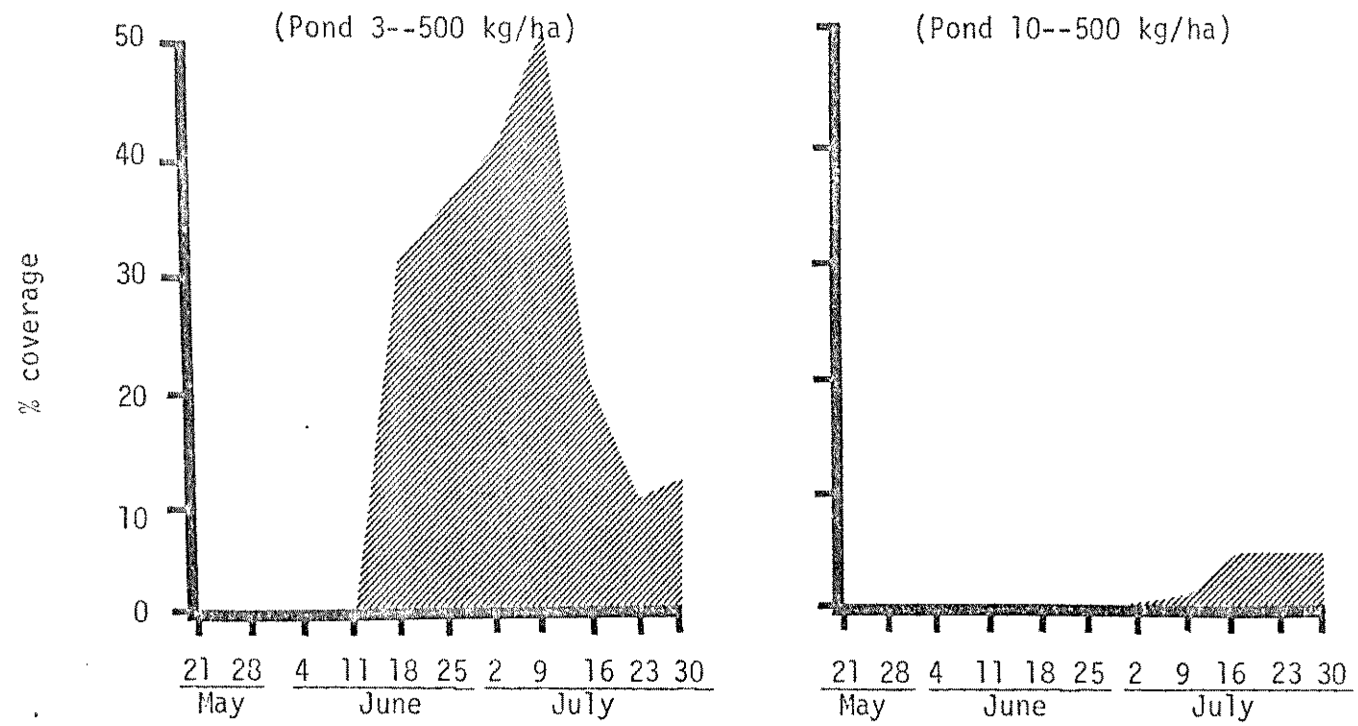

Figure 2. Continued.

LOW DENSITY OF GRASS CARP IN BARE PONDS

Low densities of grass carp were used in bare ponds because the grass carp only have to eat as fast as the vegetation can grow to prevent a standing crop of vegetation, but if the vegetation is already dense the grass carp have to feed faster than the vegetation is growing to remove the standing crop of vegetation.

Materials and Methods

Grass carp were used in bare ponds at the Wray hatchery and at the C.S.U. Foothills Campus ponds. The grass carp used were from the original Arkansas group.

Grass carp were seined and hauled by truck from Fort Collins, Colorado, to the Wray fish hatchery. The ponds had been drained and refilled to an average depth of 0.79 m. The grass carp were stocked into these ponds with no vegetation present on 17 April 1979. Six ponds were to be stocked with three different densities of grass carp, but the stocking densities were not paired evenly. Two ponds (0.28 ha, 0.32 ha) were each stocked with 1 kg of grass carp (3.6 kg/ha, 3.1 kg/ha), another two ponds (0.28 ha, 0.44 ha) were each stocked with 5 kg of grass carp (17.9 kg/ha, 11.4 kg/ha), and the remaining two ponds (0.36 ha each) were each stocked with 19 kg of grass carp (52.8 kg/ha).

Only one exclosure was placed in each pond. Vegetation was sampled and measured only at two week intervals due to the time and expense involved in traveling to the Wray fish hatchery. Thermographs, hand sampling, mapping, and weighing and drying of vegetation samples was done as in previous trials, except aerial photography was not used.

Two 0.04 ha ponds at the C.S.U. Foothills Campus were drained and refilled to an average depth of 0.72 m. Neither contained vegetation. On 4 June 1979, one pond was stocked with 1 kg of grass carp (25 kg/ha), and the other pond was stocked with 2 kg of grass carp (50 kg/ha).

One exclosure was placed in each pond. Vegetation was sampled and measured at one week intervals. A thermograph, hand sampling, mapping, and weighing and drying methods were followed as in other trials. Again, aerial photography was not used.

Results

At the Wray hatchery grass carp (averaging 0.54 kg apiece) stocked into ponds with no vegetation allowed vegetation to grow to 93%, 100%, and 0% of the height of vegetation inside the exclosure with stocking densities of about 3 kg/ha, 18 kg/ha, and 53 kg/ha, respectively, after five weeks (Figure 3).

The aquatic vegetation started its period of rapid growth between 15 May 1979, and 29 May 1979. The average daily water temperature was between 16 C to 21 C with an average daily fluctuation of 7.5 C during that time.

The types of vegetation that grew were *Z. palustris*, *P. pectinatus*, *C. kieneri*, and *Elodea canadensis*.

At the C.S.U. Foothills Campus ponds grass carp (averaging 0.67 kg apiece) stocked into ponds with no vegetation allowed vegetation in the pond to grow to 100% and 0% of the height of the vegetation inside the exclosure with stocking densities of 25 kg/ha and 50 kg/ha, respectively, after 8 weeks (Figure 4). The vegetation that grew was *C. kieneri*.

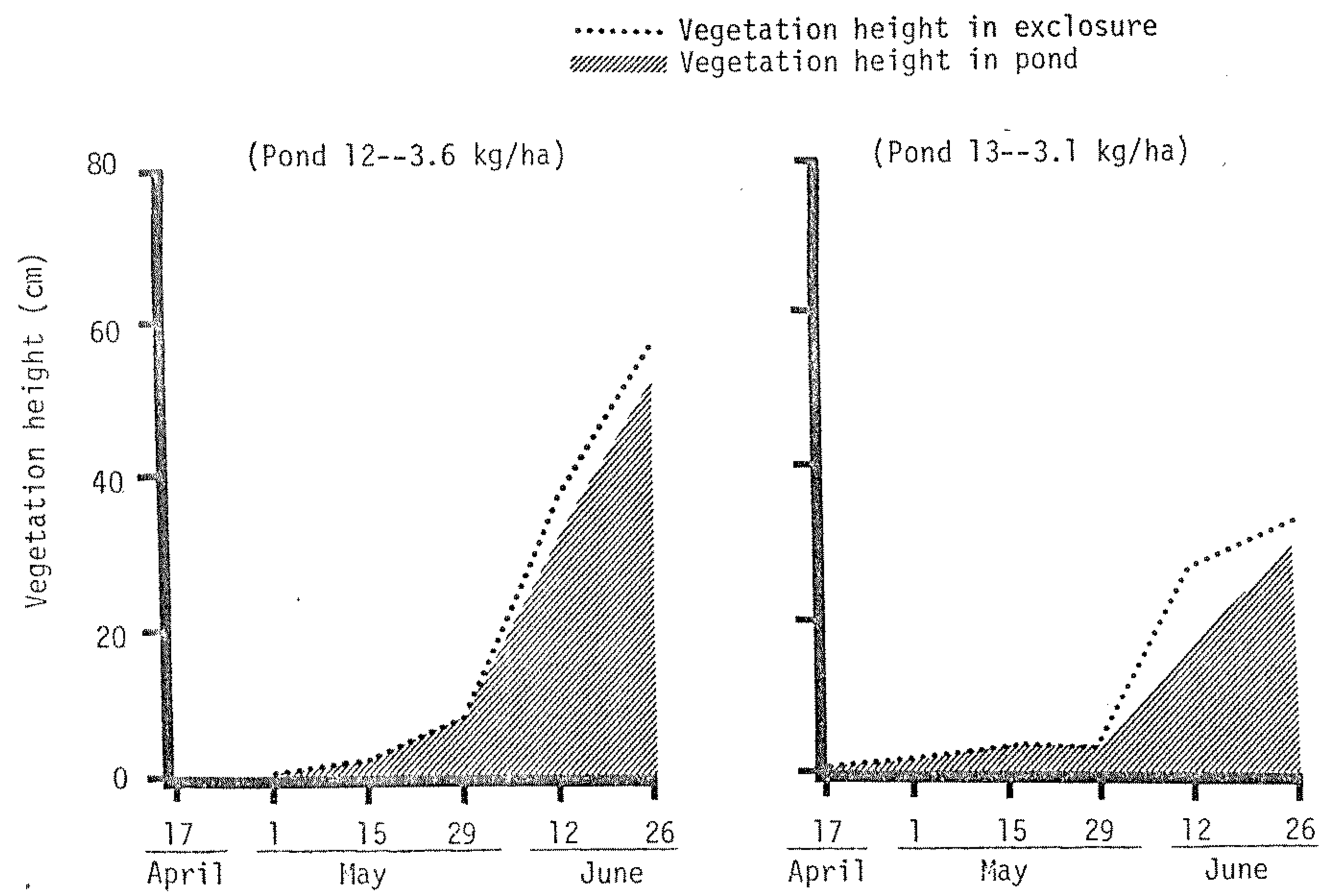

Figure 3. Results of low density of grass carp in bare ponds at Wray hatchery.

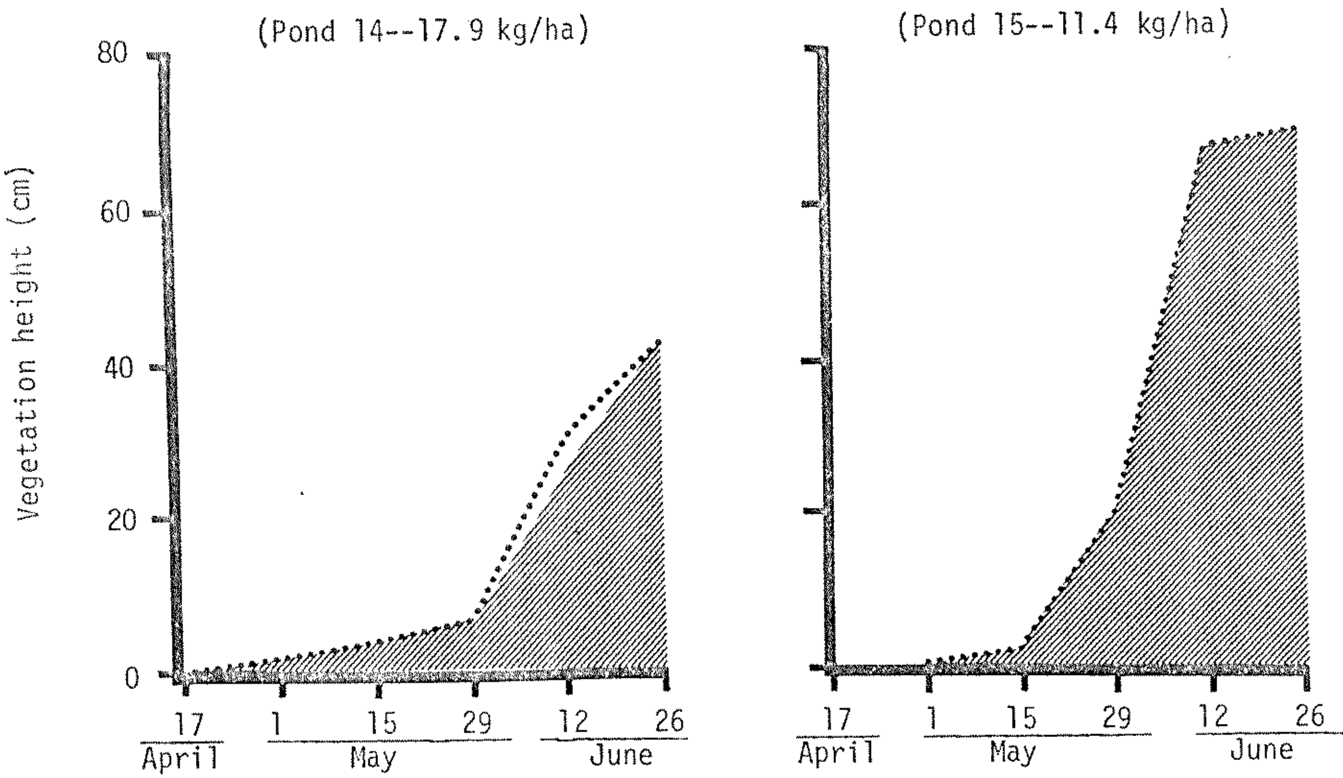

Figure 3. Continued.

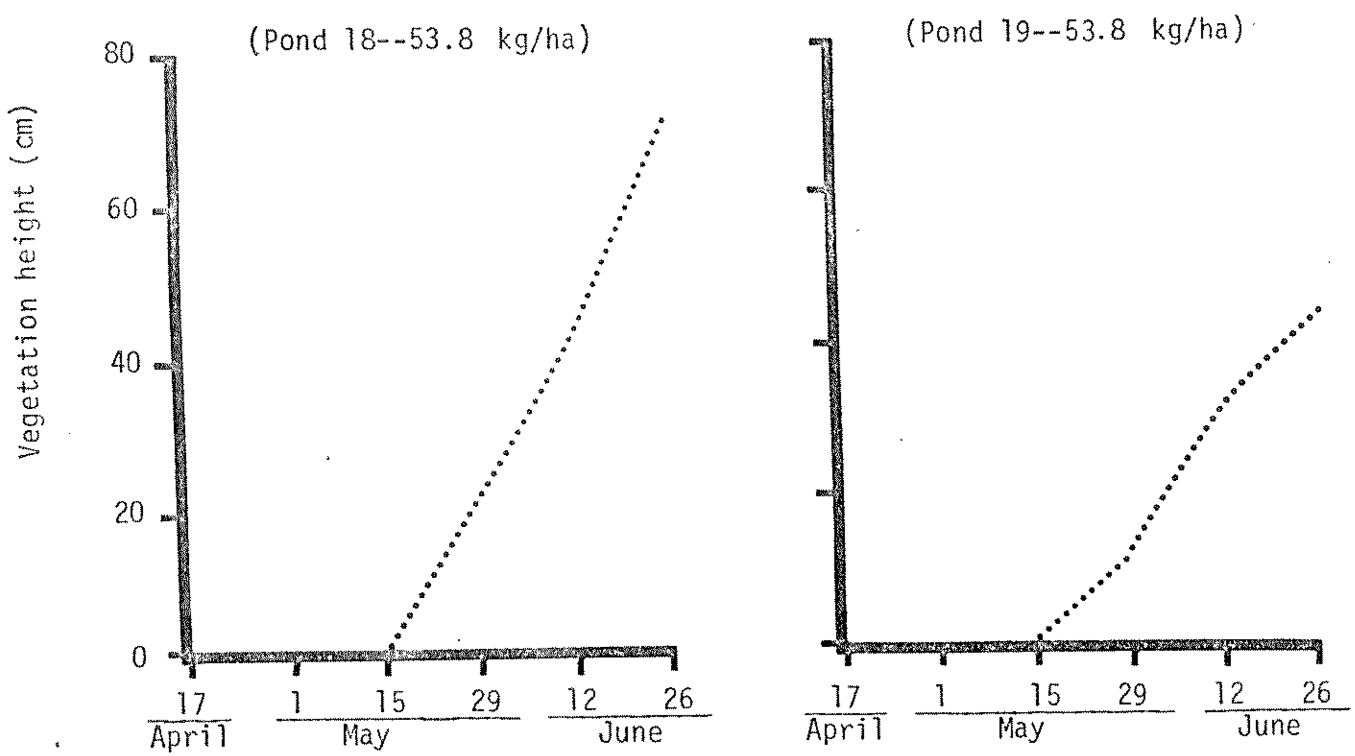

Figure 3. Continued.

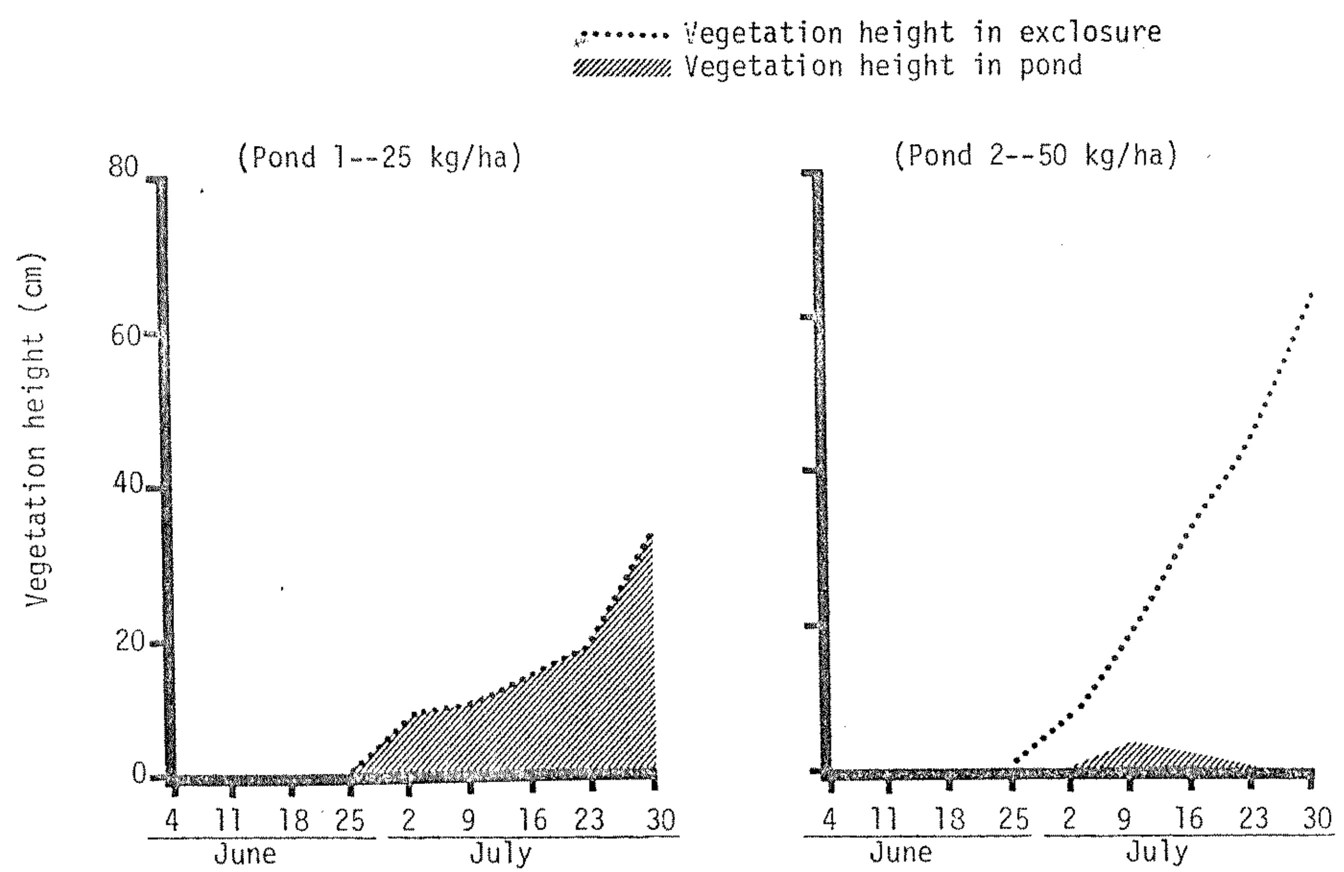

Figure 4. Results of low density of grass carp in bare ponds at C.S.U. Foothills Campus.

This trial lasted from 4 June 1979, to 30 July 1979, but the vegetation did not start growing rapidly until 25 June 1979. At that time the average daily water temperature was 21.4 C with an average daily fluctuation of 5.5 C.

DISCUSSION

The usefulness of grass carp for controlling aquatic vegetation in Colorado depends primarily on what densities of grass carp will be effective, and how water temperatures affect grass carp feeding. The practicality of using grass carp is also affected by what effect grass carp have on fish and invertebrates, difficulties in harvesting grass carp, and the mortality rate of grass carp.

Effect of Different Densities of Grass Carp on Vegetation

A certain minimum density of grass carp was needed if vegetation was to be controlled or eliminated. Grass carp had to be stocked at a density where they consumed vegetation faster than it was growing.

The following are a few grass carp stocking densities which may be used predictably in the future: a 375 kg/ha density of grass carp stocked after 11 June should consume a 60 cm stand of *Chara kieneri* in about 28 days, or a 30 cm stand of *C. kieneri* in about 14 days; a 125 kg/ha density of grass carp stocked after 11 June should consume a 66 cm stand of *Zanichellia palustris* or *Potamogeton pectinatus* in about 21 days; a 75 kg/ha density of grass carp stocked after 11 June should consume a 30 cm stand of *Z. palustris* or *P. pectinatus* in about 28 days; a 50 kg/ha density of grass carp stocked into a pond with no vegetation after 11 June should prevent the growth of any aquatic macrophytes. Those stocking rates are not the absolute minimums which will work on the specified amounts of vegetation. Also, those stocking densities were derived from grass carp weighing between 0.43 kg and 0.67 kg. Other studies indicate that grass carp eat less vegetation per unit of body weight once they grow beyond 4.5 to 9 kg. Stocking densities may be manipulated linearly. Apparently, if the quantity of aquatic vegetation doubles, then doubling the quantity of grass carp to be stocked will still result in complete elimination of the vegetation.

Much lower stocking densities can be used if reduction of vegetation is desired instead of elimination. A 125 kg/ha density of grass carp stocked after 11 June will probably remove 50% of a 70 cm stand of *C. kieneri*, and a 50 kg/ha density of grass carp stocked after 11 June will probably remove 70% of a 60 cm stand of *Z. palustris* or *P. pectinatus* by the end of August.

The reason grass carp consumed a stand of 30 cm tall *Z. palustris* or *P. pectinatus* much sooner than a 30 cm tall stand of *C. kieneri* was because *Z. palustris* not only contained more water than *C. kieneri*, but *Z. palustris* did not grow as densely as *C. kieneri*. *C. kieneri* was about 82% water, while *Z. palustris* was about 92% water. A stand of 30 cm tall *C. kieneri* weighed 526 g/m^2 (dry weight), while a stand of 30 cm tall *Z. palustris* weighed 102 g/m^2 (dry weight).

The dynamics of the growth of aquatic vegetation and the growth of grass carp are hard to predict precisely over a long period of time. Arkansas and Iowa have successfully used stockings of 9 kg/ha (25 grass carp per ha) to achieve 80-90% control of vegetation in large lakes (Bailey 1978, Mitzner 1978). Bailey (1978) calculated that when grass carp biomass reached 110 kg/ha that control of vegetation would be achieved. That biomass was achieved 2 to 3 years after stocking grass carp.

Grass carp grow as fast in eastern Colorado as they do in Arkansas and Iowa. Some of the grass carp at the Wray hatchery grew from 0.54 kg to 2.72 kg apiece in 26 weeks (12 g/day). However, grass carp stunt easily. Grass carp grew only from 0.40 kg to 0.54 kg each when fed for 4 out of 72 weeks.

Grass carp may be successful at reducing aquatic vegetation in mountain lakes since many of the lakes stratify with the water temperature in the epilimnion being above 14 C from mid-June to the end of August.

Effect of Water Temperature on Grass Carp Feeding

Sutton (1974) determined a significant correlation ($r = 0.79$) between the amount of hydrilla (*Hydrilla verticillata*) consumed by grass carp and water temperature. Opuszynski (1968) determined that intensive feeding does not occur until temperatures reach 20 C. Food consumption was 50% of body weight at 20 C, but rose to 100-120% of body weight at 22 C.

In the high density trial the grass carp ate 169% of their body weight per day in wet weight of vegetation with an average water temperature of 22.5 C, but in the 1978 medium density trial the grass carp ate 52% of their body weight per day in wet weight of vegetation with an average water temperature of 12.3 C. In the 1979 medium density trial the grass carp did not begin feeding actively until the water temperature reached 18.3 C.

The reason grass carp fed actively at 12.3 C in the fall of 1978, but did not feed actively until 18.3 C in the spring of 1979 may have been due to temperature fluctuations. At a water temperature of 12.3 C in the fall of 1978 the average daily water temperature fluctuation was

3.5 C, while at a water temperature of 18.3 C in the spring of 1979 the average daily water temperature fluctuation was 6.6 C.

In Colorado, grass carp fed effectively on aquatic vegetation from mid-June until mid-September. They continued to feed until ice on the ponds in winter prevented me from observing them. However, their rate of feeding was so slow that very high densities of grass carp would be needed to remove significant quantities of aquatic vegetation during the cold months of the year.

Effect of Grass Carp on Fish and Invertebrates

In the 1979 medium density trial, abundant populations of fathead minnows (*Pimephales promelas*) and aquatic insects (Odonata, Ephemeroptera, and Hemiptera) were present in all ponds, but only vegetation was found in gut contents of 10 grass carp selected at random from the ponds.

In the low density trial at the Wray fish hatchery, adult largemouth bass (*Micropterus salmoides*) and smallmouth bass (*Micropterus dolomieui*) were introduced into the ponds with grass carp. The bass spawned successfully and did not appear to be hindered by the grass carp.

In another experimental pond, grass carp were introduced with rainbow trout (*Salmo gairdneri*). Both species fed on floating trout pellets, but the grass carp only took a small percentage of the available pellets. This was probably due to rainbow trout being opportunistic, aggressive feeders while grass carp are slow feeders.

Harvesting Grass Carp

In the low density trial at the Wray hatchery, adult largemouth bass and smallmouth bass were introduced into ponds number 18 and 19 along with grass carp. The grass carp prevented the emergence of aquatic vegetation, and the bass spawned successfully. The adult bass were seined out with a large mesh seine allowing the bass fry to pass through the seine while the grass carp jumped over. On 26 June 1979 the bass fry were harvested by draining the pond. The outlet pipe carried thousands of bass fry through the dike and into a small concrete pool with a screened outlet. The fry were hand netted out of the kettle. The grass carp waited until there was only about 10 cm of water left in the pond before heading through the outlet pipe. At that time a mesh bag was put over the end of the outlet pipe, and the grass carp were easily collected for transfer to another pond.

After each trial at the C.S.U. Foothills Campus, grass carp were seined and transferred to holding ponds. Usually about 85% of the grass carp were removed by using two or three seine hauls. The remaining grass carp were removed by draining the pond.

Grass carp schooled tightly and tended to jump simultaneously when frightened by a net. Their jumps often cleared the top of the seine by 0.5 to 1.0 m. They have cleared the water by as much as 1.8 m. Gill nets and trap nets were tried for harvesting grass carp, but only 1% to 4% of the fish were caught.

Mortalities

Mortality of grass carp occurred from chemical poisoning and rough handling. A formalin treatment of 250 ppm for 1 hour was given to the grass carp upon their arrival from Arkansas as a prophylactic treatment. After the static treatment was to end, I turned the water back on in the holding vat to flush out the formalin. However, 45 minutes later, half of the grass carp appeared very stressed in the holding vat for the water pump had quit, and the formalin had not been flushed away.

The grass carp were immediately transferred to another filled holding vat, but all of the stressed fish died.

A second incidence of chemical poisoning was believed to have been caused by careless sparying of Banvil-D and 2,4-D along the sides of the ponds.

The grass carp were found to be fairly disease resistent. No over-wintering mortality occurred despite high fish densities and lack of food. Grass carp have been shown to be more resistent to parasites than are native fishes (Riley 1978).

Careful handling should be used with grass carp. Their scales are lost easily with rough handling and then they are subject to fungal infections. Grass carp that lost scales in the fall were able to carry the fungal infection over winter without mortality. However, if grass carp are handled roughly in the spring, they can quickly become infected with fungus and die. Transferring grass carp roughly from one pond to another caused a 15% mortality at the C.S.U. Foothills Campus.

Low oxygen levels are not a problem with grass carp. Grass carp can tolerate oxygen levels of 1.0 ppm (Henderson 1973).

SUMMARY

Grass carp were effective in controlling aquatic macrophytes in fish culture ponds in Colorado. Their feeding rate was affected primarily by water temperature and the species of aquatic macrophyte. Grass carp began feeding effectively on aquatic vegetation in Colorado in mid-June when the water temperature reached a daily average of 18.3 C, and continued until mid-September when the water temperature dropped to a daily average of 12.3 C. They consumed a dense stand of *Z. palustris* much sooner than a dense stand of *C. kieneri* of the same height, because *Z. palustris* contained much less dry matter and did not grow as compactly as *C. kieneri*.

Certain stocking densities of grass carp were successful: a stocking density of 375 kg/ha of grass carp consumed a 60 cm stand of *C. kieneri* by mid-July; a stocking density of 125 kg/ha of grass carp consumed a 66 cm stand of *Z. palustris* by mid-July; and a stocking density of 50 kg/ha of grass carp stocked into a bare pond prevented the growth of any vegetation. Complete removal of aquatic vegetation was desired for fish culture ponds, but reduction of vegetation would be desirable for a sport fishery. Reduction of vegetation was achieved with stocking densities of 40-125 kg/ha of grass carp. The stocking densities listed in this paragraph were achieved using grass carp weighing 0.43-0.67 kg apiece.

Grass carp were held in bare ponds under ice cover for two winters at densities of 960-1480 kg/ha with no observed mortality. Mortalities were observed from rough handling and subsequent fungal infections, and from accidental over exposure to formalin and Banvil-D with 2,4-D.

Grass carp grew from 0.54 kg to 2.72 kg apiece in 26 weeks with ample vegetation, but grew only from 0.40 kg to 0.54 kg apiece when fed for 4 out of 72 weeks. Only vegetation was found in gut contents of grass carp despite abundant populations of fathead minnows and aquatic insects. Grass carp did not have any deleterious effect on rainbow trout or spawning largemouth and smallmouth bass.

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APPENDICES

Appendix Table A. Vegetation standing crop outside the exclosure for medium density grass carp trial in summer of 1979.

Grass carp density (kg/ha)	Dry weight of standing crop of vegetation (kg/0.4 ha)										
	May 21	May 28	June 4	June 11	June 18	June 25	July 2	July 9	July 16	July 23	July 30
125[a]	28	29	29	43	20	10	0	0	0	0	0
125	62	65	81	142	177	175	170	149	93	101	93
250	65	111	117	173	137	180	194	240	195	161	143
250	50	102	102	96	186	120	78	60	93	93	76
375	60	70	88	175	179	40	27	15	0	0	0
375	56	64	102	130	170	53	16	0	0	0	0
500	67	105	124	120	81	38	10	0	0	0	0
500	68	117	137	140	169	170	160	95	76	59	9

[a]This was Pond 5 which contained *Z. palustris* instead of *C. kieneri*.

Appendix Table B. Vegetation standing crop inside the exclosure for medium density grass carp trial in summer of 1979.

Grass carp density (kg/ha)	Dry weight of standing crop of vegetation (kg/0.4 ha)										
	May 21	May 28	June 4	June 11	June 18	June 25	July 2	July 9	July 16	July 23	July 30
125[a]	26	29	24	50	43	49	39	40	40	40	40
125	50	67	97	195	180	202	193	200	203	203	203
250	70	109	132	207	209	210	209	203	202	200	200
250	48	109	101	110	195	192	189	211	195	200	194
375	66	76	81	166	190	195	184	186	186	194	194
375	45	70	113	109	105	119	129	104	127	160	170
500	61	96	115	118	140	196	210	205	203	200	203
500	68	116	142	136	230	225	240	230	210	202	203

[a]This was Pond 5 which contained *Z. palustris* instead of *C. kieneri*.

Appendix Table C. Weekly average water temperatures in 1979 in C.S.U. Foothills Campus fish culture ponds.

Date	Average temperature (°C)	Average temperature fluctuation (°C)
May 21	16.7	8.8
May 28	20.0	7.7
June 4	16.9	7.5
June 11	18.3	6.6
June 18	22.0	5.4
June 25	21.4	5.5
July 2	23.3	4.1
July 9	24.1	4.3
July 16	23.6	4.6
July 23	24.1	3.2
July 30	23.6	3.2