Production of Phytoplanktivorous Silver Carp in a Eutrophic Dairy Farm Impoundment[1]

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Abstract: Suitability of silver carp (*Hypophthalmichthys molitrix*) as a biological agent in controlling phytoplankton was studied *in situ* in 3 sequential dairy farm ponds in Anderson County, South Carolina. Concentrations of chlorophyll *a*, soluble orthophosphate and associated water quality parameters were measured biweekly from May 1979 through May 1980 prior to introduction of silver carp (100–150 mm total length; 23.1 g average weight) to 1 pond on 12 June 1980. Water chemistry measurements continued through October 1980. Increases of chlorophyll *a* concentrations in 1980 over 1979 values were 5 times to 7 times in ponds without silver carp and only 2 times in the pond with silver carp. In addition, the pond with silver carp showed significantly lower total hardness and calcium concentrations during 1980. These data suggest that silver carp can effectively lower phytoplankton biomass. Silver carp were harvested during December of 1980. Fish averaged 403 mm in total length and 690 g in weight. Net production for the 180-day period was 2,507 kg/ha.

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Nutrient enrichment of water systems results from an excess loading of nutrients from sources such as farm, municipal, and industrial wastes. Livestock wastes contribute nutrient levels several hundredfold in excess of recommended fertilization rates for farm ponds (Agric. Eng. Handbook 1979, Boyd 1979). Excessive nutrients result in degraded water quality and dense algal blooms (Prowse 1969, Wetzel 1975). Improving water quality and controlling

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algal blooms are important in restoring water to acceptable standards set by the U.S. Environmental Protection Agency (U.S. Environ. Protection Agency 1973).

Chemical and mechanical treatments offer at best temporary solutions in removing nutrients and/or algae, with prohibitive costs and detrimental effects as added factors. Silver carp (*Hypophthalmichthys molitrix*) show potential as a biological method in controlling eutrophication because of their algal filtering capability (Spataru 1977, Wilamovski 1972) and food preferences (Cremer and Smitherman 1980, Jhingran 1975, Kuznetsov 1977, Omarov and Lazareva 1972, Spataru 1977). Utilization of these phytophagous fish could provide reasonable long-term control of excessive algae and improvement of water quality in addition to providing impressive yields of fish production as a marketable product (Carpenter et al. 1976, Wolfarth 1978).

Objectives of this study were to ascertain baseline chemical and biological characteristics of 3 sequential eutrophic dairy farm impoundments, to evaluate success achieved by utilizing silver carp to improve water quality, and to evaluate potential fish production.

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Methods

The study area consisted of 3 sequential dairy farm ponds located in the Piedmont area of Anderson County, South Carolina. Pond I was located directly behind the barn/feedlot area, and received effluent from the washing and sanitizing of milking equipment and barn twice daily, in addition to runoff from the feedlot. Daily utilization of the watershed area exclusive to pond I by livestock during 1979 and 1980 averaged 4,500 cattle hours (i.e., 225 head of cattle 20 hours/day). Pond II was located approximately 200 m from barn/feed lot area and was separated from this area by pond I. A daily average of 900 cattle hours was estimated for pond II. Pond III, located 700 m from the barn/feedlot area, received inflow from the effluents of ponds I and II. Utilization of this new area was limited to seasonal pasturage of 15 bulls. Surface areas and volumes of ponds I, II, and III were 10,260 m^3, 0.81 ha; 14,590 m^3, 1.14 ha; and 17,200 m^3, 2.12 ha respectively.

Ponds I and II received major inputs of livestock wastes from the barn and feedlot areas. Pond I served primarily as a waste settling pond. Surface water from pond I flowed through a drainage ditch into pond II. Ponds II and III represented more typical farm impoundments.

Preceding the introduction of silver carp, standpipes in ponds II and III were cleaned to allow proper flow and retention of water levels, and screened to contain silver carp. In addition, spillways were sand-bagged and screened to prevent escape of silver carp should water inflow exceed the drainage capacity of standpipes.

Chlorophyll *a*, soluble orthophosphate, dissolved oxygen, alkalinity, pH, hardness, calcium, magnesium, and temperature were determined in duplicate at biweekly intervals for each pond (Am. Public Health Assoc. 1976, Hach 1979, Lind 1974). Collections between May 1979 and October 1979 were made in order to document water quality and algal abundance before introduction of silver carp (Wilson and Foltz 1981). Water quality determinations were continued from May 1980 to October 1980, during the presence of silver carp in pond II. Field sampling was performed between 0900 and 1100 hours.

Multiple analysis of variance was used to compare ponds with one another and to examine differences between 1979 and 1980. Paired comparisons were used to determine significant differences between ponds and years. Significance testing was at the 0.05 error level.

Pond II was treated with 1 ml Noxfish (5% rotenone) per cubic meter of water on 13 May 1980 in order to eliminate resident fishes. Total weight of resident fish recovered was <200 kg. Silver carp (100–150 mm TL) were stocked 12 June 1980 at an estimated density of 5,000 fish/ha. Average initial weight of silver carp was 23.1 g. Noxfish was again applied to pond II in order to eliminate the silver carp population on 8 December 1980. A total of 4,284 silver carp were collected. A subsample of 129 fish was randomly removed. Fish were weighed separately to the nearest 5 g and total length measured to the nearest mm. Six fish were randomly chosen for chemical analysis. Fish were weighed to the nearest 0.1 g, placed in preweighed aluminum pans, and dried for 72 hours at 60° C in order to determine percentage dry matter. Dried carcasses were individually homogenized with a Wiley Intermediate Mill and individual homogenates analyzed in triplicate for crude nitrogen, potassium, calcium, and phosphorous. Crude nitrogen was determined by the Kjeldalh method, and potassium, calcium, and phosphorous by atomic absorption spectrophotometry (Horowitz 1970).

Results and Discussion

Soluble orthophosphate concentrations during 1979 were highest in pond I and decreased progressively to pond III (Table 1). Total hardness, alkalinity, and pH demonstrated identical trends. Similarly, chlorophyll *a* was highest in pond I (186 mg/m^3) and decreased to 94 and 57 mg/m^3 in ponds II and III respectively. Dissolved oxygen showed the opposite trend that nutrients and chlorophyll *a* did, averaging 2.4, 7.0 and 7.5 mg/l in ponds I, II, and III respectively. Thus, pond I was best described as an agricultural sewage lagoon, and pond II was selected as the pond for silver carp introduction, because of its dense algal stand and suitable dissolved oxygen.

Chlorophyll *a* concentrations during 1980 were higher than corresponding 1979 values for all three ponds. This was attributed to the extended drought during the summer of 1980 and consequent diminished flushing of water through the 3 sequential ponds. However, the relative increase in chlorophyll *a*,

Table 1. Water quality characteristics (averages ± SE) of 3 sequential dairy farm ponds from June 1979 through December 1979 prior to introduction of silver carp to pond II. All water quality parameters except water temperature differed between ponds.

Pond	Soluble orthophosphate mg PO_4/liter	chlorophyll *a* (mg/m^3)	Total hardness (mg $CaCO_3$/liter)	Total alkalinity (mg $CaCO_3$/liter)	pH	Dissolved oxygen (mg/liter)	Water temperature (° C)
I	15.35 ± 2.60	186 ± 15	155.1 ± 5.6	268.7 ± 9.1	7.1 ± 0.1	2.4 ± 0.7	23.5 ± 0.5
II	1.17 ± 0.20	94 ± 11	61.1 ± 1.4	74.6 ± 1.9	6.8 ± 0.1	7.0 ± 0.6	25.2 ± 0.5
III	0.13 ± 0.02	57 ± 10	45.9 ± 1.3	45.9 ± 1.0	6.6 ± 0.1	7.5 ± 0.4	24.7 ± 0.4

that is, the 1980 value divided by the 1979 value, was lowest for pond II, the pond stocked with silver carp (Table 2). Pond I increased 7-fold from 1979 to 1980. Despite the fact that pond I drains directly into pond II, pond II only experienced a 2.47-fold increase from 1979 to 1980.

Similarly, pond II drained into pond III. Pond III, which did not contain silver carp, experienced a 5.16-fold increase during the same period (Table 2). Dissolved oxygen (Table 2), total hardness, calcium, and pH (Table 3) differed only within pond II from 1979 to 1980. Mean dissolved oxygen decreased from 7.0 mg/liter to 5.3 mg/liter in pond II, but did not differ significantly in ponds I and III. A significantly lower overall mean dissolved oxygen concentration in pond II during 1980 compared to 1979 could be due to 2 factors. Dissolved oxygen levels present during weeks 2 to 12 (approximately May 1980 through August 1980) were substantially higher than the overall average for pond II as indicated by the downward trend (Table 4). Magnitude of diel fluctuations in dissolved oxygen would be expected to be greater during presence of dense phytoplankton blooms, and sampling at about 1030 hours probably measured dissolved oxygen levels closer to the lower limit of daily fluctuations. Later, during weeks 16 to 24 when chlorophyll *a* levels were reduced to levels comparable to 1979 values, additional respiratory losses from an increasing biomass of silver carp (below) probably lowered dissolved oxygen concentrations in pond II. Total hardness and calcium decreased from 61.1 to 52.4 mg/liter and 10.9 to 9.2 mg/liter respectively (Table 3). A reduction in calcium of 1.7 mg/liter (i.e., from 10.9 to 9.2 mg/liter) was equivalent to removal of approximately 25 kg of calcium for pond II (volume = 14,588 m^3).

Utilization of silver carp in controlling phytoplankton growth and water quality has been successful in studies conducted in Southeast Asia (Ghosh et al. 1973; Prowse 1969) Europe (Kajak et al. 1975; Moav et al. 1977), as well as the United States (Henderson 1978). Although chlorophyll *a* concentrations increased in 1980, the smallest increase was found in pond II. Even

Table 2. Average values (±SE) of chlorophyll *a* and dissolved oxygen in 3 sequential dairy farm ponds. Silver carp were present in pond II during 1980.

Pond	Year	Silver carp present	Chlorophyll *a*[a] (mg/m^3)	Dissolved oxygen[b] (mg/liter)
I	1979	no	186 ± 15[c]	2.4 ± 0.7
	1980	no	1,222 ± 268	2.3 ± 0.5
II	1979	no	94 ± 11[c]	7.0 ± 0.6[c]
	1980	yes	232 ± 37	5.3 ± 0.5
III	1979	no	57 ± 10[c]	7.5 ± 0.4
	1980	no	294 ± 56	6.4 ± 0.5

[a] $F_{pond} = 96.78$, $P = 0.0001$.
[b] $F_{pond} = 23.58$, $P = 0.0001$.
[c] Significant differences between years ($P \leq 0.05$).

Table 3. Average values (±SE) of total hardness, calcium, magnesium, pH & total alkalinity during the period from mid-May to mid-October. Silver carp were present in pond II during 1980. All water quality parameters differed significantly between ponds.

Pond	Year	Total hardness (mg $CaCO_3$/liter)	Ca (mg/liter)	Mg (mg/liter)	Total alkalinity (mg $CaCO_3$/liter)	pH
I	1979	155.1 ± 5.6	20.3 ± 0.5	25.6 ± 1.4	268.7 ± 9.1	7.1 ± 0.1
	1980	152.6 ± 3.2	21.9 ± 0.5	23.6 ± 0.7	267.5 ± 8.1	6.9 ± 0.1
II	1979	61.1 ± 1.4[a]	10.9 ± 0.2[a]	8.2 ± 0.4	74.6 ± 1.9	6.8 ± 0.1[a]
	1980	52.4 ± 1.2	9.2 ± 0.2	7.0 ± 0.3	67.3 ± 1.5	6.0 ± 0.04
III	1979	45.9 ± 1.3	7.3 ± 0.2	6.7 ± 0.4	45.9 ± 1.0	6.6 ± 0.1
	1980	43.6 ± 1.2	7.3 ± 0.2	5.9 ± 0.3	49.9 ± 1.8	6.4 ± 0.1

[a] Significant differences between years ($P = 0.05$).

Table 4. Biweekly changes in dissolved oxygen and chlorophyll *a* concentration in pond II which was stocked with silver carp (mean weight = 29 g, 5,000 fish/ha) between weeks 6 and 8. Week 2 corresponds approximately to 14 May.

	Year						
	1979			1980			
		Chlorophyll *a* (mg/m^3)			Chlorophyll *a* (mg/m^3)		1980 chlorophyll *a* / 1979 chlorophyll *a*
Week	Dissolved oxygen (mg/liter)	Week	3-week average	Dissolved oxygen	Week	3-week average	
2	2.4	48		3.5	549		
4	10.2	37	48	3.7	187	522	10.9
6	4.4	59		5.9	830		
8	10.7	91		2.7	516		
10	11.2	129	88	3.9	227	303	3.44
12	8.1	45		4.3	165		
14	5.2	62		10.1	562		
16	6.7	46	78	5.2	201	280	3.59
18	3.5	126		2.1	78		
20	8.9	59		5.7	168		
22	6.4	141	113	2.6	72	120	1.06
24	6.6	138		8.8[a]	119		

[a] Water temperature during week 24 was 20° C during 1979 and 16° C during 1980.

though pond II demonstrated a higher mean chlorophyll *a* concentration during 1980 compared to 1979, the trend from weeks 2 through 24 (i.e., May through October) clearly demonstrates a reduction in total phytoplankton abundance as silver carp increased in total biomass and presumably consumed more total phytoplankton daily ($F_{regression} = 6.71$, $P = 0.0269$) (Table 4). Whereas prior to introduction of silver carp, 1980 values of chlorophyll *a* were >10-fold higher than 1979 values, the ratio declined to 3.4 to 3.6 after initial introduction of fish, and by weeks 20 to 24, had declined to levels comparable to 1979 levels (i.e., 120 mg/m^3 compared to 113 mg/m^3 in 1979). This was attributed to consumption of algal biomass by silver carp. Several studies have shown control and/or limited development of phytoplankton biomass (Kajak et al. 1975) or phytoplankton numbers (Ghosh et al. 1973, Ghosh et al. 1974, Henderson 1978) when using silver carp as a biological control.

Production of Silver Carp

Silver carp averaged 690 g (SE = 1) and 403 mm (SE = 6) total length at the end of the experimental period. Thus average weight of silver carp increased 667 g during the 180-day period of mid-May to mid-December. Net production was equivalent to 2,507 kg/ha. Nutrient content of silver carp biomass was estimated at 66 kg nitrogen, 4.0 kg calcium, 21.9 kg phosphorus and 7.9 kg of potassium (Table 5). From these values, estimates were made indicating silver carp removed 0.084 kg nitrogen, 0.03 kg phosphorus, 0.01 kg potassium, and 0.005 kg calcium per 1,000 fish per day. Estimated amounts would not be available for algal utilization because these nutrients were incorporated into fish biomass. Water chemistry and phytoplankton data substantiate this hypothesis. The impoundment immediately upstream of the pond with silver carp experienced a 7-fold increase in chlorophyll *a* concentrations from 1979 to 1980, compared to only a 2-fold increase in the presence of silver carp and a 5-fold increase downstream in the third pond. Presumably, nutrients taken up and incorporated by algae were assimilated by silver carp. This action should have acted as a nutrient drain, especially for those nutrients essential for the assimilation of fish tissue. The fact that all 3 ponds experienced an increase in average chlorophyll *a* was attributed to the extended drought during the summer of 1980 and reduced flow of water through the 3 ponds. Rainfall from May through October 1979 totaled 74 cm after 22 cm of rain during April. There were 78 days with $\geq$0.025 cm precipitation during the same period. In addition, there was only the equivalent of 1,457 hours of bright sunlight. In contrast, the same period during 1980 experienced 1,631 hours of bright sun, had 39 days with $\geq$0.025 cm of precipitation, and experienced only 58 cm of precipitation (Kish 1980, Linvill 1981). No changes in land practices in any of the 3 drainage areas occurred.

From this preliminary study, it appears that silver carp may be effective in controlling and/or limiting phytoplankton production and that substantial

Table 5. Length, weight, and chemical composition of silver carp harvested at end of 180-day growing period. Fish averaged 23 g when stocked into pond II.

Average or total	Length (mm)	Live weight (g)	Dry weight	Carcass composition (% dry matter or kg)			
				Nitrogen	Phosphorus	Potassium	Calcium
Average individual	403 ± 6	690 ± 1	155 ± 6	9.99 ± 0.09	3.29 ± 0.07	1.19 ± 0.02	0.60 ± 0.02
Calculated total[a]	na[b]	2,956 kg	665 kg	66.4 kg	21.9 kg	7.9 kg	4.0 kg

[a] For 4,284 fish harvested from 1.14-ha pond.
[b] Not applicable.

fish production can be realized in eutrophic dairy farm impoundments without supplementary fertilization. Controlled and replicated experiments are warranted in order to accurately attribute changes in phytoplankton abundance to the presence or absence of silver carp.

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