

# Biocontrol of Aquatic Plant Growth in Earthen Ponds by the White Amur (*Ctenopharyngodon idella* Val)<sup>1</sup>

by

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## ABSTRACT

This study was the first field evaluation of the white amur (*Ctenopharyngodon idella* Val.) in Florida for biological control of aquatic weeds. White amur were stocked in four 0.08 ha ponds at rates of 0, 12, 20, and 40 kg ha<sup>-1</sup>, and for nearly two years plant growth and water quality were measured monthly. Hydrilla (*Hydrilla verticillata* Royle) rapidly became the dominant plant in all ponds even though native submersed vegetation was also initially planted in the ponds. Partial weed control was achieved at the highest stocking rate; however, the stocking of white amur was increased 5 months prior to termination of the study to remove the majority of submersed vegetation and to observe changes in parameters studied. Ponds stocked with white amur contained up to 23% coverage of vallisneria (*Vallisneria neotropicalis* Marie-Vict.) at the termination of the experiments, whereas no vallisneria was found in the control pond. Changes in water quality as a result of stocking white amur were not as significant as were changes over time in the 27-month study period. There were greater numbers of benthic invertebrates and a higher standing crop of game fish in ponds stocked with the white amur. Plankton varied greatly between the ponds; however, blue-green algae were most widespread and dominant in the control pond which was not stocked with white amur. Only trends could be derived from this study due to the lack of replication; however, no widespread adverse effects of stocking the white amur were found and further testing under more natural conditions was recommended.

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## INTRODUCTION

The rapid increase in submersed aquatic weeds in Florida and the high cost of chemical weed control measures have prompted the search for effective biological control agents. Of the herbivorous fish known, Swingle (16) suggested that the white amur (*Ctenopharyngodon idella* Val.) has the greatest potential for biological control of submersed vegetation. The white amur, a member of the Cyprinidae family, has a tolerance for wide diversity in environmental parameters. It can survive extended periods of ice cover (14) and tolerates relatively low oxygen levels (21).

After the white amur becomes 25 to 30 mm in length, its diet consists strictly of vegetation. The fish has lost weight when stocked in ponds devoid of aquatic vegetation but containing an abundance of zooplankton and insect larvae. The aquatic plant preferences of the white amur vary widely, apparently because temperature, size of fish, and plant maturity (fiber content) all govern the preference of feeding. Likewise, the stocking rate of white amur required for weed control varies greatly depending on the weed species, density, latitude, and size of fish stocked (10).

Effects of aquatic weed control by the white amur on other factors of the aquatic ecosystem have been studied. The vast majority of studies conducted to determine the effects of the white amur on other fish indicates there is no direct competition (3,4,9,13,15). Indirect competition may occur when aquatic vegetation is controlled rapidly, and potential algae blooms might reduce visibility for sight feeding fishes; however, the white amur does not increase turbidity by bottom feeding activities (3,12).

The effects of the control of aquatic weeds by the white amur on water quality have not been studied extensively in natural systems. In small pools and enclosed areas, aquatic weed control by the amur imparted a brown stain to the water (2), increased potassium content of the water, but did not change the nitrogen, phosphorous, or sodium levels (3). In separate studies in Florida, the water

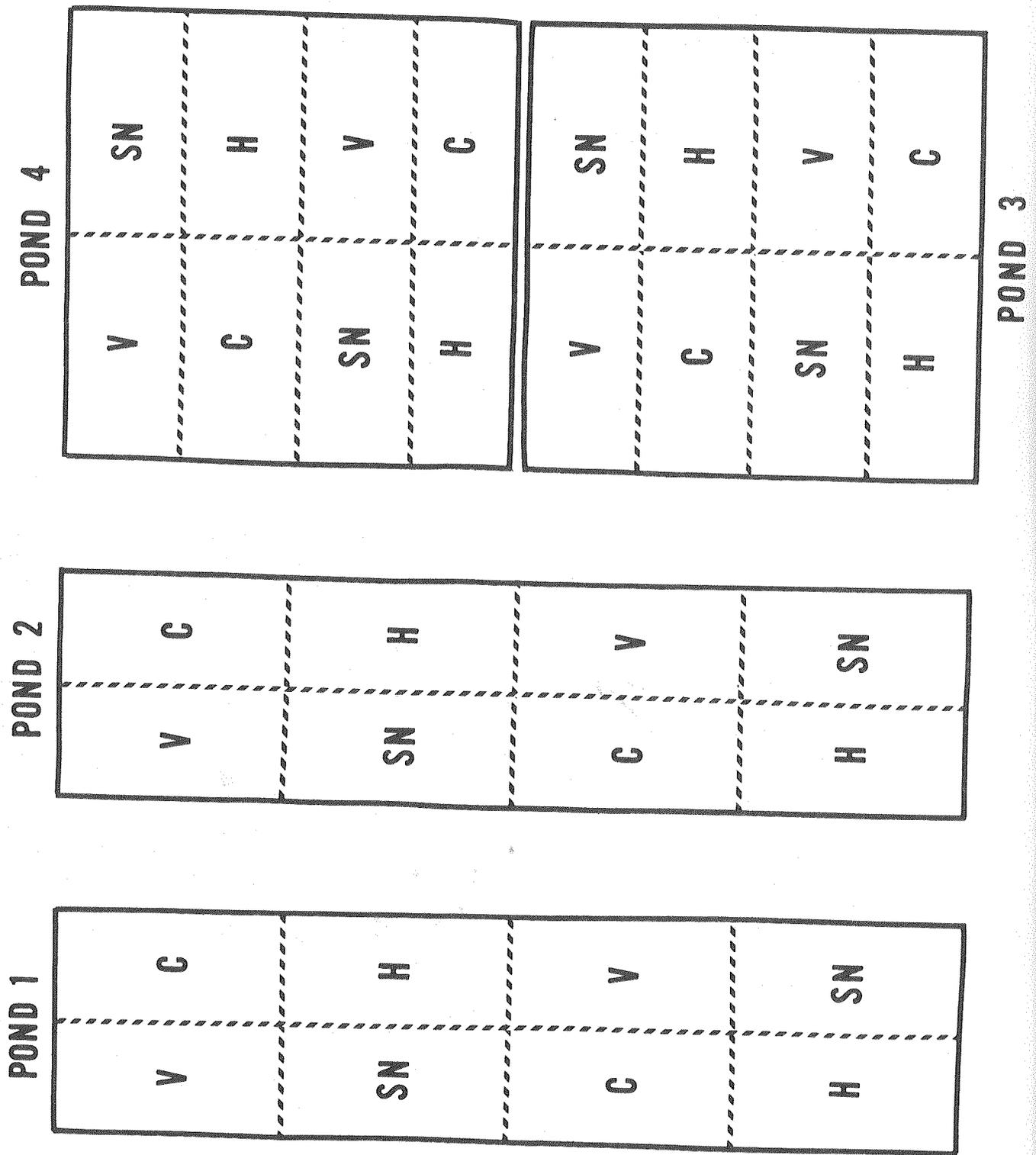


Figure 1. Diagrammatic view of four earthen ponds used to study weed control by the white amur. The location of initial plantings of submersed vegetation is indicated by: H=Hydrilla, V=Vallisneria, C=Chara, and SN=Najas.

quality in small enclosures stocked with amur showed increases in water hardness and nitrogen content but no changes in phosphorus content (11).

Due to the potential of the white amur for submersed aquatic weed control and the lack of data from Florida waters, a limited non-replicated pond study was designed to collect additional information on this fish. The main objectives of the study were to determine stocking rates required for weed control in Florida, to observe plant preferences of the fish for various aquatic plants, and to evaluate the influence of the amur on water quality and other aquatic fauna.

## METHODS AND MATERIALS

Four earthen ponds (0.08 ha) were constructed in central Florida near Orlando. In July 1971, the ponds were divided into eight equal areas, and the submersed aquatic plants hydrilla (*Hydrilla verticillata* Royle) southern naiad (*Najas guadalupensis* (Spreng.) Magnus), vallisneria (*Vallisneria neotropicalis* Marie-Vict.) and chara (*Chara* sp.) were planted in assigned plots (Figure 1). In addition, cattails (*Typha* sp.) were planted on one berm of each pond, and coontail (*Ceratophyllum demersum* L.) was scattered throughout the four ponds. Water was added to the ponds as the aquatic plants grew. The ponds were maintained at a 1.5 m depth throughout the study by periodic pumping from a deep well.

Four water samples were collected monthly from a depth of 0.5 m in each pond, and the well water was analysed periodically. Water samples were placed on ice immediately after collecting and transported to the laboratory where they were analysed for mineral content (1).

In September 1971, all four ponds were stocked with 24 *Micropterus salmoides* (average 200 g fish<sup>1</sup>), 105 *Lepomis* sp. (average 60 g fish<sup>1</sup>), and 4 to 6 liters of forage fish.

By October 1971, the ponds were full, the aquatic plants being well established and having grown to the water surface. White amur were stocked into three ponds at rates of 13, 25, and 50 fish ha<sup>1</sup> (Table 1). Stocking rates were based on rates used in Arkansas for aquatic weed control. The fourth pond was not stocked with white amur and, therefore, served as the control pond.

For the next 22 months water quality and other parameters were measured. The percent plant coverage was evaluated quarterly by swimming through the ponds and visually estimating the area covered by each submersed species.

Table 1. Stocking schedule of white amur in shallow, earthen ponds for aquatic plant control research in central Florida.

Date	Pond Number <sup>a</sup>			
	1	2	3	4
October 1971				
Number	4	1	2	—
Ave. wt. (kg)	0.8	0.9	0.8	—
No. ha <sup>1</sup>	50	13	25	—
Kg ha <sup>1</sup>	40	12	20	—
August 1973				
Number	4	15	30	—
Ave. wt. (kg)	0.8	1.0	0.9	—
No. ha <sup>1</sup>	50	187	375	—
Kg ha <sup>1</sup>	40	187	338	—
Total				
Number	8	16	32	—
No. ha <sup>1</sup>	100	200	400	—
Kg ha <sup>1</sup>	80	199	358	—

<sup>a</sup>All ponds were planted with four different types of submersed plants and stocked with sport fish. Pond 4 remained as the control pond (no white amur added) throughout the study.

In August 1973 additional white amur were stocked to increase the rate of weed control (Table 1). The total number of white amur stocked in ponds 1, 2, and 3 was 100, 200, and 400 fish ha<sup>1</sup>, respectively.

As weed control became evident in the ponds, benthic soil samples and plankton samples were collected in November 1973 and January 1974. Two Eckman dredge samples (15 cm<sup>2</sup>) were collected in each pond for each date, carefully screened through a 60-mesh screen, and the invertebrates picked and counted under a binocular microscope.

Net plankton was collected by drifting through the ponds in a boat and collecting 20 liters of surface water from random sites (2 liters per site) and filtering through a 200 mesh plankton net. Two plankton samples from each pond were collected on each sampling date. The samples were preserved with formalin and later counted in a Palmer Counting Cell.

At the termination of the study, the ponds were drained with pumps, and fish were collected, counted, and weighed. Plant samples were collected for nutrient analysis and biomass determinations.

## RESULTS

Within 3 months after planting, hydrilla had covered about the same area in each of the four ponds; the same was true for vallisneria (Table 2). Establishment of chara and southern naiad was

Table 2. Aquatic plant composition of ponds before, during, and at termination of the study of the white amur for aquatic weed control.

Months after initial stocking (date)	% coverage of ponds <sup>a</sup>	Stocking rate (kg/ha)			
		0	12	20	40
0 (Oct 71)	Hydrilla	39	38	41	43
	Vallisneria	7	4	4	10
	Naiad	51	54	41	34
	Chara	3	4	13	13
12 (Oct 72)	Hydrilla	100	63	69	88
	Vallisneria	Trace	15	14	10
	Naiad	Trace	8	1	Trace
	Chara	0	Trace	0	0
	Bare soil	0	14	16	2
			Stocking rate (total kg/ha) after restocking in Aug 73		
		0	199	358	80
27 (Jan 74)	Hydrilla	99	0	0	70
	Vallisneria	0	11	23	18
	Bare soil	1	89	77	12

<sup>a</sup>Coverage of ponds was visually estimated by swimming through the ponds and evaluating the frequency of occurrence of each plant species and bare hydrosol.

more variable with a coverage of 3 to 13% for chara and 34 to 54% for southern naiad. One year after the study was begun, hydrilla was the single species remaining in significant amounts in the control pond. Vallisneria was the same or increasing in coverage in the ponds stocked with the white amur. Southern naiad and chara had decreased in area dramatically or had disappeared in both the control pond and those stocked with the amur, and bare hydrosol was becoming evident in the ponds containing the white amur. It appeared that the white amur were eating weeds in a particular area, keeping these areas open or weedfree by eating the regrowth of surrounding aquatic vegetation. Due to the fact that hydrilla so rapidly dominated the control pond, it was impossible to determine what preference the white amur had for the four major submersed species. It was evident, however, that stocking the amur promoted the growth and coverage of vallisneria. Additional white amur were stocked in August 1973 to increase the weed control and assess its impact (Tables 1 and 2). By the termination of the study, hydrilla was completely controlled at the two highest stocking rates and greatly decreased at the lower stocking rate (Table 2).

Initial stocking rates of white amur were insufficient to satisfactorily control the hydrilla in the ponds. The initial standing crop in the ponds was large due to the rapid initial establishment of hydrilla and the occurrence of warm winters which did not appreciably slow hydrilla growth. The

white amur at the highest initial stocking rate were keeping up with the growth of hydrilla but did not remove significant portions of the standing crop. The 40 kg ha<sup>-1</sup> stocking rate probably would have controlled hydrilla in pond 1 had the plant density been decreased by low winter temperatures, application of herbicides, or mechanical removal.

The data on the nutritive content of the aquatic plants suggest that the plants remaining in the ponds stocked with white amur absorbed some of the nutrients released to the water by the fish feeding on plants in the same ponds (Table 3). In January 1974, for example, the P (phosphorous) content of hydrilla in pond 1 stocked with 80 kg ha<sup>-1</sup> was significantly greater than that found in hydrilla in the control pond (0.3 and 0.2%, respectively). Likewise, the percent N (nitrogen) content of hydrilla in pond 1 was 2.1% as compared to 1.8% in the control pond. Similar comparisons with vallisneria are impossible because vallisneria was not present in the control pond. Comparisons of hydrilla or vallisneria nutrient status in October of 1971 and 1972 are difficult to make because the fish were introduced in October 1971, and weed control had not occurred by October 1972.

Water quality measurements for the 27 monthly sampling dates were subjected to an analysis of variance using a two factorial design with the four water samples from each pond as replicates. Significant F values for available phosphorous were obtained in all cases except for between ponds and

Table 3. Nutritive content of aquatic plants in white amur ponds at the beginning, during and after the study period.

Plant Species	Pond No.	Date Collected				
		Oct. 71	Oct. 72	Jan. 74		
		% P	% P	% P	% N	Kcal/g
Hydrilla	1	.35 d <sup>a</sup>	.11 b	.27 c	2.1 c	2.9 bc
Vallisneria	1	.23 b	.07 ab	.19 a	1.5 a	3.0 c
Hydrilla	2	.28 c	.11 b	—	—	—
Vallisneria	2	.19 a	.06 a	.24 b	2.2 c	2.9 bc
Hydrilla	3	.28 c	.08 ab	—	—	—
Vallisneria	3	.18 a	.09 ab	.25 b	1.7 b	2.5 a
Hydrilla	4 (Control)	.28 c	.10 ab	.23 b	1.8 b	—
Vallisneria	4	.19 a	.09 ab	—	—	2.7 ab

<sup>a</sup> Each value is derived from a dry weight basis and is the mean of four replications. Values within a column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test. Final stocking rates (kg ha<sup>-1</sup>) of white amur: pond 1, 80; pond 2, 199; pond 3, 358, pond 4, 0.

time x between ponds. The observed F for time was higher than those obtained for between ponds. Time was of greater importance than the between pond factor (treatments) as related to water quality measurements. This is not surprising because the ponds were newly constructed and would change rapidly during the initial state of use. The well water used to maintain water levels generally contained many nutrients, and the ponds changed seasonally with the growth and production of aquatic vegetation.

Table 4 presents water quality data from January of each year of the study. Alkalinity and pH change as a function of weather and time of day, while other values are somewhat more constant with respect to diurnal changes. In January 1972 and 1973 there were no major differences in water quality (primarily due to the lack of weed control), and all ponds contained an abundant amount of

vegetation which has dramatic effects on water quality (13,18). In January 1974, pond 4 contained a complete coverage of hydrilla, pond 1 had primarily hydrilla and vallisneria (90%), and ponds 2 and 3 were about 80% cleared of vegetation. The pH and carbonate alkalinity were higher in the vegetated ponds (4 and 1) than in the other ponds. The total hardness, calcium carbonate, bicarbonate alkalinity, phosphorous, and conductivity were lower in the vegetated ponds (4 and 1) than in non-vegetated ponds. These differences are slight, and considering the total study period, the change with time was more significant than differences between ponds.

Generally, greater numbers of invertebrates were found in ponds stocked with the white amur than in the control pond, particularly in the November samples (Table 5). The principal benthic invertebrates were members of the Chironomidae.

Table 4. Selected water quality parameters of ponds and well-water during the white amur study.

Date	Pond No.	pH	Total hardness (ppm)	CaCO <sub>3</sub> (ppm)	Carbonate alkalinity (ppm)	Bicarbonate alkalinity (ppm)	Turbidity (JTU)	Available phosphorus (ppm)	Total phosphorus (ppm)	Conductivity
Jan 72	1	9.2	63	31	6.0	48	1.4	0.019	0.007	—
	2	8.8	73	38	2.0	56	2.0	0.016	0.004	—
	3	9.2	70	38	4.8	59	3.8	0.022	0.018	—
	4	9.9	59	29	11.5	43	1.6	0.038	0.011	—
Jan 73	1	8.8	71	40	5.5	59	1.4	0.002	0.019	118
	2	8.4	74	44	1.2	61	1.5	0.003	0.018	124
	3	8.8	75	44	3.0	62	1.4	0.002	0.019	120
	4	7.9	83	53	0.1	75	2.7	0.000	0.025	143
Jan 74	1	9.0	66	40	9.0	58	2.7	0.010	0.044	124
	2	8.0	102	75	0.2	83	6.4	0.008	0.138	163
	3	8.3	115	79	1.0	85	2.4	0.035	0.170	149
	4	9.2	98	60	7.0	47	1.6	0.000	0.029	93
Well-water	—	7.5	153	101	0.0	126	0.4	0.184	0.286	280

<sup>a</sup> Each value is the average of four samples taken in each pond. Final stocking rates (kg ha<sup>-1</sup>) of white amur: Pond 1, 80; Pond 2, 199; Pond 3, 358; Pond 4, 0.

Table 5. Principal benthic macro-invertebrates (no. m<sup>-1</sup>) in shallow ponds after stocking with white amur.

Invertebrate	Pond number			
	1	2	3	4
	Nov 73			
Chironomidae	4,218	5,816	8,391	2,642
Chaoboridae	1,165	400	2,797	222
Ceratopogonidae	278	333	89	0
Total invertebrates	5,761	6,771	11,543	3,086
	Jan 74			
Chironomidae	16,162	799	4,706	4,751
Chaoboridae	533	400	355	311
Ceratopogonidae	333	44	266	0
Total invertebrates	18,693	1,820	6,458	5,328

Each value is the mean of two dredge samples. Total invertebrates is the total of the three principal macro-invertebrates listed plus other less frequent occurring organisms such as Nematoda, Annelida, Odonata, etc. Final stocking rates (kg ha<sup>-1</sup>) of white amur: pond 1, 80; pond 2, 199; pond 3, 358; pond 4, 0 (control).

Interestingly, no Ceratopogonidae survived under the dense hydrilla growth in the control pond (pond 4).

No firm conclusions can be derived from the phytoplankton and zooplankton data, except that planktonic changes as a result of stocking the white amur are unpredictable (Table 6). The hydrilla was completely eliminated in ponds 2 and 3, leaving only 10 to 20% of the area vegetated with vallisneria. Total phytoplankton decreased in pond 2 and increased in pond 3 between November and January sampling dates. The zooplankton in both ponds decreased between sampling dates; however,

Table 6. Dominant, total and number of genera of phyto- and zooplankton in shallow earthen ponds in central Florida after stocking with white amur for vegetation control.

Plankton	Pond 1		Pond 2	
	Nov 73	Jan 74	Nov 73	Jan 74
Dominant Phytoplankton (%)	Mougeotia (55)	Scenedesmus (44)	Ankistrodesmus (86)	Green Unicells (49)
Total Phytoplankton (cells liter <sup>-1</sup> )	96,000	61,603	233,717	9,986
Total Genera	7	12	5	4
Dominant Zooplankton (%)	Keratella (50)	Naupli (27)	Keratella (90)	Diaptoms (53)
Total Zooplankton (cells liter <sup>-1</sup> )	298	2,237	15,188	2,533
Total Genera	2	8	4	7
	Pond 3		Pond 4	
	Nov 73	Jan 74	Nov 73	Jan 74
Dominant Phytoplankton (%)	Peridinium (82)	Ceratium (94)	Peridinium (62)	Merismopedia (60)
Total Phytoplankton (cells liter <sup>-1</sup> )	199,800	1,821,470	8,141	132,401
Total Genera	3	4	8	14
Dominant Zooplankton (%)	Keratella (100)	—	Keratella (67)	Naupli (60)
Total Zooplankton (cells liter <sup>-1</sup> )	5,970	—	407	4,749
Total Genera	1	—	2	5

Final stocking rates (Kg ha<sup>-1</sup>) of white amur: pond 1, 80; pond 2, 199; pond 3, 358; pond 4, 0 (Control).

the number of genera found increased between November and January in pond 2 and decreased in pond 3.

The plankton in pond 4 (control) increased in January, while the phytoplankton in the other vegetated pond (pond 1) decreased in January. The only Cyanophyte or blue-green algae found in significant number was in the January samples taken in the control pond. Chlorophytes and dinoflagellates were predominant in ponds stocked with the white amur.

The control pond 4 had a very low standing crop of sport fish in comparison to the other ponds which were stocked with the white amur (Table 7). Twenty-four *Micropterus* and 105 *Lepomis* were stocked in pond 4; however, 27 months later only 25 *Micropterus* and 142 *Lepomis* were harvested. Survival, growth, and reproduction of sport fish in ponds stocked with the white amur were much more extensive than in the control pond. All white amur were accounted for except for one of the initially stocked fish (Oct. 71) in pond 1. Average growth of the three fish in pond 1 for the 27-month study was 8.8 kg.

## DISCUSSION

The most intensively studied portion of this investigation was the water quality changes resulting from weed control accomplished by the white amur. There has been speculation that white amur stocking would cause turbidity, over nutrification, and massive blooms of undesirable algae. No sig-

Table 7. Standing crop of fish harvested from white amur ponds after termination of study and drainage in January 1974.<sup>a</sup>

Species	Pond Number			
	1	2	3	4
<i>Micropterus</i>				
Number	61	40	98	25
Weight (kg)	13.8	9.8	9.1	2.9
<i>Lepomis</i>				
Number	267	626	1,116	142
Weight (kg)	15.4	41.4	27.5	6.8
<i>Total</i>				
Number	328	666	1,214	167
Weight (kg)	29.2	51.2	36.6	9.7
No. ha <sup>-1</sup>	4,100	8,325	15,175	2,088
Kg ha <sup>-1</sup>	365	690	458	121
<i>Ctenopharyngodon</i>				
Number	7	16	32	—
Weight	42.5	56.8	82.4	—
No. ha <sup>-1</sup>	88	200	400	—
Kg ha <sup>-1</sup>	531	710	1,030	—
Gain kg ha <sup>-1</sup>	451	511	672	—

<sup>a</sup>Final stocking rate (ka ha<sup>-1</sup>) of white amur; pond 1, 80; pond 2, 199; pond 3, 358; pond 4, 0 (control).

nificant nutrient changes occurred in the ponds after the initial stocking; however, satisfactory weed control did not result. After additional white amur were stocked in August 1973, very rapid hydrilla control in ponds 2 and 3 occurred. Total P increased from January 1973 values by a factor of 9 in both ponds after hydrilla control was achieved. Available P in pond 2 doubled and increased from 0.002 to 0.035 ppm P in pond 3. These changes appear dramatic in magnitude, but the values are still low for central Florida waters (17).

Daniel (5) extensively studied the nutrient status of ponds in Wisconsin treated with commonly used aquatic herbicides (Diquat and Endothal) on *Myriophyllum* species. In ponds where weeds were chemically controlled, he found over a 20-fold increase in total P and over a 30-fold increase in available P 8 days after treatment with these contact herbicides. Phosphorous values did not return to anywhere near pretreatment values for a several month period, when plant regrowth began to re-absorb the excess nutrients. In comparison to chemical control, the biological control reported in our study contributed approximately only 1/2 the total phosphorous and 1/3 of the available P to the pond water. Differences in plant biomass and P content of the plant tissue were not nearly sufficient to explain the vast differences between

Daniel's study and our study in P loading of the pond water. Similar P releases from chemically treated aquatic plants were found in pools in Florida (7). Further studies comparing the effects of chemical versus biological weed control in Florida are in progress.

Much of the difference between chemical and biological control in P loading of the pond water can be attributed to the white amur. Hydrosol sediments have a large capacity to absorb excess P from the water (6), but fast, excessive P increases in the water cannot be buffered rapidly enough to maintain the P balance in the system. Daniel and others (8) have noted that rapid increases in P content of water as a result of chemical weed control are due to the rapid, initial breakdown of plant cell walls and subsequent loss of soluble cell constituents. Studies have shown that the white amur uses these cell constituents most readily and utilizes about 50% of them (19). The slow release of nutrients from partially digested plant (fecal) material of the white amur apparently results in less nutrient pollution than the use of chemicals for weed control. As the fecal material sinks to the pond bottom to decompose slowly, the hydrosol apparently is able to maintain a more desirable P budget in the aquatic system. This was reflected in the plankton data in Table 6 where no massive, undesirable algal problems were encountered. The presence of aquatic plants in lakes and ponds also helps maintain a nutrient balance between components of the aquatic system. The selective control of hydrilla in ponds 2 and 3, leaving a 10 to 20% coverage of vallisneria, undoubtedly helped stabilize the ponds' nutrient balance during the rapid control of hydrilla. In pond 1, the pond stocked at the lowest rate of white amur, 30% hydrilla control resulted in increased P and N in the remaining plants in comparison to plants in the control pond. Nutrifcation of the water in pond 1 was relatively unaffected at this level of hydrilla control, and plankton populations were very diverse.

No changes in water turbidity were noted, except in pond 2, where rapid increases in emergent vegetation had to be controlled before termination of the experiments. Attempts to remove white amur by seine and electro-fishing were planned, and *Typha* and *Pontederia* in all ponds were harvested by hand. This activity caused the higher turbidity levels in pond 2 late in the study period.

The standing crop of gamefish remaining in the white amur ponds at the termination of the study was high compared to most Florida lakes. Orange

Lake, one of the best sport fishing lakes in Florida, has between 75 and 150 kg ha<sup>-1</sup> standing crop of game fish (20). Pond culture is expected to have high standing crops of sport fish due to the lack of undesirable and competitive forage and trash fish. The important trend in this study was the increased standing crop of sport fish in ponds stocked with white amur.

The stocking rate of white amur required for hydrilla control in central Florida is near 50 white amur ha<sup>-1</sup> or 150-200 kg ha<sup>-1</sup> if no mechanical or chemical treatments are used to remove the initial standing crop of hydrilla, which is often 25 to 35 mt ha<sup>-1</sup> fresh weight. In pond 1, the initial stocking was at this level, and weed control was being approached before restocking in August 1973. Upon removal of the fish in January 1974, one of the white amur initially stocked was missing (compare Tables 1 and 7), and had this fish been present, the 33% increase in stocking rate (by having 4 white amur in pond 1, rather than 3) would probably have been sufficient to provide satisfactory weed control in pond 1 without restocking. Subsequent studies in Florida have shown that a lower stocking rate of white amur is required when the fish is used in conjunction with chemical control methods.

This study supports what Swingle (16) indicated, that the white amur is capable of controlling our worst waterweeds. When environmental impact and management techniques are thoroughly understood, this fish may well become an important weed control agent and a means of converting waste plant material into a usable fish resource.

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