THE USE OF GRASS CARP FOR BIOCONTROL OF AQUATIC WEEDS AND THEIR IMPLICATION FOR[1] NATURAL RESOURCES AND FISHERIES IN FLORIDA

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ABSTRACT

The results of two studies to evaluate the ecological impact of grass carp (*Ctenopharyngodon idella* Val.) in Florida are discussed. Although one of the studies is still in progress, the other has been completed. After one year's background data had been collected, four ponds ranging from 2.03 to 12.15 ha were stocked with grass carp at a rate of 67 kg/ha and monitored for an additional two years. Changes in fish populations are discussed. Adverse effects were noted in two ponds, but it is concluded that the grass carp was not directly responsible. It is recommended, however, that grass carp not be stocked in ponds with sparse vegetation. One of the ponds with a heavy initial infestation of the plant *Hydrilla verticillata* Royle supported an extremely healthy native fish population at the end of the study in spite of the presence of a huge biomass of grass carp (511 kg/ha).

The study in progress is being conducted on four lakes ranging from 36 to 2,024 ha. In this study, the grass carp has demonstrated the ability to completely control hydrilla with a stocking rate of 49 fish per ha. It is postulated that the effects of the grass carp on water quality are much less than would be expected by other forms of aquatic weed control. In a 2,024 ha reservoir, the grass carp has not controlled Eurasian watermilfoil (*Myriophyllum spicatum*).

INTRODUCTION

Any discussion of grass carp (*Ctenopharyngodon idella* Val.) in Florida should be put into perspective by preceding it with a short discussion of hydrilla (*Hydrilla verticillata* Royle). Florida received the South African aquatic plant through the aquarium industry in about 1960. By 1965 hydrilla was established in approximately 4,049 ha of Florida waters (Figure 1). In 1970 this aquatic macrophyte was reported in about 20,243 ha (Figure 2) and

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[1] Cooperative study by the Department of Natural Resources Bureau of Aquatic Plant Research and Control in Tallahassee, the University of Florida in Fort Lauderdale and Gainesville, the Florida Game and Fresh Water Fish Commission in Tallahassee, and Orange County Pollution Control at Orlando.

in 1976 was found in an estimated 283,401 ha of Florida's 1.01 million ha of fresh water (Figure 3). Approximately 80,972 ha of the infestation was considered dense.

RESULTS AND DISCUSSION

Florida has been researching the grass carp since 1968. One of the earliest and certainly the most controversial, studies was the Four Pond Study. One of the objectives of this research was to determine the impact of the grass carp on native sport fishes. Two of these ponds (Pasco and Suwannee) were designated as fisheries impact ponds and the fish populations were sampled. However, due to shortcomings in experimental design and technique, fisheries impact conclusions are confusing. Based on blocknet data, Pasco Pond experienced a 91% reduction by weight in the largemouth bass population. Suwannee Pond showed a 74% reduction in harvestable size bass. Population structures and indices were altered. An analysis of the data for population structures and dynamics indices yielded a confusing fact. Of 21 parameters comparable by blocknet, nine went in exactly opposite directions. If a cause-and-effect relationship existed between the presence of grass carp and the adverse effects experienced in the fish populations of these ponds, the direction of change should be consistent between ponds. The degree of change would be an individual expression of the particular pond, however, the direction should be consistent.

After reevaluation of the raw data, an alternative explanation to the drastic changes in the fish populations of Suwannee and Pasco Ponds became apparent. In Suwannee Pond, the rotenone was not contained within the blocknet samples and an estimated 272.2 kg of fish were killed outside the net. A sample of approximately one-third of the kill showed 57% by number was largemouth bass. Weight extrapolations showed 68% of the total largemouth bass biomass of the lake were killed in this sampling. Trammel nets were set in Pasco Pond and combined with blocknets removed 46% by weight of all largemouth bass in or above the 25.4 cm class. This represented a 29% removal by weight of the total largemouth bass population. Quarterly rotenone shoreline samples were taken in these two ponds for two years, and semiannual electrofishing was conducted for the same period. It is probable that overzealous sampling was responsible for the adverse effects on the fish populations of these two ponds.

As a systems check, the total fish population at renovation from a third pond (Broward) was analyzed and compared with the final populations of the two fisheries ponds. Baseline data were not available for Broward Pond, but a comparison of the final populations is subjectively useful. Broward Pond has unique value in the fisheries study for three reasons. First, it was the only pond that had a large initial standing crop of submerged macrophytes (predominantly hydrilla) making it the only type of lake that would be intentionally stocked with grass carp for weed control. Secondly, the fish populations of Broward Pond were not subjected to the same intense sampling pressure as were Pasco and Suwannee Ponds. Thirdly, Broward Pond contained a large population of grass carp at the termination of the study.

Broward Pond was heavily infested with weeds, thus offering protection from predators and food for rapid growth of the grass carp. These factors resulted in excellent survival of grass carp. At renovation, 86 grass carp per ha (410 kg/ha) were recovered from an initial stocking of 116 per ha. During the last 10 months of the study, approximately 50 grass carp were removed from this pond for stomach content analysis. If included in the population, these fish would bring the residual grass carp population to approximately 111 individuals (511 kg) per ha. By comparison, 6.9 grass carp/ha (3.03 kg/ha) and 1.7 grass carp/ha (3.6 kg/ha) were removed from Pasco Pond and Suwannee Pond, respectively (Table 1).

The bass population in Broward at renovation consisted of 442 individuals per hectare (111 kg/ha), with evidence of good reproduction and recruitment (Table 2). Admittedly, there was no baseline data, but had we initially sampled this pond as intensively as the other two, perhaps the fish population would not have been so healthy. Broward was a relatively new pond and its fish population was probably in a state of expansion. However, other lakes in Florida, Lake Talquin for example, have bass populations recorded that exceed 112 kg per hectare according to blocknet samples (Ware and Smith 1972).

The panfish population was also excellent in this pond. There were more than 611 harvestable adults per hectare (Table 2). Good reproduction and recruitment were evident in these species. The grass carp has been accused of devastating the shallow water fishes. Total renovation values showed 5819/ha, 8191/ha, and 37,072/ha of shallow water fishes for Pasco, Suwannee and Broward Ponds, respectively (Table 2). The pond with the largest grass carp biomass also had the largest standing crop of shallow water fishes.

Although there are no baseline diversity data for Broward Pond, the fish population appeared to be in good condition at renovation. The pond has a high Shannon-Wiener value (1.93) and a low dominance index (0.372). Pasco Pond showed values of 1.23 and 0.67 for Shannon-Wiener and Simpson indices, respectively, while Suwannee showed 0.81 and 0.78 for these parameters (Table 3). If 7.0 and 1.7 grass carp per hectare were adversely affecting the sport fish populations in Pasco and Suwannee Ponds, respectively, it would seed that Broward Pond with 111 grass carp/ha (511 kg/ha) would not have the good structure, dynamics, and bioindices exhibited by the fish populations of that pond.

The conclusions that can be drawn from this study are clouded by several factors. First, it is apparent that initial sampling in Pasco and Suwannee Ponds did considerable damage to the fish populations prior to grass carp stocking. Secondly, background fisheries data are based solely on blocknet sampling. Although blocknet sampling may have been the best technique for estimating the initial fish population, the wide disparity between final blocknet estimates and the correct assessment of the fish populations obtained by total renovation at study termination, casts serious doubts on the accuracy of the blocknet technique. Finally, the apparent changes in the fish populations of Pasco Pond was adversely affected; the changes in the fish population of Suwannee were mixed; and the final game fish population in Broward Pond was excellent.

An explanation for the differences in the final condition of the fish populations in Broward, Pasco and Suwannee Ponds may be found in the dissimilarities in their initial macrophyte communities. The relatively sparse amount of submerged aquatic vegetation in Suwannee and Pasco Ponds must have played an integral part in their ecosystems as refuge for small fish and substrate for invertebrate fauna. The elimination of this essential amount of vegetation by the grass carp would be expected to be harmful to the fish populations. Broward Pond, however, had an abnormally abundant standing crop of submerged macrophytes before the grass carp were stocked. Even after this vegetation was removed, the robust stand of emergent vegetation remaining must have been sufficient to fill the necessary roles of macrophytes in the ecology of the pond. It is, therefore, not surprising that the native fish populations of Broward Pond were healthy even with an enormous residual population of grass carp.

The grass carp is being studied in Florida for the specific purpose of controlling plants in lakes, like Broward Pond, that have an over-abundant biomass of submerged vegetation. The grass carp does not belong in ponds with normal or sparse macrophyte communities. Fortunately, small grass carp do not appear capable of surviving in such lakes. Although 96% of the grass carp survived in Broward Pond, only 3% survived in Pasco Pond and only 1% in Suwannee Pond (Table 1).

According to research conducted in the Game and Fresh Water Fish Commission, the Department of Natural Resources, and the University of Florida, it appears that the low survival rate of grass carp in Pasco and Suwannee Ponds was due to predation by largemouth bass. The dense vegetation in Broward Pond offered a refuge and food for rapid growth, thus enhancing survival of the grass carp.

Although aquatic macrophytes are a very necessary part of the aquatic ecosystem, excessive vegetation is known to have an adverse effect on sport fish populations. Bennett (1962) reported that a 50 percent cover of Potemogeton caused a 58% reduction in fish yield even though fishing pressure was up 157% for the same period. In his paper, Bennett concluded that vegetation can sometimes be directly responsible for overpopulation and stunting of fish populations. Heman, Campbell and Redmond (1969) and Michaelson (1970) experienced similar results. Buck, Baur and Rose (1975) showed better fish production in pools where vegetation had been reduced by grass carp relative to heavily vegetated control pools and pools where a herbicide had been used to reduce vegetation. Other authors, Thomaston (1962), Pfeiffer (1967), Buck and Thoit (1970), Ebert (1972), Hichman and Congdon (1972), Rasmussen and Michaelson (1972), and Barnett and Schneider (1974) have documented the adverse effects of excess vegetation on fish populations. In a 1966 report available from the Florida Game and Fresh Water Fish Commission, it is recommended that troublesome aquatic weeds such as Elodea spp. be allowed to cover no more than two percent of the water surface. Fishery biologists in the Commission presently believe 60% or more cover of hydrilla in lakes is beneficial to sport fish populations (Forrest Ware, personal communication). Regardless of the proposed usage of a particular water body, you can get too much aquatic vegetation. It appears obvious then that "leave hydrilla alone" is not among our choices.

Traditionally, Florida contends with the aquatic weed problem in three ways: water level fluctuation, mechanical control and chemical treatment. Drawdowns are very effective in weed control and have many beneficial side effects for fish and wildlife. Unfortunately, relatively few water bodies have the proper physical configuration to facilitate dewatering. Cost for mechanical removal ranges from $988 to $3705 per hectare per treatment and in some cases requires two to four treatements per year. With a plant such as hydrilla, that reproduces by fragmentation, mechanical methods can result in a more widespread problem. In Florida cost for chemical control of aquatic plants varies from $247 to $711 per hectare per treatment and again, multiple treatments are sometimes needed for year round control. Side effects of chemical control are often undesirable. The liquid formulation of hydrothol 191, effective on hydrilla at 3 ppm, has been shown to have a 24 hour TLm at 0.2 ppm for bluegill (Blackburne et al. 1971). Recent Dutch studies have shown that Diuron at a concentration of 0.1 ppm resulted in lack of fish ovarian development and heart damage (Hans von Zon, personal communication). Diuron has also been shown to block development of such zooplankters as Daphnia (Kersting 1976). Adverse side effects of herbicides on fish were noted by van Dord et al. (1974). Also with chemical control, 100% of the nutrients available in the plant are returned to the system for further plant growth.

In theory, biological control has many desirable attributes. First, one treatment costing as low as $50/ha can be effective for many years. Second, the large standing crop of plants is removed slowly. Finally, plant nutrients are tied up in the bodies of the control agents. However, the purposeful introduction of any exotic weed control agent, especially in an ecosystem such as Florida's, should be carefully analyzed, and the decisions must be based on facts generated by solid research.

After the Four Pond Study, the Florida Department of Natural Resources (DNR) initiated a cooperative large lake study with the Florida Game and Fresh Water Fish Commission (GFC) and the University of Florida. Of the Eight Lakes Project, the DNR is responsible for research on three lakes (Bell, Clear and Holden) and shares joint responsibility of GFC on Deer Point Lake. On these lakes it is the responsibility of DNR to monitor weed control and water quality. Lake Bell in Pasco County is a 36 ha lake and was stocked with 1,780 grass carp. Clear Lake, also in Pasco County, is a 64 ha lake and received 3,180 grass carp. Lake Holden in Orange County, a 103 ha lake, received 5,080 grass carp. This stocking represents a rate of 49 fish per hectare. The lakes were stocked in October 1974. Deer Point Lake in Bay County is a 2,025 ha open-ended reservoir which was stocked with approximately 100,000 grass carp.

Control was obtained more rapidly and more completely in Lakes Bell, Clear and Holden than had been planned (Figure 4). Lake Holden in particular, received over-control. This is a culturally eutrophic lake with the sediments and water column overloaded with nutrients. Lake Holden receives a calculated 6,186 kg of total nitrogen and 707 kg of total phosphorus annually (Dawkins 1977). The Department of Natural Resources is currently removing grass carp from this system in an effort to reach a balance and allow beneficial vegetation to return to portions of the littoral zone. It has been demonstrated by Sutton et al. (1978) that hydrilla can be removed from a system by grass carp and/or chemicals, and replaced by eel grass.

The last of the grass carp to be stocked in Deer Point Lake were stocked in September of 1977. However, the bulk of the 100,000 fish were stocked in February, 1975. Illinois pondweed (Potamogeton illinoensis), which was present in problematic proportions, is greatly reduced. However, the primary target plant, Eurasian watermilfoil, Myriophyllum spicatum, is still present at pre-grass carp levels (Figure 4). Pondweed is preferred by grass carp over Eurasian watermilfoil, and now that the Illinois pondweed has been controlled, a reduction in milfoil is expected. After the seasonal "die off" this winter, it is expected that the grass carp will control milfoil regrowth, if sufficient numbers of fish remain in the lake.

The main research query of this portion of the Eight Lake Study involves the effects of biological weed control, with grass carp, on water quality. Although significant changes occurred from 1975 to 1976, there appears to be little indication of a cause-and-effect relationship (Tables 4 and 5).

Trends are more noticeable when 1976 and 1977 values are compared. Lakes Bell and Holden show an overall increase in nutrient related parameters, and Lake Clear experienced a decline in the same parameters. Several possible explanations exist for the trends noted in these lakes and are probably due to a combination of several factors. The most feasible of the explanations involves the relative amounts of nutrient run-off received by each lake. As discussed earlier, Lake Holden is a culturally eutrophic lake receiving both domestic and industrial nutrients. Lake Bell is almost completely surrounded by homes and also receives industrial run-off. Clear Lake has very few homes surrounding it and much more marginal vegetation to act as a buffer zone. Therefore, the improvement in water quality in Clear Lake is probably due to the relatively low rate of nutrient input from its watershed coupled with the reduction of nutrient cycling from the bottom mud due to the removal of macrophytes. Another possible explanation lies in the relative depths of these lakes. Lakes Bell and Holden have an average depth of 3.05 and 3.87 m, respectively, with deep (11.58 m) holes biasing the average. Clear Lake has an average depth of 4.5 m and a more uniform bottom morphology. It is possible that the deeper areas of Clear Lake act as a "nutrient sump", thus reducing nutrient availability. It is also possible that the dredge holes in Lakes Bell and Holden serve this same function and without them, parameter values would have been exaggerated. An important point is that with biological control, some of the nutrients are converted to fish flesh whereas all nutrients are returned to the water column or hydrosoil when chemicals are used.

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Table 1. Number and weight of grass carp stocked and recovered from the three study ponds.

Pond	Stocked per ha number/kg	Recovered per ha number/kg	Percent increase (+) or decrease (-) number/kg
Pasco	193/67	6.9/3.0	-97/-96
Suwannee	296/67	1.7/3.6	-99/-95
Broward	116/67	111.2/510.9	-4/+760

Table 2. Composition of principal sportfish species per hectare at study termination.

	Pasco Pond			Suwannee Pond			Broward Pond		
	number	number harvestable	weight (kg)	number	number harvestable	weight (kg)	number	number harvestable	weight (kg)
Largemouth bass *Micropterus salmoides*	70.2	16.1	8.7	828.4	33.4	27.7	433.1	181.3	110.9
Pan fish *Lepomis macrochirus* *L. microlophus* *L. gulosus* *Pomixis nigromaculatus*	7131.9	226.8	37.3	13099.7	589.0	57.1	7249.0	1346.6	178.6
Brown bullhead *Ictalurus nebulosus*	99.6	49.4	18.0	239.1	227.7	55.8	393.7	101.3	13.3
Total	7269.0	292.3	64.0	14167.2	820.1	140.6	8085.8	1629.2	302.8
Shallow water species	5819.3			8190.5			37072.2		
Grass carp *Ctenopharyngodon idella*	6.9		3.0	1.7		3.6	111.2		510.9

Table 3. Shannon-Wiener index of diversity and Simpson's index of dominance for Pasco, Suwannee and Broward Ponds at the time of study termination.

	Pasco	Suwannee	Broward
Shannon-Wiener	1.23	0.81	1.93
Simpson	0.67	0.78	0.37

Table 4. Values for Student's t statistic (P) for paired data from Lakes Bell, Clear, Holden and Deer Point Reservoir (March 1975 - December 1975 X March 1976 - December 1976).

Parameters	Lakes			
	Bell	Clear	Holden	Deer Point
Dissolved Oxygen	+0.164	+0.304	+0.075	+0.075[1]
Temperature	-0.089	-0.007*	-0.019*	-0.158
Conductivity	+0.007*	-0.950	-0.144	-0.942
Turbidity	+0.001*	+0.011*	+0.717	+0.722
Extinction Coefficient	-0.064	+0.833	-0.876	+0.824
pH	-0.325	+0.846	+0.039*	-0.051
Alkalinity	+0.018*	+0.904	+0.847	+0.724
Chlorophyll	-0.126	+0.895	-0.266	-0.035*[2]
Ortho Phosphate	-0.066	-0.088	-0.068	-0.514
Total Phosphorus	+0.085	+0.160	+0.257	-0.251
Kjeldahl Nitrogen	+0.252	+0.146	-0.302	-0.760
Nitrate	+0.955	+0.320	-0.178	-0.041*
Total Zooplankton	+0.038*	+0.048*	-0.188	+0.385

[1] Sign (+ or -) indicates direction of change.
[2] * indicates significance at $P = 0.05$.

Table 5. Values for Student's t statistic (P) for Paired data from Lakes Bell, Clear and Holden and Deer Point Reservoir (March 1976 - December 1976 X March 1977 - December 1977).

Parameter	Lakes			
	Bell	Clear	Holden	Deer Point
Dissolved Oxygen	+0.038*	-0.602	-0.220	-0.197[1]
Temperature	-0.671	+0.625	+0.316	+0.010*[2]
Conductivity	+0.001*	_0.103	+0.114	+0.040*
Turbidity	+0.001*	-0.980	+0.015*	+0.388
Extinction Coefficient	+0.897	-0.088	+0.340	-0.085
pH	+0.002*	-0.343	+0.575	+0.014*
Alkalinity	+0.001*	-0.193	+0.343	+0.189
Chlorophyll	+0.283	-0.049*	+0.136	-0.417
Ortho Phosphate	+0.272	-0.399	+0.258	-0.290
Total Phosphorus	+0.039*	-0.049*	-0.180	+0.382
Kjeldahl Nitrogen	+0.577	-0.266	+0.023*	+0.001*
Nitrate	+0.811	-0.422	+0.840	-0.779
Total Zooplankton	-0.167	_0.381	+0.460	-0.354

[1] Sign (+ or -) indicates direction of change.
[2] * indicates significance at P = 0.05.

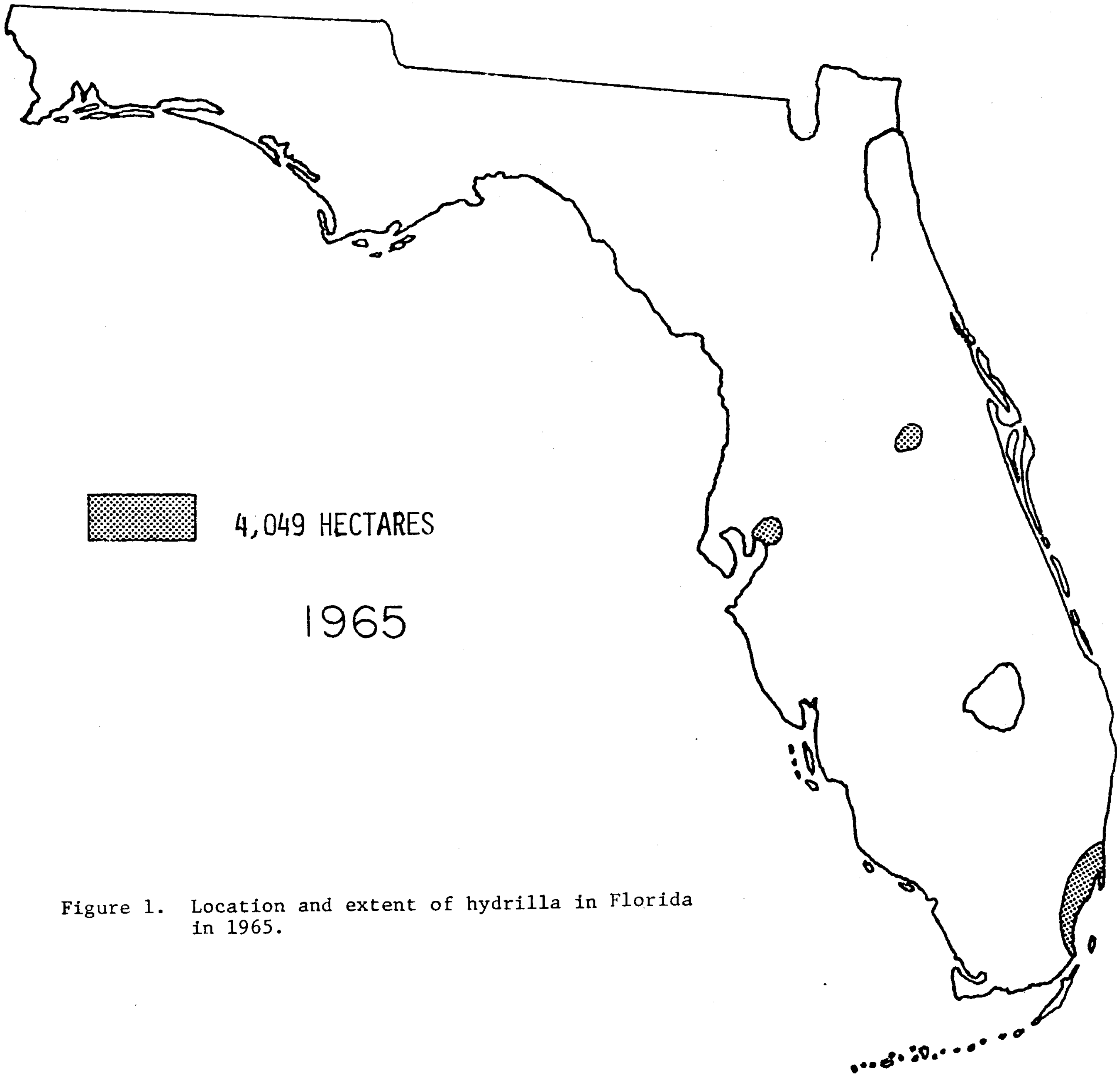

Figure 1. Location and extent of hydrilla in Florida in 1965.

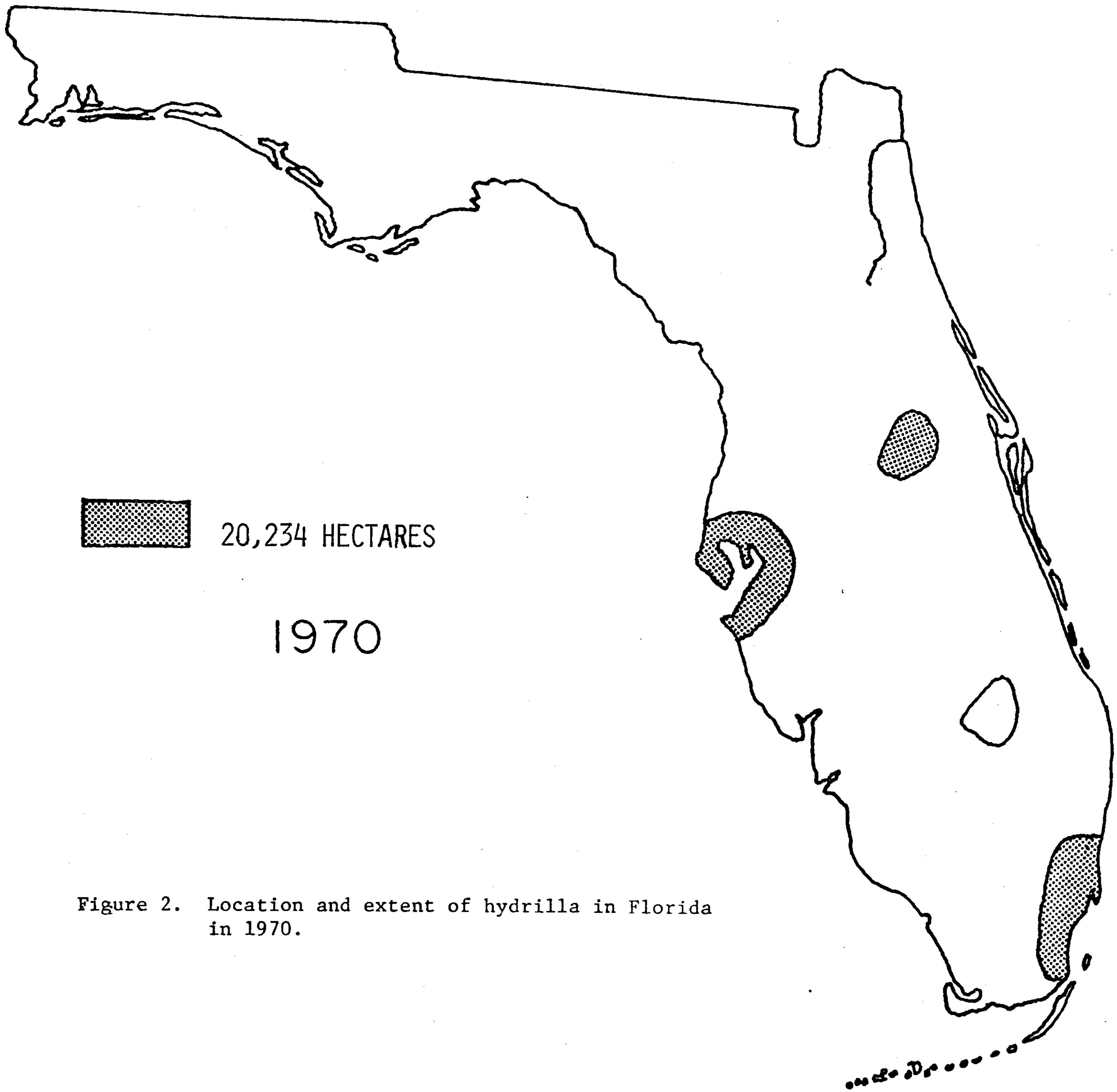

Figure 2. Location and extent of hydrilla in Florida in 1970.

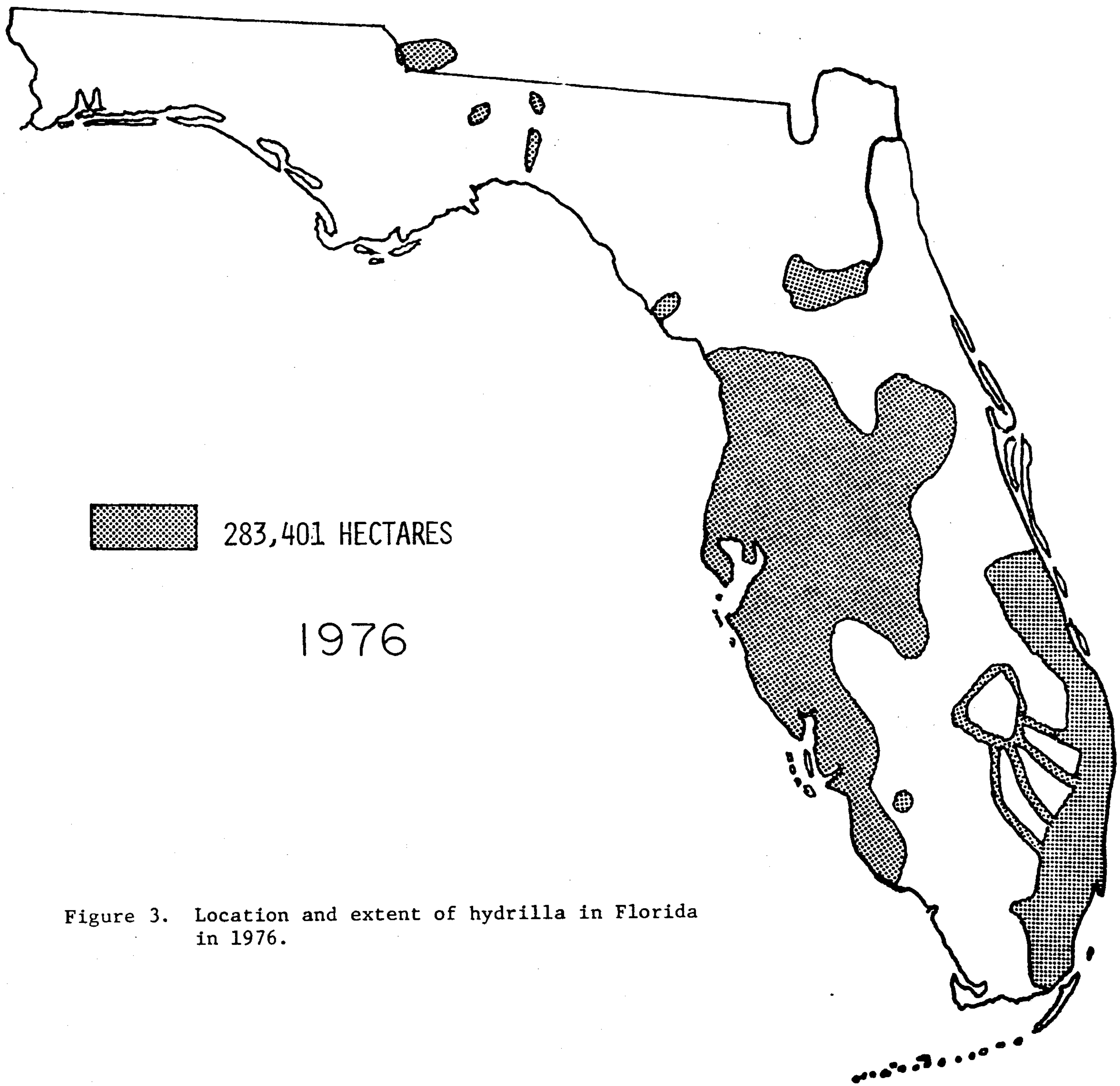

Figure 3. Location and extent of hydrilla in Florida in 1976.

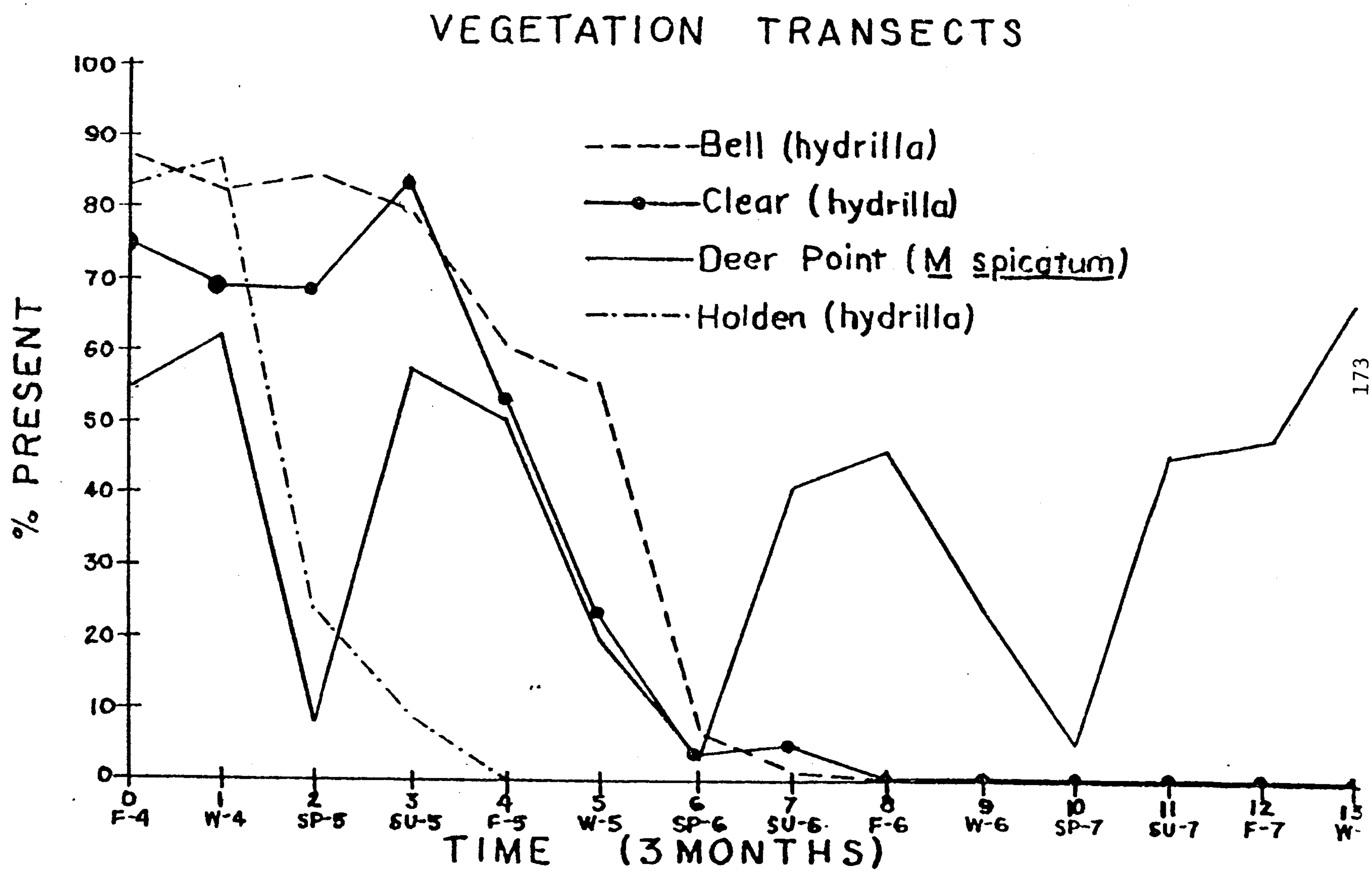

Figure 4. Changes in target macrophyte species.

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