J. Aquat. Plant Manage. 29: 24-28

Enhanced Biological Control of Waterhyacinth Following Limited Herbicide Application

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ABSTRACT

Eighty percent of a 6 ha lake in northcentral Florida was sprayed incrementally beginning in August 1985 with the herbicide 2,4-d to gradually reduce the surface coverage of waterhyacinth. Herbicide treatments occurred at 3 to 4 week intervals, and approximately 15% of the lake was treated on each date. The remaining untreated plants were surrounded by a floating barrier along one shore and left in the lake to serve as a reservoir for waterhyacinth weevils, which were present at an initial mean density of 3.2 adult weevils/m^2. Weevil production in October 1986 raised the weevil density to 3 times that observed in October 1985 and the number of feeding scars was twice that observed in December 1985. The resultant heavy feeding damage reduced plant density and biomass severely and by April 1987, no live waterhyacinth plants remained in the lake. Calf Pond was subsequently invaded by waterlettuce and as of November 1990 was extensively colonized by this aquatic weed.

Key words: *Eichhornia crassipes*, biocontrol, *Neochetina* spp.

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INTRODUCTION

Waterhyacinth (*Eichhornia crassipes* Mart. Solms), quickly dispersed across the southeastern United States following its first introduction to the region in the 1880's, and has caused significant water management problems in the state of Florida for at least 90 years (Schardt 1987). By the early 1970's, the infestation of waterhyacinth in Florida was estimated to be in the tens of thousands of hectares and biological control efforts were initiated to augment mechanical and chemical control methods. Two host-specific phytophagous weevils, *Neochetina eichhorniae* Warner and *N. bruchi* Hustache (Coleoptera: Curculionidae) were imported from Argentina and released in Florida in 1972 and 1974, respectively. These insects readily established and are now found virtually everywhere that waterhyacinth occurs in the state. The effects of feeding damage on the plant by weevil adults and larvae have been well documented (Cofrancesco 1984, DeLoach and Cordo 1983, Goyer and Stark 1984, Irving and Beshir 1984, Wright 1984) and clearly these insects can reduce the size and extent of waterhyacinth infestations. Since 1985, fewer than 3300 hectares (8000 acres) of waterhyacinth have been reported annually in Florida (Schardt 1987). This has occurred over a period of time in which the number of hectares chemically controlled has been declining (Schardt 1986). It is felt that the decline is due in part to a more systematic and coordinated "maintanence management" approach to herbicide control (Langeland 1987), as well as cumulative stress from feeding damage by these insects. A third insect, *Sameodes albiguttalis* (Warren) (Lepidoptera: Pyralidae), was also released in Florida in 1977, and presumably feeding damage by these larvae has imposed further stress on the waterhyacinth population (Center 1981,1984, Center and Durden 1981).

Although there has been a decline in the total acreage of waterhyacinth in Florida and other states in the southeastern United States, at some intensively used sites such as flood-control canals and recreational lakes plant biomass is still excessive and herbicides continue to be used to manage the weed. More than 10,900 ha (27,000 acres) of waterhyacinth were treated in Florida in 1987, at an approximate cost of $2 million (Schardt 1987), indicating the scope of the problem. In these situations, frequent use of an herbicide causes a rapid and extensive loss of habitat for the waterhyacinth weevils. Adult insects are mobile, but eggs, larvae, and pupae are not and these life history stages are reduced drastically as a secondary effect of herbicide application programs. Weevil populations have a much slower rate of increase than waterhyacinth populations and as a result, regrowth of a weed mat after spraying will be favored until the insect population can once again reach effective levels. A cycle of repetitive herbicide application at selected sites may thus preclude effective biological control by the weevils (Center and Durden 1986).

An examination of case histories of biological weed control invariably shows the need for some level of use of alternate control methods to acheive satisfactory reduction of the pest in all circumstances (Haseler 1981). Perkins (1977) did preliminary work on integrating chemical and biological control to combat waterhyacinth. An ecosystem modeling study by Vega (1978) on the effects of different control practices on waterhyacinth regrowth showed that a combination of biological control and herbicide application was the only simulated control practice examined that reduced weed growth for a sustained period. Center et al. (1982) demonstrated that control of waterhyacinth could be obtained using a combination of plant growth retardant and *N. eichhorniae* under conditions in which use of the weevils alone did not result in adequate control. Field research in a 0.4 ha pond by Haag (1986a,b) showed that weevil densities enhanced by herbicide application could cause sufficient stress to eliminate a waterhyacinth infestation in one growing season.

These findings indicate that chemical and biological control of waterhyacinth need not be mutually antagonistic, but instead can be effectively integrated to provide the desired level of pest supression. The goal of the present study was to use limited chemical control to enhance the ambient level of waterhyacinth weevil population density at a field site and to monitor the effects of increased insect feeding damage on waterhyacinth plants to substantiate the biocontrol potential of these insects.

METHODS AND MATERIALS

Calf Pond is a shallow 6 ha (15 acre) lake in northcentral Florida which was partially (80%) covered with waterhyacinth at the outset of the study in 1985. While it is not known how long *Neochetina* weevils have been in this lake, qualitative plant samples collected by G. Buckingham and C. Bennett (unpublished data) in October 1983 yielded a mean density of 0.4 weevils per plant.

In August 1985, a floating PVC barrier was placed across the west side of the lake, enclosing approximately 1 ha of waterhyacinth plants (Figure 1). The boom was adjusted during the study as the water level in the pond rose or fell, so that unsprayed plants were neither stranded by low water nor allowed to overflow the barrier during high water. Beginning on 6 August, and continuing at 3 to 4 week intervals through 25 November, the remaining plants in the lake were sprayed with: 2,4-D (amine salt of 2,4 - dichlorophenoxyacetic acid) at a rate of 2.2 kg/ha; a surfactant (0.25% v/v); and a polymeric drift control agent (.012% v/v). Approximately 15% of the plants in the lake outside the barrier were sprayed with this formulation on each date and a total of 2.8 ha of waterhyacinth plants were treated in 1985. There was some regrowth of waterhyacinth plants in the treated area of the lake in early

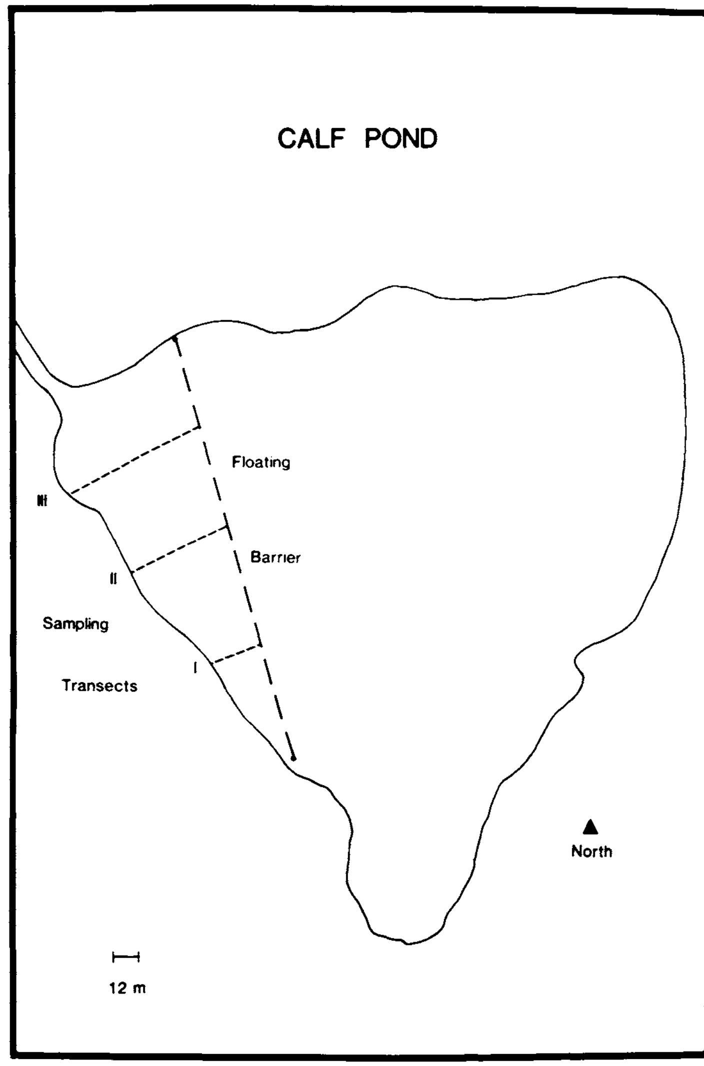

Figure 1. Diagram of Calf Pond showing location of sampling transects across the untreated area.

1986 and these plants were resprayed with the same herbicide formulation on 1 April 1986 and finally on 30 May 1986. Thus the total area of waterhyacinth plants treated during the study was approximately 3.5 ha.

Plant and insect populations were sampled monthly from August 1985 to March 1987 at 20 m intervals along 3 widely-separated transect lines in the untreated area. Beginning at the shore, at each sampling interval, a 0.25 m² frame was thrown without apparent bias into the weed mat. The total number of plants within the frame was counted. Five plants were then removed at random and each was placed in a separate bag. The adult weevils on each of these plants were immediately counted and placed into separate plastic vials. Three replicates of each 5-plant sample were collected at each 20m interval, and all plant and insect specimens were brought back to the laboratory. If local conditions such as low rainfall left a sampling interval near shore dry and without plants, no data were collected and these were considered missing values, not zeros. Similarly, as plants died in the sampling area and created open water zones, if a sampling interval fell into one of these zones it was treated as a series of missing values and no zeros were used to calculate means.

Plants were measured to determine the height of the tallest leaf, and the number of live and dead leaves. The number of adult feeding scars on each of the first three leaves (position 1, 2, and 3) (Center 1981) were also counted. Roots were removed from the remainder of the plant, and a dry weight determination was made by drying all live and dead plant material in a 75 C oven for 24 to 48 hours. The method of calculation of monthly dry plant biomass per m² used monthly averages for plant density and plant weight, hence no standard errors are available for this parameter. Weevil adults were preserved in 70% isopropyl alcohol and later identified to species and sex.

RESULTS AND DISCUSSION

Weevil density on untreated plants increased from 3.2 to 31.0/m² from August to September 1985 (Figure 2). This increase is most likely due to both the production of a fall generation of weevils (typically occurring at this time in northern Florida) and to net movement into the untreated area by existing weevils. Previous small-scale studies using limited herbicide application to allow waterhyacinth weevils to move from sprayed to unsprayed plants showed that the adults moved from adjoining areas of declining plant quality to healthy plants, at least over short distances (Haag 1986 a,b). At Calf Pond, the plants to be treated in the open area of the lake floated randomly in response to local wind conditions, and they were not always in direct contact with the confined plants in the reservoir area. Often there was a space of open water at least 100m wide between the two areas. Therefore insect adults had intermittent opportunities to move by crawling from treated plants onto reservoir plants during this study. Adult weevils are strong fliers (Buckingham and Passoa 1986) and would be able to fly easily across this relatively short distance; however, we did not find any adults with wing muscles in our September and October samples. Adult

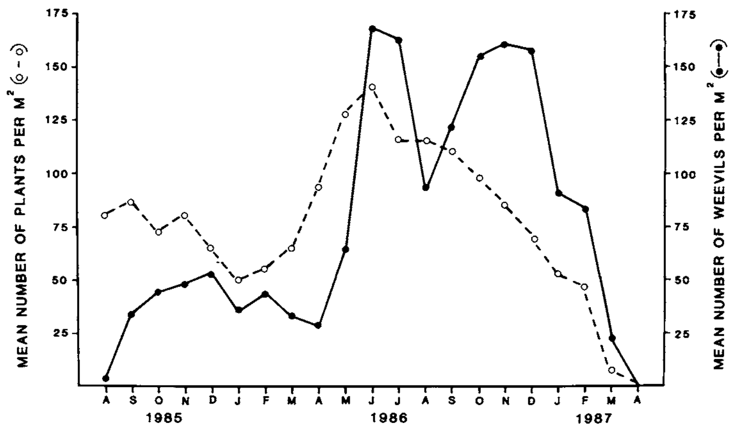

Figure 2. Changes in the density of *Neochetina eichhorniae* weevils and waterhyacinth plants in the untreated area in Calf Pond from August 1985 to April 1987.

weevil densities increased slightly through the fall and winter, then declined to a low of 27.6/m² in April 1986.

There was little change in the plant population attributable to weevil feeding through fall and winter of 1985 (Table 1). Leaf height peaked in September at 44.5 cm, then declined as frost damage killed the longer leaves. Winter freezes typically cause loss of most plant material above the crown in northern Florida and the canopy does not reach its full height again until midsummer (Center and Spencer 1981). At Calf Pond height of the tallest leaf again reached a maximum in September (51.8 cm) and

TABLE 1. CHANGES IN THE WATERHYACINTH POPULATION AT CALF POND FROM AUGUST 1985 TO APRIL 1987.

	No. of Plants[a]	Ht. tallest leaf (cm)	No. Live leaves	No. dead leaves	Dry Wt.(g) Per Plant
1985					
Aug	240	42.8 ± 0.5[b]	7.9 ± 0.1	4.5 ± 0.1	10.2 ± 0.2
Sep	120	45.5 ± 0.6	7.2 ± 0.1	3.4 ± 0.2	12.2 ± 0.2
Oct	135	44.5 ± 0.5	7.0 ± 0.1	2.7 ± 0.1	9.7 ± 0.3
Nov	135	43.0 ± 0.6	7.1 ± 0.1	3.7 ± 0.2	10.6 ± 0.4
Dec	135	39.4 ± 0.4	6.6 ± 0.1	3.5 ±0.1	8..8 ± 0.3
1986					
Jan	135	–[c]	–[c]	–[c]	8.5 ±0.3
Feb	104	13.5 ± 0.4	1.1 ± 0.2	10.8 ± 0.2	7.8 ± 0.3
Mar	120	14.8 ± 0.3	3.0 ± 0.1	10.9 ± 0.2	6.5 ± 0.2
Apr	135	12.8 ± 0.2	6.6 ± 0.1	7.8 ± 0.3	4.3 ± 0.3
May	135	18.0 ± 0.3	6.9 ± 0.1	4.4 ± 0.3	3.3 ± 0.1
Jun	135	27.6 ± 0.5	7.7 ± 0.1	2.1 ± 0.2	4.2 ± 0.1
Jul	135	40.2 ± 1.0	8.1 ± 0.1	2.9 ± 0.1	6.8 ± 0.2
Aug	135	43.8 ± 1.0	8.3 ± 0.1	2.9 ± 0.1	9.0 ± 0.3
Sep	135	51.8 ± 1.0	7.2 ± 0.1	5.0 ± 0.2	10.5 ± 0.4
Oct	135	52.5 ± 0.7	7.7 ± 0.1	4.9 ± 0.2	12.2 ± 0.4
Nov	135	45.0 ± 0.9	7.0 ± 0.1	5.0 ± 0.2	14.0 ± 0.5
Dec	135	41.6 ± 0.9	6.6 ± 0.1	4.5 ± 0.2	12.4 ± 0.6
1987					
Jan	135	43.4 ± 1.0	4.0 ± 0.3	7.3 ± 0.	10.4 ± 0.4
Feb	120	17.0 ± 0.7	1.5 ± 0.2	8.1 ± 0.2	8.1 ± 0.4
Mar	26	28.8 ± 1.6	9.2 ± 0.5	5.1 ± 0.4	8.9 ± 0.8
Apr	0	–[a]	–[a]	–[a]	–[a]

[a]Total number of plants examined.
[b]Values are means ± standard error.
[c]Winter frost damage prevented observation.
[d]No waterhyacinth plants present in the lake.

October (52.5) 1986, similar to the pattern seen in 1985. Production of six to eight live leaves during the growing season is typical for most waterhyacinth plants (Center and Spencer 1981) and plants at Calf Pond conformed to this range (6.6 - 8.3).

The large increase in adult weevil density seen in June 1986 (167.9/m²) is attributed to the successful overwintering of pupae from eggs laid by the fall generation of adults. The weed mat in the reservoir area was stable and undisturbed by wind action and the confined nature of the mat may have kept temperatures in the mat slightly warmer than usual, leaving more viable plant material for larval feeding and pupal survival.

The increase in adult weevil density is reflected by an increase in feeding scars per leaf from May to July (Table 2). This occurred when plant growth rate is typically high, however, and there was no apparent effect on the number of live and dead leaves or on dry weight per plant. Of interest is the relatively slow increase in dry plant biomass per unit area (425 to 584 g/m²) in Calf Pond, when a more dramatic increase would be expected at this time. Center and Spencer (1981) reported a May through June increase in dry plant biomass of 1400 to 2500 g/m²in the absence of weevils in a northcentral Florida lake. Although periodic measurements of water quality in Calf Pond were not made, the continuing presence of alligatorweed in the lake and the subsequent invasion and colonization of the lake by waterlettuce provide anecdotal evidence against attributing changes in waterhyacinth growth pattern to a decline in water quality over the course of the study.

TABLE 2. EFFECTS OF WATERHYACINTH WEEVIL FEEDING ON PLANTS AT CALF POND FROM AUGUST 1985 TO APRIL 1987.

	No. of Plants[a]	*Feeding Scars Per Leaf Position* 1st	2nd	3rd	Dry Plant Biomass g/m²
1985					
Aug	240	69.0 ± 3.5	84.1 ± 3.1	98.8 ± 3.3	815.8
Sep	120	75.0 ± 5.4	95.0 ± 5.7	101.3 ± 5.2	1049.3
Oct	135	64.0 ± 4.0	78.1 ± 4.5	77.5 ± 4.4	703.1
Nov	135	46.0 ± 4.5	69.2 ± 5.2	77.6 ± 5.1	842.1
Dec	135	41.1 ± 3.9	67.0 ± 4.1	69.5 ± 4.8	573.8
1986					
Jan	135	–[c]	–[c]	–[c]	421.2
Feb	105	43.0 ± 4.0	–[c]	–[c]	427.7
Mar	120	12.6 ± 1.3	25.5 ± 2.9	30.3 ± 2.3	422.5
Apr	135	9.6 ± 0.9	10.3 ± 0.7	11.4 ± 0.7	398.0
May	135	23.6 ± 2.0	22.7 ± 1.5	19.7 ± 1.5	425.0
Jun	135	55.8 ± 3.5	71.4 ± 2.6	61.3 ± 2.6	584.1
Jul	135	79.1 ± 4.7	106.5 ± 4.4	106.6 ± 2.6	789.5
Aug	135	38.1 ± 2.4	49.5 ± 2.6	59.2 ± 3.5	1034.2
Sep	135	47.7 ± 3.3	61.1 ± 3.0	60.3 ± 2.7	1157.9
Oct	135	80.3 ± 5.9	106.6 ± 5.3	95.9 ± 5.5	1180.1
Nov	135	108.7 ± 8.1	156.7 ± 8.3	111.3 ± 7.4	1183.3
Dec	135	101.3 ± 8.4	124.2 ± 7.4	102.1 ± 6.2	862.9
1987					
Jan	135	86.7 ± 11.0	110.6 ± 8.7	107.2 ± 7.4	550.5
Feb	120	87.0 ± 12.6	101.0 ± 15.1	113.4 ± 19.4	382.3
Mar	26	86.2 ± 11.1	106.8 ± 11.5	110.6 ± 10.8	72.6
Apr	0	–[a]	–[a]	–[a]	0

[a]Total number of plants examined.
[b]Values are means ± standard error.
[c]Winter frost damage prevented observation.
[d]No waterhyacinth plants present in the lake.

The number of adult weevils decreased to 88.8/m² in August 1986, in part as a result of natural mortality. In addition, we found numerous weevil adults with wing muscles in August and September, indicating that insects had the ability to disperse to other waterhyacinth infestations at this time. Another generation of weevils was produced in October 1986 and weevil density increased to 153.4/m². This is more than 3 times the weevil density in October 1985 and corresponds to a marked increase in feeding activity and mean number of feeding scars per leaf (101 to 156 in November 1986). The number of feeding scars per leaf was more than twice as high in November and December of 1986 than in 1985. The intensity of larval feeding was not measured in our study but based on other reports (Center 1987) we assumed that larval feeding damage was significant. Plant density in December 1986 (68 plants/m²) was comparable to mean densities in December 1985 (65 plants/m²), and dry plant biomass was actually higher in 1986 (862 g/m² vs 573 g/m²). However, the higher weevil densities and resultant feeding damage by larvae and adults through January and February severely impinged upon the overwintering ability of this waterhyacinth population. Plant density continued to fall and by March 1987 plant density was less than 9 plants/m², and dry plant biomass averaged only 72 g/m². Large expanses of open water were apparent and in April 1987 no viable waterhyacinth plants remained in the reservoir area. The lake was subsequently invaded by waterlettuce (*Pistia stratiotes* L.) and as of November 1990 was extensively colonized by this species.

We believe that to achieve successful biocontrol of waterhyacinth it is important to have high levels of adult and larval feeding damage in the fall, when the plant growth rate has slowed down. One way to accomplish this is to apply herbicides after fall emergence of adults, so that the insects are concentrated on a reservoir population of plants which is allowed to overwinter. The increased feeding stress by adults as well as newly hatched larvae reduces the ability of the plant to overwinter by lowering stored energy reserves and making the plant more susceptible to frost damage. This scenario is supported by the findings of Luu and Pesacreta (1988) who determined that one of the weak points in the life cycle of waterhyacinth is in October in the southern United States, when plants are actively translocating carbohydrates to the stembase. Any interruption of this process would be more detrimental than similar damage at other times in the plant life cycle. Spring regrowth is reduced and if in addition a large spring generation of weevils is present to attack the plants, a weed mat can be eliminated.

Conclusions concerning changes in number of live and dead leaves and dry plant weight as a result of weevil feeding at this site cannot be made, since baseline data on plant growth form were not collected prior to beginning the experiment. A severe frost in January 1986 damaged many plants in the lake, resulting in a ratio of live to dead leaves of 3.0/10.9. There was no comparable frost in 1987, and the ratio of live to dead leaves was 9.2/5.1. These ratios are probably not directly related to effects of phytophagous insect feeding damage. The greater average height of the tallest shoots in March 1987 (28.8 cm) compared to March

1986 (14.8 cm) suggests that daughter ramets were not being produced in 1987 by the stressed plant population. When confined, the growth form of waterhyacinth becomes vertical as shoots compete for light (Penfound and Earle 1948). Plants held behind the floating barrier in Calf Pond would have been space-limited and shoots would therefore have attained a greater mean height. One confounding factor is the tendency of waterhyacinth to produce new daughter plants to fill open water, which eventually occurred at Calf Pond as entire heavily damaged plants decayed in March 1987. In our study we did not specifically note the occurrence of daughter plants. Center and Durden (1986) reported that in plant stands which had endured continuous high levels of feeding damage, plant stature, leaf size, and leaf shape became more uniform with time. They suggested that such characteristics could be used to assess waterhyacinth infestations regarding degree and longevity of weevil infestation in order to predict a decline.

Effective control of waterhyacinth at this site was obtained within 2 years, employing the combined stresses of insect feeding damage and space limitation. Other authors have reported control or elimination of waterhyacinth within 9 months to 6 years. This time frame is heavily dependent on both the nutritional quality of the waterhyacinth plants and their past history with respect to initial weevil colonization and subsequent use of herbicides. Studies are currently underway to address the former issue, and more work is needed to answer the latter question as well.

ACKNOWLEDGEMENTS

We sincerely thank Gary R. Buckingham, who suggested this field site to us, provided many valuable suggestions during the conduct of the study, and critically reviewed the manuscript. We would also like to thank Judy Gillmore, Margaret Glenn, Jackie Jordon, Blair Sigfried and Dan Thayer for their assistance in the field and lab. Joe Joyce and Bill Haller generously provided field support, equipment and supplies. Access to the field site was kindly provided by both Mr. Dave Maehr and Mrs. G. B. Rape, and the other homeowners at Calf Pond. This work was supported in part by funding from the U. S. Department of Agriculture, ARS Cooperative Agreement No. 58-7B30-3-570 and the Center for Aquatic Plants, Institute of Food and Agricultural Sciences. Additional funds were provided by a generous grant from the Florida Chapter of the Sierra Club. Published as Journal Series No. R-01239 of the Florida Agricultural Experiment Station.

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