UNC-WRRI-86-225

MANAGEMENT PROGRAM

FOR

HYDRILLA (A MONOECIOUS STRAIN) IN NORTH CAROLINA

by

K. A. Langeland
Assistant Professor
Department of Crop Science

and

G. J. Pesacreta
Graduate Research Assistant
Department of Zoology

School of Agriculture and Life Sciences
Agricultural Research Service
North Carolina State University
Raleigh, North Carolina 27695

"The research on which the report is based was financed in part by the United States Department of the Interior, Geological Survey, through the North Carolina Water Resources Research Institute."

Agreement No. 14-08-0001-G924
WRRI Project No. 70039
USGS Project No. 04

Two hundred and fifty copies of this publication were printed at a cost of $325.10 or $1.30 per copy.

ABSTRACT

Diquat, endothall, fluridone, fenac, and dichlobenil were evaluated to determine their effectiveness for controlling a monoecious strain of hydrilla (*Hydrilla verticillata*) in North Carolina lakes. Diquat and endothall were effective for controlling hydrilla when sufficiently large areas were treated, but more than one annual application may be necessary to maintain control. Granular endothall gave effective control of hydrilla in an impoundment with a high rate of water exchange. Application of fluridone resulted in year-long hydrilla control but control did not persist into the following growing season. Fenac was difficult to apply and resulted in only marginally effective control. Hydrilla was not controlled by dichlobenil. A management plan is presented that incorporates the use of diquat, endothall, fluridone, and sterile grass carp for biological control.

ACKNOWLEDGMENTS

Appreciation is expressed to the following individuals whose help was essential for completion of the project. Fred Tarver assisted with data collection and herbicide application in 1984. Bo Burns monitored effectiveness of 1985 herbicide applications in the Umstead Park Lakes while on internship from Duke University to the North Carolina Division of Water Resources. John Warner assisted with herbicide applications and monitored effectiveness in Woodlake and Dunaway's Pond. Maria Pallotta typed and patiently corrected the manuscript.

Financial support for this project was provided in part by the North Carolina Agricultural Research Service, North Carolina Division of Water Resources, United States Army Corps of Engineers (Wilmington District), and by a grant from the United States Department of the Interior, Washington, D.C., through The University of North Carolina Water Resources Research Institute.

DISCLAIMER STATEMENT

TABLE OF CONTENTS

Abstract ii

Acknowledgments. iii

List of Tables v

Summary and Recommendations. vi

Introduction 1

Materials and Methods 7

Results and Discussion 7

Literature Cited 18

Appendix 1 22

Appendix 2 26

LIST OF TABLES

Page

Table 1. Herbicides evaluated for controlling a monoecious strain of hydrilla in North Carolina lakes. 8

Table 2. Reduction of hydrilla (*Hydrilla verticillata*) density (cross sectional area of recording fathometer tracing occupied by hydrilla images)in Sycamore Lake (North Carolina) in 1984 and 1985, as compared to 1983, after applications of fenac. . . 10

Table 3. Reduction of hydrilla (*Hydrilla verticillata*) density (cross sectional area of recording fathometer tracing occupied by hydrilla images) in Reedy Creek Lake (North Carolina) after application of endothall. 13

Table 4. Hydrilla density (percent cross sectional area of recording fathometer tracings occupied by hydrilla images) in Big Lake (North Carolina) before (8/83) and after application of fluridone. 14

Table 5. Frequency of occurrence (sample size = 16) of several submersed aquatic macrophytes in Woodlake (North Carolina) after application of fluridone (4AS) on May 30, 1984. 15

SUMMARY AND RECOMMENDATIONS

Grass carp were evaluated for hydrilla management in small ponds in North Carolina in a previous study (Hodson et al. 1984). Based on these results, we recommend use of this biological control practice in small ponds that qualify for permitting by the North Carolina Wildlife Resources Commission. Data are insufficient on which to base recommendations for stocking grass carp in large, multiple-use reservoirs where the fish population cannot be totally manipulated. Sterile grass carp were stocked in Lake Wheeler in October 1985 to evaluate their effectiveness for controlling hydrilla and to monitor effects on sportfish populations.

Diquat, endothall, and fluridone (pending EPA registration) should be incorporated into a management program for hydrilla in North Carolina reservoirs. These herbicides can all be effective for managing monoecious hydrilla but will have somewhat different use patterns. Fluridone will give season-long control where relatively large area applications can be made and where water exchange is not excessive. Diquat or endothall should be applied in early to mid-June, before hydrilla reaches problem levels. This spring application may result in season-long control, but a second application should be made in mid-August if regrowth is apparent. Granular endothall should be used in lakes such as Reedy Creek that have relatively high flushing rates.

Human health safety for using these herbicides in North Carolina waters was evaluated in an earlier report (Langeland and DeMont 1984, manuscript in review), and it was concluded that a large margin of safety exists when use is according to EPA label instructions. However, these compounds can be hazardous in concentrated form and all precautions, such as wearing safety clothing, must be followed to protect the applicator's safety.

Environmental safety of using these herbicides has previously been reviewed (Shireman and Haller 1979). Indirect impacts to the immediate treatment area may occur as a result of temporarily removing the macrophyte community, but direct effects to non-target organisms are temporary or negligible. The applicator must, however, be cognizant of potential impacts on the environment. For example: caution should be exercised when applying diquat to enclosed areas because a fish kill may occur due to oxygen depletion when the macrophyte and phytoplankton communities are both temporarily removed.

Continued research should be conducted to determine the effects of repeat herbicide applications on hydrilla populations in following years. The use of slow-release formulations of herbicides should be evaluated further for hydrilla control in impoundments with high flushing rates and for small area and fringe applications. Dichlobenil should also be evaluated further for these purposes.

INTRODUCTION

Surface waters are managed for several different intended uses, including recreation, navigation, irrigation, flood prevention, and potable water. All of these water uses can be severely impacted by the prolific growth of aquatic plants. Introduction of exotic plant species which have aggressive growth habits, nutrient enrichment of surface waters, and increasing water use demands have resulted in extensive aquatic weed management programs throughout the world.

North Carolina's thousands of acres of reservoirs which provide recreation, water supply, flood protection, and hydropower; natural rivers which serve for recreation and commercial navigation; coastal drainage canals that provide drainage and protect agricultural and residential areas from flooding; and an excess of 63,000 small impoundments that are vital for irrigation of agricultural land are threatened by a host of aquatic weeds. Hydrilla [Hydrilla verticillata, (L.f.) Royle], an exotic aquatic plant that was recently introduced into North Carolina, is causing severe problems in lakes and ponds and represents an even greater threat for the future.

Hydrilla is a submersed aquatic plant that probably originated in Asia (Cook and Luond, 1982). Unique and highly specialized physiological and biological adaptations allow hydrilla to invade a wide variety of aquatic habitats and competitively exclude native and more beneficial aquatic plants (Haller and Sutton 1975; Van et al. 1978). Because of the growth habit and prolific reproductive capabilities of hydrilla, it causes detrimental impacts on sport fish populations (Colle and Shireman 1980) and severely limits recreational, domestic, industrial, and agricultural water use (Shireman and Haller 1982). Expensive measures to manage the plant are therefore necessary. For example, $12 million to $20 million is spent annually in the state of Florida on aquatic weed control; and the majority of this expenditure is for hydrilla control (Riley, Florida DNR, personal communication).

The first discovery of hydrilla in the United States was two small infestations at separate locations in Florida in 1959. By the late 1960s hydrilla was causing severe problems in major water bodies of every watershed throughout Florida. Hydrilla is currently distributed, and causing serious problems, throughout the southeastern United States as far north as Delaware and as far west as the Imperial Valley Drainage District of California (Haller 1982).

Hydrilla was first discovered in North Carolina in 1979. A 1980 survey conducted by the North Carolina Department of Agriculture revealed 13 hydrilla infestations in the Raleigh, N.C. area, all within the Neuse River drainage basin. Two newly constructed reservoirs, Falls of the Neuse and B. Everett Jordan, are in close proximity to these infestations. The potential for dispersal of hydrilla into these reservoirs is of great concern because over half of this 27,000 acre combined surface area is potentially colonizable by submerged macrophytes. Hydrilla has subsequently been identified in other drainage basins and appears to be spreading rapidly in the state. Soon after the initial discovery it was identified in Hyco Reservoir in the Roanoke River drainage basin, and in 1985 it was identified in Lake Gaston, a 8,219 ha impoundment of the Roanoke River. A 324 ha infestation in Woodlake in Moore County extends hydrilla's range into the Cape Fear basin, and farm ponds in northern Randolph County extend it to the Yadkin-Pee Dee basin.

Most of the research on hydrilla control presently being done in this country centers around biological, chemical, or physical control methods, or some combination of these methods.

Biological control methods generally focus on the use of herbivorous fish such as grass carp (Ctenophayngodon idella). Grass carp was introduced into the U.S. in 1963 (Bitting 1974) and is reported to exist in 35 states (Guillory and Gasaway 1978). The herbivorous habits of the species (Avault 1965; Stott 1967; Prowse 1971; Michewicz et al. 1971; Bardach et al. 1973) and its effectiveness in controlling hydrilla and other aquatic macrophytes (Sutton 1974; Kilgen 1978; Lembi et al. 1978; Lewis 1978; Mitzner 1978; Bailey 1978; Colle et al. 1980) has been reported previously. The effect of grass carp on native species has been studied in several cases (Ware and Gasaway 1977; Colle and Shireman 1980; Forester and Avault 1978; Baur et al. 1979; Forester and Lawrence 1978; Bailey 1978), and reported results range from no effect to beneficial or detrimental.

Because of concern over the environmental impact of a breeding population of grass carp, attempts have been made toward developing a sterile fish with similar herbivorous characteristics. Hybridization between herbivorous fish and other Cyprinids has been attempted since 1964. The first hybrid carp (Ctenopharyngodon Idella ♀ x Hypophthalmichthys nobilis ♂) were spawned in the United States by Malone (Lynch, 1979). Although the development of this fish caused a great deal of initial excitement, consistent hydrilla control has not been achieved (Shireman, 1984, personal communication). Surgical sterilization of grass carp is currently being tested. This procedure is time consuming, however, and gonadol regeneration usually occurs within 12 months. The most recent and promising development has been production of a sterile triploid grass carp. Trials with this fish indicate that it is effective for controlling hydrilla. Refinement of the technique for producing this fish is necessary, however, because complete sterility of eggs cannot yet be achieved (Allen 1983).

Extensive research has been conducted in the past ten years by the United States Army Corps of Engineers to develop technology for mechanical harvesting and removal of hydrilla and other aquatic weeds. This research has generally revealed that harvesters cannot be adapted to use in a large number of water bodies (i.e. to operate where obstructions such as stumps and piers occur), cannot keep pace with the rapid growth rate of the plants, and does not yield cost effective aquatic weed control.

Large-scale lake drawdown has been investigated for hydrilla control. Temporary control has been achieved where soils are porous enough to allow dessication of vegetative propagules, however; dessication does not occur in organic or clay soils. Rapid recolonization occurs from areas where control was not achieved (Haller 1984, personal communication).

Most aquatic weed control is accomplished by the use of herbicides. Although hundreds of chemicals have been evaluated for hydrilla control, only diquat, endothall, dichlobenil, fenac (drawdown only), and fluridone (experimental use permit only) are effective and at the same time meet the strict toxicological and environmental persistence criteria to be registered by EPA for aquatic weed control. Water use restrictions following herbicide application further limit the choice of herbicide for a particular site.

Diquat is a widely used aquatic herbicide. It rapidly kills hydrilla on contact at a treatment rate of 2 ppm, but rapid regrowth can occur. Diquat is not persistent in the water column. In Florida, diquat residues were shown to be non-existent 14 days after treatment with .5 ppm diquat (McKenzie 1969). Complete degradation in 8-11 days has been observed after treatment with 1.0 ppm diquat. Disappearance of diquat from water has been attributed to absorption by suspended solids and hydrosoil, and by breakdown by ultraviolet light (Simsiman et al. 1976). Diquat persists in the hydrosoil, where it is completely inactive, for six months to one year (Newbold 1975). Based upon persistence and toxicity data there are no restrictions on use of water for swimming or fishing after application of diquat, but water may not be used for consumptive uses (i.e., irrigation or consumption by livestock or humans) until 14 days after treatment.

Endothall is also a widely used aquatic herbicide that is effective against hydrilla. It is sold as the dipotassium salt and as the dimethylalkylamine salt. The dipotassium salt is relatively non-toxic to fish and is more widely used for aquatic weed control. Concentration of endothall (2 ppm) was reduced by 50% in water four days after treatment and was non-detectable after 36 days (Sikka and Rice 1973). After 44 days endothall was non-detectable in the hydrosoil. Endothall has a low toxicity to mammals and is not bioaccumulated by fish. Swimming is therefore allowed in endothall-treated water 24 hours after treatment, and fish taken from the water 3 days after treatment may be eaten. Water cannot be used for irrigation, agricultural sprays, or consumption until 14 days after treatment when the application rate is between 0.35 and 3.0 ppm.

Dichlobenil has been recommended for hydrilla control. However, because a 90-day waiting period is required before using the water it is not widely used.

Fenac is a broad-spectrum aquatic herbicide that is registered only for application to lake bottoms after the water has been removed. Fenac is relatively persistent in the environment, but it has low toxicity to mammals and aquatic organisms and does not bioaccumulate (Sikka et al. 1982). Because of the constraint of having to draw a water body down to use fenac and because of the difficulty of application (almost exclusively by air in large water bodies), fenac is not widely used for aquatic weed control.

Fluridone is a new aquatic herbicide which may result in longer term hydrilla control relative to diquat or endothall (McCowen et al. 1979; Grant et al. 1979; Parka et al. 1978). Fluridone is relatively non-toxic to mammals and aquatic organisms, does not bioaccumulate in fish, and does not pose an environmental threat at recommended treatment rates[1]. Fluridone is not highly persistent in the aquatic environment. In Indiana ponds, the half life of fluridone in water was 21 and 26 days for surface and bottom applications, respectively (West and Parka 1981). Only 4% of the initial fluridone concentration remained after 21 days. Fluridone was non-detectable in the hydrosoil after 56 days. Registration of fluridone for aquatic weed control by the EPA is currently pending.

It was learned in 1983 that the hydrilla populations in North Carolina represented a different strain than those found previously in the southeastern United States. In North Carolina a monoecious strain occurred compared to a pistillate, dioecious strain previously known (Langeland and Schiller 1983). Subsequent studies have indicated that the monoecious hydrilla strain has various growth characteristics that differ from the dioecious strain[2] and that it produces seed (Langeland and Smith 1984). Because state-of-the-art methodology for hydrilla management has been developed for the dioecious strain in more southern states, it is essential that these be evaluated for effectiveness on the monoecious hydrilla strain in the more temperate climates.

A project was begun in 1983 to study the phenology of hydrilla in North Carolina lakes and to evaluate the effectiveness of lake drawdown, biological control, and herbicides for hydrilla management (Hodson et al.

---

[1]Sonar Technical Manual. 1981. Elanco Products Co.

[2]Annual Report - 1984, Aquatic Weed Control Investigations, Agricultural Research Service, U.S. Department of Agriculture, Davis, California.

1984). Results of herbicide evaluations in this initial study were variable but offered preliminary data for implementation of larger scale hydrilla management evaluations. This report presents the results of expanded evaluations of herbicides for management of the monoecious strain of hydrilla in North Carolina lakes and offers recommendations for hydrilla management based on these findings.

MATERIALS AND METHODS

Various herbicides and formulations were applied to established populations of a monoecious strain of hydrilla in several North Carolina lakes during 1983-85 (Table 1). All liquid formulations were tank-mixed with 0.3% polyacrylamide copolymer. Liquid fluridone was surface applied, whereas liquid endothall was injected with three-foot drop hoses. Fenac was applied to exposed lake bottom after drawdown by handgun and pickup truck mounted sprayer in 1983 and by helicopter-mounted boom in 1984. Granular and pelleted formulations were applied using a centrifugal spreader.

Recording fathometers (Aqua Meter 394, with a 9^{o} transducer or Lawrence X-15A, with a 15^{o} transducer) were used to measure hydrilla control by calculating reduction in cross-sectional area (RCA) of the tracings that were occupied by hydrilla images before and after application of the herbicides. Several fathometer transects traversed each treated area (Appendix 1). In Woodlake, control was also evaluated as reduction in frequency of hydrilla occurrence. A grapple was randomly lowered along transects to measure the presence or absence of vegetation.

RESULTS AND DISCUSSION

Basin morphometry caused great difficulty in applying fenac. Drawdown of Sycamore Lake was begun on September 4, 1983 to give the clay hydrosoil, which tends to hold moisture, ample time to dry. However, be-

Table 1. Herbicides evaluated for controlling a monoecious strain of hydrilla in North Carolina lakes.

Herbicide	Rate (kg ai/ha)	Spray Volume (L)	Date of Appl	Plot Size (ha)	Location
Diquat (2L)	4.5	95	8/84	1.6	Lake Anne
Endothall (3L)	25.9	95	6/84	2.4	Reedy Creek Lake
Endothall (3L)	25.9	95	8/84	-	"
Endothall (10.1G)	25.9	-	6/84	1.2-fringe	"
Endothall (10.1G)	33.9	-	6/85	2.4	"
Fluridone (4AS)	1.7	95	9/83	5.7[2]	Big Lake
Fluridone (5SRP)	1.7	-	5/84	1.4	"
Fluridone (5P)	1.7	-	5/84	1.4	"
Fluridone (4AS)	2.3	38	5/85	20.2	Woodlake
Fenac (1.5L)	21.8	379	12/83	4.2	Sycamore Lake
Fenac (1.5L)	21.8	95	11/84	15	"
Dichlobenil (10G)	11.2	-	2/85	0.8	Dunaway's Pond
Dichlobenil (10G)	16.8	-		0.8	"

[1]All liquid formulations were tank-mixed with 0.3% polyacrylamide copolymer.

[2]Applied as two successive 2.85 ha applications 7 days apart.

cause of the large drainage area to lake volume, the lake refilled several times after the initial drawdown when rainfall occurred. Fenac was applied in December when the hydrosoil had finally become dry enough and was not frozen. Fenac appears to have resulted in good hydrilla control. Complete control was observed in the deeper water of the plots, but regrowth occurred along the shallow edges. We initially attributed this to poor coverage along the edges or to the herbicide washing down the slope before it was incorporated. However, nature intervened in 1984 with heavy rains in the spring to make evaluation of fenac plots difficult. High turbidity caused by erosion of clay soils into the lake caused a very shallow euphotic zone and thermocline that caused a large reduction in hydrilla coverage throughout the lake (Pesacreta 1986). Transects over untreated portions of the lake bottom had similar tracing patterns as treated plots (Table 2).

Sycamore Lake was drawn down again in September 1984, and fenac was applied to the entire lake bottom by helicopter in November. Hydrilla density was reduced on most transects at peak biomass (September) in 1985 (Table 2). Heavy precipitation did not occur in Spring 1985 as in 1984, and the maximum depth to which hydrilla occurred (2.2 m) was similar to 1983 (2.4 m). Therefore, the observed reductions in hydrilla density were probably a result of herbicide application. Hydrilla control was fair to good in the more open areas of the lake as observed in transects 3-6. These areas probably received the best coverage of the herbicide. In comparison, poor control was observed on transects 1, 2 and 7 where most of the hydrilla on the transects is close to shore or in protected areas that could not be reached with the helicopter. Likewise, aerial observation (data not included) revealed poor control under a transmission line that traverses the lake, indicating lack of herbicide coverage. Fenac may

Table 2. Reduction of hydrilla (*Hydrilla verticillata*) density (cross sectional area of recording fathometer tracing occupied by hydrilla images) in Sycamore Lake (North Carolina) in 1984 and 1985, as compared to 1983, after applications of fenac.

Reduction of Hydrilla Density (%)		
1984	1985	Transect
56 (untreated)	9	1
62	22	2
83	57	3
86	63	4
80 (untreated)	76	5
55 (untreated)	64	6
68 (untreated)	2	7

have utility for hydrilla control in North Carolina where application to exposed bottoms is more easily accomplished. However, because of the difficulty of applying the herbicide following reservoir drawdown, the difficulty of reaching many areas of lakes where shorelines are heavily forested, and the uncertainty of application with respect to atmospheric conditions, fenac will have only limited use for hydrilla management in North Carolina.

In a previous report we observed nil to poor control of monoecious hydrilla with diquat (Hodson et al. 1983). It was suggested that this was a result of small plot size, method of application, and/or date of application rather than tolerance by hydrilla. Excellent control of monoecious hydrilla in this study supports this idea and demonstrates that diquat should be included in a hydrilla management program in North Carolina. Three weeks after herbicide application (WAHA), 82, 86, 91 and 92% RCA was observed on four transects. Although additional data were not collected, visual observations revealed that hydrilla did not return to problem levels in 1984. Hydrilla did regrow to problem levels in 1985. This is expected because diquat is a non-persistent, contact herbicide that does not affect hybernacula (tubers and turions). Annual or twice-a-year applications of diquat will be necessary for maintenance control of monoecious hydrilla in North Carolina unless repeat applications in consecutive years reduce hybernacula.

Control of monoecious hydrilla with endothall was highly variable, ranging from poor to excellent during our 1983 study (Hodson et al. 1984). Poor control was thought to be related to those factors described above for diquat, especially dilution of herbicide in small plots where fringe areas were treated adjacent to deep water. Therefore, in 1984 three-foot drop hoses were used along with tank mixing a sinking agent (polyacrylamide copolymer) to facilitate placement of the herbicide in proximity to the weeds, and granular endothall was used for fringe applications.

Application of endothall with drop hoses in June 1984 did not improve performance of the herbicide over June 1983 treatments. However, poor control with endothall after the June 1984 application can be explained by a characteristic of Piedmont lakes that causes difficulties in aquatic weed control. These impounded streams often have very high drainage basin to volume ratios that allow for high flushing rates (Pesacreta 1986). Under normal flow conditions, the water in Reedy Creek Lake has a residence time of 11.2 days. Following treatment, a rainfall of approximately 3 inches occurred which undoubtedly caused severe dilution and flushing of the herbicide. Fair control was observed after application of endothall with drop hoses in August 1984 (Table 3).

Based on fathometer tracings, granular endothall gave fair levels of control with fringe applications in 1984 and good longevity. Both transects showed greater than 50% control 12 weeks after application without retreatment. This is fairly good considering the fringe nature of the plots and rain that occurred after application. In addition to fathometer tracings, direct visual observation of areas treated with granular endothall were made. Large areas devoid of hydrilla could be observed, indicating very good control.

Granular endothall was applied to Reedy Creek Lake in 1985 to facilitate placement of the herbicide where sufficient herbicide could be absorbed by the vegetation before it was diluted or flushed out of the lake. Excellent control was observed four and six WAHA and regrowth was still below pre-treatment density twelve WAHA (Table 4). A second application in mid-August would probably have resulted in control for the remainder of the

Table 3. Reduction of Hydrilla (*Hydrilla verticillata*) density (cross-sectional area of recording fathometer tracing occupied by hydrilla images) in Reedy Creek Lake (North Carolina) after application of endothall.

Formulation	Application	Reduction of Hydrilla Density (%) at Weeks After Application				
		2	3	4	6	12
3L	6/84	5	5		0	
		44	44		12	
		56	61		53	
3L	8/84		67			
			70			
			77			
10.1G [1]	6/84	46	49		67	54
		24	17			55
10.1G	6/85			88	93	25
				91	95	49
				96	96	37

[1] fringe applications

Table 4. Hydrilla density (% cross sectional area of recording fathometer tracings occupied by hydrilla images) in Big Lake (North Carolina) before (8/83) and after application of fluridone.

Formulation	Date of Application	Date:	8/83	9/84	5/85	6/85	9/85
5 SRP	5/84		80	0	17	80	100
			68	0	26	66	82
			46	-	32	58	63
			67	0	21	98	100
5 P	5/84		50	0	36	47	68
			58	0	20	75	90
4 AS	9/83		90	0	48	90	100
			95	0	50	100	100
			65	0	55	80	98

Table 5. Frequency of occurence (sample size = 16) of several submersed aquatic macrophytes in Woodlake (North Carolina) after application of fluridone (4AS) on May 30, 1985.

Common Name (Genus species)	Date:	Frequency of Occurence (%) 6/3/85	6/26/85	7/30/85	8/30/85	10/17/85
Hydrilla (*Hydrilla verticillata*)		63	86	67	0	0
Slender niad (*Najas minor*)		100	57	0	0	0
Bladderwort (*Utricularia sp.*)		50	14	0	0	0
Stonewort (*Nitella sp.*)		100	100	100	100	100

growing season and, perhaps, would have reduced density in 1986. A decision was made not to treat for practical and economic reasons because park activity was essentially complete for the year. Two applications and evaluation of effects in the following year should be planned for the future.

Application of fluridone 4AS to 5.7 ha in the upper end of Big Lake in September 1983 and fluridone 5P and 5SRP to the fringe in the lower end of the lake in May 1984 resulted in complete hydrilla control throughout the 1984 growing season (Table 4). It was hoped that control would be observed at least through 1985 because longer term control with fluridone had been previously suggested (McGowen et al. 1979 Grant et al. 1979). However, hydrilla growth began normally in the spring of 1985 and reached, at least, as great a density toward the end of the growing season as before treatment in 1983 (Table 4).

Application of fluridone 4AS to 20.6 ha of hydrilla in Woodlake in May 1985 resulted in complete control throughout the 1985 growing season (Table 5).

In contrast to the hydrilla monocultures present (at least almost totally dominated) in all other lakes in this study, Woodlake offered the opportunity to observe the effects of fluridone on other submersed macrophytes in a mixed community. In Woodlake, fluridone resulted in complete control of slender naiad (*Najas minor*) and bladderwort (*Utricularia sp.*), whereas stonewort (*Nitella sp.*), a macrophytic algae, was not affected (Table 5). Similarly, muskgrass (*Chara sp.*) was not affected by fluridone applications in Big Lake. This specificity against higher plant life may be ecologically important where macrophytic algae, that do not cause as serious a water-use problem, can be maintained for habitat or bottom stabilization. Similar maintenance of macrophytic algae would result after application of the dipotassium salt of endothall but diquat or the amine formulation of endothall are also effective against algae.

Dichlobenil could be a useful herbicide to use for hydrilla if it was shown to be effective for controlling monoecious hydrilla because it is soil active and should be useful for small area control around beaches and docks where large area vegetation control in the lake is not desirable. We did not observe any suppression of hydrilla growth after preemergence application of dichlobenil. Therefore, further testing will be necessary with this herbicide.

LITERATURE CITED

Allen, J.K. 1983. Analysis of ploidy of putative triploid grass carp (Ctenopharyngodon idella), 1983 brood of Malone's sterile white amur. Unpublished manuscript. School of Fisheries, WH-10 University of Washington, Seattle. 5 pp.

Avault, J.W., Jr. 1965. Preliminary studies with grass carp for aquatic weed control. Prog. Fish Cult., 27(4). 207.

Bailey, W.M. 1978. A comparison of fish populations before and after extensive grass carp stocking. Trans. Amer. Fish. 107:181-206.

Bardach, J.E., J.H. Riglher, and W.D. McLarney, 1973. The status and potential of aquaculture, particularly fish culture, Vol. 2, Wiley-Interscience, New York.

Baur, R.J., D.H. Buck and C.R. Rose. 1979. Production of Age-0 largemouth bass, smallmouth bass, and blue-gills in ponds stocked with grass carp. Trans. Amer. Fish. Soc. 108:496-498.

Bitting, L.E., Sr. 1974. Field uses of invert emulsion. Hyacinth Control J. 12:34-35.

Colle, D.E., J.V. Shireman and R.W. Rottmann. 1978. Food selection by grass carp fingerling in a vegetated pond. Trans. Amer. Fish. Soc. 107:149-152.

Colle, D.E., and J.V. Shireman. 1980. Coefficients of condition for largemouth bass, bluegill, and redear sunfish in hydrilla-infested lakes. Trans. Amer. Fish. Soc. 109:521-531.

Cook, C.D.K., and R. Luond. 1982. A revision of these genus Hydrilla (Hydrocharitaceae). Aquat. Bot. 13:485-504.

Forester, J.S., and J.W. Avault, Jr. 1978. Effects of grass carp on freshwater red swamp crawfish in ponds. Trans. Amer. Fish. Soc. 107:156-160.

Forester, J.S., and J.M. Lawrence. 1978. Effects of grass carp and carp on populations of blue gill and largemouth bass in ponds. Trans. Amer. Fish. Soc. 107:172-175.

Grant, D.E., L.C. Warner, W.R. Arnold, and S.D. West. 1979. Fluridone for aquatic plant management. Proc. So. Weed Sci. Soc. 32:293.

Guillory, V., and R.D. Gasaway. 1978. Zoogeography of the grass carp in the United States. Trans. Amer. Fish. Soc. 107:105-112.

Haller, W.T. 1978. Hydrilla - a new and rapidly spreading aquatic weed problem. Florida Agric. Exp. Sta. Circular. S-245, 13 pp.

Haller, W.T. and D.L. Sutton. 1975. Community structure and competition between hydrilla and vallisnera. Hyacinth Control J. 13:48-50.

Hodson, R.G., G.J. Davis, and K.A. Langeland. 1984. Hydrilla management in North Carolina. Water Resources Research Inst. of Univ. of N.C. Rep. No. 217. 46 pp.

Kilgen, R.H. 1978. Growth of channel catfish and striped bass in small ponds stocked with grass carp and water hyacinths. Trans. Amer. Fish. Soc. 107:176-180.

Langeland, K.A. and D.H. Schiller. 1983. Hydrilla in North Carolina. Aquatics 5:8-14.

Langeland, K.A. and C.B. Smith. 1984. Hydrilla produces viable seed in North Carolina lakes. Aquatics 6:20-21.

Lembi, C.A., B.G. Ritenour, E.M. Iverson, and E.C. Forss. 1978. The effects of vegetation removal by grass carp on water chemistry and phytoplankton in Indiana ponds. Trans. Amer. Fish. Soc. 107:153-155.

Lewis, W.M. 1978. Observations on the grass carp in ponds containing fingerling channel catfish and hybrid sunfish. Trans. Amer. Fish. Soc. 107:153-155.

Lynch, T. 1979. White amur experience leads to development of grass carp hybrid. Aquacult. Mag. 6:33-36.

McCowen, M.C., C.L. Young, S.D. West, S.J. Parker, and W.R. Arnold. 1979. Fluridone, a new herbicide for aquatic plant management. J. Aquat. Plant Manage. 17:27-30.

Michewicz, J.E., D.L. Sutton and R. D. Blackburn. 1972. The white amur for aquatic weed control. Weed Sci. 20:106.

Mitzner, L. 1978. Evaluation of biological control of nuisance aquatic vegetation by grass carp. Trans. Amer. Fish. Soc. 107:135-145.

Newbold, C. 1975. Herbicides in aquatic systems. Biol. Conserv. 7:96-118.

Parka, S.J., W. R. Arnold, M.C. McCowen, and C. L. Young. 1978. "Fluridone: A New Herbicide for Use in Aquatic Weed Control Systems," Proceedings, European Weed Research Council, 5th Int Symp. Aquatic Weeds, pp. 179-187.

Pesacreta, G. J. 1986. Water chemistry observations in Piedmont North Carolina lakes that contain hydrilla. Ph.D. dissertation. In preparation.

Prowse, G.A. 1971. Experimental criteria for the study of grass carp feeding in relation to weed control. Prog. Fish. Cult. 33(3), 128.

Shireman, J.W. and W.T. Haller. 1979. The ecological impact of integrated chemical and biological weed control. Center for Aquatic Weeds IFAS, University of Florida, Gainesville. 333 pp.

Sikka, H.C., E.J. Pack, H.T. Appleton, R. Hsu, and D. Cunningham. 1982. Environmental Fate, Effects, and Health Hazards of Fenac. USAE, WES, Vicksburg. 85 pp.

Sikka, H.C. and C.P. Rice. 1973. Persistence of endothall in aquatic environment as determined by a gas-liquid chromotography. J. Agr. Food Chem. 21:842-850.

Simsiman, G.V., T.C. Daniel and G. Chesters. 1976. Diquat and endothall: their fates in the environment. Residue Reviews. 62:131-174.

Stott, B. 1967. Aquatic weed control by grass carp (*Ctenopharyngodon idella* Val.). Proceedings of the Third British Coarse Fish Conf. 62.

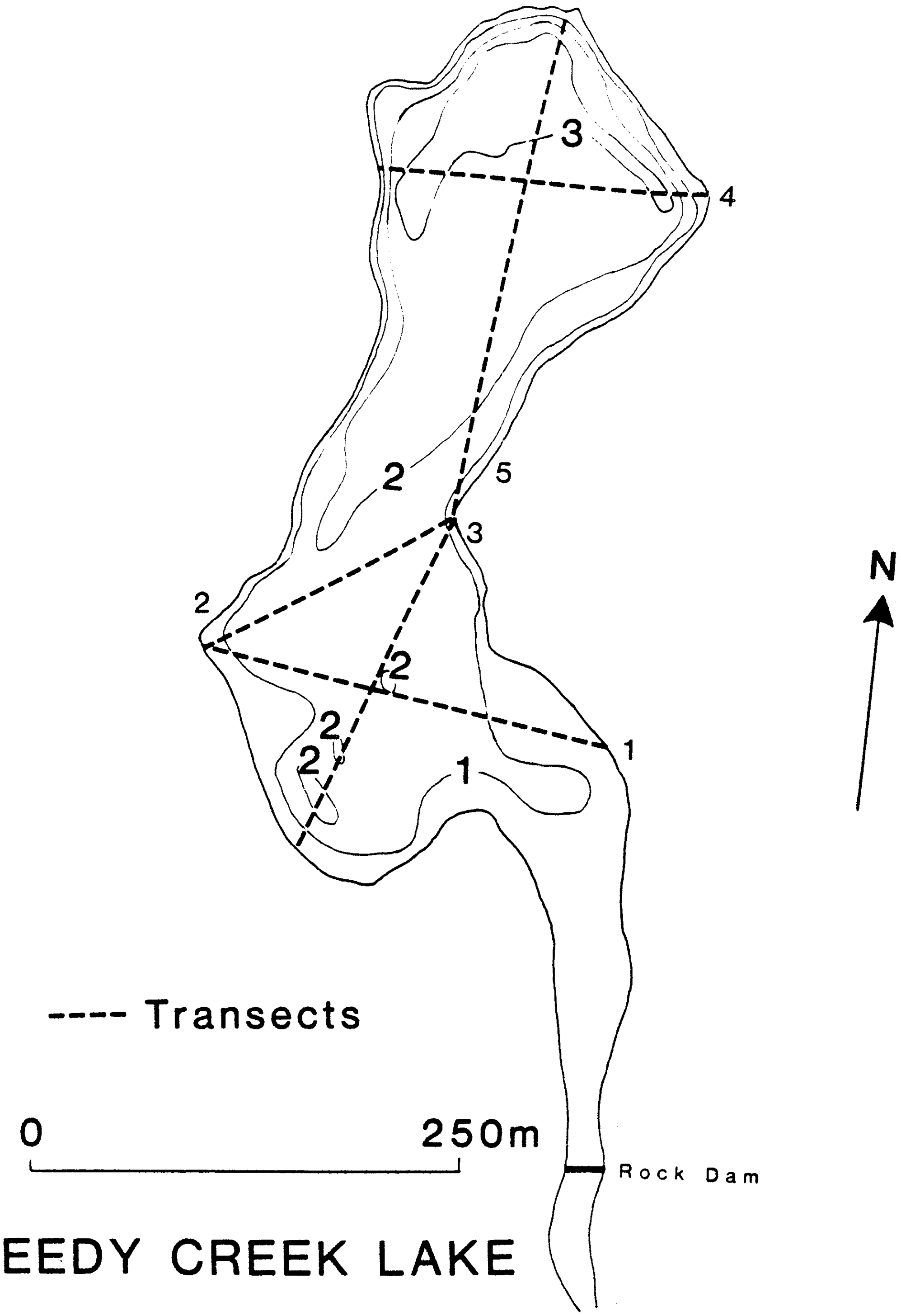
Sutton, D.L. 1974. Utilization of hydrilla by the white amur. Hyacinth Control Journal 12:66-70.

Van, T.K., W.T. Haller, G. Bowes, and L.A. Garrad. 1977. Effects of light quality on growth and chlorophyll composition in hydrilla. J. Aquatic Plant Manage. 15:29-31.

Ware, F.J. and R.D. Gasasway. 1977. Effects of grass carp on native fish populations in two Florida lakes. Proc. Ann. Conf. Southeast Assoc. Game Fish Comm. 30.

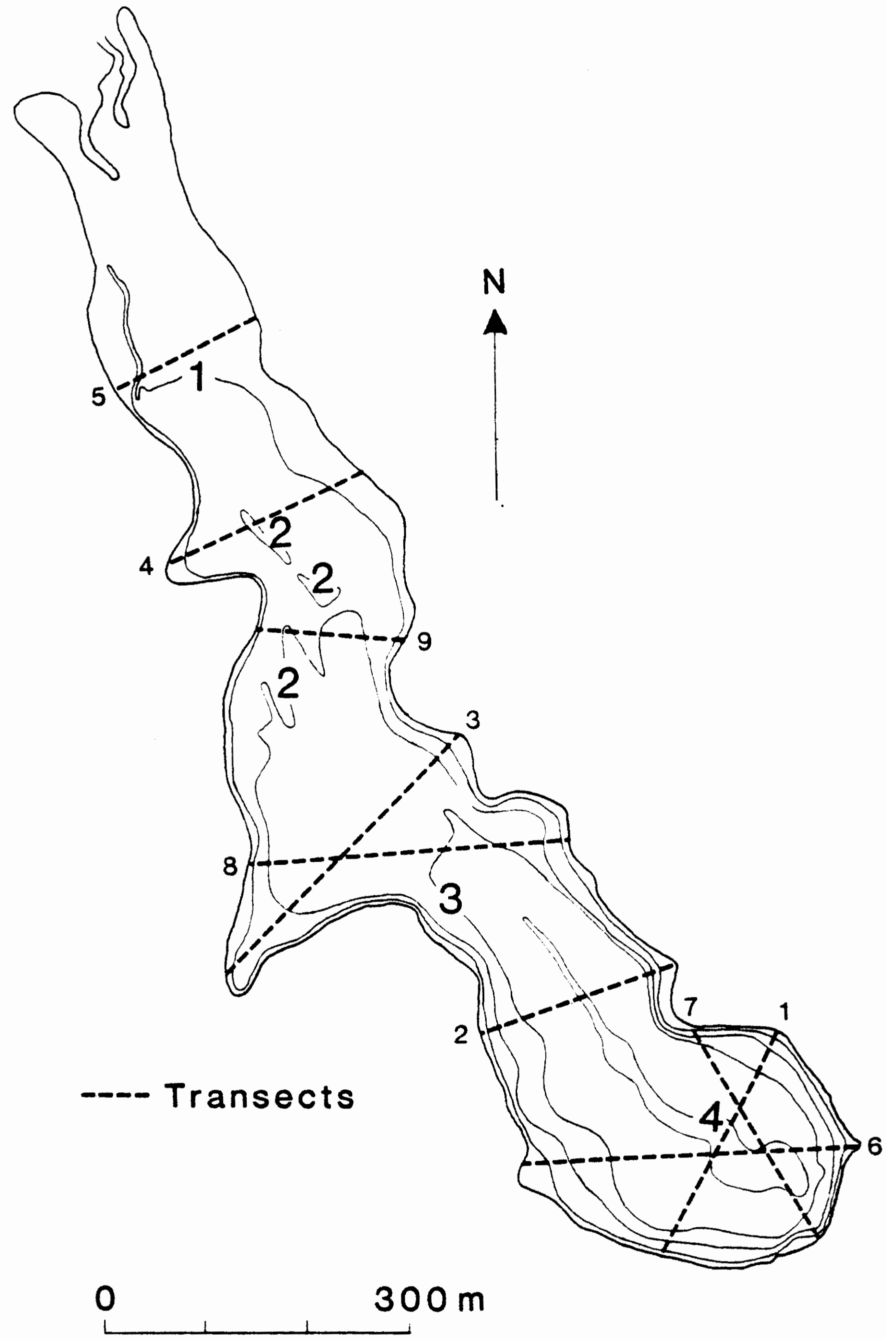
West, J.D. and S.J. Parka. 1981. Determination of the aquatic herbicide fluridone in water and hydrosoil: Effect of application method on dissipation. J. Agric. Food Chem. 29:223-226.

Appendix 1. Location of transects in North Carolina lakes where a recording fathometer was used to measure the efficacy of various herbicides for hydrilla (Hydrilla verticillata) control. Location of transect numbers on each map indicates starting position for each fathometer run.



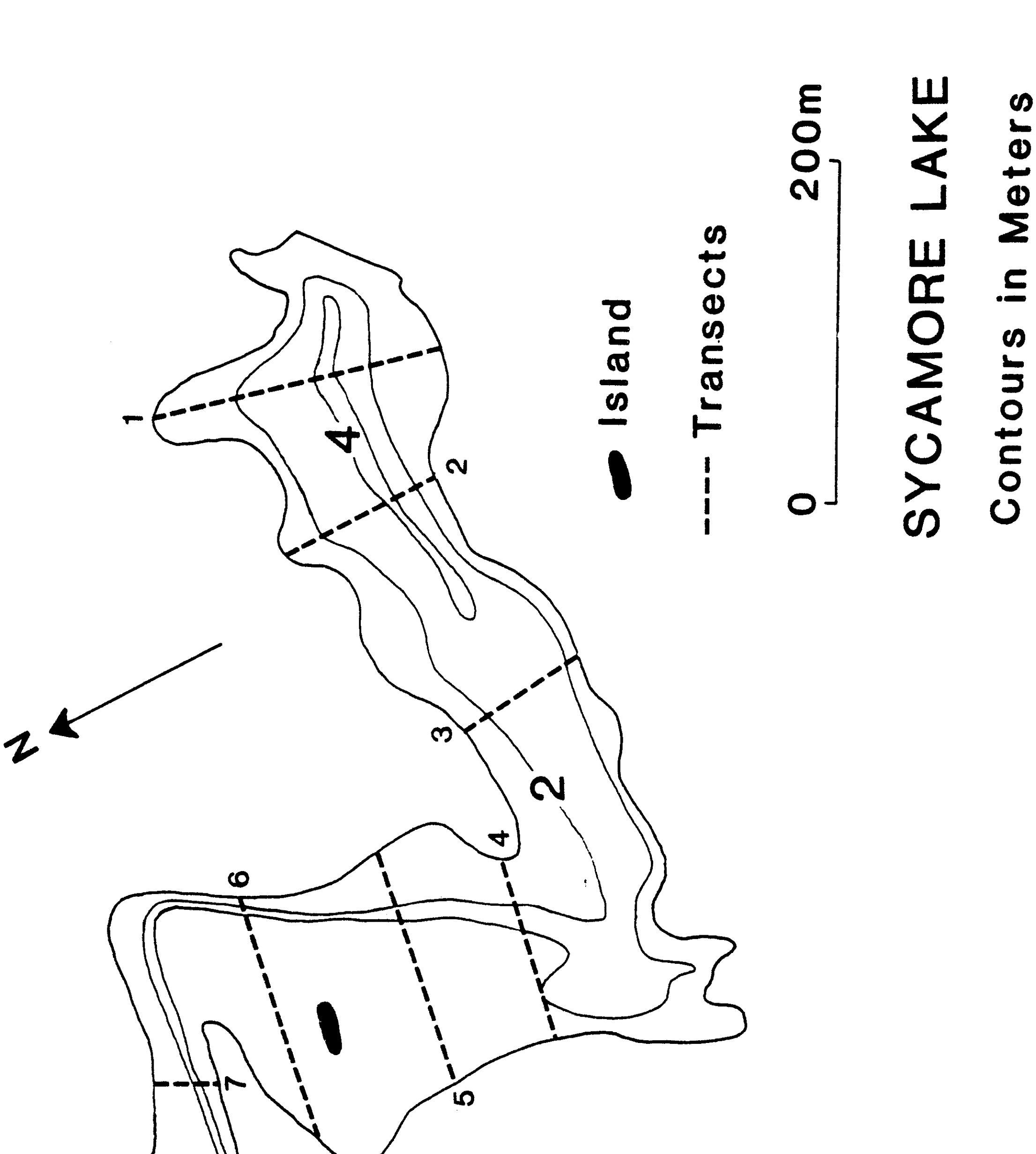
REEDY CREEK LAKE

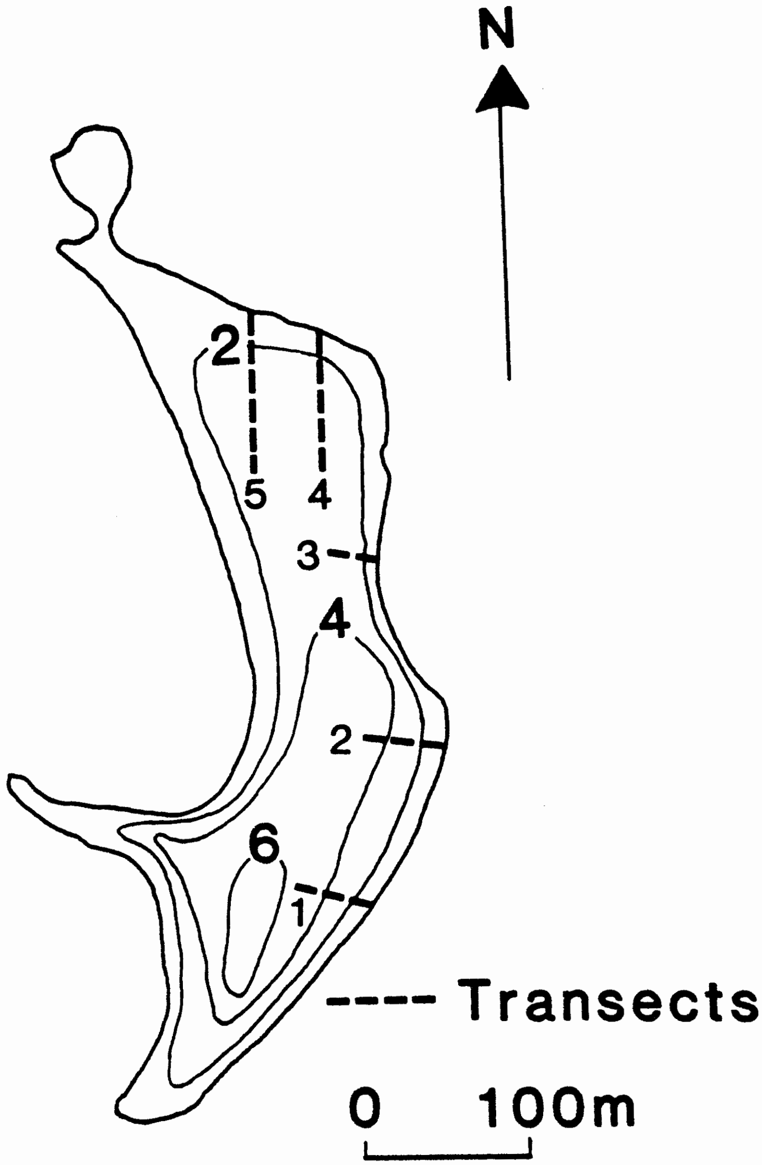
Contours in Meters



BIG LAKE

Contours in Meters


N
1
2
3
4
5
6
7
4
2
Island
Transects
0
200m
SYCAMORE LAKE
Contours in Meters



LAKE ANNE

Contours in Meters