AQUATIC PLANT CONTROL RESEARCH PROGRAM

US Army Corps of Engineers

MISCELLANEOUS PAPER A-83-3

PROCEEDINGS, 17TH ANNUAL MEETING, AQUATIC PLANT CONTROL RESEARCH PROGRAM

16-18 NOVEMBER 1982

SACRAMENTO, CALIFORNIA

Environmental Laboratory
U.S. Army Engineer Waterways Experiment Station
P.O. Box 631, Vicksburg, Miss. 39180

June 1983

Final Report

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The 17th Annual Meeting of the U.S. Army Corps of Engineers Aquatic Plant Control Research Program was held in Sacramento, California, on 16-18 November 1982, to review current research activities and to afford an opportunity for presentation of operational needs.

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PREFACE

The 17th Annual Meeting of the U.S. Army Corps of Engineers Aquatic Plant Control Program was held in Sacramento, California, on 16-18 November 1982. The meeting is required by Engineer Regulation (ER) 1130-2-412 paragraph 4c and was organized by personnel of the Aquatic Plant Control Research Program (APCRP), Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss.

The organizational activities were carried out and presentations by WES personnel were prepared under the general supervision of Dr. John Harrison, Chief, EL. Mr. J. Lewis Decell was Program Manager, APCRP. Mr. W. N. Rushing, APCRP, was responsible for planning and chairing the meeting assisted by Mr. Robert L. Lazor.

COL Tilford C. Creel, CE, was Commander and Director of the WES at the time of this meeting and during the preparation of the proceedings report. Mr. F. R. Brown was Technical Director.

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AGENDA

17th Annual Meeting
U.S. Army Corps of Engineers
AQUATIC PLANT CONTROL RESEARCH PROGRAM

Sacramento, California
16-18 November 1982

TUESDAY, 16 November 1982

10:00 a.m. -6:00 p.m.	Registration—Main Lobby
6:30 p.m.	Reception—Mansion Inn Patio (weather permitting) otherwise, Terrace Room Foyer

WEDNESDAY, 17 NOVEMBER 1982
General Session, Terrace Room

8:00 a.m.	Registration continues—Terrace Room Foyer
8:40 a.m.	Call to Order and Announcements —W. N. Rushing, Waterways Experiment Station (WES)
8:50 a.m.	Welcome to the Sacramento District —LTC Henry Lee, Deputy Commander, USAE District, Sacramento
9:00 a.m.	California Department of Boating and Waterways (CDBW) Role in Aquatic Plant Management —Ms. Marty Mercado, Director, CDBW
9:20 a.m.	The 1983 Meeting—Format and Purpose —J. L. Decell, Manager, Aquatic Plant Control Research Program, WES
9:25 a.m.	Black Hat/White Hat Presentation Carlton Layne, U.S. Environmental Protection Agency
9:40 a.m.	BREAK
10:10 a.m.	USAE Division/District Presentations—Aquatic Plant Problems —Operations Activities
12:00 noon	LUNCH
1:30 p.m.	Field Operations Studies —W. N. Rushing, Presiding
	Waterhyacinth Management in the Sacramento-San Joaquin River Delta, California —J. L. Decell, WES
1:40 p.m.	Biological Control —E. A. Theriot, WES
1:55 p.m.	Chemical Control —W. N. Rushing, WES
2:10 p.m.	Mechanical Control —H. W. West, WES

2:20 p.m.	Control of Eurasian Watermilfoil in the Okanogon River and Lake Osoyoos, Washington, Using 2,4-D/Adjuvant Mixtures —J. Killgore, WES
2:35 p.m.	Large-Scale Management Test of the Use of the White Amur for Control of Problem Aquatic Plants at Lake Conway, Florida —R. L. Lazor, WES
3:00 p.m.	BREAK
3:30 p.m.	Herbivorous Fish for Aquatic Plant Control in Irrigation Canals in Western United States* —T. Jackson, U.S. Fish and Wildlife Service Denver, Colorado, Presiding
3:35 p.m.	A Water Management Perspective on Herbivorous Fish* —D. Breitzman, U.S. Bureau of Reclamation Boulder City, Nevada
3:50 p.m.	Applied Research with Hybrid Grass Carp and Grass Carp —P. Beaty, Coachella Valley Water District Coachella, California
4:05 p.m.	Efficacy Evaluation of Grass Carp and Hybrids —G. Otto, U.S. Bureau of Reclamation Denver, Colorado
4:20 p.m.	The Future of Herbivorous Fish in Aquatic Plant Management —T. Jackson
4:35 p.m.	Activities with Herbivorous Fish in Georgia —W. Thomaston, George Game and Fish Commission Fort Valley, Georgia
4:50 p.m.	Activities with Herbivorous Fish in South Carolina* —D. L. Johnson, South Carolina Water Resources Commission Columbia, South Carolina
5:00 p.m.	Adjourn for the Day

THURSDAY, 18 NOVEMBER 1982
General Session, Terrace Room

8:00 a.m.	Biological Control Technology Development —E. A. Theriot, WES, Presiding
8:20 a.m.	Microbiological Control of Eurasian Watermilfoil —H. Gunner, University of Massachusetts Amherst, Massachusetts
8:35 a.m.	Efficacy Studies of the Insect, *Sameodes,* on Waterhyacinth in Florida —T. D. Center, U.S. Dept. of Agriculture Fort Lauderdale, Florida
8:50 a.m.	Overseas Searches of Insects on Hydrilla in Southeast Asia and Australia —J. K. Balcuinas, U.S. Department of Agriculture Fort Lauderdale, Florida

* Presentation not submitted for inclusion in Proceedings.

9:05 a.m.	Status of the Fungii, *Cercospora* and *Fusarium,* for Aquatic Plant Control —R. Charudattan, University of Florida Gainesville, Florida
9:20 a.m.	Chemical Control Technology Development —H. E. Westerdahl, WES, Presiding
9:40 a.m.	Characterization and Identification of Naturally Occurring Growth Regulators for Aquatic Plants —D. F. Martin, University of South Florida Tampa, Florida
9:55 a.m.	BREAK
10:25 a.m.	Development and Production of Controlled Release 2,4-D for Field Evaluation* —F. W. Harris, Wright State University Dayton, Ohio
10:40 a.m.	Development of Fiber Carriers for Controlled Release of Fluridone —R. L. Dunn, Southern Research Institute Birmingham, Alabama
10:55 a.m.	Herbicide Evaluation Program —T. K. Van, U.S. Dept. of Agriculture Fort Lauderdale, Florida
11:05 a.m.	Effects of Organic Matter Added to Sediments on the Growth of Aquatic Plants —J. Barko, WES, Presiding
11:20 a.m.	Mechanical Control Technology Development —H. W. West, WES, Presiding
11:35 a.m.	Evaluating Control of Populations of Submerged Aquatic Macrophytes —J. Killgore, WES, Presiding
11:50 a.m.	Final Wrap-up
12:00 noon	LUNCH
1:30 p.m. -4:00 p.m.	Corps of Engineers R&D Review Terrace Room
3:00 p.m. -5:30 p.m.	Hamilton Room FY 84 Civil Works R&D Program Review —R&D Office, OCE (Corps of Engineers Representatives only)

* Presentation not submitted for inclusion in Proceedings.

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U.S. Army Corps of Engineers
AQUATIC PLANT CONTROL RESEARCH PROGRAM

Sacramento, California
16-18 November 1982

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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
acre feet	1233.489	cubic metres
cubic feet	0.2831685	cubic metres
cubic feet per second	0.2831685	cubic metres per second
feet	0.3048	metres
gallons per minute	3.785412	cubic decimetres per minute
gallons (U.S. liquid)	3.785412	cubic decimetres
horsepower (550 foot-pounds per second)	745.6999	watts
knots (international)	0.5144444	metres per second
miles (U.S. statute)	1.609347	kilometres
ounces (U.S. fluid)	29.57353	cubic centimetres
pounds (force) per square inch	6894.757	pascals
quarts (U.S. liquid)	0.9463529	cubic decimetres
square miles	2.589998	square kilometres
tons (mass) per acre	0.22	kilograms per square metre
tons (2000 lb mass)	907.1847	kilograms
yards	0.9144	metres

17th Annual Meeting
U.S. Army Corps of Engineers

AQUATIC PLANT CONTROL RESEARCH PROGRAM

INTRODUCTION

As part of the Corps of Engineers (CE) Aquatic Plant Control Research Program (APCRP) it is required that a meeting be held each year to provide for professional presentation of current research projects and review current operations activities and problems. Subsequent to these presentations, the Civil Works Research and Development Program Review is held. This program review is attended by representatives of the Civil Works and Research Development Directorates of the Office of the Chief of Engineers; the Program Manager, APCRP; and representatives of the operations elements of various Division and District Engineer Offices.

The overall objective of this annual meeting is to thoroughly review Corps aquatic plant control needs and establish priorities for future research, such that identified needs are satisfied in a timely manner.

The technical findings of each research effort conducted under the APCRP are reported to the manager, APCRP, U.S. Army Engineer Waterways Experiment Station (WES), each year in the form of quarterly progress reports and a final technical report. Each technical report is given wide distribution as a means of transferring technology to the technical community. Technology transfer to the field operations elements is effected through the conduct of demonstration projects in various District Office problem areas and through publication of Instruction Reports (IR), Engineering Circulars (EC), and Engineering Manuals (EM). Periodically, results are presented through publication of an APCRP Information Exchange Bulletin which is distributed to both the field units and the general community. Public-oriented brochures, movies, and speaking engagements are used to keep the general public informed.

The printed proceedings of the annual meetings and program reviews are intended to provide Corps management with an annual summary to ensure that the research is being focused on the current operational needs on a nationwide scale.

The contents of this report include the presentations of the 17th Annual Meeting held in Sacramento, California, 16-18 November 1982.

THE ROLE OF BOATING AND WATERWAYS IN AQUATIC PLANT MANAGEMENT IN THE DELTA

by
Marty Mercado*

This morning I would like to give you a little background on the Delta and the nature of California's waterhyacinth problem. I would also like to explain how the state's recreational boating agency (Cal Boating) got involved in battling the hyacinth and how our management program evolved with regards to the many concerns that Californians had on the use of herbicides in the Delta.

The primary responsibilities of Cal Boating are to provide funds for local boating facility projects and to promote boating safety throughout the state. So, when the Delta became inundated with waterhyacinths, we did not expect to be in the forefront of the battle to control this water weed.

The Delta consists of more than 700 miles** of navigable waterways. There are no clear-cut boundaries. Some will say that it starts in Sacramento; extends west to Contra Costa County, which is near San Francisco; and then down to Tracy and Stockton in San Joaquin County. The lifelines of the Delta are the Sacramento and San Joaquin Rivers. Other streams in the Delta create an intricate system of sloughs and backwaters.

The Delta is a key feature in California's supply distribution network, and the surrounding countryside includes some of the state's prime agricultural lands. In addition, the Delta is one of the most popular recreational areas in the state. It is a paradise for fishermen, swimmers, waterskiers, and boaters. Its proximity to major population centers, such as Sacramento and San Francisco, makes the Delta a favorite weekend retreat. Many people from Southern California also vacation in the Delta, renting houseboats to explore its many sloughs with names like Disappointment, Potato, and Steamboat. With the important role the Delta has in this state, the introduction of the hyacinth was to eventually create serious concerns for the people who depend on it for their livelihood and recreation.

How did the hyacinth get into the Delta and how long has it been there? No one knows for sure. Some say it has been in the Delta for about 20 years, if not longer. One theory as to how it was introduced into the system was that someone brought the plant back from Florida to add to their fish pond and then later discarded it in the Delta.

However it got there, the hyacinths began to multiply. After the drought of 1976-1977, the hyacinth became more prevalent in the southern part of the Delta. In 1981, the plant reproduced at such a rapid rate that it clogged navigation channels and marinas in the southern and eastern sections of the Delta. It was estimated then that the plant covered about 250 miles.

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* Director, California Department of Boating and Waterways, Sacramento, California.

** A table of factors for converting U.S. customary units of measurement to metric (SI) units is presented on page xi.

It was during this time that representatives of the San Joaquin County Delta Marine Association, a group of marina owners and other people operating recreation-oriented businesses in the Delta, brought the waterhyacinth problem to the attention of Cal Boating at one of our commission meetings. The group was seeking assistance and advice as to how the invasion of the hyacinth could be combated. While we recognized the severity of the problem and its impact on recreational boating, at that time we had no authority or funds to conduct any type of waterhyacinth management program. Little did we suspect that this would soon change.

Members of the Delta Marine Association contacted their state senator and assemblyman. They showed the legislators the magnitude of the problem and convinced them that something needed to be done.

In November of 1981, Senator John Garamendi and Assemblyman Patrick Johnston held a public hearing to receive testimony from various Federal, State, county, and private agencies as to the economic impact of the hyacinth problem, the extent of the encroachment, and the involvement of governmental agencies in dealing with waterhyacinths. The result from the hearing and a follow-up session with Johnston, Garamendi, and the appropriate State directors, including myself, was the introduction of legislation last January to designate Cal Boating as the lead State agency. The bill also appropriated $125,000 from the Harbors and Watercraft Revolving Fund for a control program.

There are many reasons why Cal Boating was chosen as the lead agency to coordinate the State's activities and work with the Corps. Generally, though, it was felt that since the major impact of the hyacinth infestation was on recreational boating that the State's boating agency should conduct the program. The plant was diminishing the recreational opportunities for the public by clogging the waterways, and it was severely impacting the recreational boating industry in the area. Also, the mats were creating safety hazards to boaters in hiding debris. It was recognized that if a control program was not initiated, eventually marine life would be threatened and agricultural interests would be adversely affected if the plant began to clog irrigation pumps and spread into the irrigation system.

Even before Cal Boating was officially given the authority to conduct the program, we had begun working with the Corps from the Sacramento District Office and the U.S. Army Engineer Waterways Experiment Station to develop a management program. When legislation was signed into law June 14, 1982, we were well on our way to finalizing the Corps' recommendation for controlling the hyacinth.

The WES team recommended three control methods: mechanical, biological, and chemical (applying 2,4-D and diquat). The next step was to adapt these recommendations, especially the one pertaining to herbicides, for use in California.

Many Californians are worried about the effects pesticides and herbicides have on the soil, water, plant life, and wildlife. Of course, the focus of these concerns is on the effects the chemicals will have on peoples' lives now and the lives of future generations. To put our control program in perspective, you need to know that a great deal of attention had recently been focused on chemical spraying programs.

The aerial spraying of malathion to eliminate medfly highlighted the fears that many people had about the use of chemical sprays. In the state's north coast forest range, citizens had been protesting the spraying of 2,4-D to kill shrubs that crowd out the conifers.

Some people decry these protests as purely emotional outbursts of an uninformed or misinformed public. Whether this is true or not is really not the issue. It is not that you or I know what will not harm the public, but what the public perceives will harm them. Because of this, we need to be sensitive to peoples' apprehensions.

To respond to the concern that some people had about the spraying of Weedar 64, we decided to go beyond what was legally required to use this 2,4-D compound. We had the Department of Fish and Game and the State Water Resources Control Board comment on any negative impacts that the spraying of Weedar 64 might have. Later we established an interagency task force to monitor the application and the impact the herbicide might have on water quality within a spray area. Agencies on this task force were the Department of Fish and Game, Department of Food and Agriculture, Department of Health Services, the central and regional Water Quality Control Boards, the U.S. Department of Agriculture, and the agricultural commissioners from the two counties involved in the spraying program.

In addition to this, Cal Boating made various efforts to keep the public informed about the program and to give them opportunities to comment on the control methods. A special meeting was held in August, before the spraying began, to explain the program to the public and the press. A few days before spraying was scheduled to start, we released information to the media on where the spraying would take place and when. From the time we began developing the program, members of the Cal Boating staff were readily available to answer questions from the public. We also spent a great deal of time talking to the press, explaining what the program did and did not entail.

We proceeded cautiously in devising a management program, some delays in implementing the control measures did result. I believe, though, that the steps we took to gain the confidence of the public were an important part of developing the program. No public program should operate in a vacuum. Nor should the managers of the program be unresponsive to the public. In the long run, we benefited from acting instead of reacting to the concerns people had about applying herbicides in the Delta.

This is by no means to say that we will not continue to have public concern over the use of 2,4-D or other herbicides in the Delta. The spraying program will receive criticism most likely from those opposed to the use of herbicides in any amount.

Our department, the Corps, and the other agencies involved in managing the waterhyacinth in the Delta will have to remain sensitive to these concerns and will have to continue to take extra steps to maximize environmental and health safeguards.

USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

Lake Champlain Aquatic Plant Control Program

by
COL W. M. Smith, Jr.*

A ten-year program to harvest aquatic nuisance plants from Lake Champlain, Vermont, began in 1982 with the removal of 76 acres of water chestnut and 150 acres of Eurasian watermilfoil from the lake. Removal was accomplished through mechanical harvesting supplemented by hand pulling. The density of water chestnut infestation made the total amount harvested somewhat less than had been anticipated. The total cost of this year's work was $171,855.

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USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

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by
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The aquatic growth control operations at the New Orleans District (NOD) consist of the Removal of Aquatic Growth Project (Operations and Maintenance funds) and the Aquatic Plant Control Program (Construction General funds). The section has 4 office and 23 field personnel. Control of floating and submerged aquatics was accomplished during FY 82. This report gives the status of the program during FY 82.

The Army Quarterboat Tambour was salvaged and all personnel reassigned to shore crew units during late FY 81 and early FY 82. This change resulted in 5 shore crew units being established at new duty stations. Presently, we have 11 two-man crews stationed at 8 duty stations. Overall, we have increased our control capabilities from 24,393 acres in FY 81 to 44,528 acres in FY 82. The herbicide 2,4-D was used during 95 percent of our operations and diquat, aquathol K, and cutrine plus were used during the other 5 percent.

Control operations were aimed mainly at waterhyacinth, but alligatorweed, pennywort, water paspalum, waterlettuce, and hydrilla were also sprayed.

A contract for aerial spraying resulted in 2,002 acres (included in above figure) being controlled during September 1982. Many waterways between Houma, Louisiana, and Morgan City, Louisiana, were sprayed for control of waterhyacinth during these 8 days of operations.

Water samples were collected by Corps office personnel and analyzed by the University of Southwestern Louisiana (contract) for 2,4-D residue. Samples were collected at various intervals of time after spraying occurred to correlate time to residue of herbicide. Results have shown that after approximately 10 days, traces of the herbicide remained.

Construction General funds were used under the cooperative program to fund the Louisiana Department of Wildlife and Fisheries (contract) for work-in-kind under the cost-sharing program. An audit was conducted and $110,000 was paid to the State for these services. The State sprayed 15,156 acres with these monies. Construction General funds were used by Corps crews to control 13,900 acres and Operations and Maintenance funds paid for control of 28,626 acres by Corps crews (figure excludes aerial spraying).

An Army Pesticide Applicators Training Session was conducted at the New Orleans District in May 1982 to certify Corps supervisors and applicators in the categories of aquatic pest control and industrial and rights-of-way pest control. The Aquatic Growth Control Section at the District attended the Louisiana Pesticide Applicators Association annual meeting in November 1982 for State

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pesticide applicators certification. Several Corps employees were recertified at that time.

During FY 82 the Large-Scale Operations Maintenance Test (LSOMT) conducted by the U.S. Army Engineer Waterways Experiment Station (WES) and funded by NOD on waterhyacinth in Louisiana was concluded. Biological agents were released and several reports by WES on this study were prepared and released.

The Aquatic Growth Control Section has been busy with an ongoing A-76 contract feasibility study which was initiated in July 1982. This study will determine if the NOD operations stay in-house or are awarded to outside contractors.

USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

North Central Division, St. Paul District

by
Wayne Koerner* and Bruce Sabol**

St. Paul District's Aquatic Plant Control Program serves the states of North Dakota, Minnesota, and Wisconsin. Of the three states in our area, Wisconsin has been the most active in seeking assistance.

The District's major effort in the program presently is a study for Buffalo Lake (Figure 1), a 2500-acre impoundment on the Upper Fox River located in Marquette County, Wisconsin. Since the removal of rough fish in 1970, various species of submerged aquatic plants have proliferated at nuisance level densities resulting in decreased recreational usage. Although Buffalo Lake is one of over 90 lakes in Marquette County, it accounts for almost 50 percent of the county's available surface area. The lake has a mean depth of 4.5 ft with a maximum depth of 8 ft. The lake would make a fine recreation attraction to nearby population centers if the submergent vegetative growth were controlled.

In the summer of 1974, the Buffalo Lake Improvement Association began a mechanical weed harvesting program to improve the lake. Five small cutting machines were used to cut the aquatic vegetation. In 1975, the University of

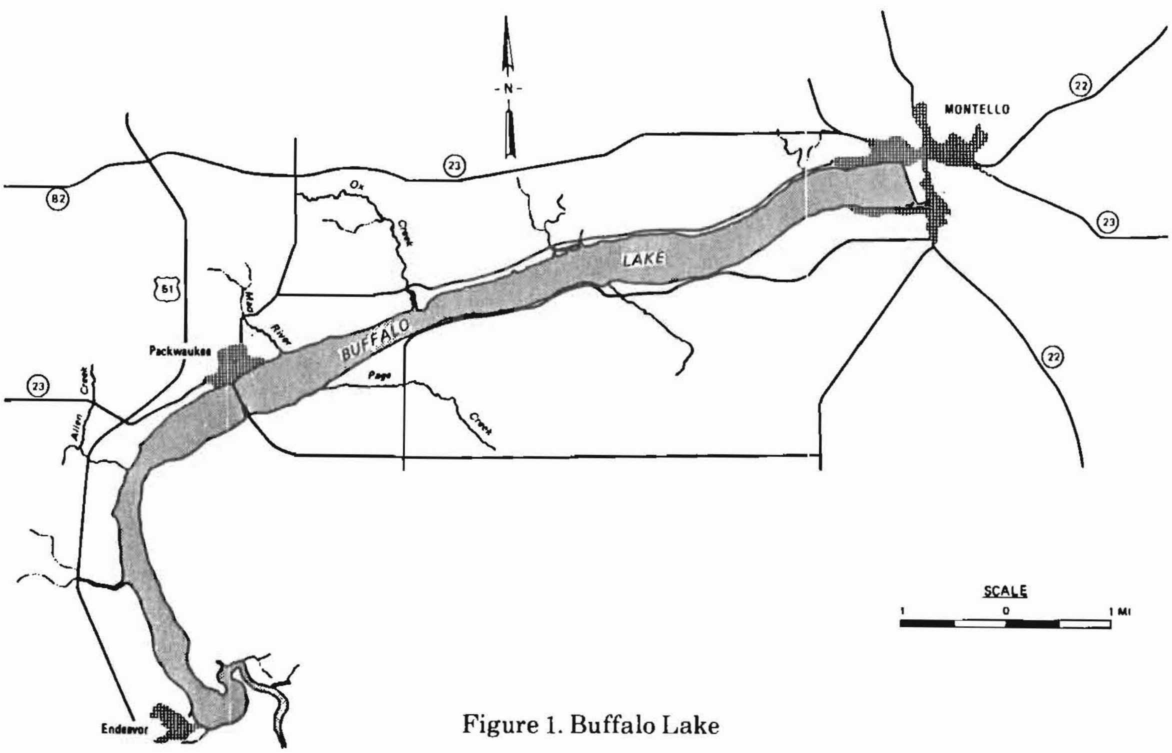

Figure 1. Buffalo Lake

* U.S. Army Engineer District, St. Paul; St. Paul, Minnesota.
** U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Wisconsin Mechanical Engineering Department designed a stationary removal system for floating vegetation. These harvesting efforts have been unsatisfactory and were terminated following the 1981 season.

It has been concluded by preliminary studies that the problem at Buffalo Lake was severe, a control program was needed, and the program would be economically justified based on preliminary estimates of costs and benefits. Mechanical and chemical control alternatives were considered for Buffalo Lake. Mechanical methods were selected because it was felt that chemical methods would be ineffective given the current pattern within the impoundment and the diversity of the aquatic plant community. The District subsequently requested the assistance of the U.S. Army Engineer Waterways Experiment Station (WES) to analyze selected mechanical control options using the HARVEST model developed at WES (Hutto 1981, 1982). The objectives of the study conducted by WES were to:

a. Quantitatively describe distributions of aquatic plants within a selected area of Buffalo Lake during early and late summer periods.

b. Predict the operational time required (using HARVEST) to conduct mechanical control operations with onshore disposal of aquatic plant material for:

   (1) Selected harvestable areas within the lake totaling approximately 20 percent of the lake area.

   (2) Two different harvesting systems, each with two different mixes of equipment.

   (3) Plant density conditions during early and late summer periods.

METHODS

During early summer and late summer periods, quantitative plant density distribution within the lake was estimated using aerial photographs and field sampling data obtained concurrently. A treatment area was selected based on lake usage considerations in which plants would be maintained below nuisance level densities. Plant density distribution estimates within this area, the locations of prospective shore disposal sites, and the performance specifications for several commonly used mechanical harvesting systems were used as inputs to the HARVEST model. The model was then run to simulate mechanical control during early and late summer periods. A flow diagram of this overall methodology is illustrated in Figure 2. Individual steps in this methodology are briefly described below. A more thorough discussion of the methods used and the results obtained may be found in Sabol (1983).

Plant density mapping

Aerial photography and associated ground truth data collection were used to map and quantify the distribution of aquatic plants; these procedures are discussed in detail in Leonard (1983). The aerial photography missions were flown during each summer sampling period producing true color and false color infrared imagery at a scale of 1:16,000, 1:8,000, and 1:4,000. Patches of aquatic plants visible from this imagery were traced directly onto a mylar base map (appropriate scale enlargement of U.S. Geological Survey 1:24,000 map of Buffalo Lake area).

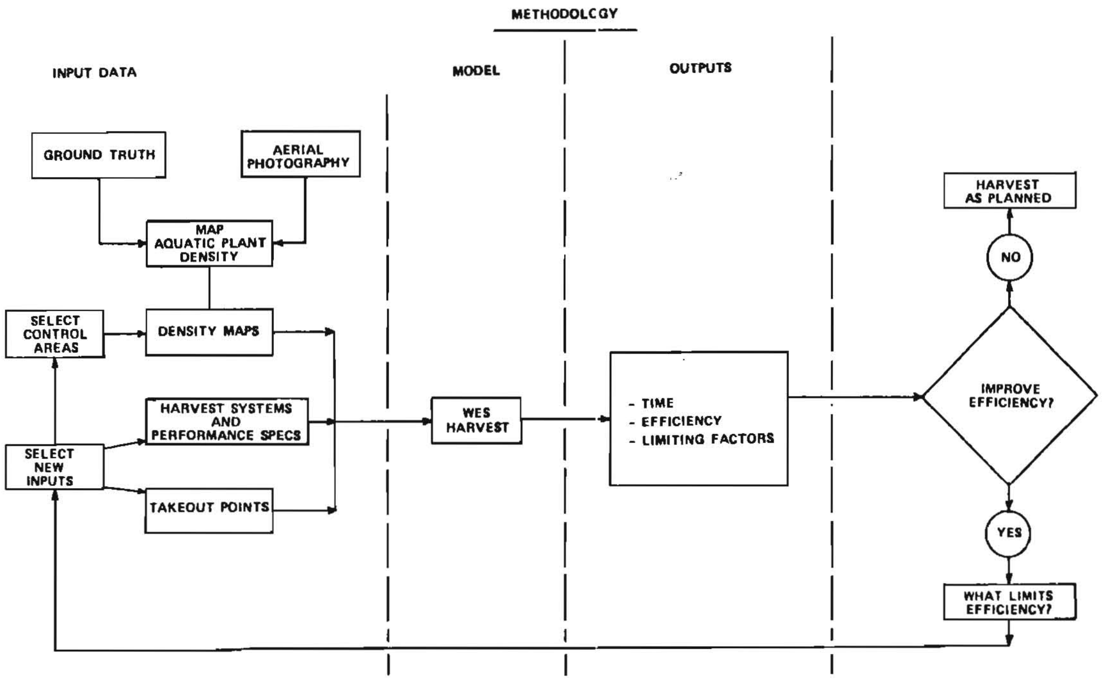

Figure 2. Overview of methodology

Ground truth sampling for quantitative plant densities was accomplished by collecting samples with the WES aquatic plant biomass sampler (Sabol 1983) using a modified stratified random sampling design. Fifteen evenly spaced transects perpendicular to the long axis of the lake were established between Montello and Packwaukee (Figure 1). A cluster of three randomly placed, full-depth samples was collected near the center of each visually distinct patch along each transect. Sample plants were weighed and converted to density units (mass/area). The three individual samples taken per patch were averaged to give an estimate of patch mean plant density.

Sampling transects and field sampling stations were located on each patch-mapped base map drawn for each sampling period. The entire area of each patch, delineated from the aerial photograph, was assumed to contain a uniform plant density equal to the mean of the individual samples collected from within that patch. In this way the plant density for the entire lake between Montello and Packwaukee was quantitatively estimated.

Delineation of harvest sites

The portion of the lake between Montello and Packwaukee was determined to be in the greatest need of mechanical control. Within this portion a pattern for the area in which plants would be maintained below the nuisance level density was selected without specific regard to the location of plant infestations. This area consisted of two 150-ft-wide swaths parallel to the shore on either side of the lake, 300 ft offshore; and 100-ft-wide channels perpendicular on the shore every 2000 ft which acted to connect the offshore swaths (Figure 3). This pattern covered 276 acres, approximately 19 percent of the lake area between Montello and Packwaukee.

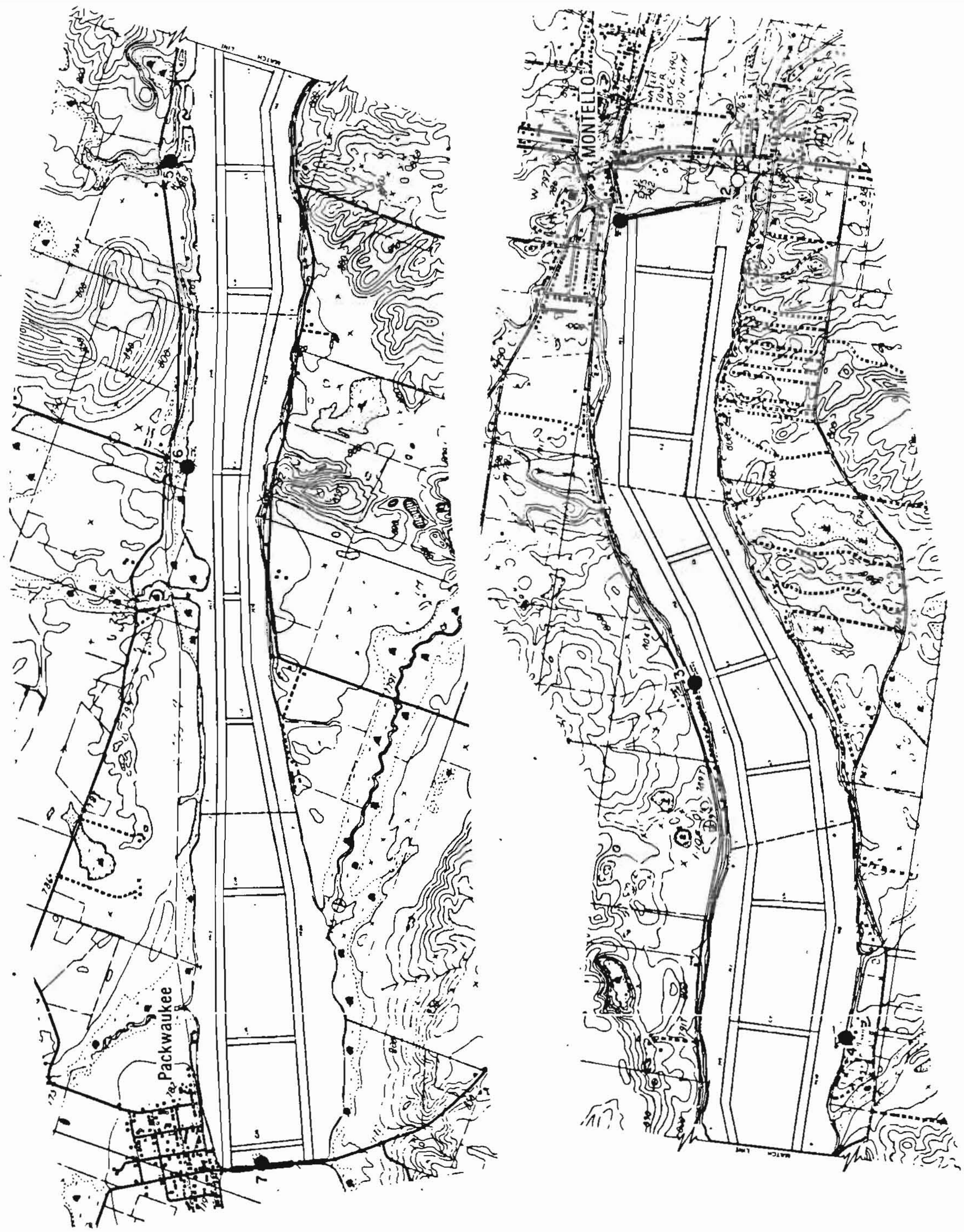

Figure 3. Harvesting treatment areas and disposal sites (black circles)

The next step toward delineation of the actual harvest sites was to locate shore disposal sites. Reconnaissance of the lake between Montello and Packwaukee revealed seven sites at which shore disposal and upland trucking of harvested plant material (if desired) would be physically possible. These sites are illustrated in Figure 3.

Based on the location of the nearest shore disposal site, the area to be harvested was divided into regions. Within each region site boundaries were drawn such that the distance to the regional disposal site from the closest corner of the harvest site was minimized. Using this procedure, 36 sites were established ranging in area from 0.7 to 21 acres (Figure 3).

To determine the actual sites to be harvested during each summer period, harvest site criteria were applied. These included:

a. Only areas with a density of 2 tons/acre or more would be harvested.

b. To minimize harvester turning time in relation to actual working time:

(1) Only sites greater than 300 ft in length would be harvested.

(2) The maximum length of a low density plant area within a plot would be 300 ft. For lengths longer than this, separate plots would be established.

Using these criteria, 25 sites containing a total of 165 acres with a mean density of 5.9 tons/acre were delineated during the early summer period, and 32 sites containing a total of 213 acres with a mean density of 7.9 tons/acre were delineated during the late summer period.

Digitized plant density grid arrays of each of these sites were generated from the lake-wide density maps and were used as input to HARVEST.

Selection of harvesting systems

Because of the large area to be harvested, it was determined that only large harvesting systems would be able to complete harvesting operations in a timely manner. There are a variety of harvesting systems commercially available; those manufactured by the Aquamarine Corporation have been the most widely used in this country (Cannelos 1981). The Aquamarine H8-650 and H-400 harvesters (largest harvesters manufactured by Aquamarine) and the Aquamarine T-650 transport unit were selected for simulation. Performance specifications, required as input to HARVEST, were determined from operational performance test data (Culpepper and Decell 1978).

Conditions simulated

For each actual harvest site delineated during each summer period, harvesting operations with onshore disposal were simulated using the Aquamarine H8-650 and the H-400 harvesters working alone and with the support of one T-650 transport unit. Only full-depth harvesting was simulated because of the extremely shallow and uniform depths in the lake.

MODEL PREDICTIONS AND DISCUSSION

Predictions

Total operational times divided into major functional components are summarized for early and late summer aquatic plant conditions and are presented in Figures 4 and 5, respectively. These predicted time components are:

WORK — Actual amount of time the harvester spends collecting plant material.

WAIT — Amount of nonproductive time spent by the harvester waiting for a transport unit or the amount of time the harvester spends transporting harvested material to shore when no transport unit is used.

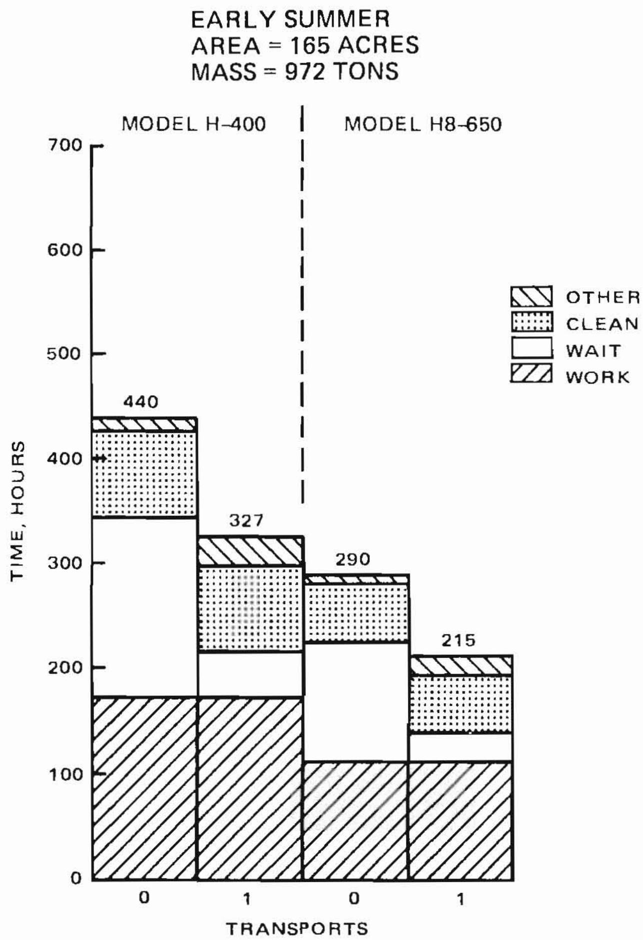

Figure 4. Predicted harvesting times for early summer

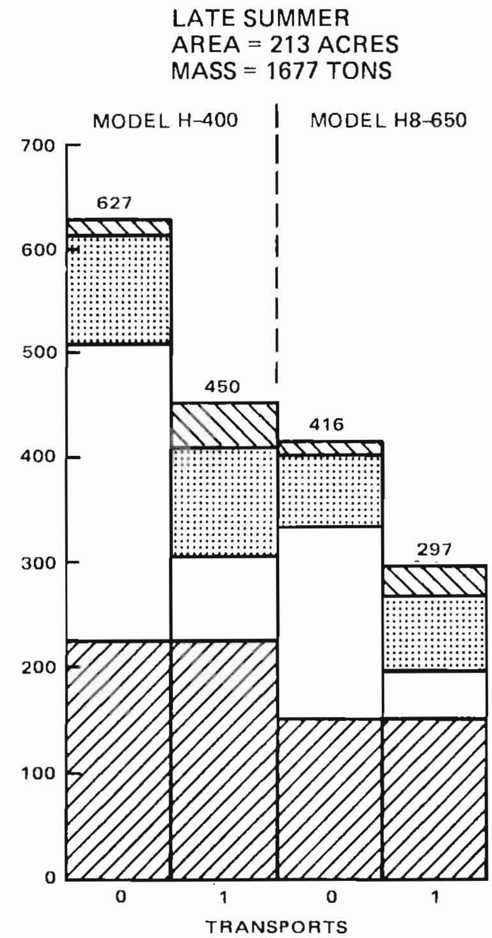

Figure 5. Predicted harvesting times for late summer

CLEAN—Amount of time the harvester spends making clean-up passes through the harvested site.

OTHER—Amount of time spent by the harvester performing other operations such as turning around between passes and off-loading onto a transport.

The operational times for both systems were less in early summer, when total harvestable mass was 972 tons, than in late summer, when total harvestable mass was 1677 tons. During both summer periods, the H8-650 working alone required less time to effect control operations than the H-400 harvester working with a transport unit. The addition of the transport considerably reduced total operational time for both systems during both periods. The most obvious strategy for improving operational efficiency is to find an economical means of reducing WAIT time.

At all simulated harvesting sites, the harvester operated at a maximum effective cutter width (cutter width minus 2 ft for overlap) and usually at full speed. Based on the cutter width and maximum collection rate inputs for the harvesters simulated, HARVEST would simulate the H8-650 and H-400 as running at full speed in all plant densities below 12.4 tons/acre and 13.9 tons/acres, respectively. Consequently, the simulation predicted the harvesters would run at full speed in all early summer harvest sites but would be required to reduce harvesting speed slightly in several of the late summer harvesting sites. At the plant density levels encountered in Buffalo Lake, maximum harvester working speed and cutter width are the factors that limited the harvester's plant collection rate.

HARVEST as an operational planning tool

The field-determined production rates cited by other authors using the same equipment (Cannelos 1981; Culpepper and Decell 1978; McGehee 1979; Wile and Hitchin 1977) are within the range of production rate values predicted for the respective individual harvest sites in this simulation study (Sabol 1983). The wide range of both the empirically determined and the simulated production rate values indicates the sensitivity of production rates to operational conditions such as plant density and disposal site distances. The use of "rule-of-thumb" production rate estimates for cost estimation (Sassic 1982) can result in making incorrect planning decisions because of overestimation or underestimation of costs. Additionally, such estimates do not provide an accurate basis for selecting the most cost-effective harvesting system from available options.

The most cost-effective mix of equipment can be determined from model outputs based on total hourly operational costs for each individual piece of equipment. As a purely hypothetical example, assume that the hourly rates for an H-400 harvester, an H8-650 harvester, and a T-650 transport unit are $80/hr, $110/hr, and $100/hr, respectively. Applying these rates to the harvesting times predicted for the early summer period (Figure 4) would result in the following total operating costs:

Harvester	*Number of Transports*	*Cost ($)*
H-400	0	35,200
	1	56,860
H8-650	0	31,900
	1	45,150

Using these assumed rates, the H8-650 harvester working without a transport unit would be most cost-effective. The important point in this particular example is that, although the addition of a transport unit increases harvesting system efficiency, this increase is proportionally less than the increased system costs due to the addition of a transport unit. Different hourly rates could obviously result in another mix of equipment being the most cost-effective.

Another aspect of HARVEST which makes it useful as an operational planning tool is the ease with which "what if" questions can be addressed. At present, only a single iteration of the model cycle (Figure 2) has been run. However, additional runs should be made to identify means of reducing operational costs. Such possible means include:

- Location or construction of additional disposal sites.
- Use of higher speed transport units.
- Use of in-lake disposal for harvesting areas a great distance away from the nearest shore disposal site.

Operational savings resulting from these practices would then be weighed against costs (if any) of implementing them. Total operational costs for all options would then be compared.

SUMMARY

Procedures for evaluating alternative aquatic plant mechanical control techniques have been described and demonstrated. The demonstration involved predicting the mechanical control system that was most cost-effective in harvesting submerged aquatic plants in Buffalo Lake, Wisconsin.

To maintain the treatment areas, i.e. the 276 acres of parallel boat trails and connecting trails, at below nuisance level plant densities would require harvesting 165 acres at an overall density of 5.9 tons/acre in early summer, or harvesting 213 acres at an average density of 7.9 tons/acre by late summer.

Total simulated system times required for the Aquamarine H8-650 and the H-400 harvesters working alone and with a T-650 transporter to perform the control operation are as follows (Figures 4 and 5):

Harvester	*Transports*	*Period*	*Total Hours*
H-400	0	Early summer	440
H-400	1	Early summer	327
H-400	0	Late summer	627
H-400	1	Late summer	450
H8-650	0	Early summer	290
H8-650	1	Early summer	215
H8-650	0	Late summer	416
H8-650	1	Late summer	297

REFERENCES

Cannelos, G. 1981. "Aquatic Plants and Mechanical Methods for Their Control," U.S. EPA Contract No. 68-01-5965, The Mitre Corp., McLean, Va.

Culpepper, M. M., and Decell, J. L., 1978. "Mechanical Harvesting of Aquatic Plants Field Evaluation of the Aqua-Trio System," Vol I and II, Technical Report A-78-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Hutto, T. D. 1981. "Prediction of Equipment Performance for Optimal Mechanical Harvesting of Submerged Aquatic Plants." *Proceedings, 15th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review,* Miscellaneous Paper A-81-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 197-213.

Hutto, T. D. 1982. "Simulation Modeling of Mechanical Control Systems," *Proceedings, 16th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review,* Miscellaneous Paper A-82-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 33-50.

Leonard, J. M. 1983. "Handbook for Obtaining and Using Aerial Photography to Map Aquatic Plant Distribution," Instruction Report (in press), U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

McGehee, J. T. 1979. "Mechanical Hydrilla Control in Orange Lake, Florida," *Journal of Aquatic Plant Management,* Vol 17, pp 58-61.

Sabol, B. M. 1983. "Biomass Sampling Techniques for Submerged Aquatic Plants," Aquatic Plant Control Research Program Information Exchange Bulletin (in press), U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Sabol, B. M. 1983. "Simulated Mechanical Control of Aquatic Plants in Buffalo Lake, Wisconsin," Miscellaneous Paper (in press), U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Sassic, N. M. 1982. "Harvesting: The Future of Aquatic Plant Control?" *Aquatics,* Vol 4, No. 1, pp 14-16.

Wile, I., and Hitchin, G. 1977. "An Assessment of the Practical and Environmental Implications of Mechanical Harvesting of Aquatic Vegetation in Southern Chemung Lake," Ministry of the Environment, Ontario, Canada.

USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

North Pacific Division, Seattle District

by
Robert M. Rawson*

The Seattle District became involved in aquatic plant control in 1977, when the Washington State Department of Ecology requested assistance in establishing a statewide program for the control of Eurasian watermilfoil. At that time, milfoil was disrupting water use in several high-use lakes in the Seattle area and in Banks Lake, a Bureau of Reclamation reservoir in eastern Washington. Milfoil also was affecting the tourist industry in British Columbia, due to infestations in the Okanogan lake chain.

Lake Osoyoos is the last lake in the Okanogan chain. Two thirds of the lake is in British Columbia and the downstream third is in Washington. Lake Osoyoos became a focal point for the early operational efforts because it drains into the Okanogan River, which in turn drains into the Columbia River. The Department of Ecology and Okanogan County worked in the lake to try to keep milfoil from becoming a major problem, prior to the approval of the Seattle District's operational program.

The District requested assistance from WES because of the unique situation in the Okanogan drainage area. We have funded WES research in prevention methodologies for four years, and have accumulated data on aerial surveillance, diver-operated suction dredges, fragment barriers, hand-harvesting, conventional herbicides, and herbicides used with inverting oils and polymers.

The District's Aquatic Plant Management Program was approved by the Office, Chief of Engineers, in June 1980. The ongoing work in Lake Osoyoos (2,4-D granular applications) and the operation of a fragment barrier in the Okanogan River were brought under the cost-share program and a new program was started in the Seattle area consisting of harvesting and the use of fiberglass bottom screens.

The milfoil status and the control work in the Seattle area have remained fairly constant in the 3 years our program has been in operation. The situation in eastern Washington, however, has changed very rapidly as milfoil populations continue to move downstream. Until 1980, milfoil was limited to Osoyoos Lake and the upper part of the Okanogan River. In 1980, pioneer colonies were discovered at the mouth of the Okanogan River, which resulted in a chemical treatment in 1981. Following the 1981 treatment, pioneer colonies were found downstream of Wells Dam. This year, we verified colonies down to Crescent Bar in Wanapum Reservoir, and observed many fragments downstream of that. Our main problem in fighting this spread of milfoil, besides the fragmentation of

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* U.S. Army Engineer District, Seattle; Seattle, Washington.

existing plants, is the lack of a chemical treatment option which could be used in flowing water. This is one problem currently being addressed by WES.

We also have a problem in the Pend Oreille River. Heavy milfoil populations were first discovered in 1979 in the two United States reservoirs. Downstream migration may not be a problem due to the nature of the two Canadian reservoirs and the deep intakes of the dams. In the past 2 years, however, milfoil has moved approximately 10 miles upstream. Although milfoil would not be able to bypass Albeni Falls Dam on the river, it could be carried around the dam by boat and could cause very serious problems in Pend Oreille Lake. We are considering a public information program to try to minimize risks from boaters.

Looking at the downstream progression in the Columbia River in the last 3 years, we foresee milfoil becoming established in all of the Columbia River reservoirs within the next few years.

Present milfoil populations in the Columbia River are small and predicting the future impact is difficult; but, we must assume that treatment will be required in some areas to maintain public use of the water. We are very short on treatment options and feel that the work being done to test herbicides with adjuvants is important. The District will continue to support the WES research program.

USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

North Pacific Division, Portland District

by
Fred Paveglio*

Eurasian watermilfoil *(Myriophyllum spicatum)* was positively identified from two locations in the Portland District during 1980. Milfoil growth had become a problem at Blue Lake, a 25-acre public recreation area, located 5 miles east of Portland. Blue Lake has been the recipient of Federal funds provided by the U.S. Environmental Protection Agency to control the aquatic plant infestation. To date, the program has failed to control milfoil. Specimens of Eurasian watermilfoil have also been collected from a network of sloughs on Sauvies Island, located just north of Portland on the Columbia River. No other infestations of milfoil in the Portland District have been documented at this time. Based on these milfoil infestations, a letter from the Oregon Department of Agriculture establishing themselves as a potential sponsor for the Aquatic Plant Control Program was received by the Portland District in May of 1980.

In order to determine the prevalence of milfoil infestations in the Portland District, a reconnaissance survey was initiated. A plant taxonomist from Oregon State University was contracted to conduct the survey. The following methods were used to evaluate the extent of milfoil infestation within the District:

a. A search for specimens of milfoil in major herbaria within the Portland District was made to determine when and where this species had been collected previously.

b. The major river systems including the Clackamas, Columbia, Cowlitz, Deschutes, John Day, Lewis, Rogue, and Willamette Rivers were spot checked for the presence of milfoil. In addition, localities of milfoil obtained through the herbarium search were checked.

c. Thirty-six County Extension Service agents in the State of Oregon were contacted by letter to see if they knew of any places where milfoil existed.

Specimens in the genus *Myriophyllum* were collected from 28 locations during the reconnaissance survey. Eleven of these specimens found in backwaters associated with the Columbia and Willamette Rivers as well as in isolated ponds and Corps reservoirs were identified by WES as Eurasian watermilfoil. The infestations had primarily impacted fish and wildlife habitat. No milfoil was reported by the County Extension Service agents.

The information obtained through the reconnaissance survey was included in a draft Reconnaissance report and sent to the Oregon State Department of Agriculture. Programs to control and prevent the spread of Eurasian watermilfoil in the Pacific Northwest have met with limited success. Chemical treatment is not readily accepted and methods for treatment of milfoil in flowing waters are

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* U.S. Army Engineer District, Portland; Portland, Oregon.

currently being explored. In light of the problems associated with the control of Eurasian watermilfoil in the Pacific Northwest, the following recommendations are made in the draft Reconnaissance report:

a. The Corps of Engineers should remain in an alert posture and continue a low level monitoring plan to survey and inventory areas that could be infested by milfoil and could create environmental and economic damage in the Portland District.

b. The findings should be reassessed as required to determine if an aquatic plant control program should be initiated.

c. The State should assist the Corps in carrying out the monitoring plan by indicating areas to be inventoried and by sending voucher specimens from infested waters located during their surveys to the Corps for positive identification.

Aquatic Plant Control Program funds received by the Portland District for FY 82 were used to initiate the monitoring plan proposed by the Reconnaissance report. The Portland District contracted WES to assist in the development of a rapid identification methodology for Eurasian watermilfoil.

The following methods were used to rapidly assess the degree of Eurasian watermilfoil infestation in the Willamette and Lower Columbia Rivers.

a. The rivers were surveyed from light aircraft flown at approximately 800 ft.

b. Plant beds observed were noted on aerial photos with a scale of 1″ = 500′.

c. Representative sites from each river were selected and checked by boat to obtain species composition. Each milfoil infestation was ranked as having a light, medium, or heavy infestation.

Ninety locations were identified during the aerial survey that appeared to have submerged aquatic plants on the Willamette River. Four areas representative of the river were identified and sampled by boat to obtain species composition. These four areas contained 40 of the total 90 locations identified from the air that appeared to support aquatic plants. Of the 40 areas sampled, 19 contained Eurasian watermilfoil. The most dense beds of Eurasian watermilfoil were located at the upper reaches of the river. Eurasian watermilfoil was found growing mainly in oxbows and sloughs. However, specimens were collected from shallow water near the bank of the main channel at two locations. The locations occupied by milfoil impact important areas for fish and wildlife in two ways: (1) by usurping space that could be occupied by native plants; and (2) by dominating shallow productive areas. No commercial or recreational boating was impacted by the milfoil. However, access for sportfishing boats was limited in several of the backwater areas.

On 145 miles of the Columbia River, 12 areas were identified that appeared to support aquatic plants. The 12 areas were checked by boat to obtain species composition. Native watermilfoil (*Myriophyllum exalbecens*) was identified at five of the locations. No Eurasian watermilfoil was collected from the Columbia on this survey.

The information obtained from the monitoring plan initiated by the Portland District clearly identifies a growing problem created by Eurasian watermilfoil. The impact of milfoil thus far has been on fish and wildlife habitat with the exception of Blue Lake. The results of our monitoring program have been presented to the State Department of Agriculture.

The State of Oregon has limited funds and personnel, which prohibits their entering into the Aquatic Plant Control Program at this time; however, the Department of Agriculture supports our recommendation to continue the monitoring plan. In addition, a committee composed of all State agencies with authority over state waters has been appointed to coordinate with us on our monitoring program. The information obtained by the monitoring program will facilitate the development of an aquatic plant control program if, at a later date, Eurasian watermilfoil reaches a problem level within the Portland District. In the interim, we hope that the research to develop biological control of milfoil continues and an acceptable and effective method of control is developed before Eurasian watermilfoil reaches a problem level in the Portland District.

USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

Aquatic Plant Control Operations Support Center

by
James T. McGehee*

The Aquatic Plant Control Operations Support Center (APCOSC) was formally established in fiscal year 1981. The Center is located within the National Resource Management Section, Construction-Operations Division of the Jacksonville District.

CENTER RESPONSIBILITIES

The policies, functions, and procedures for the use of Center services are set forth in Engineer Regulation 1105-2-811. The regulation describes the relationship between the APCOSC; the Office, Chief of Engineers (OCE); and the U.S. Army Engineer Waterways Experiment Station (WES) and establishes the following functions of the Center:

a. Provide technical guidance to Corps Districts in planning phases of aquatic plant control programs.

b. Provide technical guidance to Corps Districts in the operational phases of aquatic plant control programs.

c. Provide technical expertise and/or operational personnel and/or equipment to respond to localized short-term critical situations created by excessive growths of aquatic plants.

d. Provide assistance to OCE for the training and certification of Corps application personnel.

e. Upon request, assist WES in field application and evaluation of newly developed control techniques or procedures.

f. Provide assistance to OCE in the development of a comprehensive Corps-wide aquatic plant control program.

FISCAL YEAR 1982 ACTIVITIES

Table 1 provides a listing of the services performed by the Center and the types of users to which these services were provided during FY 82. A total of 161 requests for assistance were received and responded to by the APCOSC. This represents an increase of 97 requests or 151 percent over the FY 81 effort. Since established, the Center has responded to a total of 242 requests. During FY 82, Corps Districts accounted for 49 or 30.4 percent of the total services provided. The next most frequent user was WES with 28 or 17.4 percent of the services. On a cumulative basis, 94 or 58.4 percent of the requests from non-Corps organizations came from private industry with 25 requests or 15.5 percent of the total. The most

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* U.S. Army Engineer District, Jacksonville; Jacksonville, Florida.

Table 1
Aquatic Plant Control Operational Support Center
Fiscal Year 1982
Support Assistance Through 30 September 1982

Type Assistance	Corps *OCE*	*WES*	*Div.*	*Dist.*	*Other Federal*	*Other Country*	*State Local*	*Indus-try*	*Priv-ate*	*Total*
Planning	9	12	1	22	5	0	2	5	0	56
Operations	3	10	2	22	10	2	13	18	3	83
Research	0	6	0	1	0	0	3	2	3	15
Training	0	0	2	4	1	0	0	0	0	7
Totals	12	28	5	49	16	2	18	25	6	161

frequently requested service was operational assistance. There were 83 operational requests or 51.5 percent of the total.

There were 56 planning services performed during the year. The services ran from simple explanations of the aquatic plant control planning process for Districts new to the program to detailed assistance in the formulation of planning documents. Significant activities included onsite problem identification and program design recommendations for Sacramento and Wilmington Districts. The Center also worked with the Sacramento District and OCE in reducing the documentation required to start an operational program in California.

Operationally oriented services accounted for the largest portion of the work for the year. The Center collected 43,500 alligatorweed flea beetles and shipped them to six separate organizations. The beetles are not overwintering in large numbers in the northern range of alligatorweed enabling an early start in control. Users have reported faster and better control of the plants by reintroduction of the insects from south Florida at the very beginning of the growing season in their area. The Center provided significant operational recommendations to the Charleston District and was able to release a small amount of funds for the District to begin an operational program. The remainder of the operational services consisted of providing information or evaluations on the potential use of specific chemical, biological, or mechanical control methods.

Research services primarily consisted of providing background information to researchers on current or past operational procedures or reviewing reports and proposed procedures from an operational standpoint. The most significant research assistance item was performed for the WES in California. The Center worked closely with WES in designing and carrying out an operational management test for the State of California in the San Joaquin Delta. Personnel and equipment were mobilized to the State and waterhyacinth plants were treated with 2,4-D and diquat. The WES and APCOSC complemented each other in delivering an exceptionally successful test of waterhyacinth control and herbicide residues as a starting point for operational control of waterhyacinths in the Delta.

The Center conducted two 20-hr pesticide application training courses for the Lower Mississippi Valley Division. A total of 34 District personnel attended the courses in which all categories of pesticide application were taught. At the conclusion of the training many of the personnel successfully completed the State certification examination for their respective states.

Assistance was provided to OCE during the year on 12 occasions. The services included review and/or recommendations on general operational situations in other District programs, and operational review of reports. The Center has proposed and is cooperating with OCE in the development of revised planning procedures that may reduce the time, funding, and reporting requirements in the planning phases of new aquatic plant control programs.

STATUS OF THE APCOSC

The original estimated exenditure for FY 82 was $60,000. Actual cost for the year was $32,060. The estimate was based on the filling of two additional personnel spaces to fully staff the Center. Only one of the spaces was filled, late in the year. These funds are to cover personnel salaries for time expended for minor services and general maintenance of the Center functions. All travel and significant commitment of manpower for services were paid for by the using Corps elements.

Based on the number and types of requests received during FY 82, it appears that the APCOSC is continuing to perform the function for which it was established. During FY 82, the APCOSC was able to conduct three major efforts which required the expenditure of significant manpower and resources. These efforts, combined with the reduction of District field personnel, increased the need for additional administrative personnel in the District and an additional space was allocated to the APCOSC during the District reorganization. This should allow the APCOSC to at least function at the FY 82 level without neglecting the Jacksonville District aquatic plant control program. The cooperation which existed between WES and APCOSC during the field test in the San Joaquin Delta in California demonstrated that the two organizations can function as envisioned during the establishment of the APCOSC. Such cooperation should greatly expand the Corps' ability to respond to the increasing nationwide aquatic plant program.

PROBLEMS AND CORRECTIVE ACTIONS TAKEN OR PROPOSED

The major problem affecting the APCOSC and the overall aquatic plant control program remains the same as last year: funding. North Carolina, South Carolina, Delaware, California, Texas, Alabama, and several other states now have established hydrilla infestations. North and South Carolina have taken aggressive approaches in addressing the hydrilla program; however, to date, these areas have not been funded in the Corps' aquatic plant control budget. The Jacksonville District has been able during the past two fiscal years to release funds for limited control of vegetation in Lake Marion, S.C.; however, these funds have had minimal impact on the overall program.

The spread of hydrilla and Eurasian watermilfoil is now seriously limiting the Corps' ability to adequately support both the operational and research programs under the $5.0 million limitation of Public Law 89-298. Since this funding ceiling was established when waterhyacinth was the major problem species in the United States, the Corps would be fully justified in actively pursuing with both the Office of Management and Budget and Congress an increase in the $5.0 million limitation and full funding to the limit of the increased cap.

USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

South Atlantic Division, Jacksonville District

by
Joseph C. Joyce*

AUTHORIZATION

The Jacksonville District conducts aquatic plant control operations under three separate authorizations:

a. The River and Harbor Act of 1899 - Chapter 425; Section I of this act is also known as the Removal of Aquatic Growths Project (RAGP) and provides for the control of aquatic weeds in Federally authorized navigation projects such as the St. Johns River (Florida) or the Mississippi River. The RAGP is limited to the five Gulf Coast states of Florida, Alabama, Mississippi, Louisiana, and Texas. This program is funded 100 percent by the Corps of Engineers Operations and Maintenance General budget and there is no funding ceiling.

b. Public Law 89-298, 1965; This act is also known as the Aquatic Plant Control Program (APCP) and provides for the control of all nuisance species in public waters of the United States for the purpose of navigation, flood control, agriculture, public health, recreation, or any other waterway use. The APCP is a cooperative program and the costs are divided by the Federal (70%) and local (30%) governments. The program is funded by the Corps of Engineers Construction General budget and has an annual funding ceiling of $5.0 million.

c. Project operations and maintenance—Under the Corps' authority to operate and maintain authorized water resource development projects, such as Lake Seminole or Lake Lanier, the Corps can conduct aquatic plant management activities on vegetation that interferes with project purposes. These operations are funded 100 percent by the Corps under the operation and maintenance budget for each project.

MAJOR PROBLEM SPECIES

The major problem species which required control efforts during FY 82 were:

Emersed species

Cattail—*Typha* spp.
Giant cutgrass—*Zizaniopsis miliacea*
Paragrass—*Panicum purpurascens*
Torpedograss—*Panicum repens*
Water paspalum—*Panicum fluitans*
Spatterdock—*Nuphar luteum*

Floating species

Waterhyacinth—*Eichhornia crassipes*
Waterlettuce—*Pistia stratiotes*
Common duckweed—*Lemna minor*
Giant duckweed—*Spirodela polyrhiza*

Submersed species

Eurasian watermilfoil—*Myriophyllum spicatum*
Brazilian elodea—*Egeria densa*
Hydrilla—*Hydrilla verticillata*
Cabomba—*Cabomba* spp.
Pondweed—*Potamogeton* spp.

* U.S. Army Engineer District, Jacksonville; Jacksonville, Florida.

FISCAL CONSTRAINTS

Funding is the only real constraint for aquatic plant management. Estimated costs (dollars per acre per treatment) for the various control methods are shown below. It is beyond the scope of this discussion to explain each of the herbicides,

Species	*Chemical*	*Mechanical**
Floating:		
Waterhyacinth	35-50	30-7,000
Waterlettuce	50	-
Emergent:	75	30-88
Submersed:		
Hydrilla	115-250	30-630
Milfoil	115	30-630

* Depends upon plant density and disposal method. Acceptable levels of control usually are at the upper end of cost range.

application techniques, or types of mechanical operations utilized. However, chemical control is the predominant method of control in the Southeastern United States, probably accounting for over 95 percent of total expenditures for aquatic plant control activities. Mechanical control has not gained widespread acceptance due to high costs, lack of adequate disposal methods, lack of development of profitable by-products, lack of adequate operational capability, and other logistical considerations. No specific operational costs are available for biological control programs. However, bio-control generally has high initial research and development costs in order to identify, isolate, and clear the bio-control agent for release into the United States.

As noted earlier, the Corps of Engineers Aquatic Plant Control Program is currently legislatively limited to $5.0 million annually. When this funding limit was established, the most severe nationwide aquatic plant problem was waterhyacinth and the $5.0 million would have been adequate to fund the required control operations. However, at the present time, hydrilla has become a serious problem in the Southeast and Southwest, and is spreading northward. Simultaneously, Eurasian watermilfoil has rapidly expanded in the Northwest, Midwest, Northeast, and Midsouth regions. The expansion of these latter two species has rendered the $5.0 million funding limit unrealistic. Legislation has been introduced in recent years to raise this funding level; however, to date, nationwide congressional support has not been great enough to increase the limit.

MAGNITUDE OF CONTROL PROGRAM

Tables 1 and 2 provide a summary of the FY 76-82 acres treated and herbicide usage, respectively, by the public agencies in the State of Florida. Of significant note is the fact that, even though the number of species treated has increased, the total acreage treated has decreased. This trend is especially true of floating species such as waterhyacinth and is due to adoption of a maintenance control program developed by the Jacksonville District. This program manages the

Table 1

Acres of Vegetation Treated
Under the Corps' Program

Plant Type	*FY-76*	*FY-77*	*FY-78*	*FY-79*	*FY-80*	*FY-81*	*FY-82*
Floating	71,923	57,887	59,251	46,924	45,962	28,320	30,680
Hydrilla	--	--	6,748	11,754	14,290	11,864	10,218
Minor plants	--	--	30	265	973	1,637	2,380
Total	71,923	57,887	66,029	58,943	61,225	41,821	43,278

Table 2

Jacksonville District
Aquatic Plant Control Program

Herbicide	*FY-82*	*FY-81*	*FY-80*	*FY-79*	*FY-78*	*FY-77*	*FY-76*
2,4-D Amine	19,120	15,189	17,220	17,342	20,872	33,278	39,281
Diquat	9,897	13,867	17,761	18,349	5,626	--	--
Copper Complex	12,306	24,840	41,841	49,937	18,340	–	--
Hydrothol 191	1,428	6,601	13,528	4,270	50	–	--
Hydout (lb)	11,926	5,100	156,875	482,760	134,350	–	--
Aquathol - K	35,701	19,381	13,567	8,205	--	--	--

infestation of a nuisance species at the lowest level possible; therefore, less herbicide is required and less decaying vegetation is deposited in the hydrosoil. Table 2 illustrates this reduction in the amount of herbicide usage.

All of the herbicides utilized in the program are labeled for use in public waters by the Environmental Protection Agency. However, each of these herbicides has various use restrictions and the applicator is responsible for making a reasonable effort to notify potential water users of these restrictions. In order to meet this requirement, the Jacksonville District utilizes public notices in the newspaper and warning signs prior to herbicide treatments.

OPERATIONAL CONSIDERATIONS

There are various operational considerations which are routinely evaluated prior to aquatic plant control operations. These are generally grouped into five broad categories as discussed below:

a. ***Use of the water body.*** The primary consideration is that the control method does not significantly interfere with known major uses of the water body. This is particularly true with herbicidal control due to label restrictions but would also be true of mechanical boom systems which would interfere with navigation.

b. ***Type of plant.*** The plant species, its growth potential, and its susceptibility to the various techniques will determine the methods used and the frequency of control efforts.

c. ***Water quality.*** Water quality is important due to its effects on the efficiency of herbicides and as it is affected by the decomposition of the decaying vegetation or mechanical harvester generated turbidity. The primary water quality constituents which the applicator should consider are hardness, turbidity, temperature, and dissolved oxygen.

d. ***Physical conditions.*** Natural or man-made obstructions, access points, water flow, depth, mechanical disposal areas, and weather can affect the logistics of the control techniques.

e. ***Fish and wildlife.*** Endangered species present, spawning seasons, fishing tournaments, and hunting seasons will affect the intensity and timing of control programs.

In 1976, the Jacksonville District developed a management strategy for addressing the above concerns in order to control waterhyacinth in the St. Johns River. This control strategy was published in the WES Miscellaneous Paper A-77-3.

PROGRAM PROJECTIONS

Due to the biological nature of the aquatic plant problem and the exponential growth rate of the main nuisance exotic species, a dependable sustained base level of funding is required to maintain control. Fluctuations in the level of control caused by budget reductions will allow these problem species to expand to levels which cause economic and environmental stress. The continued success of the Corps' operational aquatic plant control program is dependent upon a consistent funding policy and continuation and expansion of the maintenance control project.

USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

South Atlantic Division, Wilmington District

by
Richard Jackson*

The Wilmington District's aquatic plant control program has been dormant for the last 5 to 7 years. We originally entered into a contract with the State of North Carolina in 1960 to control alligatorweed. In 1970, the program was amended with a supplement to the State Design Memorandum to include control for Eurasian watermilfoil. Within the last few years, several lakes in the William B. Umstead State Park just west of Raleigh, N. C., developed a severe waterweed problem. The original identification of the plant in question was Brazilian elodea. As you may have guessed by now, it was later correctly determined to be hydrilla. In response to this discovery, the State established an ad hoc hydrilla committee to investigate what hydrilla is and what State agencies and other efforts could be focused on the problem. As a result of the report of the ad hoc committee, the Governor of the State of North Carolina established an Interagency Council on Aquatic Weed Control with Dr. Jay Langfelder, Assistant Secretary for Natural Resources and Community Development, as its chairman. Three other committees were established under the Interagency Council: an Education Committee headed by Dr. Joe Phillips, a Control Committee headed by Dr. Greg Smith, and a Research Committee headed by Dr. Jim Stuart. The Governor also designated the Office of Water Resources of the N. C. Department of Natural Resources and Community Development as the lead agency for the State in coordinating with the Corps of Engineers.

In response to the request from the State to participate in their aquatic plant control program for the control of hydrilla, the Wilmington District began a supplement No. 2 to the State Design Memorandum and an environmental assessment. In January 1982, we completed our assessment and the finding of "no significant impact" was signed on 23 September 1982 and the supplement for the Design Memorandum was approved by the Chief's Office on 4 October 1982. Our program is ready at this time, lacking only Federal funds. The State has been more than helpful in this regard. They have cost-share money in hand, both for FY 82 or 83, and they have also notified the North Carolina Washington office of an interest in supporting Senate Bill 2050 to increase the ceiling on the Aquatic Plant Control Program.

There are two issues that I would like to mention to this group. First, since there is a ceiling on the amount of money available in any given year and since more states are wishing to take advantage of the program, we will have to look more carefully at how much of our resources are used for research as opposed to treatment. It seems to me that a high priority must be put on actual control.

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* U.S. Army Engineer District, Wilmington; Wilmington, North Carolina.

Secondly, I think the Corps of Engineers needs to be sensitive to the concerns of health officials when proposing chemical treatment. As new areas of the country become involved, I think, we will see a lack of ready acceptance of many of the chemicals that are commonly used in the deep south. I don't believe that we can continue to simply refer to the EPA-approved label as being sufficient. For example, we know of 12 persons in the Raleigh area that have ecological illness. They are vitally concerned about what our program may do their health. We must be able to respond to these concerns in a professional, responsible manner if we expect to gain acceptance.

USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

South Pacific Division, Sacramento District

by
Keith Steele*

Streams draining about one third of California (approximately 65,000 square miles) flow through the Sacramento-San Joaquin Valley and Delta. The Sacramento River flowing from the north contributes about 80 percent of the flow, and the San Joaquin River from the south about 15 percent. Over the years, development of water resources in the valley has significantly altered the natural flow. The primary change has been reduction of peak winter and spring flows and the augmentation of low summer and fall flows. This regulation has created a relatively stable freshwater environment in the Delta.

The Delta's 60 major tracts and islands separated by 700 miles of waterways are developed primarily for agricultural purposes. Many of the meandering sloughs and waterways have aesthetic qualities which make the Delta attractive to various boating and other recreational uses. Since the Delta is located near large population centers such as San Francisco, Sacramento, and Stockton, there are many people using this valuable resource. Water-dependent visitor days in the Delta in 1980 were estimated to be over 5.5 million. Most of the waterways are only suitable for shallow draft and small craft operation since depths during low water periods range from 5 to 10 ft. The Delta climate is typically warm and rainless in the summer with cool, moderately wet winters.

Waterhyacinth was observed in California as early as 1904 in Babel Slough about 10 miles southwest of Sacramento. Reports of hyacinth during the 1930s and 1940s recorded the plants in the Merced and Fresno County areas in streams tributary to the San Joaquin River to the south of the Delta. In 1972 local interests expressed concern about waterhyacinth in the Merced River as a potential flood problem. Although hyacinth has been in the Delta for many years, the amounts have only increased significantly in the past few years. The most severe infestation was in the fall of last year when the plants infested about 200 miles of waterways.

Marinas, boat harbors, and other facilities are numerous in the Delta. Over 150 commercially operated marinas provide about 10,000 dock slips for a wide variety of boats. In addition, there are about 180 boat launch lanes. All the recreation activities such as boating, fishing, and waterskiing are adversely affected by the hyacinth. The plants create safety hazards to boaters and obstruct water diversion and pumping facilities. Together the Bureau of Reclamation and the State of California deliver over 5.5 million acre-feet of water annually to central and southern California for agricultural, municipal, and industrial purposes. The Bureau has expended hundreds of thousands of dollars the past few years removing the plants at their Delta-Mendota Canal pumping facility.

* U.S. Army Engineer District, Sacramento; Sacramento, California.

The Sacramento District became actively involved in the Delta hyacinth problem in the fall of last year when the California Department of Boating and Waterways (CDBW) requested our assistance. Since that time considerable coordination has taken place between the public and the various Federal, State, and county agencies. Starting in January of this year, assistance from the WES and the Jacksonville District was initiated. WES recommendations for an interim control program were provided to the CDBW in May. These recommendations included mechanical, biological, and chemical methods of control. California legislation passed in June provided $125,000 to the CDBW for use in hyacinth control for the Delta. However, the political climate in the State administration has been very cautious in using chemicals to combat biological problems. To help expedite the implementation of the chemical portion of the control program, the CDBW has contracted with WES for assistance. In September and October, WES, assisted by Corps personnel from the Jacksonville District, used 2,4-D and diquat herbicides to spray about 50 acres of hyacinth. They plan to continue with this method in March-April of next year.

WES is also assisting the U.S. Department of Agriculture with biological control methods. The weevil (*Neochetina bruchi*) has been established at several locations in the southern Delta.

The Sacramento District has requested authority and funding for assistance from the Federal Aquatic Plant Control Program. Although approval has been received for the Sacramento District to prepare a State Design Memorandum and Environmental Impact Statement, funds for these tasks were not available. It is not expected that Federal funds will be made available before FY 84.

USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

South Pacific Division, Los Angeles District

by
Lynn Almer*

The Los Angeles District (LAD) is one of three Districts under the South Pacific Division. Our boundaries include southern California, southern Nevada, the southwestern corner of Utah, all of Arizona except the northeastern corner, and the western portion of New Mexico.

LAD has been only marginally involved in the Aquatic Plant Control Program. Our involvement to date has been to contact the State of Arizona and several agencies in southern California in order to identify lakes with aquatic weed problems.

The Arizona Game and Fish Department (AGFD) has identified 32 lakes within the state as having aquatic weed problems. Eight of these lakes are under the ownership of the State of Arizona. The dominant weed problem is watermilfoil. Heavy aquatic weed growth has resulted in reduced recreational use of the lakes, especially for sportfishing access. Aerial photography and background water quality data are available for nearly all of the lakes. The AGFD has purchased a harvester for mechanical clearing of the lakes. The harvester was first used this past summer and it is viewed as a short-term response to the aquatic weed problem. The AGFD has requested assistance from the District in their pursuit of a long-term solution.

Several State and county agencies were contacted in an attempt to identify lakes with aquatic weed problems in the southern California area. None of the agencies contacted had a comprehensive view of the problem. Several lakes were identified, of which two were being cleared (one mechanically, one chemically) and one was under study. Mechanical means are being used for weed removal at Big Bear Lake where milfoil, coontail (*Ceratophyllum demersum*), and smartweed (*Potamogetan amphibium*) are the dominant aquatic weed problems. The chemical diquat is being used at Lake Gregory for weed control. The State of California and the City and County of San Diego are conducting ongoing studies at Lake Murry where hydrilla is the dominant weed problem. It appears that no one agency in the southern California area has had funds to identify all lakes with aquatic weed problems; as a result, the extent of the aquatic weed problem in southern California is unknown.

Upon identification of the presence of lakes in Arizona and southern California with aquatic weed problems, a budget was prepared requesting funds for preparation of reconnaissance reports (one for Arizona, and one for Southern California). Funds are needed if the Los Angeles District is going to work with other agencies in identifying and combating the aquatic weed problem.

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* U.S. Army Engineer District, Los Angeles; Los Angeles, California.

USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

Southwestern Division, Tulsa District

by
James R. Skaggs, Jr.*

The Tulsa District has two projects with infestations of Eurasian watermilfoil (*Myriophyllum spicatum*): Pat Mayse Lake and Robert S. Kerr Lock and Dam and Reservoir. The infestation on Robert S. Kerr is considered to be insignificant since there is no indication at this time that the plant will return to the previous large acreage or create the problems that were experienced in 1976 through 1979. The infestation at Pat Mayse Lake, on the other hand, has caused serious problems creating conditions necessary for a control program.

Pat Mayse Lake, located in northeast Texas, has 6000 surface acres, excellent water quality, and is utilized by the City of Paris, Texas, for domestic water supply. Eurasian watermilfoil was first discovered in Pat Mayse in June 1978 and involved approximately 50 acres of infestation. Subsequent surveys disclosed a steady expansion of the plant within the lake. However, mild weather conditions experienced during the winter of 1980-81 resulted in a veritable explosion of the watermilfoil. By the spring of 1981, approximately 400 acres of the plant was present. On 5 July 1981, a drowning was directly attributed to the Eurasian watermilfoil at the Lamar Public Use Area. By the fall of 1981, approximately 1000 acres of the plant existed, creating serious access and safety problems. Of primary concern were the impacts on public use areas, quasi-public use areas, and the City of Paris water intake structure. Approximately 90 percent of the recreational shoreline became inaccessible, all seven swimming beaches were closed, and three of the project's eight boat ramps became unusable.

As a result of the adverse impacts associated with the infestation, it became apparent in the spring of 1981 that an aquatic plant control program should be initiated. However, due to a shortage of funds, Tulsa District was forced to delay treatment until 1982. A chemical control program was developed and scheduled for 1982 with aquathol, a granular formulation of the dipotassium salt of endothall, the herbicide selected. The preferred chemical 2,4-Dichlorophenoxy-acetic acid (2,4-D) was not selected due to the objections expressed by both the Texas Department of Health and the Campbell Soup Company, a 50 percent water user in the City of Paris. Treatment was scheduled to begin 14 June 1982, which coincided with the time the Campbell Soup plant would be closed 2 weeks for annual maintenance. Closure of Campbell Soup enabled the City of Paris to utilize the city's reserve water supply, Lake Crook, during the treatment period. The Aquathol label requires that use of treated water for domestic or irrigation purposes be delayed a minimum of 7 days. One week prior to the scheduled treatment date, heavy rains occurred resulting in inundation of the watermilfoil

*U.S. Army Engineer District, Tulsa; Tulsa, Oklahoma.

by 10 ft of floodwater. This resulted in cancellation of the control program since treatment could not be conducted within the referenced critical 2-week time frame.

Shortly after cancellation of the 1982 program, the decision was made to initiate action for an Emergency Exemption Permit for the treatment program in 1983. It was apparent that the 2-week time frame in June was too restrictive and that the permit was needed to provide more flexibility. North Texas State University (NTSU) was contracted to collect data in support of the permit application. In this study, vegetative mapping, aerial photography, biomass measurements, and horizontal dispersion measurements were obtained. In addition, NTSU did some limited work on the biodegradation rate of endothall utilizing water from Pat Mayse Lake.

The NTSU study revealed that high water levels experienced throughout May, June, and July 1982 had a significant impact on the plant. Biomass was reduced by approximately one third, stress growth was apparent, and increased fragmentation of the plant was evident. In August 1982, when the lake level returned to normal pool evaluation, there was approximately 500 acres of watermilfoil present. However, the effects of high water on the watermilfoil infestation appear to be only temporary in nature since the reduction in acreage can mainly be contributed to reduced biomass and shoot density. Based on data collected from the study, it was shown to be highly improbable that detectable levels of endothall could reach the City of Paris water intake structure.

A recent inspection (October 1982) revealed that the increased fragmentation resulted in rapid development of new areas of infestation. In addition, since August the plant has recovered considerably from the earlier effects of high water. The Emergency Exemption Permit application will be forwarded through proper channels to the Environmental Protection Agency in late November 1982.

USAE DIVISION/DISTRICT PRESENTATIONS
AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

Ohio River Division, Nashville District

by
Harold T. Sansing*

The Nashville District is the southernmost of four Districts within the Ohio River Division. We are responsible for water control management in the Cumberland River Basin; however, we do overlap with the Tennessee Valley Authority (TVA) in the adjacent Tennessee River Basin in that we are responsible for operation of navigation facilities in that system. The drainage area of both the Cumberland and Tennessee Basins amounts to some 60,000 square miles of which 20,000 is in the Cumberland River Basin. We manage ten reservoir projects. The purposes of each vary but individually may include hydropower, navigation, flood control, recreation, and water supply. Reservoir projects on the Cumberland were designed and constructed on an individual basis beginning in the mid 1940's. All authorized projects are more or less complete so that we are now in a phase of evaluating water control management of these projects as a system. Featured as part of the evaluation process for developing management alternatives will be the consideration of methods necessary for aquatic plant control.

The District has been fortunate to this date in that we have not, by original design or otherwise, experienced serious aquatic plant problems. In the past we have noted some aquatic plant growth (mostly *Najas* species) on major projects, but these have been localized and did not interfere significantly with project purposes. We do have one small project on the Upper Cumberland, Martins Fork Lake, that is now experiencing an extensive growth of *Najas guadalupensis*. The surface area of this project is some 360 acres of which approximately 60 acres, or 17 percent, is infested with this species. This is a relatively young reservoir and, considering the life history of this particular species, we are not expecting a major problem here.

The Tennessee River system, managed by TVA, has not been so fortunate. The Tennessee River originates in Knoxville, flows in a southwesterly direction to make a loop through northern Alabama, then again crosses Tennessee in a rortherly direction to enter the Ohio River downstream of the mouth of the Cumberland. The system is composed of some 37 reservoirs and has had a history of aquatic plant problems, particularly in the southernmost loop through Alabama. Major problem species include Eurasian watermilfoil, spineyleaf naiad, and the recently introduced exotic *Hydrilla verticulata*. The latter species is of particular concern to us at this time due to our responsibilities for work on the Tennessee-Tombigbee Waterway (TTWW).

The Nashville District is responsible for design and construction of the northernmost Divide Cut Section of the TTWW. The TTWW makes a navigation

* U.S. Army Engineer District, Nashville; Nashville, Tennessee.

connection from the Yellow Creek embayment of the Tennessee River just upstream of Pickwick Dam, south to the Gulf of Mexico in Mobile, Alabama. The Divide Cut Section extends some 40 miles from the mouth of Yellow Creek across the Divide into Mackey's Creek Basin and terminates at the Bay Springs Lock and Dam. The lock and dam will back up a lake of approximately 6000 acres and is scheduled for filling in the summer and fall of 1983. The surface elevation will be regulated with that of Pickwick Lake. It is not known at this time whether scheduled drawdown of Pickwick will be the only treatment necessary for control of aquatic plants, particularly *Hydrilla*. We anticipate developing certain pre-impoundment information to be used for prediction and delineation of expected problem areas.

The TVA now has an extensive ongoing physical and chemical control effort in areas of the Tennessee River. A Memorandum of Understanding exists between the Tennessee Valley Authority and the Nashville District whereby we share expertise in review of environmental problems. We anticipate this can be effectively used in developing documentation and control of *Hydrilla* (other species as well) if such becomes a threat to project management.

CORPS FIELD OPERATIONS STUDIES

Biological Control of Waterhyacinth in the Sacramento-San Joaquin River Delta

by
Edwin A. Theriot*

Although the scope of the waterhyacinth problem in the California Delta is small comparable to the southeastern United States, its impact is potentially just as severe. The Delta is an intricate system of waterways which provides an essential water supply for agriculture, industry, recreation, and human consumption in the western United States. The recent increase of the waterhyacinth problem in the Delta has decreased the capability of the waterways to provide the resources demanded. As a result of the successful management of waterhyacinth in the southeastern United States, biological control methods have been implemented in the Delta to reduce the problem.

We first observed the waterhyacinth problem in the Delta at the request of the Sacramento District in February 1982. At that time, however, the area had a much greater problem, severe flooding. In June, at the request of the California Department of Boating and Waterways (CDBW), we met with State and Federal agencies. As a result of these meetings, the Aquatic Plant Control Research Program (APCRP) at the U.S. Army Engineer Waterways Experiment Station (WES) was contracted by CDBW to develop a plan to implement biocontrol techniques in the Delta and to coordinate the effort.

PURPOSE AND OBJECTIVES

The purpose of the biological control effort in the Sacramento-San Joaquin River Delta is to apply biocontrol experimental technology in conjunction with chemical and mechanical methods to achieve rapid control of the waterhyacinth infestation.

The objectives of the project are:

a. Determine the necessary and sufficient means for establishment of a complex of biocontrol agents in the Delta to achieve rapid dispersal and buildup.

b. Determine the rate of dispersal and buildup of the biocontrol agents.

c. Demonstrate the effectiveness of the organisms in conjunction with chemical and mechanical means for the management of waterhyacinth.

BIOLOGICAL CONTROL AGENTS

Based on preliminary observations and data provided by the State and the Sacramento District, we have recommended that the following biological control agents be released in the Delta as soon as possible:

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* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

a. ***Neochetina bruchi.*** *N. bruchi* (chevroned waterhyacinth weevil) has been released in the southeastern United States and is partially responsible for a significant reduction of the waterhyacinth problem in Louisiana.

b. ***Neochetina eichhorniae.*** *N. eichhornia* (mottled waterhyacinth weevil) is the predominant weevil species in Louisiana and is credited as the major cause of the waterhyacinth reduction in Louisiana.

c. ***Sameodes albiguttalis.*** Although *S. albiguttalis* (Argentine waterhyacinth moth) is a more recent introduction into the United States, it is potentially as efficacious as the *Neochetina* spp. It has a life cycle one third as long as *Neochetina* spp. and oviposites nearly four times as many eggs; therefore, it has the capability of increasing its population much more rapidly.

d. **Contingent biocontrol agents.** Other agents will be recommended for release as their ability to impact waterhyacinth is demonstrated in ongoing studies, assuming that they are adequately host specific for introduction into California. Two candidate organisms are:

(1) *Cercospora rodmanii* (Deuteromycete), an endemic fungal plant pathogen.

(2) *Arzama densa* (pickerelweed moth), native to the United States.

IMPLEMENTING BIOCONTROL METHODS

Collection of agents

Neochetina bruchi and *N. eichhorniae* are to be collected from field sites in Louisiana and Texas for shipment to California. *Sameodes albiguttalis* will be collected from our greenhouse population at WES, mated, and the eggs and first instar larvae shipped to California. *Sameodes* will be established in greenhouse facilities by the California Department of Food and Agriculture (CDFA), Biocontrol Group. All biocontrol agents will be inspected by U.S. Department of Agriculture (USDA) personnel in quarantine facilities at Albany, Calif., before release into the Delta.

Release of agents

Four release sites will be strategically located in the Delta to ensure rapid dispersal of the biocontrol agents throughout the infested area. All agents will be established in each of the four release sites.

Initially, a minimum of 500 adults of each *Neochetina* spp. will be released in each site to ensure rapid dispersal and to increase the possibility of overwintering. At least 2000 eggs and first instar of *Sameodes* will be released in each site. Secondary releases of the agents will be made in the primary release sites in 1983 to ensure a rapid establishment and buildup.

Monitoring

Release sites will be monitored prior to release and on a quarterly basis thereafter. Waterhyacinth will be collected randomly from each site for determination of biomass, density, height, and daughter plant production. *Neochetina* adults and larvae, and *Sameodes* larvae and pupae will be collected from the plants for identification and quantification.

Five sites will be established throughout the Delta to monitor the dispersal and buildup of the insects. Light traps will be used to collect *Neochetina* and

Sameodes adults at each site and insect damage to waterhyacinth in the area will be noted.

CDFA will assist WES in the monitoring.

Schedule of events

Following is a list of major milestones for the project:

October 1982—Initial release of *N. bruchi*

March 1983—Verification of establishment and overwintering of *N. bruchi*

April 1983—Initial release of *N. eichhorniae* and *S. albiguttalis*

April 1983—Secondary releases of *N. bruchi*

June 1983—Secondary releases of *N. eichhorniae* and *S. albiguttalis*

March 1984—Verification of establishment and overwintering of *N. eichhorniae* and *S. albiguttalis*

March 1984—Completion of the dispersal phase for all agents.

ACCOMPLISHMENTS

Thus far the USDA has made two releases of *N. bruchi* in the Delta in Old River. Approximately 400 insects in various stages within infested plants were released in the area.

In September we collected 756 *N. bruchi* from a site in Texas and shipped them to California. Dr. Lloyd Andres of the USDA and members of the CDFA screened them and assisted us in two releases. We placed 200 adults in the USDA Old River site and 576 in Trappers Slough. The CDBW has obtained permission from the land owners to use a site in the northeast Delta for a third site and a fourth site, up the San Joaquin River near the San Luis National Wildlife Refuge, has been selected.

This project is a cooperative effort involving CDFA, USDA, and WES. The WES is responsible for the overall coordination of the effort under the authority granted by the CDBW.

CORPS FIELD OPERATIONS STUDIES

Chemical Control

by
William N. Rushing*

Approximately 1000 acres of waterhyacinth infest the waterways of the Delta area of the San Joaquin and Sacramento Rivers in northern California. Almost every acre of infested water is intensively used for recreation, navigation, water supply, or a combination of these uses. Intense pressure from people impacted resulted in the California legislature appropriating funds for a waterhyacinth control program. The California Department of Boating and Waterways, hereafter referred to as Cal Boating, was designated as the lead agency responsible for implementation of the program. The WES became involved through contacts from Cal Boating and also by request for assistance from the Sacramento District. Extensive documentation is on file describing our involvement and the events to date. A recommended waterhyacinth control plan was submitted and the fall chemical program described in this paper was developed from that plan. Another item of background information significant to this documentation is the designating of the Waterhyacinth Task Force by the Director of Cal Boating. This task force is composed of approximately 12 members from local, State, and Federal agencies whose assignment is to oversee the program. Specifically related to the chemical work, a document was assembled, hereafter referred to as the Waterhyacinth Task Force (WTF) Document, which sets forth the operational plan for the conduct of the entire chemical control program in extensive detail. These directives and procedures were followed to the letter in the conduct of the fall program.

OBJECTIVE

The principal objective of this chemical control effort was to demonstrate to all concerned that the two herbicides approved for use on waterhyacinth in California can be applied without any significant detrimental effect to the environment. The herbicides in question were diquat and Weedar 64. The Task Force's main concern was with the Weedar 64, or 2,4-D, which is a restricted pesticide in California. Diquat is not restricted and thus was not under the same intense scrutiny as the 2,4-D.

SITE SELECTION

After considerable evaluation of all information at our disposal we began the process of selecting the sites. This resulted in the selection of two general areas for accomplishing the work—Disappointment Slough and Middle River in the stretch from the Atchison, Topeka, and Santa Fe Railroad crossing to Empire Cut. These

* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

two test areas were selected from a list of five given us by the Task Force. Figure 1 is a section of the Delta map showing the two general areas as Area 1 and Area 2, respectively. Figures 2 and 3 are sections from the 1:20,000-quadrangle maps showing the areas in more detail and showing specific sites within each area.

FIELD PROGRAM PREPARATION

The field crew brought the spray pump and associated supplies and equipment with them; these would have been very difficult, if not impossible, to obtain on location. A 17-ft boat with a 115-hp outboard was obtained and was ideal for the job. It took approximately 2 days to prepare the entire rig for field use. The field crew transported the boat and other equipment to Paradise Point on Disappointment Slough. In the meantime, in preparation for the field effort, Mr. Jim McGehee and Mr. Larry Thomas of Cal Boating took the California State test and became certified applicators. We were required to have a certified applicator on location for the field program.

PERMIT APPLICATION

In California, permits are required for the application of restricted materials such as 2,4-D. These permits are obtained from the County Commissioner's office of the County where the materials are to be applied. First, an overall permit for the whole effort is required giving the locations of sites where the restricted material is to be used. Then, on a daily basis, a Notice of Intent (NOI) is required for the specific site of application with a map attached showing the site. The restricted materials permit is good for the calendar year in which it is submitted; an NOI must be applied for 24 hr before the intended application and is good for 24 hr after the intended time of application. An NOI can be updated or changed by telephone or in person at the Commissioner's office. Needless to say, all of these permit procedures were followed in the strictest detail during the exercise.

Two other procedural matters were discussed during a meeting with the County Commissioner and staff: storage of pesticides and disposition of empty containers. Briefly, all pesticides whether restricted or not must be stored under lock and key and empty containers must be placed in authorized disposal areas after a disposal permit has been obtained from the County Commissioner's office with the number, type of containers, transporting vehicle, and operator designated. A copy of this permit must be handed to the disposal area supervisor. For our program, a locked storage area was procured at Paradise Point Marina and the empty containers were properly disposed of after the operation was over.

SPRAY OPERATION

We were prepared to begin application in Disappointment Slough out of Paradise Point on Friday, 24 September 1982, but rainy weather set in. On Monday, 27 September, we were stopped again by winds gusting to 25 to 30 knots. Although it is not specified on the label of either Weedar 64 or diquat, the rule we followed was no spraying of pesticides unless the winds were below 10 knots. I felt that this was extremely important because of the many and varied vegetable

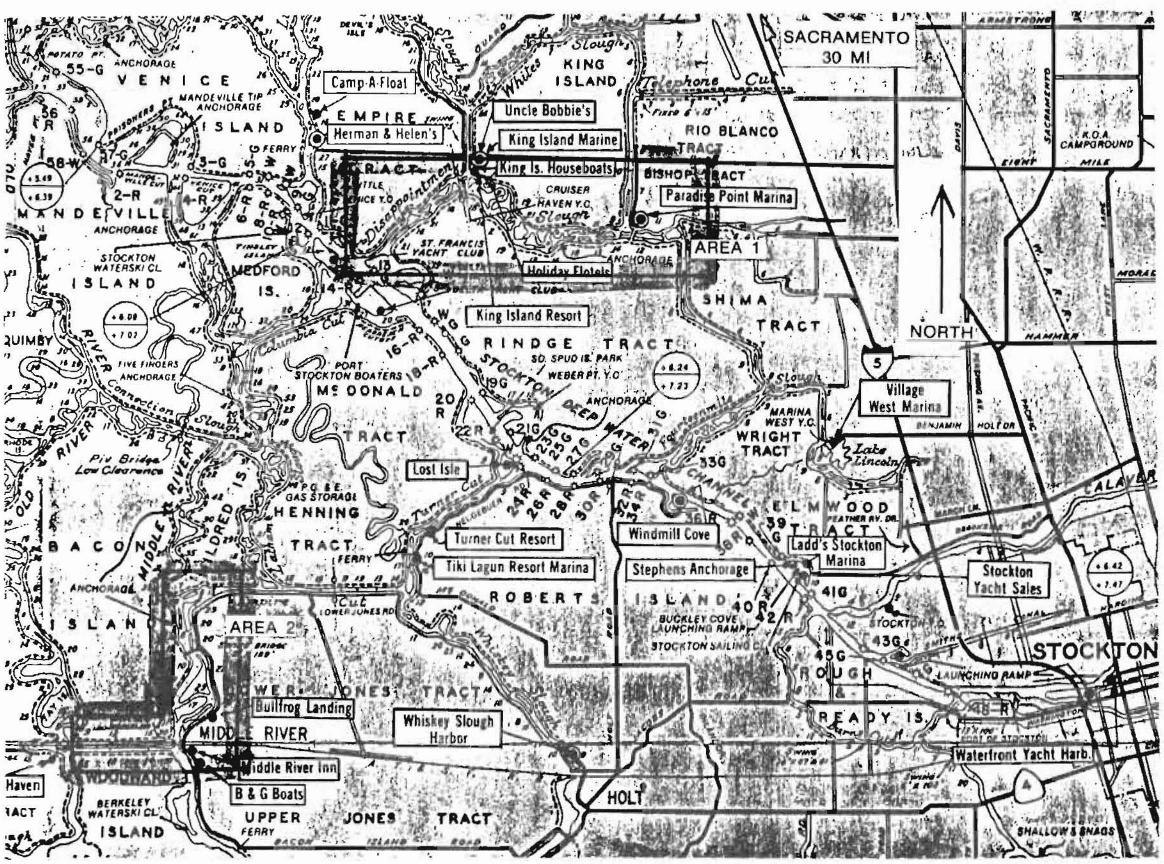

Figure 1. Vicinity map, Sacramento San Joaquin River Delta

crops in the Delta area—including grapes, which are ultrasensitive to 2,4-D. However, on Monday, 27 September, the media had been invited to witness the beginning of the spray operation and there was no time to notify them of our decision not to spray. We spent the major portion of the day calibrating the equipment by spraying plain water. This was sufficient to demonstrate to media cameras how the operation would work in a real situation when the weather permitted.

The weather on Tuesday, 28 September, was perfect, so the operation began with the crew spraying diquat on approximately 12 acres of waterhyacinth in and around Paradise Point and westward along Disappointment Slough. The spray crew was instructed to spray around the edges of as many areas of waterhyacinth as practical and to work themselves west from Paradise Point. No specific sites were designated for the diquat spraying since it did not require a water sampling operation for residue studies as did the 2,4-D work. The tank mix for the diquat work was 0.75 gal diquat, 6 oz. of Nalcotrol drift retardant, and 4 oz. of Ortho X-77 spreader surfactant per 100 gal water. There is no restriction on nozzle pressure for diquat. This treated approximately 1 acre of waterhyacinth.

By Friday, 1 October, the crews had sprayed 21 total acres of waterhyacinth in Disappointment Slough. On Thursday, 30 September, we carried out our first test with 2,4-D (Weedar 64) at Site 1, Area 1 (see Figure 2), spraying 1 acre of plants. The tank mix for the 2,4-D was 1 gal Weedar 64 and 6 oz. Nalcotrol in 100 gal water for 1 acre. With 2,4-D there is a 30-psi nozzle pressure restriction. Water samples were collected as per the protocol set up in the WTF Document. Samples were collected before, during, and after the application upstream, downstream, and within the site as called for by the WTF.* On Friday, 1 October, 5 acres of plants was sprayed with 2,4-D at Site 2, Area 1 (see Figure 2). This site consisted of five islands surrounded with a band of waterhyacinth of about 1 acre each. On Saturday, 2 October, we conducted the final 2,4-D test of the program on Site 3, Area 1, spraying about 2 acres of plants. Water samples were collected at Sites 2 and 3 as described for Site 1.

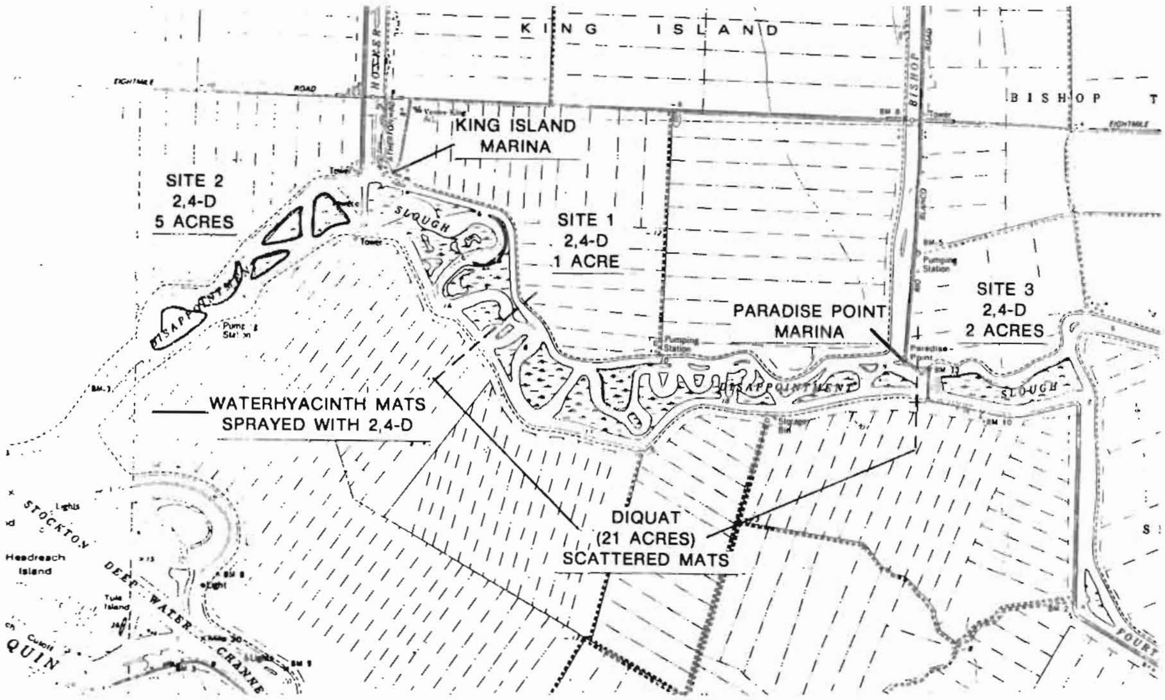

Figure 2. Site map, Disappointment Slough

We had originally selected a site at Middle River for a 2,4-D test but when we submitted the NOI the agriculture commissioner's representative in the area cancelled it. A local farmer was washing potatoes with water out of the river very near the selected site. On Saturday, 2 October, the spray crew moved to Middle River and began spraying diquat within the areas shown on Figure 3. By Monday, 4 October, they had sprayed a total of 28 acres in Area 2 around B&G Boats, Bullfrog Landing, Railroad Cut, and north toward Empire Cut. This ended the fall spray program.

WATER SAMPLE ANALYSES

The water samples collected on the 2,4-D tests were analyzed by the U.S. Department of Agriculture (USDA) at Davis, Calif. (Table 1). Note that the

* Pacific tides affect the direction of water flow throughout the Delta. The amount of effect varies with location. The point here is that times of low and high tides had to be calculated very carefully for the test sites so that the direction of flow was the same for a site throughout a sampling period. A change of flow during a test sequence would have changed what was designated as "upstream" and "downstream."

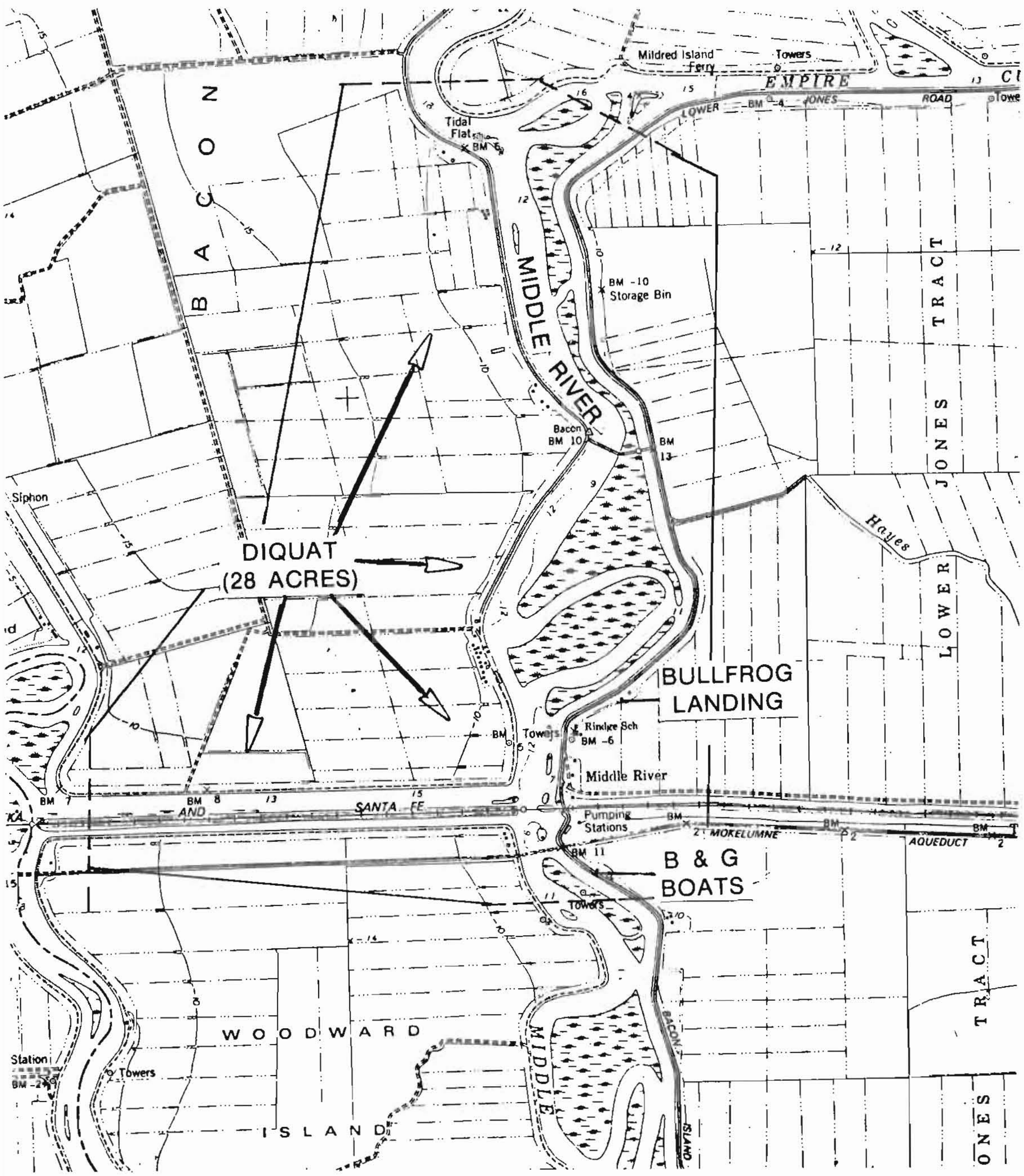

Figure 3. Site map, Middle River

highest value obtained in the entire study was 0.013 ppm from Site 2. This is still an order of magnitude below the allowable tolerance for 2,4-D which is 0.1 ppm, established by the U.S. Environmental Protection Agency. Additional water samples from the study have been analyzed by an independent laboratory. Their values are approximately the same as those obtained by the USDA group. All values fell well below the tolerance. Previous studies have shown that diquat control operations leave no undesirable residues and do not adversely impact the aquatic environment.

Table 1

Residue of 2,4-D Contained in Samples Taken From Applications Made to Control Waterhyacinth in the Sacramento River Delta

Site 1* — *Treatment Date: 9/30/82

Sample No.	*Location**	*Time*	*Corrected ppm*
Pretreatment			
1 A	A	1650	0
2 B	B	1652	0
3 A	C	1710	0
Posttreatment			
6 A	D	1803	0.008
7 A	C	1807	0.006
8 A	D	1833	0
9 A	C	1834	0.003
10 A	D	1903	0
11 A	C	1905	0
12 A	D	1935	0
13 A	C	1936	0.008
14 A	A	1942	0.004
15 A	B	1948	0

Site 2* — *Treatment Date: 10/1/82

Sample No.	*Location***	*Time*	*Corrected ppm*
Pretreatment			
1 A	A	1210	0
2 A	B	1215	0
3 A	C	1220	0
Posttreatment			
5 A	A	1240	0
6 A	E	1250	0
7 A	C	1315	0
8 A	B	1318	0
9 A	C	1330	0
10 A	B	1330	0
11 A	E	1341	0
12 A	B	1415	0.0005
13 A	C	1418	0
14 A	E	1420	0.0006
16 A	C	1428	0
17 A	E	1445	0.013
18 A	B	1447	0.0008
20 A	B	1515	0.0005
21 A	C	1520	0
25 A	A	1600	0.003

Site 2* — *Treatment Date: 10/1/82

Sample No.	*Location†*	*Time*	*Corrected ppm*
Pretreatment			
22 A	F	1535	0
23 A	G	1540	0
24 A	H	1545	0
Posttreatment			
26 A	F	1615	0.006
27 A	G	1615	0
28 A	F	1645	0
29 A	G	1550	0.004
30 A	F	1630	0
31 A	G	1631	0
33 A	G	1646	0.0006
34 A	H	1652	0

Site 3* — *Treatment Date: 10/2/82

Sample No.	*Location‡*	*Time*	*Corrected ppm*
Pretreatment			
1 A	A	1010	0
2 B	B	1020	0
Posttreatment			
4 B	A	1040	0.0002
5 A	B	1100	0
6 B	C	1105	0
7 A	B	1130	0
8 B	C	1130	0
9 A	B	1200	0.002
10 B	C	1200	0
11 A	B	1230	0
12 B	C	1230	0
13 A	B	1300	0
15 A	B	1330	0
16 B	C	1330	0
17 A	A	1340	0.0009

* A. Upstream end of plot.
B. 400 ft from upstream end, at diversion.
C. Downstream end of plot.
D. 50 yards downstream.

** A. Upstream end of plot.
B. Downstream end of plot.
C. 50 yards downstream.
D. Downstream end of diversion.
E. Upstream end of diversion.

† F. 50 yards downstream.
G. Downstream end of plot.
H. Upstream end of plot.

‡ A. Upstream end of plot.
B. Downstream end of plot.
C. 50 yards downstream.

CONCLUSIONS AND RECOMMENDATIONS

Properly applied, Weedar 64 can be used to control waterhyacinth in the California Delta environment without resulting in the buildup of undesirable chemical residues. Diquat can be used effectively to kill waterhyacinth in the Delta. Since it is a contact herbicide, however, care must be taken to wet the entire target area for adequate results. The systematic nature of 2,4-D makes it somewhat easier to use since the herbicide's active ingredient can be transported throughout the plant. Further, it is concluded that waterhyacinth control operations can be performed in the Delta using standard outboard boats equipped with the proper spray hardware. Even though crews are restricted to 30-psi nozzle pressure when applying 2,4-D, they can spray the edges of waterhyacinth mats, move on to other areas, and return to treat another swatch after those plants treated on the first pass have died. Therefore, I see no need for expensive airboat equipment for Delta operations. I recommend that a spray program using available chemicals be designed to start early in the spring of 1983. The impact on the waterhyacinth populations treated before they become too widespread should make a considerable difference in the amount of waterhyacinth with which Delta users will have to contend in mid to late summer.

ACKNOWLEDGMENTS

Although many people and agencies contributed to the success of this study, a few are due special recognition: Bill Satow and Larry Thomas of Cal Boating who sponsored the work, Keith Steel of the Sacramento District who was our Corps contact, Carl Tennis of the U. S. Bureau of Reclamation who loaned us the boat and assisted in many other ways, Ron Mason and staff of the Sacramento District Bryte Yard facility who loaned us space and equipment and gave of their time, Jim McGehee of the Jacksonville District who helped me coordinate the program, Terry Reynolds and staff of the Paradise Point Marina out of which we conducted the operation, and especially the spray crew for the entire study, Eddie Knight and Johnny Mason of the Jacksonville District's Palatka Area Office.

Waterhyacinth Management in the Sacramento-San Joaquin Delta Using Mechanical Control Techniques

by
H. Wade West*

In order to effectively deal with aquatic plant problems in the Sacramento-San Joaquin River Delta on a long-range basis, a management plan should be developed that considers not only the plant populations, but also the water-use-related problems that are caused by both the size and the location of these plant populations. In addition, the level of control necessary or desirable to restore water uses in a reasonable length of time must be determined. Depending upon the level of infestation and the threshold nuisance level, the management scheme can include one or more of three levels of management: prevention, maintenance, and/or control. The management techniques should include the use of mechanical methods in addition to biological and chemical methods depending upon water-use restrictions, control objectives, and environmental considerations.

In order to select the optimum mechanical control techniques, a significant amount of time is required to collect the necessary data. In the case of the Delta, while a significant amount of information was already available, both "quantitative" data and "time" were not available that would have allowed for a more extensive analysis. The mechanical methods identified by the U.S. Army Engineer Waterways Experiment Station (WES) are described in the following paragraphs and are limited to those that can be quickly implemented based on the limited analysis, and with a minimum amount of additional data collection. Implementation of these mechanical methods will have a twofold benefit. First, it will initiate a control program that in many cases will remove the problem from the water-users doorsteps; and, second, it will constitute the first phase of the longer range management program necessary to effect control of the plant population(s) on a Delta-wide basis.

RECOMMENDED MECHANICAL CONTROL METHODS

The following mechanical and physical systems should be employed at various locations throughout the Delta. Because mechanical control is the most site-sensitive method, the specific locations of some of the recommended systems cannot be determined without additional site analysis. It is recommended that:

a. Boom assemblies be designed and emplaced at selected marinas. An example of a boom system is illustrated in Figure 1.

b. Pusher boats and conveyors be used inside the marina to remove the existing plants remaining after initial installation of boom systems.

* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

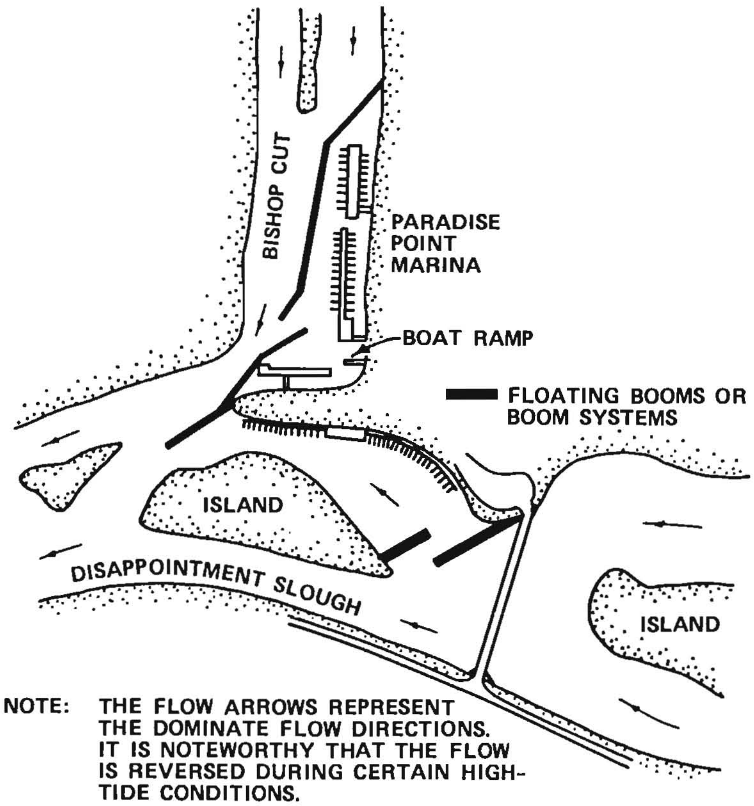

Figure 1. Example of booms emplaced in waterways

c. Small capacity harvesters and/or boom systems be strategically located in the main Delta waterways to minimize the redistribution of existing plant infestations.

d. Large mechanical harvesters be used only after analytical evaluation of performance and cost have been conducted.

e. Where feasible, plants be chopped (mowed) in place and left in the waterway.

f. For water intake structures, small gridded fences and/or booms be installed in low flow areas.

Properly designed and emplaced boom assemblies will divert floating mats of waterhyacinths away from the entrances to marinas and provide a static collection point to facilitate periodic removal. For marinas, the location and configuration of these assemblies will be dependent upon the density of plant infestations, marina layout, water and wind currents, and the type, size, and number of vessels using the facility. They will also have to be fitted with safety devices such as lights and signs. Boom assemblies can usually be purchased and/or constructed locally.

Pusher boats should be used, where necessary, to supplement operations. They should have at least a 35-hp outboard motor with a long shaft and a three-bladed propeller. It should be fitted with bow-mounted, hydraulically operated rake, 16 to 20 ft wide.

Harvester systems vary from small capacities (<10-ton capacity) to large systems (>10-ton capacity). Some are multicomponent systems, with or without

Table 1
Commercially Available Mechanical Control Systems

Company	*Type of Equipment (Capacity)*	*Cost, 1981 Dollars*
Allied Aquatics International	Harvester (800 ft^3)	223,000
	Harvester (1200 ft^3)	330,000
	Harvester (2500 ft^3)	450,000
	Pusher boat (35-hp motor)*	10,500
	Conveyor	24,000
National Car Rental (Mudcat)	Harvester (160 ft^3)	22,500
	Harvester (300 ft^3)	36,378
	Harvester (450 ft^3)	55,739
	Harvester (650 ft^3)	75,672
	Harvester (800 ft^3)	91,940
	Conveyers (various widths)	10,700 to 17,400
	Trailers (all above)	3,000 to 19,500
Dredge Masters International (Aquarmarine Corporation)	Harvester (650 ft^3)	72,000
	Transporter (650 ft^3)	55,000
	Conveyer (various widths)	16,000
	Trailers	12,000
Limnos Limited	Harvester (continuous processor-hammermill/30 tons/hour)	65,000
	Transporter (19 tons)	45,000
Lantana Boatyards	Mower (continuous cutting/chopping)	90,000

* Pusher (or tow) boats can be constructed by local firms by providing design specifications for the hydraulic rakes and motors.

onboard processors, that reduce the onboard volume of the plant material. A list of presently available systems and their costs is shown in Table 1.

Evaluation of the potential use of commercially produced mechanical harvesting systems was not included in the recommendations because the performance of these systems is highly dependent on the conditions at the problem site. Specific data on the physical characteristics of the environment are needed in order to adequately assess whether or not a commercial system could be efficiently and economically used in any of the Delta waterhyacinth-infested areas. However, once the data are available, computer models, such as the WES HARVEST Model, could be used to stimulate performance and calculate cost of various harvesting systems in the Delta's plant-infested environments.

In addition to the possible purchase of production level commercial systems (listed in Table 1), there are various firms (Table 2) who have identified themselves as having the capability to conduct mechanical harvesting operations. These firms should be contacted to solicit information relative to their respective capabilities in order to initiate the process of evaluation. In the event that it is deemed desirable to include such systems in the future overall control program, it will be necessary that these evaluations be completed prior to that time. The following is a recommended plan for completing this evaluation:

a. A letter would be sent to each prospect soliciting information relative to their systems and capabilities.

b. First-level evaluation would rank the relative potential of these systems. This would be done on the basis of identified concept, data on past successes and failures, and knowledge of waterhyacinth problems in general.

Table 2

Sacramento-San Joaquin Delta, California, Firms With Waterhyacinth Mechanical Management Capability

Bill Dutra Construction Company P.O. Box 338 Rio Vista, CA 94571	Herman Miller P.O. Box 2163 Stockton, CA 95201
Altosar Corporation 14 Melanie Drive Mississauga, ON L5S 163	Omni Marine Services 1409 West 7th Street Long Beach, CA 90813
Aquamarine Corporation 225 N. Grand Avenue Wankesha, WIS 53186	Sportronics 129 Oxbow Marina Drive Isleton, CA 95641
California Water Harvesters P.O. Box 2206 South San Francisco, CA 94080	South Hampton Towing Company 1 Bailey Street Vallejo, CA 94590
California Steamship Agency and Charting Company, Inc. 351 California Street San Francisco, CA 94104	Jack K. Seals 19315 Hwy 18 Apple Valley, CA 92307
Delta Humus Company P.O. Box 89 Holt, CA 95234	Sportronics, Inc. 40 North Main Street Lodi, CA 95240
Delta Environmental Services Company 7028 Richmond Plaza Stockton, CA 95207	Fisher Engineering P.O. Box 307 Rio Vista, CA 94571
Tod Ellis 2440 Norton Napa, CA 94558	Glen Henderson 4530 Burgundy Drive Oakley, CA 94561

c. Based on the degree of potential determined in step *b,* selected firms would be visited to provide an opportunity for first-hand discussions and/or short demonstrations.

d. A second-level evaluation would be conducted that included the additional information and/or data obtained in step *c.*

e. For those systems showing the most potential, performance predictions should be conducted using existing WES models that simulate operational scenarios in described problem environments.

f. A summary of the evaluations would be compiled to serve as a basis for decisions should a competitive bid process be used to include commercial systems into the overall program.

Regardless of the level of effort devoted to evaluating this aspect of the program, it is anticipated that no system could be identified, selected, and put into operation before early 1984.

Treatment of Eurasian Watermilfoil in Flowing Waters Using 2,4-D/Adjuvant Formulations

by
K. Jack Killgore*

Eurasian watermilfoil (milfoil) is rapidly establishing in the Columbia River drainage system. Milfoil is currently interfering with various water uses in this drainage system such as clogging irrigation water intakes, interfering with recreational boating navigation, and reducing water flow velocities. The prodigious number of viable milfoil fragments being produced from existing source colonies and the large amount of habitat suitable for establishment of the plant will require a comprehensive and ongoing aquatic plant management program for this drainage system. An important element of the management program is to have an adequate number of treatment options that satisfy specific environmental, social, and economic requirements. Unfortunately, most alternative treatment techniques have been developed for lentic systems and, thus, their use in flowing water is usually limited.

The herbicide 2,4-D has been proven effective for controlling milfoil in the relatively lentic habitats of the Columbia River drainage system (Killgore 1981). However, application of 2,4-D (and other conventional herbicides) in flowing water systems can result in the herbicide dispersing away from application sites. Thus, the time that an effective herbicide concentration remains among submersed aquatic plants after application is reduced. Adjuvants have recently been used with conventional herbicides to enhance the contact properties of the herbicide to the aquatic plant (Blackburn 1976; Wortley 1977; Bitting, 1974). As a result, the use of adjuvants in flowing water may allow an effective herbicide concentration to remain in contact with the plant long enough to provide control.

PURPOSE OF STUDY

The purpose of this study was to determine if selected adjuvants could be used with 2,4-D dimethylamine (DMA) to effectively reduce milfoil in flowing water systems. The results will be used by the U.S. Army Engineer District, Seattle, and other participating agencies to help plan their overall program for managing milfoil in the Columbia River drainage system.

OBJECTIVES

The field study was aimed at determining whether 2,4-D DMA used with an invert or polymer in flowing water systems increases: (1) the retention time of 2,4-D DMA within the water column and milfoil colonies, where applications are made; and (2) the extent and duration of milfoil control. A third objective during

* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

these field studies was to monitor site-specific physical and chemical variables that may be related to the expected efficacy and environmental compatability of the 2,4-D/adjuvant formulations.

METHODS AND MATERIALS

The study site was located in the upper Okanogan River between Lake Osoyoos and Zosel Dam at Oroville, Wash. (Figure 1). The Okanogan River originates in British Columbia and flows south into Washington where it empties into the Columbia River (313 km). Four lake basins were formed along the Okanogan River during the most recent advance and retreat of glaciers. The southernmost basin contains Lake Osoyoos. Water from the Okanogan River is used to irrigate crops (mostly apples) on adjacent lands. Milfoil colonies along the Okanogan River study site occurred mainly in the deeper, steeply trapezoidal main channel of the river. Milfoil was not present on the very shallow shelfs of variable width on each side of the main channel. The mean water depth in the portions of the main channel supporting milfoil was 2 m during the field study.

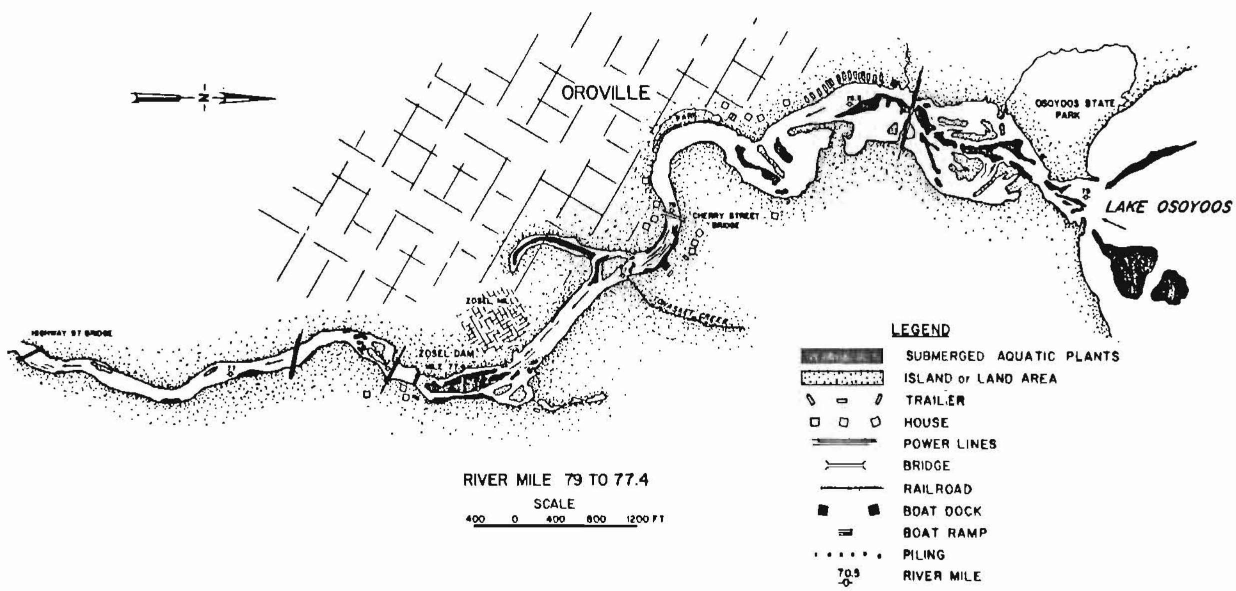

Figure 1. Okanogan River 2,4-D/adjuvant study site

Adjuvants used in the field study were:

a. ***Nalquatic polymer.*** This in combination with a liquid herbicide forms a matrix increasing the density of the formulation. The matrix attaches to the target plant and permits prolonged contact of the herbicide to the plant.

b. ***403 inverting oil.*** This invert formulation consists of an emulsion of water, liquid herbicide, and inverting oil. The oil encapsulates the herbicide/water solution enhancing the adherence of the emulsion to the target plant.

The polymer and invert were mixed with a liquid formulation of 2,4-D DMA (Weedar 64). A granular formulation of the butoxyethanol ester (BEE) of 2,4-D (Aqua-Kleen) was applied for comparison. A granular formulation of 2,4-D can reduce the concentrations of residue in the water by confining portions of the herbicide at the soil surface (Faust 1971). Thus, 2,4-D granular may be suitable for use in flowing water systems. The application rates for the polymer and granular plot were 18 kg 2,4-D acid/0.4 hectare and 9 kg 2,4-D acid/0.2 ha, respectively, whereas the invert plot received 5 kg 2,4-D acid/0.4 ha. Table 1 summarizes the herbicide formulations, the application rates, and the application techniques.

Specific selection of plot locations was based on the size and location of milfoil colonies observed in the study site (see Figure 1). The reference plot was upstream of all three treatment plots followed by the 2,4-D/invert, 2,4-D/polymer, and the 2,4-D granular plot. The 2,4-D/invert and 2,4-D/polymer plot were located along the flow of the river 915 m apart. Due to a lack of sites with adequate milfoil abundance conducive for plot establishment, the 2,4-D granular plot was positioned approximately 150 m below the 2,4-D/polymer plot. There was a 2-day interval between herbicide application on each plot. Application began at the most downstream plot (2,4-D granular), followed by the 2,4-D/polymer and 2,4-D/invert. All plots were 0.4 ha in size except the 2,4-D granular plot which was 0.2 ha. Milfoil was the only aquatic plant within the plots.

In all plots, data were gathered before, during, and for 2 months after herbicide application (July-September) on water quality, flow rates, 2,4-D concentrations in water and milfoil samples, and changes in plant height (Table 2). A dye test was conducted in the study site prior to herbicide application to determine 2,4-D dispersal sampling stations that represent the probable locations for detecting maximum 2,4-D concentrations in the water. Rhodamine WT, a fluorescent dye, was applied in each of the three treatment plots. The horizontal and vertical

Table 1
Summary of Herbicide Application

Plot	*Application Rate*	*Application Technique*
2,4-D BEE granular	9 kg 2,4-D acid/0.2 ha	Granular cyclone spreader mounted on airboat.
2,4-D DMA/Nalquatic Polymer	18 kg 2,4-D acid/11 ℓ Nalquatic/757 ℓ water/0.4 ha applied at 45 ℓ/min; concentration of 2,4-D from the trailing hose = 19.0 mg/ℓ	Nalquatic in-line suction feed system mounted on airboat; subsurface delivery of herbicide formulation through 61-cm-long trailing hose with straight solid stream nozzles.
2,4-D DMA/403 invert	5 kg 2,4-D acid/38 ℓ 403/132 ℓ water/0.4 ha applied at 12 ℓ/min; concentration of 2,4-D from the trailing hose = 8.4 mg/ℓ	Minnesota Wanner mechanical invert pump mounted on airboat; subsurface delivery of herbicide formulation through 61-cm-long trailing hose with cone spray nozzles.

Table 2
Sampling Scheme

		Sampling Frequency																		
		Hours											*Days*							
Parameter	*Before Treatment*	*0*	*1/8*	*1/4*	*3/8*	*1/2*	*5/8*	*3/4*	*7/8*	*1*	*2*	*4*	*1*	*2*	*4*	*8*	*16*	*32*	*64*
Water quality and water velocity	X*	--**	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--	X	X
Herbicide residue - water treatment and reference plots	X	X	--	X	--	X	--	X	--	X	X	X	X	X	X	X	X	X	-
Dispersal stations	X	X	X	X	X	X	X	X	X	X	X	X	X		--	--	--	--	--
Herbicide residue - milfoil	X	X	--	X	--	X	--	X	--	X	X	X	X	X	X	X	X	X	X
Plant height	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	X

* Sampled.
** Not Sampled.

distribution of the dye concentration was measured along transects across the river located downstream of each treatment plot. From these data, two permanent sampling stations for monitoring 2,4-D dispersal were located along each transect.

RESULTS

Water quality

A summary of the physical and chemical water quality parameters is shown in Table 3. Except for stream velocity and flow rates, there were appreciable differences in the values among plots throughout the study. Based on these data, the Okanogan River can be characterized as a moderately hard water lake (i.e., hardness ranged from 100 to 120 mg/ℓ $CaCO_3$) with relatively little suspended or dissolved solids (i.e. turbidity ranged from 5 to 10 JTU).

Average stream velocity and flow rates were proportional to milfoil density. As milfoil density decreased in response to treatment, stream velocity increased. Average stream velocities measured outside the milfoil colonies before treatment were approximately twice that of the velocities measured within the colonies. According to a U.S. Geological Survey gauging station below Zosel Dam (see Figure 1), there was a slight variation in the flow rates ranging from 37 to 56 m^3/sec during the first 2 weeks after treatment. However, there was negligible change in the water level within the study site (above Zosel Dam).

Table 3
Summary of Water Quality Measurements

Plot	*Temperature °C*	*Conductivity µmhos*	*Dissolved Oxygen mg/l*	*pH*
2,4-D Granular	18.0 – 24.4 21.9 ± 2.8	187 – 250 229 ± 17.4	7.2 – 9.4 8.7 ± 1.0	8.5 – 8.9 8.7 ± 0.2
2,4-D/Polymer	18.2 – 24.2 21.8 ± 2.7	198 – 245 231 ± 11.3	8.5 – 9.2 8.9 ± 0.3	8.5 – 8.8 8.7 ± 0.1
2,4-D/Invert	18.2 – 24.1 21.5 ± 2.6	197 – 233 228 ± 6.8	8.9 – 9.0 9.0 ± 0.1	8.5 – 8.9 8.6 ± 0.2
Reference	18.4 – 23.7 22.0 ± 2.4	196 – 264 235 ± 20.5	6.6 – 9.5 8.3 ± 1.3	8.5 – 8.9 8.6 ± 0.2

Plot	*Total Alkalinity mg/l $CaCO_3$*	*Total Hardness mg/l $CaCO_3$*	*Turbidity JTU*	*Average Stream Velocity cm/sec*	*Flow Rate m^3/sec*
2,4-D Granular	115 – 125 120.5 ± 4.2	100 – 120 108.8 ± 10.3	5 – 10 6.2 ± 2.5	15.2 – 24.3 18.3 ± 6.1	6.4 – 10.1 8.5 ± 1.8
2,4-D/Polymer	115 – 135 127.5 ± 8.7	100 – 115 127.5 ± 8.7	5 – 10 6.0 ± 2.0	13.7 – 19.8 16.5 ± 3.0	11.9 – 15.1 13.1 ± 1.7
2,4-D/Invert	120 – 130 123.7 ± 4.8	100 – 115 105.0 ± 7.1	5 – 10 6.0 ± 2.0	7.3 – 9.4 8.5 ± 2.2	3.2 – 5.7 4.4 ± 1.2
Reference	120 – 135 126.2 ± 7.5	100 – 110 106.2 ± 4.8	5 – 10 7.1 ± 2.5	3.0 – 7.3 5.2 ± 2.1	1.6 – 4.1 2.8 ± 1.2

NOTE: Each parameter is represented by the range and the mean ± 1 standard deviation.

2,4-D residue in water

The 2,4-D concentrations in water are shown in Figures 2-4. Each data point represents the mean of three or more values. The majority of detectable residue levels were found 0 to 2 hr after treatment. The highest concentration was detected in the polymer plot (69 μg/ℓ). Higher residue levels were found in the downstream dispersal sampling station than inside the granular and polymer plot. Conversely, higher residue levels were found inside the invert plot than in

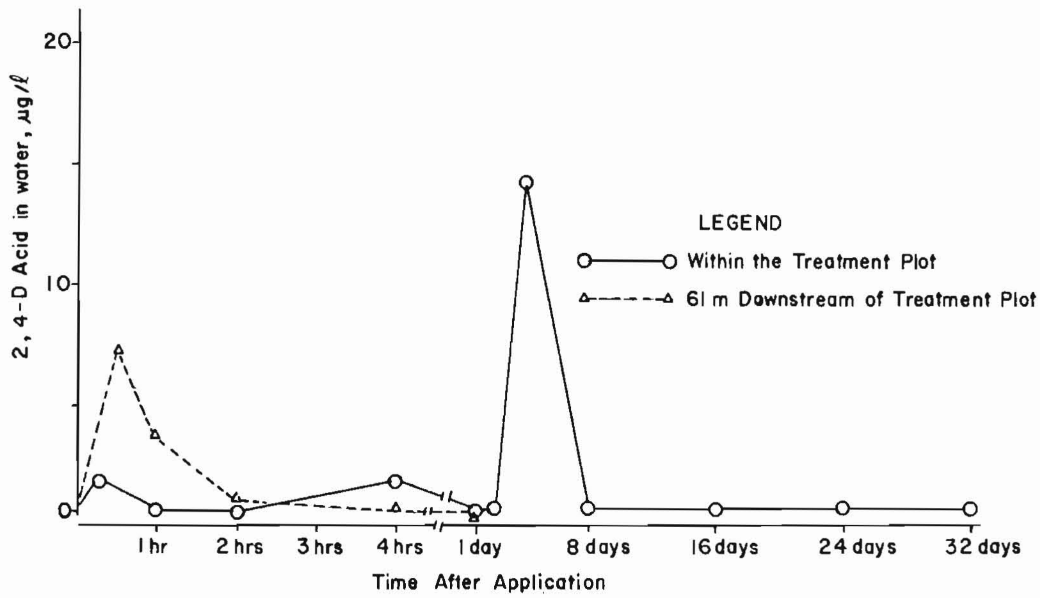

Figure 2. 2,4-D residue in the water after the 2,4-D granular application

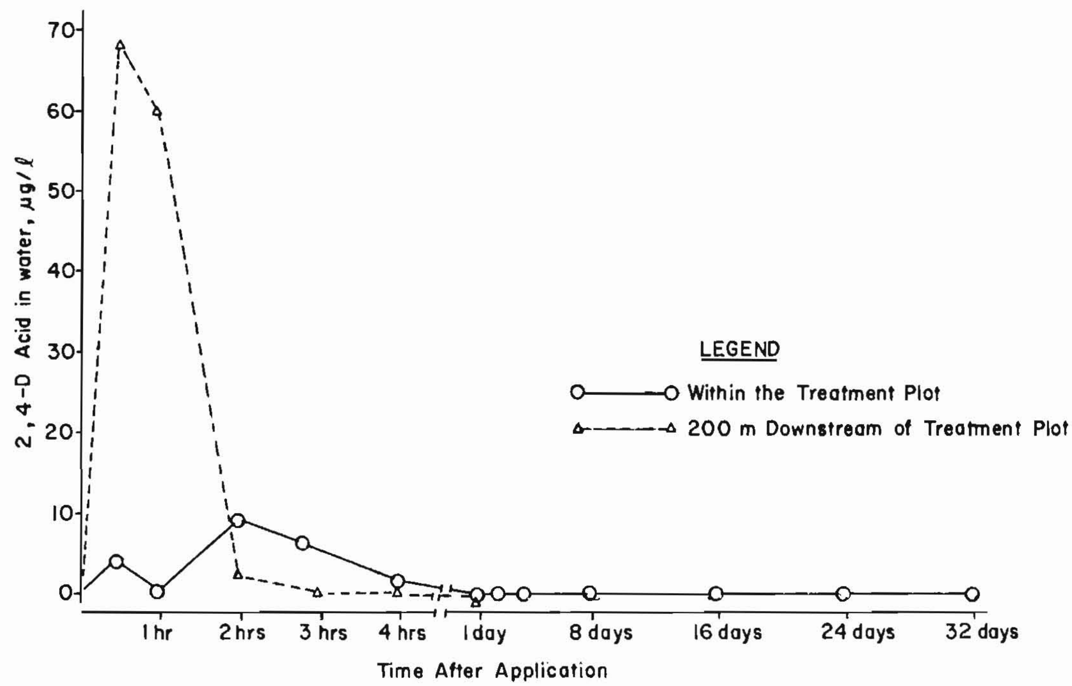

Figure 3. 2,4-D residue in the water after the 2,4-D/polymer application

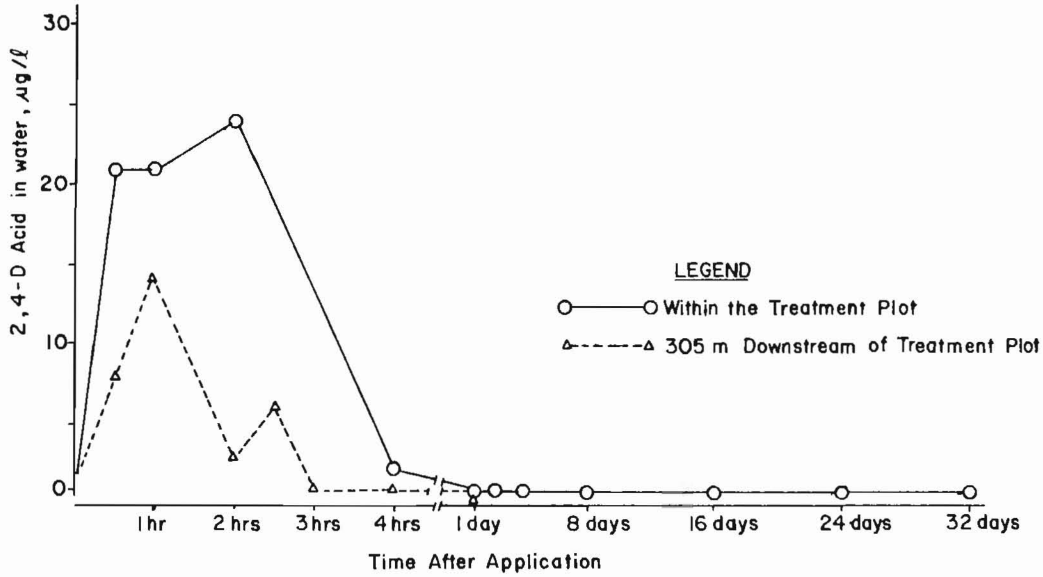

Figure 4. 2,4-D residue in the water after the 2,4-D/invert application

the downstream dispersal sampling station. As anticipated, the granular plot was contaminated from the application of the upstream polymer plot. However, no interplot contamination was evident between the other plots. The 2,4-D concentration in the water was nondetectable in the plots 1 to 2 days after treatment and thereafter, except for the granular plot resulting from interplot contamination.

2,4-D residue in milfoil

Figure 5 shows the mean of 2,4-D concentrations in the milfoil over time. There was an average of four times the level of 2,4-D in the milfoil than in the water during the first day after application. The highest concentration was 2400 µg/ℓ; it was found in the invert plot 30 min after treatment. The 2,4-D levels remained detectable in the milfoil 32 days after treatment in the invert and granular plot (540 and 29 µg/ℓ, respectively); however, the highest levels were found during the first 24 hours after treatment. These data also reflect interplot contamination between the granular and polymer plot as a second distinctive peak (Figure 5).

Effects of 2,4-D on milfoil

All treatment plots showed similar symptoms of 2,4-D toxicity. The milfoil initially became flaccid followed by the appearance of swollen regions and a loss of buoyancy. Approximately 4 to 8 days after treatment, an abaxial curl of the terminal appeared and the plants appeared chlorotic. Finally, defoliation of the shoots was observed 2 to 3 weeks after treatment. Although these treatment effects were evident in the majority of the plants, they did not develop throughout the entire plot and were not uniform throughout a given plant. The reference plot remained unchanged throughout the study.

All treatment plots showed a reduction of milfoil plant height (Figure 6). In order of decreased plant height 64 days after treatment, the 2,4-D granular plot

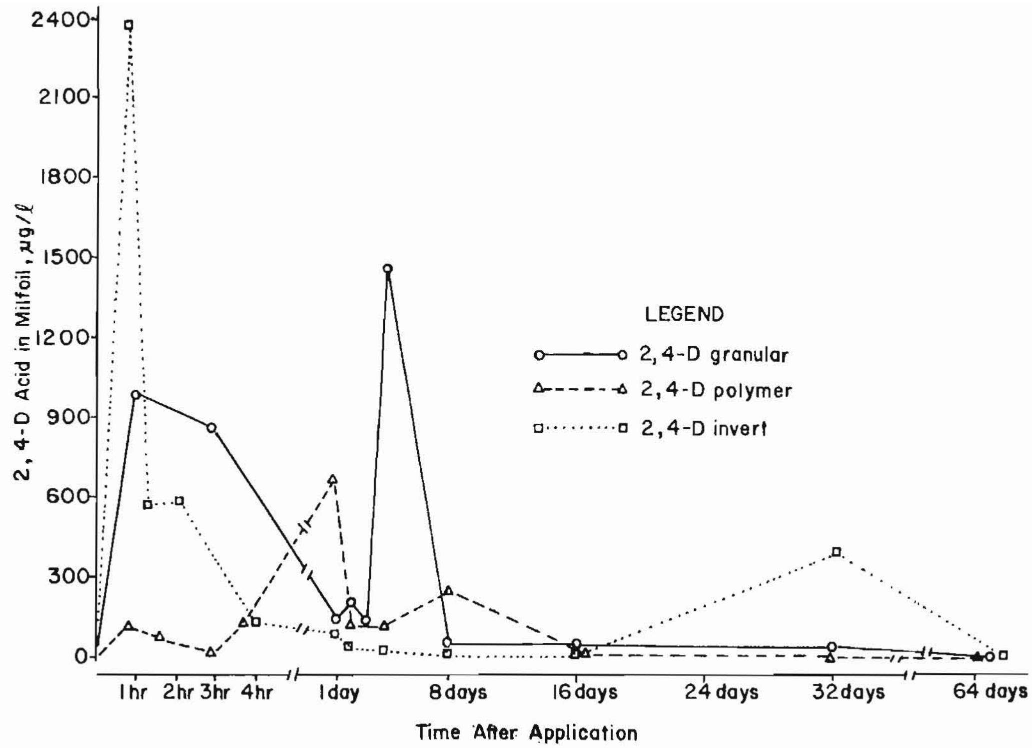

Figure 5. Mean 2,4-D residue in the milfoil within the treatment plots after application

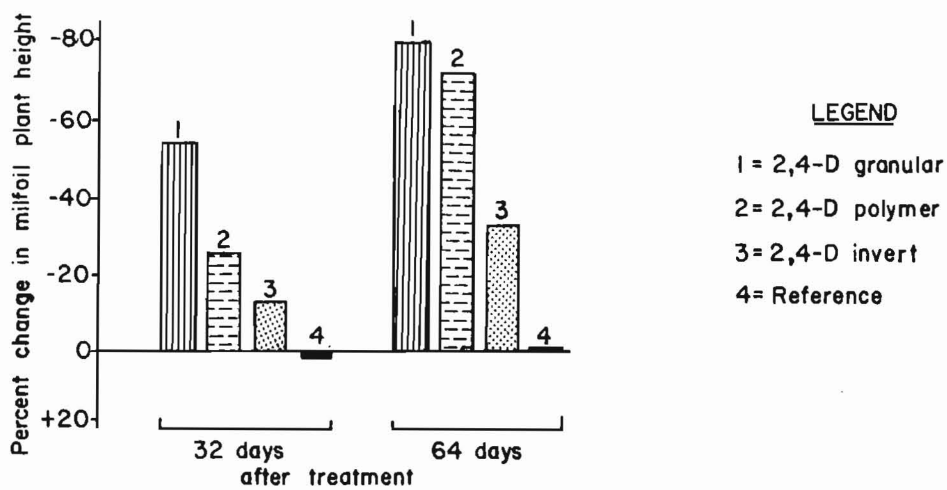

Figure 6. Change in milfoil plant height over time for the treatment and reference plots

showed the highest reduction (78 percent) followed by the polymer plot (72 percent) and the invert plot (38 percent). The reference plot exhibited a slight increase in plant height 32 days after treatment but decreased by 3 percent 2 months after treatment. Based on a review of the data, the degree of reduction of plant height in the granular plot was probably attributed to subsequent addition of 2,4-D from the polymer plot.

DISCUSSION

The dissipation of 2,4-D from the areas treated will depend on several processes. Hydrolysis, photolysis, vaporization (Zepp 1975), and biological metabolization (Hemmet and Faust 1968) contribute to the dissipation of 2,4-D. Metabolism of the 2,4-D by the plants also provides a major role in herbicide decomposition (Crafts 1964) and subsequent disappearance from the aquatic environment. Applications of 2,4-D in flowing water, however, can become diluted from its longitudinal dispersion (Faust 1971) which can decrease the level of the herbicide below detectable limits in a matter of hours. A study by Foret and Barry (1979) showed that dilution of 2,4-D applied in slow moving water (5-18 cm/sec) was a key factor in explaining the low 2,4-D levels measured in the treatment area and in the downstream dispersal station. In this study, the 2,4-D that was not in direct contact with the milfoil apparently moved downstream from the application site and was subsequently detected at the dispersal sampling stations. Thus, dispersal was obviously one means of disappearance of the 2,4-D and the rate was dependent on the hydrodynamics. The 2,4-D which remained in contact with the plant was apparently adequate to effect reduction of the milfoil. The level of 2,4-D remaining in the treatment area was not only a function of the water velocity, but also the application rate and the type of adjuvant used.

These data suggest that the invert was more efficient than the polymer in maintaining the residence time of 2,4-D in the treatment areas. Even at the low application rate of 5 kg 2,4-D acid/0.4 ha, there was a 38 percent plant height decrease in the invert plot and the 2,4-D remained detectable in the milfoil 32 days after treatment. However, the application of the 2,4-D/polymer did result in a 78 percent decrease in plant height when applied at maximum application rates. Additional research is required to compare these adjuvants at different application rates and water velocities.

Granular formulations of the 2,4-D can also provide adequate results. Tests have shown that approximately 66 percent of the herbicide is released from the granules in the first day (Fleming and May 1962). This initial release may be followed by a prolonged release of the remaining formulation although the persistence of the 2,4-D will be dependent on oxygen levels and temperature (Schultz and Harmon 1974) as well as water velocity. Roots of milfoil are more likely to be killed from granular formulations because of the roots' close association to the soil-water interface. Once the 2,4-D is absorbed into the roots, it moves readily to the shoots (Funderburk and Lawrence 1963). Unfortunately, interplot contamination did not allow an assessment of the long-term release rate of the 2,4-D from the granules or retention time of the 2,4-D within the areas treated. However, the 2,4-D granular plot had the lowest herbicide concentration in the water compared to the adjuvant plots and a relatively high initial concentration in the milfoil the first 48 hr after application. These results may indicate that the 2,4-D was being rapidly absorbed and translocated by the plant soon after application.

CONCLUSIONS AND RECOMMENDATIONS

Based on this study, the following conclusions and recommendations are noted:

a. Regardless of the adjuvant used, a certain amount of herbicide will disperse downstream when applied in flowing water. The rate and level of this dispersal will be dependent on the water velocity.

b. Adjuvants apparently enhance the contact properties of the 2,4-D, resulting in varying levels of plant control depending on application rates and water velocity.

c. Further studies are recommended to (1) compare the use of 2,4-D DMA/ adjuvant formulations in various water velocities at different application rates, and (2) monitor retention and dispersal rates of the 2,4-D granular formulation in flowing water.

ACKNOWLEDGEMENTS

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REFERENCES

Bitting, L. E., Jr. 1974. "Field Uses of Invert Emulsion," *Journal of Aquatic Plant Management,* Vol 12, pp 34-35.

Blackburn, R. D. 1976. "Effective Control of an Aquatic Weed Nuisance," *Public Works Magazine,* May 1976.

Crafts, A. A. 1964. "Herbicide Behavior in the Plant," *The Physiology and Biochemistry of Herbicides,* L. J. Audus, ed., Academic Press, New York.

Foret, J. A., and Barry, R. J. 1979. "Time Course Studies on 2,4-D Amine in Slow Moving Waters," Technical Report A-79-1, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Faust, S. D., 1971. "Fate of Organic Pesticides in the Aquatic Environment," *Symposium, 161st Meeting of the American Chemical Society, 29-31 March, Los Angeles, Calif.*

Fleming, R. B. I., and May, R. 1962. "Aqua-Kleen—To Determine the Leaching Rate of 2,4-D Ester at Different Temperatures," Internal Industrial Hygiene Report to G. S. Christopher and G. E. Smith, Vector Control Branch, Tennessee Valley Authority.

Funderburk, H. H., Jr., and Lawrence, J. M. 1963. "Absorption and Translocation of Radioactive Herbicides in Submersed and Emersed Aquatic Weeds," *Weed Research,* Vol 3, No. 4, pp 304-311.

Hemmett, R. B., Jr., and Faust, S. D. 1968. "Biodegradation Kinetics of 2,4-dichlorophenoxyacetic Acid by Aquatic Microorganisms," *Residue Review,* Vol 29, pp 191-207.

Killgore, K. J. 1981. "Eurasian Watermilfoil Treatment with 2,4-D, Diquat, and Endothall at Reduced Application Rates," *Proceedings, 15th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 17-20 Nov 1980, Savanna, Ga.*, Miscellaneous Paper A-81-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Killgore, K. J., and Payne, B. S. 1983. "Field Methods to Measure Aquatic Plant Treatment Method Efficacy and Site Variables," Internal Working Document (in preparation), U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Schultz, D. P., and Harmon, P. D. 1974. "Residues of 2,4-D in Pond Waters, Mud, and Fish," *Pesticides Monitoring Journal,* Vol 8, No. 3, pp 173-179.

Wortley, G. E. 1977. "The Use of Polymers In the Application of Aquatic Herbicides," *Proceedings, Southern Weed Science Society,* Vol 30, pp 345-351.

Zepp, R. G., et al. 1975. "Dynamics of 2,4-D Esters in Surface Waters," *Environmental Science and Technology*, Vol 9, No. 13, pp 1144-1150.

CORPS FIELD OPERATIONS STUDIES

Large-Scale Operations Management Test of the Use of the White Amur for Control of Aquatic Plants at Lake Conway, Florida

by
Robert L. Lazor*

BACKGROUND

In January 1976, the Waterways Experiment Station (WES) initiated a comprehensive field study at Lake Conway near Orlando, Fla., to assess the overall effectiveness of the white amur as a biological macrophyte control agent. This large-scale operations management test (LSOMT) consisted of basically three major phases: (1) collect approximately 12 months of baseline physical, chemical, and biological data; (2) stock Lake Conway with enough white amur to control, but not totally eradicate the aquatic plants; and (3) continue collecting environmental data for at least three poststocking years.

The primary purposes of the LSOMT were to: (1) test the effectiveness of the white amur on an operational scale, (2) document the responses of various portions of a large ecosystem to the presence of the white amur, and (3) provide information to enable potential users to extrapolate the results of this study to other aquatic ecosystems.

DATA SOURCES

The following is a list of major areas of study, objectives of each item of work, and the Florida contractors who executed the tasks:

a. ***Water and sediment chemistry.*** The purpose of this work was to describe temporal water chemistry and sediment chemical and physical parameters, and identify significant changes possibly caused by introduction of the white amur. This work was conducted by Orange County Pollution Control Board, Orlando.

b. ***Plankton and benthic invertebrates.*** The objectives of this work were to determine plankton (phytoplankton and zooplankton), and benthic and periphytic community responses to the losses or changes in the aquatic macrophyte community. These studies were conducted by the Department of Environmental Engineering, University of Florida, Gainesville.

c. ***Fish, waterfowl, and aquatic mammals.*** The objectives of this phase were to describe the fish community in Lake Conway and evaluate any possible shift in species dominance brought about by direct competition for food or cover, or displacement of native fish as a result of introduction of white amur. The Florida Game and Fresh Water Fish Commission conducted this aspect of the project.

d. ***Herpetofauna.*** This work concerned an evaluation of reptiles and amphibians in Lake Conway and changes in population dynamics resulting from an

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alteration in littoral habitat caused by introduction of white amur. This was studied by the University of South Florida, Tampa.

e. ***Aquatic macrophytes.*** In this study, the purpose was to describe the distribution, biomass, and species composition of the major aquatic plant species in Lake Conway, determine the rate of removal of the target species, and describe the effects on the remaining plant community. This work was conducted by the Florida Department of Natural Resources, Tallahassee.

f. ***Hydrology and nutrient sources.*** This work was to quantify the sources of external nutrient loading, describe internal nutrient cycling, and determine the loss rate of macronutrients in the Lake Conway system emphasizing those compounds potentially influenced by the white amur. This was studied by the Department of Environmental Engineering, University of Florida, Gainesville.

g. ***Ecosystem response model.*** This work consisted of developing a model that simulates the response of an aquatic ecosystem to the introduction of white amur. This work was conducted by the School of Forest Resources and Conservation, University of Florida, Gainesville.

Individual contractors collected and analyzed data, conducted physical and chemical analyses, and identified organisms as required. At the onset of the study, all raw data were sent to WES where they were stored on tape for access by the WES computer. However, after the second year of study, it was decided that individual contractors would update and manage their own data using a computer system of their choice. At the termination of the study, data from all of the contractors were gathered and are now stored on a single data tape at WES. This tape, with attendant species codes and programs to retrieve and perform summary statistics on the data, is available to interested parties and is described more fully in a paper by Blancher and Miller (1983).

STUDY YEARS

To facilitate report preparation and data handling during the study, this project was considered to consist of four separate years. Although individual starting times during the baseline year differed slightly for each contractor, the following delineation was followed:

Jan 1976 - Aug 1977	Baseline Year
Sep 1977 - Aug 1978	Poststocking Year I
Sep 1978 - Aug 1979	Poststocking Year II
Sep 1979 - Aug 1980	Poststocking Year III

THE LAKE CONWAY SYSTEM

Description

Lake Conway is a five-pool system of approximately 1800 acres located in Orange County in Central Florida on the southeast edge of the city limits of Orlando. From north to south the pools in Lake Conway are: Lake Gatlin, East and West Pools (Little Lake Conway), then Middle and South Pools. Compared to many southern lakes, the pools are fairly deep. Half to three fourths of the area in the lake is deeper than 3 m and much is deeper than 6 m.

Water level

Diminished rainfall coupled with typically high evaporation rates and rapid infiltration of rainwater caused a noticeable drop in Lake Conway water levels during the latter part of the 1970s. This caused the pools to become more isolated from one another; the connections between Lake Gatlin and West Pool and between Middle and East Pools were no longer navigable by boat.

Nutrient levels

Concurrently with the drop in water level, there was a considerable increase in the rate of residential development around the lake and in the Orlando area. Although this could have caused a dramatic influx of nutrients into the lake, it appears that, for the most part, this did not take place although subsurface seepage from septic tanks and storm water runoff cannot be discounted as sources of nutrient input; however, these were relatively minor. In general, the water chemistry of lakes in the Orlando area appears to be influenced in large part by leaching from sedimentary deposits that were laid down after the Oligocene Period and little affected by nutrient input from residential or commercial development.

WHITE AMUR STOCKING RATES

On 9 September 1977, white amur purchased from the Fish Farming Experiment Station at Stuttgart, Ark., were introduced into Lake Conway. The fish were stocked in the fall to avoid heat stress. All fish were monosex female (Stanley 1976) to reduce chances of reproduction. Fish barriers (Therriot 1977) were erected at three sites to keep the fish within the lake system. However, decreasing water levels throughout the study period effectively restricted the movement of fish out of the lake and made the barriers superfluous.

Nearly 8000 white amur averaging 0.32 kg were released. Stocking density ranged from 3 to 5 fish per acre, and the weight of fish varied from 0.25 kg to 0.61 kg.

Stocking rates for Lake Conway were based upon a white amur stocking rate model (for a discussion of the WES model for predicting stocking rates see Schramm 1983) and knowledge of individual pool characteristics. The primary objective of the Lake Conway Study was not to totally eradicate all vegetation; stocking densities were kept to a minimum so that vegetation would be gradually reduced. At the onset of the project it was determined that plants should be removed from the lake within 4 years.

RESULTS

Areas affected

Aquatic macrophytes. White amur stocked at the rate of 3 to 5 fish per surface acre substantially (more than 90 percent) reduced levels of three common aquatic plants: hydrilla, nitella, and potamogeton. The fourth common plant, vallisneria, which is not readily eaten by amur, was consumed to some extent but increased slightly in one of the pools by the end of the study.

Native fish. As plants were removed at Lake Conway, largemouth bass and other forage fish did not utilize shallow-water habitats but became concentrated in deep-water areas. Fish dependent upon vegetation, such as the blue spotted sunfish, declined in block net samples following plant removal, although total numbers of harvestable fish (perhaps because they had become concentrated in study areas) increased. Although data were somewhat variable, it appears that the robustness of large (>300 mm) largemouth bass, because of increased food availability (as a result of loss of cover), increased slightly.

Angler success. The species-directed success rate improved as a result of macrophyte removal at Lake Conway. During 1979 (when plant removal was quite noticeable) the bass success rate was about double, sunfish rate was 19 percent higher, and crappie success rate was higher than during the previous year.

Food habits—white amur. White amur fed preferentially on nitella, hydrilla, and potamogeton. When these plant species became scarce, the fish ate filamentous algae, cattail, and various other nonpreferred food items. They did not appear to feed upon fish, aquatic insects, or other invertebrates.

Food habits—ducks. The ring-necked duck and American coot fed on crustaceans, aquatic insects, and plants throughout the study. As the vegetation declined, large numbers of amphipods were found in the stomachs of ducks. Presumably these invertebrates were more available to predators as plant cover was removed. The same trend was noted with largemouth bass.

Phytoplankton. All pools had significantly fewer phytoplankton species during the second and third poststocking years than during the prestocking year. Lake Gatlin had significantly fewer species than all other pools during the prestocking period; however, this pool became very similar to the rest of the system during the first and second poststocking years. One of the most dramatic shifts in the phytoplankton community following white amur introduction was the elimination of the summer dominance of *Chlorophyta* and *Chrysophyta*. These were replaced by high levels (greater than 75 percent) of *Cyanophyta* (blue-green algae) throughout the entire year. Phytoplankton diversity gradually decreased in all pools throughout the 4-year study; the greatest change occurred in South and Middle Pools. With the exception of Lake Gatlin, total numbers of phytoplankton were significantly greater in all pools during the second and third poststocking periods than during either the prestocking or first poststocking periods.

Chlorophyll-a. For the prestocking and first poststocking periods, chlorophyll-*a* concentrations were not significantly different among South, Middle, East, and West Pools; however, Lake Gatlin exhibited significantly higher levels. During the second and third poststocking periods, chlorophyll-*a* values were not significantly different among pools. The Carlson Trophic State Index values for South, Middle, East, and West Pools exhibited maximum levels during the third poststocking period while highest values for Lake Gatlin occurred during the prestocking period.

Periphyton. With the exception of the fall samples, populations of attached algae (periphyton) were significantly lower after stocking white amur at Lake

Conway. During the poststocking period, total periphyton species increased in each pool. With the exception of East Pool, mean annual diversity was greater for this group after the removal of the plants. Because aquatic plants provide a substrate for attached algae, removal of macrophytes substantially reduced periphyton. However, as total numbers decreased, diversity values increased as a larger number of niches became available.

Zooplankton. Although the total number of zooplankton species in each pool declined during the entire study period, the mean number of species per sample for South, Middle, West, and Lake Gatlin during the poststocking period was not significantly different from the prestocking period.

Areas unaffected

Benthic macroinvertebrates. The number of species of benthic macroinvertebrates did not change significantly in any pool during the 4-year study; however, significant among-pool differences, evident during the prestocking period, largely disappeared during the second and third poststocking periods. In addition, very little change in species composition or species diversity was evident in the Conway System during the 4-year study period. However, significant reductions in density occurred during the poststocking period for the flatworm *Dugesia* and the snail *Goniobasis.* Both of these invertebrates are associated with surfaces of aquatic macrophytes and numbers were probably reduced along with decline in numbers of plants. However, mean annual macroinvertebrate density estimates for the Conway System declined after introduction of the white amur. Macroinvertebrate biomass decreased progressively at shallow stations from winter of the first poststocking year through the second poststocking year, but deep stations remained relatively constant throughout the 4-year study. However, with the exception of changes in numbers of *Dugesia* and *Goniobasis,* the benthic community appeared to be unaffected by white amur.

Sediment chemistry. No changes in nutrients or trace elements in sediments were evident as a result of introduction of amur at Lake Conway.

Water chemistry. Dissolved calcium, total hardness, and total alkalinity decreased in certain pools, and sodium and potassium increased in the lake through time. However, these changes were the result of diminished rainfall and reduced water levels and not presence of the white amur.

Herpetofauna. As a group these animals were affected more by clearing of littoral vegetation for residences than removal of aquatic macrophytes by white amur. However, three species of turtles, two herbivorous (*Pseudemys floridana* and *P. nelsoni*) and a snail eater (*Sternotherus odoratus*), decreased in numbers and probably were affected to some extent by macrophyte removal.

Waterfowl. Waterfowl numbers declined during the poststocking period. Although potential food sources were removed by fish, changes in populations of birds reflected state-wide conditions.

Aquatic mammals. The water rat and other mammals such as otters, raccoons, and opossum depend on aquatic plants in littoral habitat at Lake Conway. Residential development, not the presence of the amur, affected these plants and reduced numbers of mammals.

Confounding factors

Rainfall. In 1977 total rainfall was 38.1 in., considerably less than the average annual of 50 in. Decreased rainfall caused water levels to drop dramatically in the lake during the latter period of the study period.

Diminished water levels. Sodium and potassium, which originate from solution of sedimentary deposits, increased (because of concentration) as water levels declined. However, calcium, which was pumped into the uppermost pool of the system, declined in the lower pools during the study. This was the result of the lakes becoming more isolated from one another and the calcium-rich waters did not circulate throughout the system.

Residential development. Many new homes were built on the shores of Lake Conway during the study. While these effects were not quantified, the major impact of this action was loss of littoral habitat. Nutrient input to the lake did not appear to be dramatically increased (based on chemical studies) by residential development during the study.

DISCUSSION OF MAJOR FINDINGS

Because white amur stocking rates were designed to control excess aquatic macrophyte growth at Lake Conway, there were no apparent adverse effects to the biota that would be attributed to introduction of white amur. Decreasing water levels and removal of shoreline habitat for residences caused greater habitat loss than introduction of the fish. The water and sediment chemistry exhibited no changes that could be attributable to macrophyte control by white amur. Changes in numbers of waterfowl paralleled state-wide trends. The decline in mammal observations was the result of shoreline clearing. Benthic organisms exhibited no particular change during the study period. Sportfishing was enhanced as a result of plant removal, with negligible effects to the native fish population. Although reptiles and amphibians exhibited significant declines during the study period, in general, their changes could not be related to introduction of the fish.

The most notable change that occurred following amur introduction and plant removal was an increase in phytoplankton abundance. The increase may be the result of elimination of competition by macrophytes and possible release of low levels of nutrients from fecal pellets. However, as discussed by Hestand and Carter (1978), much of the phosphorus from amur fecal material may not be readily available for uptake by plankton. Regardless of the degree of nutrient release following stocking of amur in Lake Conway, the macrophytes were replaced by phytoplankton. The increase in zooplankton density during the first and second poststocking periods was in response to elevated numbers of phytoplankton. The abrupt decrease during poststocking year III was the result of large numbers of phytoplankton cells which are not readily eaten by zooplankters.

Aquatic macrophytes are dependent on nutrients in the sediments (Wetzel 1975, Barko and Smart 1980) although they can also remove phosphorus from the water. The result is often nutrient limitation for phytoplankton (Phillips, Eminson, and Moss 1978). Barko and Smart (1980) reported that *Egeria densa, Hydrilla verticillata,* and *Myriophyllum spicatum* were capable of deriving phosphorus exclusively from the sediments. They reported that, in phosphorus-limited systems, macrophytes can enhance phytoplankton productivity by returning to the water column phosphorus that might otherwise remain immobilized in the sediments. However, Lake Conway is not a phosphorus-limited system, and macrophytes did not play a significant role in making nutrients available for phytoplankton growth.

At Lake Conway, it was determined that the objective would be to control, rather than irradicate, the aquatic macrophytes. As a result, plants were reduced over a 2-year period until their numbers were barely detectable. This caused minimal impacts to the native biota in the system. Disruptions to the nutrient regimen and to the native and sportfishery, which have been documented at other studies when fish had been stocked at many times the density used at Lake Conway, were not noted during this project.

REFERENCES

Barko, J. W., and Smart, R. M. 1980. "Mobilization of Sediment Phosphorus by Submersed Freshwater Macrophytes," *Freshwater Biology,* Vol 10, pp 229-238.

Blancher, E. C., II, and Miller, A. C. 1983. "Data Management System for the Large-Scale Operations Management Test at Lake Conway," Miscellaneous Paper (in preparation), U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Hestand, R. S., and Carter, C. C. 1978. "Comparative Effects of Grass Carp and Selected Herbicides on Macrophyte and Phytoplankton Communities," *Journal of Aquatic Plant Management,* Vol 16, pp 43-50.

Phillips, G. L., Eminson, D., and Moss, B. 1978. *Aquatic Botany,* Vol 4, pp 103-126.

Schramm, H. L. 1983. "The White Amur Stocking Rate Model," Miscellaneous Paper (in preparation), U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Stanley, J. G. 1976. "Production of Monosex White Amur For Aquatic Plant Control," Contract Report A-76-1, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Theriot, R. F. 1977. "The Large-Scale Operations Management Tests (LSOMT) With the White Amur at Lake Conway, Orlando, Florida." *Proceedings of the Research Planning Conference on Aquatic Plant Control Program,* Miscellaneous Paper A-77-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., pp 87-96.

Wetzel, R. G. 1975. *Limnology,* Saunders, Philadelphia, Pa.

STATE AND OTHER FEDERAL FIELD OPERATIONS STUDIES

Applied Research with Hybrid Grass Carp and Grass Carp

by
Paul R. Beaty*

The Coachella Valley Water District, Imperial Irrigation District, U.S. Bureau of Reclamation, California Department of Water Resources, and California Department of Fish and Game are jointly sponsoring a research program to evaluate the effectiveness of hybrid grass carp (female grass carp, *Ctenopharyngodon idella,* × male bighead carp, *Hypophthalmichthys nobilis*) in controlling problem aquatic vegetation. In addition, the impact of the hybrids on resident fishes, benthic macroinvertebrates, and water quality is also being studied. The hybrid is believed to be sterile, thus avoiding potential environmental problems caused by overreproduction.

In 1980 fish screens were installed in the Coachella Canal (capacity 1200 cfs) and the Wormwood Lateral 3 Canal (capacity 60 cfs) to create experimental sections. Baseline plant data showed high variability among the test sections. As a result, exclosures were constructed within each test section to serve as controls. Hybrid grass carp were then introduced at stocking rates varying from 50 to 250 kg/ha.

During the summer of 1982 all test sections showed significantly lower plant densities in the stocked portions of the canals than in the exclosure controls. The plant species controlled included hydrilla (*Hydrilla verticillata*), milfoil (*Myriophyllum spicatum*), sago pondweed (*Potamogeton pectinatus*), and curlyleaf pondweed (*Potamogeton crispus*). In addition, hydrilla stem lengths in the test section with the lowest stocking rate increased markedly after water temperatures declined in the fall. This may be due to a temperature-related change in feeding by the hybrids.

Plant consumption by grass carp, surgically sterilized to prevent breeding should they escape, were compared with the hybrids in partitioned nonoperational experimental canals. The grass carp consumed significantly more vegetation than the hybrids.

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* Coachella Valley Water District, Coachella, California.

STATE AND OTHER FEDERAL FIELD OPERATIONS STUDIES

Efficacy Evaluation of Hybrid Grass Carp on Irrigation Canals

by
N. Eugene Otto*

Grass carp have been used for centuries in China to control aquatic vegetation. More recently, they have been used successfully for weed control in water conveyance systems in the Soviet Union, East Germany, and The Netherlands. In the United States, however, the use of grass carp has been limited by fears that they would inevitably escape from stocked areas, overpopulate, and adversely affect natural aquatic ecosystems.

In the late 1960s many of these fears were allayed when Soviet and Hungarian researchers crossbred female grass carp (*Ctenopharyngodon idella*) with male bighead carp (*Hypophthalmicthys nobilis*), another fish of Asian origin, to produce what appears to be a sterile hybrid. Hybrid grass carp are now being produced commercially in the United States, but in very limited numbers. Their potential use for aquatic weed control provides an environmentally attractive means for dealing with a serious and growing water system maintenance problem in irrigation canals.

In 1980, the Bureau of Reclamation's Division of Research, in a cooperative agreement between the Reclamation's Lower Colorado Region, U.S. Fish and Wildlife Service, Coachella Valley Water Users Organization, Imperial Irrigation District of California, and three State of California agencies, initiated a study with hybrid grass carp to evaluate their effectiveness in controlling aquatic weeds in test canals and their effects on the aquatic environment. The Division of Research staff's responsibility in these studies was to determine the effectiveness of the hybrid fish in controlling aquatic vegetation. The summary of progress made during the 3-year study is presented herein. The other cooperators were responsible for development of fish handling and management techniques and determining effects on aquatic environment (reported elsewhere).

Study sites on two canals within the Imperial and Coachella water users organizations' projects were established in 1980 to determine the background aquatic vegetational characteristics in the canals. In mid-1981 hybrid grass carp were introduced into the canal test sections which ranged from 0.6 to 1.0 km in length. Certain areas in these test sections required the establishment of exclosure areas to evaluate aquatic weed growth under grazing pressure from herbivorous fish. Efforts to establish test section reaches of the test canals were unsuccessful because of the transient and unpredictable nature of aquatic weed infestations from year to year. Stocking rates ranged from 145 to 190 kg/ha in the initial studies.

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* U.S. Bureau of Reclamation, Denver, Colorado.

These study sites were sampled in May, July, August, and October of 1982 following hybrid fish introduction. Biomass production, vegetative tuber production, species identification, and plant community populations were determined within and outside comparative control areas during this study period. These studies were conducted by utilization of scuba diving techniques. In addition, environmental parameters relating to aquatic plant growth have been monitored during the course of these field investigations.

Summarizing the effects of fish grazing on aquatic plants at the end of 1982, the studies show some promising reduction of aquatic weed populations. Biomass was found to be the most reliable indicator of vegetational utilization (Figures 1 and 2). There was, however, considerable variability among the test sections of the canals. Other parameters such as subterranean vegetational tuber production, stem density, and stem lengths were less significant indicators of the herbivorous fish effects on the aquatic plant populations. Dominant plant species were hydrilla, Eurasian watermilfoil, followed by sago pondweed, curlyleaf pondweed, southern naiad, and filamentous blue-green algae.

Plans are being made to continue these studies in southern California to further determine the effectiveness of the hybrid grass carp in controlling aquatic weeds

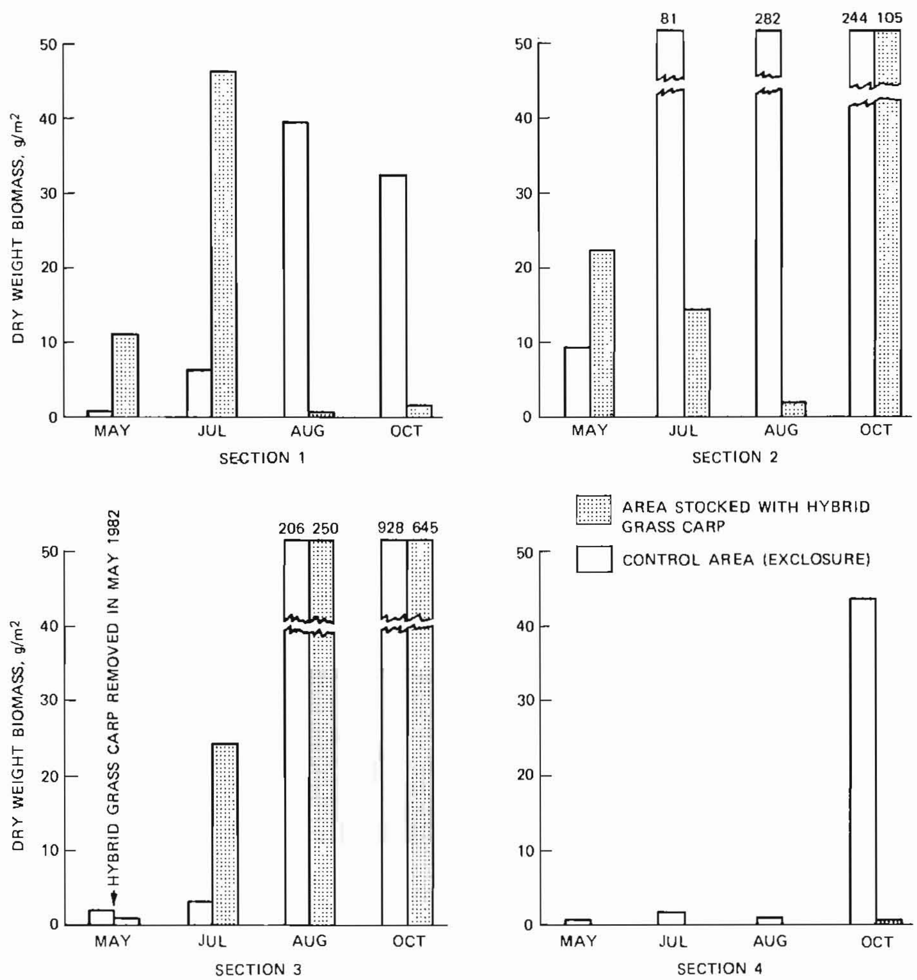

Figure 1. Combined dry weight biomass of hydrophytes collected in four test sections of the Wormwood Canal Lateral 3 during the 1982 growing season

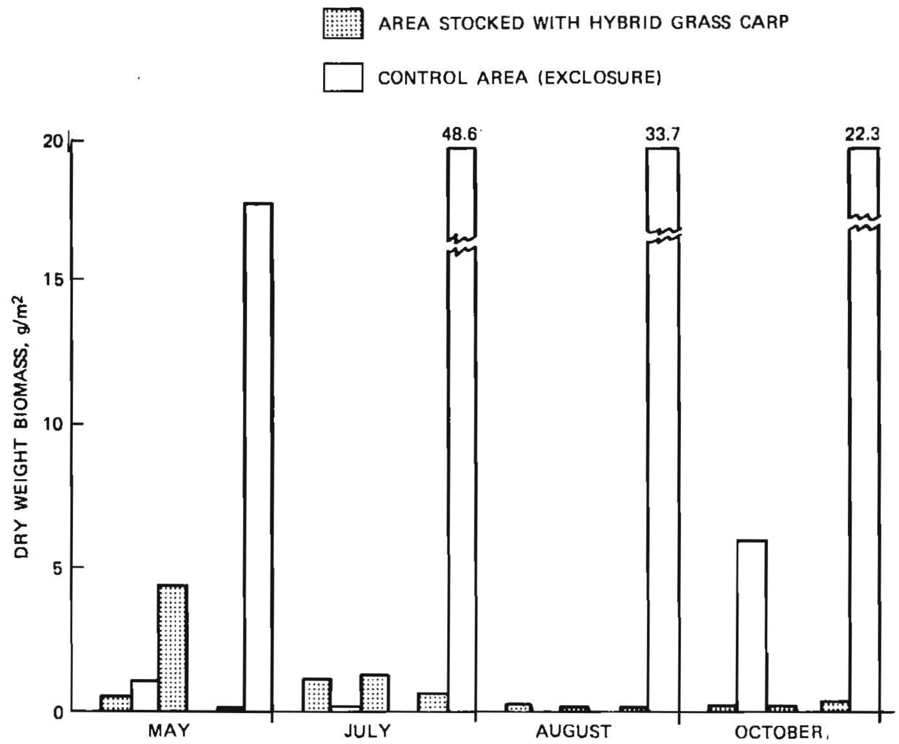

Figure 2. Combined dry weight biomass of hydrophytes collected in reach 27 of the Cochella Canal during the 1982 growing season

in canals, stocking rates, fish handling, fish movement, and effects of the fish on the aquatic environment. Other geographical areas are being considered for field evaluation of herbivorous fish for canal weed control, particularly the Rocky Mountain and Pacific Northwest areas.

ACKNOWLEDGMENTS

These efficacy studies were conducted by Environmental Sciences Section staff botanists F. L. Nibling, J. S. Thullen, and J. E. Boutwell in cooperation with Paul Beatty, Lead Scientist, and staff of Coachella Valley Water District, Hybrid Amur Research Group.

STATE AND OTHER FEDERAL FIELD OPERATIONS STUDIES

The Future of Herbivorous Fish in the United States

by
U. Thomas Jackson*

An outlook on the future of herbivorous fish for aquatic plant management in the United States is available from close inspection of past and present conditions regarding the use of grass carp or white amur (*Ctenopharyngodon idella*). Since initial introduction into the United States in 1963 and commercial production by the late 1960s, the grass carp has been one of the most controversial fish species in the country. This controversy is largely a product of legitimate concern, misinformation, political and emotional appeal, erroneous assumptions, and peer pressure combined in varying proportions at different times and places over the past two decades. The extent to which grass carp have stirred Americans' emotions is evidenced by two instances where the controversy has carried final decisionmaking into State courts.

Grass carp have been stocked into inland waters in most of the United States, often in violation of State fish and wildlife regulations. Documented instances of such wrongdoing have fueled the emotional/political aspects of the controversy and have served to perpetuate an atmosphere in which biological information (fact) about the fish has been overlooked and/or overshadowed. Overstatements in the popular press of both the pros and cons of grass carp introduction for aquatic plant control have frequently polarized the issue into opposing schools of misunderstanding.

Increasing public interest in grass carp has supported a "black market" for the fish in some states banning importation. Widespread public interest is attributable to (1) demonstrated effectiveness of grass carp in controlling a variety of nuisance aquatic plants at significantly reduced costs compared to traditional control methods, (2) curiosity in the unique biology of grass carp as a temperate-adapted aquatic herbivore, and (3) increased visibility, intensity, and distribution of aquatic plant problems. At present, public use of these fish is permitted in all or part of only ten states, but four of these recently reversed earlier prohibitions, which may signal future changes in other states. Grass carp research is ongoing in over 12 states.

The extent of future grass carp use in managing aquatic vegetation is dependent on resolution of both real and perceived conflicts with other water-based renewable natural resources and their management. Resolving these conflicts hinges on mitigating or eliminating the concern for development of self-sustaining grass carp populations in U.S. waters. An economically and politically efficient approach to this problem will be in the development of practical methods to produce large numbers of sterile fish. Evidence for the utility of this approach is

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available from the dramatic upsurge of national interest accompanying recent production of hybrid grass carp (female grass carp × male bighead carp) which hold potential as a sterile alternative or complement to grass carp. Forthcoming studies on chemical sterilization of grass carp and the already available technologies for surgical sterilization and production of all-female stocks are likewise targeted at resolving perceived resource conflicts related to possible natural reproduction. Sterile fish are of particular biological and political interest in areas of the country where grass carp importation has been limited or nonexistent. However, sterilized stocks could also benefit regions where grass carp are already widely distributed for vegetation management by minimizing the number of introduced fertile fish available to any localized reproducing populations in nontarget habitats such as large rivers like the Mississippi.

With major resource conflicts reduced or eliminated, the future of grass carp in the United States is dependent on developing innovative and biologically thoughtful management strategies designed to reduce troublesome aquatic vegetation biomass, but maintain viable, productive aquatic plant populations. One promising approach to this objective is to consider aquatic plant control from the perspective and information base of grazing management. From this viewpoint, aquatic vegetation control becomes the technology to anticipate, adjust, and integrate fish-grazing intensity, diversity, and distribution in relation to the life history (including phenology) of target plant populations and communities responding to sustained predation. Although this technique is information- and management-intensive, it emphasizes continuous cropping rather than intermittent harvest or large-scale destruction of aquatic plants and views plant "control" as a series of management iterations (adjustments) necessary to achieve any desirable equation between plant removal and plant production over time or space.

The real potential of this approach is that it seeks a dynamic counterbalance between two naturally continuous but generally opposing processes: biomass reduction by herbivory vs. biomass elaboration by primary production. Successful grazing management is thus process oriented because it emphasizes adjustment in the basic mechanism (primary production) which generates aquatic plant problems rather than merely treating the symptom (nuisance biomass) of such problems. As a result, a grazing perspective of troublesome water plants is biologically and ecologically more consistent with the way(s) in which aquatic systems function in transferring energy and materials to organisms (plants) at rates which can create impediments to various water uses. This focus on process rates is an important management tool because it directs control efforts at reducing the rate rather than at removing the process. Cost reductions resulting from this attitude toward macrophyte control would be measured in significant economic and environmental savings, particularly in multiple use waters which could be managed for the reduced presence rather than the scheduled absence of aquatic vegetation to accommodate the mix of uses and users. In this regard, recent innovations and discoveries in terrestrial grazing management have important implications for future development of aquatic grazing programs despite the obvious differences between terrestrial and aquatic ecosystems.

The idea of aquatic grazing management is essentially a call for broad-spectrum hybridization between fishery biology and aquatic botany. Such a concert could produce new or merged information and methodologies tuned to the important role that grazing animals can play in changing or maintaining the productivity, diversity, and distribution of plants. During a period of academic parallel evolution, the two disciplines have independently developed techniques and expertise pertinent to the emergence of underwater grazing management. These separate capabilities could now be combined into a quantum leap in aquatic plant management technology. Other jumps in American know-how have often been produced as academic or technical hybrids.

Despite its potential applications, development of grazing management as an aquatic plant control strategy in the United States will require significant changes in perspective and approach by those managing aquatic systems. Such change is technologically and economically feasible, but will encounter considerable institutional and psychological inertia which must be overcome for any large-scale application. Resistance to this concept is inherent in the technological traditions of U.S. aquatic pest control, water management, and aquatic resource utilization, including the 20th century American emphasis on the recreational aspects of freshwater fishes. However, these traditions are dynamic and are already expanding to accommodate technical innovations like integrated pest management and changes in perspective such as the National Aquaculture Act of 1980 (PL 96-362). Use of freshwater fish as grazing animals to help control problem aquatic "pastures" can be viewed as an extension of these developing techniques and attitudes regarding water resources. Acceptance of this idea for U.S. aquatic plant management depends on the extent to which time, economics, and problem plant distribution dictate the need for change. At present rates, the future of herbivorous fish in the United States is now.

STATE AND OTHER FEDERAL FIELD OPERATIONS STUDIES

Update on the Status of Aquatic Plants in Georgia, 1982

by
Wayne Thomastown*

Several aquatic weeds have become problems in parts of the Southeast and have the potential of becoming a major problem throughout Georgia. At the present time, aquatic weeds are not major problems in Georgia except for Lake Seminole on the Georgia-Florida-Alabama border. Many of the species currently exist in relative small acreages and are scattered throughout the state (Table 1). A problem does exist in their potential for rapid dispersion and growth. If these weeds are left unchecked, they will pose a serious threat to agriculture, recreation, and industry in the state. It is important that control methods be initiated now before these plants become firmly established.

The plants that are expected to present the greatest problems are hydrilla (*Hydrilla verticillata* Royle), alligatorweed (*Alternanthera philoxeroides* Mart.), waterhyacinth (*Eichhornia crassipes* (Mart.) Solms), giant cutgrass (*Zizaniopsis* sp. Michx), Eurasian watermilfoil (*Myriophyllum spicatum* L.), and *Lyngbya* sp., a filamentous algae. In some localized areas, these weeds have already become problems.

DISTRIBUTION, LOCATION, AND TREATMENT

Hydrilla, at the present time, is primarily confined to Lake Seminole. However, it has been located in Radium Springs in Dougherty County and a small pond in Worth County. The 10 acres in Radium Springs located near Albany has been treated several times with various chemicals. When this weed was initially identified, there was a 100 percent coverage of the area. This infestation has been treated using Komen-Diquat combinations and Komeen alone, by gravity, by spraying, and by lowering the water level before applying the chemicals. This area was also treated with Hydout pellets. Each treatment was successful in the lower end (100 percent control) but largely ineffective in the upper end (75 to 85 percent control). There is approximately 70,000 gpm of water flowing from an underground stream into this spring which obviously caused the chemical to be washed out before it had much herbicidal effect.

Five gallons of Komeen (3 ppm) was used in chemical treatments of hydrilla in the Worth County pond. The herbicide was sprayed directly onto the weed mats from the shoreline with a carbon-dioxide-powered sprayer. This treatment gave an apparent 100 percent control.

Lake Seminole, located on the Georgia-Florida-Alabama state lines, has received a few treatments by the Corps of Engineers with some success. However,

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* Georgia Department of Natural Resources, Fort Valley, Georgia.

Table 1
Location, Infestation, and Types of Aquatic Weed in Georgia Waters

Weed	*Acreage*	*Location*
Hydrilla	2500	Lake Seminole
	10	Radium Spring
Alligatorweed	500	Lake Seminole
	50	Lake Jackson
	Trace	Ebenezer Creek
	Trace	Savannah River
	Trace	Altahama River
	Trace	Lake Walter F. George
	Trace	Lake West Point
Waterhyacinth	10	Satilla River
	150	Lake Seminole
	Trace	Suwannee River
	100	Lake Worth
Giant cutgrass	5000	Lake Seminole
	100	Lake Worth
	10	Lake Jackson
	Trace	Lake Sinclair
	1000	Coastal area
Eurasian watermilfoil	8500	Lake Seminole
	200	Lake Blackshear
	100	Lake Worth
	Trace	Lake Seminole

without a full-scale attempt, the hydrilla eventually will spread over a large portion of the lake.

Alligatorweed has been in Lake Seminole for several years, and has now spread throughout the state. This weed has been sprayed with 2,4-D in an attempt at control. The alligator flea beetle has been distributed on the alligatorweed with some evidence of damage. However, extremely cold winters have often killed the entire beetle population. Attempts will continue to be made to establish these insects. At the present time, it is not known what effect this action might have. The beetles presently being utilized are collected from Ebenezer Creek in extreme southeast Georgia where they have had some effect controlling the weed. Alligatorweed has spread throughout the state and in all probability will eventually become a tremendous problem in oxbow lakes, sloughs, and slow-moving waters. It is not expected that it will become a bad problem in the fast-flowing streams that flood each winter. Alligatorweed has been present in the Walter F. George Reservoir in small patches only for several years, but recently it has begun to spread. It is mere speculation as to whether the weed will become a major problem in this particular area.

The acreage of waterhyacinths in Lake Seminole varies from year to year. Also, small acreages occur on the lower part of the Suwannee River and in Lake Worth. It is not expected that hyacinth will be much of a problem in the northern section of the state due to the cold weather.

There is a heavy infestation of giant cutgrass on Lake Seminole. It also exists in lakes Jackson, Sinclair, Worth, and Blackshear, and probably in many other areas not yet identified. It is estimated that there are several thousand acres of giant cutgrass on the Georgia coast. Small patches of this plant have been sprayed on Butler Island with Dowpon M, which gave fair results, but this treatment was not followed up with any other action. It is not known if it will become a problem in other Georgia lakes.

Lyngbya sp. is becoming well established in isolated areas throughout the state. At the present time, the biggest problem is in Lake Blackshear near Cordele, Ga. It also can be found in Lakes Worth and Seminole and in many ponds throughout the state.

Lyngbya has been treated using Diquat, Aquazine, and some forms of Endothall. Some test plots were applied using Hydrothal 191 and Hydout. The results with Hydrothal 191 appeared promising but unforeseen water level fluctuations made it impossible to evaluate. *Lyngbya* has been 100 percent controlled with several different chemicals in the spring of the year. However, within a period of about 3 weeks to 1 month the algae reappeared. Apparently, this is all the time required for the *Lyngbya* to completely reinfest an area.

Although grass carp (*Ctenopharydodon idella*) are illegal in Georgia, a few have been recovered in streams. A few permits have been issued for monosex and triploid grass carp in carefully selected ponds.

OBJECTIVES OF A WEED CONTROL PROGRAM IN GEORGIA

The objectives of a weed control program include:

a. Keep an up-to-date inventory on lakes and streams to determine when these weeds might be present. This is accomplished with existing fisheries personnel and is usually done with routine performance of other tasks.

b. Check the expansion of hydrilla when possible, realizing that eradication as such is virtually impossible. Considerable expenditures of effort and money may be worthwhile if the spread of this weed can be prevented.

c. Control *Lyngbya* in Lake Blackshear. Methods of eradication are not known. However, *Lyngbya* continues to spread throughout Lake Blackshear and surrounding areas. The main problem with the control of *Lyngbya* is the tremendous speed with which it can repopulate an area once it has been killed.

d. Control alligatorweed, probably in two phases: (1) biological control using the flea beetle and any other insect that might be useful, and, if this is not successful, (2) use of herbicides.

e. Use herbicides in an attempt to control hyacinth, giant cutgrass, Eurasian watermilfoil, and *Egeria* sp.

f. Be aware of the possibility of utilizing grass carp, monosex or triploids, for control of some aquatic weeds.

CONCLUSIONS

The development of an efficient aquatic weed control program in any area should be considered based upon its long-range effects. Georgia's program has only been in effect for approximately 4 years but considerable expertise and experience have been gained. Immediate effects, although only temporary in nature, have been derived from these actions. Chemical control is generally short lived and applications of herbicides often must be made several times a year for several years in varying situations.

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

In-House Research

by
Edwin A. Theriot*

Biological control has proven itself as a method for management of aquatic plants. Research conducted or sponsored by the Corps' Aquatic Plant Control Research Program (APCRP) has resulted in the reduction of alligatorweed in the southeastern United States with the introduction of insects, most notably the *Agasicles* flea beetle. More recently we have demonstrated that a combination of insects and pathogens has dramatically reduced the waterhyacinth population in Louisiana. We are working on several approaches to refine our methodology on waterhyacinth and are looking at some old and new approaches for control of submersed aquatics.

I would like to talk today about our in-house research efforts. The APCRP is presently funding five in-house research studies at the U.S. Army Engineer Waterways Experiment Station (WES) in Vicksburg, Miss. Three of the studies deal with waterhyacinth, one with hydrilla, and one with alligatorweed.

SAMEODES TEMPERATURE TOLERANCE STUDY

Purpose and objectives

The purpose of this study was to establish baseline information on the overwintering capability of *Sameodes albiguttalis*. The specific objective was to develop models for estimating the proportion of third instar *S. albiguttalis* larvae that will be killed when subjected to a constant low temperature. The larvae were subjected to six different temperatures (+6, +4, +2, -2, -4, and -6°C) in the laboratory for varying lengths of time.

Results

Exposure to +6°C and +4°C produced no significant difference in mortality from control groups. Results for the +2, -2, -4, and -6°C temperature all exhibited mortality and were analyzed using a Minimum Logit Chi-square procedure. This method produced a linear graph which indicates the predicted mortality for a particular test temperature (Figure 1).

Exposure to +2°C was shown to cause mortality. The model indicates that 90 percent mortality resulted after only 48 hr exposure to this temperature (Figure 1). Results of tests performed at -4 and -6°C were statistically indistinguishable. Ninety-five percent mortality was estimated to occur after 9 to 11 hr exposure. Exposure to -2°C is estimated to require an increase in duration of two to three times that of -4 or -6°C exposure before the same level of mortality is reached. This study has been completed and a final report is being prepared.

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* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

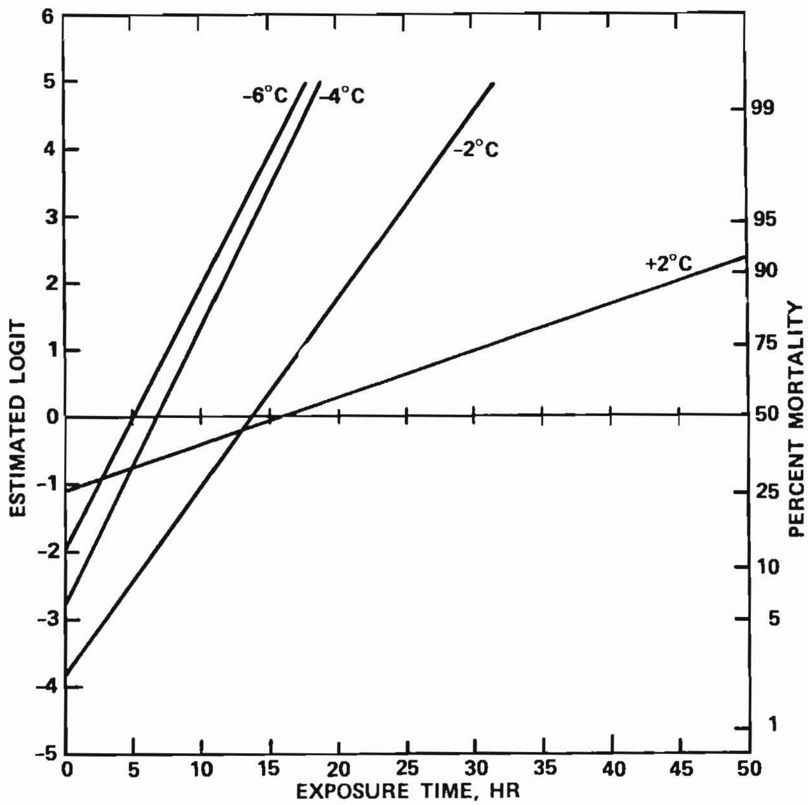

Figure 1. Predicted mortality of third instar *S. albiguttalis* larvae resulting from exposures to +2, -2, -4, and -6° C

CERCOSPORA INFECTIVITY ENHANCEMENT STUDY

Purpose and objectives

The purpose of this study was to enhance the infectivity of the *Cercospora rodmanii* formulation on waterhyacinth. The objectives of this study were to verify compatibility of potential enhancing agents with the *C. rodmanii* formulation, and to evaluate the ability of compatible agents to increase the infectivity of the *C. rodmanii* formulation on waterhyacinth.

Twelve potential enhancing agents were evaluated:

a. ***Yeast extract.*** Yeast extract is commonly used to stimulate growth in nutrient preparations for microorganisms.

b. ***Amino acids.*** Amino acids have been found to stimulate germination of pathogenic fungi. Glutamic and aspartic acids were tested.

c. ***Glucose.*** Many incidences of stimulation of germ tube production and elongation by glucose have been documented in the literature.

d. ***Nutrient agar.*** Nutrient agar is a widely used growth medium for microorganisms in the laboratory and its viscosity could be easily manipulated to a suitable consistency.

e. ***Biological surfactant.*** Tween products have a wide laboratory use as a wetting and dispersing agent. Tween 20, 60, and 80 were tested. These agents differ in the degree of surfactant action that they exert on the formulation.

f. ***Sodium alginate.*** Sodium alginate is the salt of a gelatinous polysaccharide extracted from kelp. Sodium alginate has been used as a carrier for herbicides in swift streams because of its extreme viscosity and low solubility.

g. ***Gum xanthan.*** Gum xanthan is a polysaccharide produced by the bacterium *Xanthomonas campestris*. When mixed with water in low concentrations, the gum forms a highly viscous solution that can be used as a "sticker."

h. ***Ortho X-77 Spreader.*** Ortho X-77 is a surfactant commonly used with herbicides for control of aquatic plants. Results of a previous study suggested that Ortho X-77 Spreader enhanced the viability formulation.

i. ***Super Slupper.*** Super Slupper is a starch polymer capable of absorbing 300 to over 1500 times its weight in water to form a viscous humectant.

Results

The results of the study were as follows:

a. All of the individual agents, except Ortho X-77 Spreader, were compatible with the *C. rodmanii* formulation. Compatibility of Ortho X-77 could not be determined due to conflicting results in viability tests.

b. All combinations of agents tested were compatible with the formulation.

c. Effects of compatible test agents on infectivity of the *C. rodmanii* formulation could not be determined because the formulation, although viable in the laboratory cultures, did not infect waterhyacinth.

It was unfortunate that we were unable to obtain a *C. rodmanii* formulation that was infectious to fulfill the objectives of the study. However, I understand that Abbott Laboratories, the maker of the formulation, has corrected this problem. Charudattan will discuss in his paper* the results of similar studies with the formulation.

LARGE-SCALE OPERATIONS MANAGEMENT TEST WITH INSECTS AND PATHOGENS FOR THE CONTROL OF WATERHYACINTH IN LOUISIANA

Purpose and objectives

This was a continuation of a study (funded by the New Orleans District) to demonstrate an operational capability of selected combinations of insects and pathogens for control of waterhyacinth. The general objectives of this study were to (a) determine the necessary and sufficient means for establishment of effective field populations of test organisms, (b) demonstrate the effectiveness of test organisms when used at an operational scale, and (c) determine environmental limitations on the test organisms.

The biological control agents being tested in this study included:

a. ***Cercospora rodmanii***—a plant pathogenic fungus endemic to the United States.

b. ***Sameodes albiguttalis***—the Argentine waterhyacinth moth imported from South America.

c. ***Neochetina bruchi***—The cheveroned waterhyacinth weevil from South America.

d. ***Neochetina eichhorniae***—the mottled waterhyacinth weevil also from South America.

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* Page 115 of this proceedings.

Results

Cercospora rodmanii has been applied on a large scale on two sites in Louisiana. One of the test sites near Lake Theriot received its application in April of 1980. By July 1981, the biomass of waterhyacinth within the test site was reduced by more than 50 percent. During this time *Neochetina* spp. had become well established within the site. The combination of *Cercospora* and *Neochetina* was responsible for the decrease in biomass. In October of 1982 approximately 40 percent of the site exhibited open water compared to 100 percent infestation when the study began (Figure 2).

The moth *Sameodes albiguttalis* was first released in Louisiana in August 1979. It has continued to increase its range and is well established in southern Louisiana. Our annual fall survey has shown that *Sameodes* has increased its range since 1981 as much as 60 miles.

The *Neochetina* spp. population continues to exert its stress on waterhyacinth throughout the state. However, the Louisiana Department of Wildlife and Fisheries has completed the 1982 waterhyacinth survey and has noted an increase of invested acreage from approximately 350,000 to 435,000. This is not surprising. We think that the extremely cold winter of 1981 caused the drop out of large populations of waterhyacinth, which also means that the heavy investation of insects on the plants was lost. Heavy seedling production of waterhyacinth in the spring with a low weevil population explains the increase in infested acres in Louisiana.

The test sites will continue to be monitored through April 1983 and a final report will be prepared in September 1983.

BIOLOGICAL CONTROL OF *HYDRILLA VERTICILLATA*

Purpose and objectives

The purpose of this study was to develop microbial biocontrol agents that would reduce the growth and reproduction of hydrilla, and maintain it at an acceptable level. The objectives were:

- *a.* Conduct a survey of the microflora associated with hydrilla.
- *b.* Screen microbial isolates for their ability to produce lytic enzymes specific for components of hydrilla.
- *c.* Identify promising candidate agents.
- *d.* Demonstrate the ability of candidate agents to produce pathogenesis on hydrilla.

Results

Four sites containing hydrilla have been surveyed. Hydrilla samples have been collected in spring and fall from Lake Traford in southern Florida, Lake Theriot in Louisiana, Lake Conroe in Texas, and Imperial Valley in California. Over 200 bacterial and fungal isolates have been screened for their ability to utilize cellulose or pectin. A total of 33 organisms have been selected as candidate control agents: 5 bacteria and 28 fungi. We are presently testing these agents in test tube bioassay studies for their ability to attack hydrilla.

a. April 1980, pretreatment

b. October 1982, 2-1/2 years posttreatment

Figure 2. *Cercospora rodmanii* large-scale application site near Lake Theriot, Louisiana

The next step will be to scale up the inoculum using liquid fermentation and to evaluate these candidate agents in large 200-gal tanks in host specificity and efficacy studies. Hopefully, a candidate agent will be ready for field evaluation late in 1983.

ALLIGATORWEED SURVEY

Purpose and objectives

The purpose of this study was to evaluate effectiveness of biocontrol agents on alligatorweed in the southeastern United States. The objectives of the study were:

a. Obtain information from Federal and State agencies involved in aquatic plant management on the status of alligatorweed and its biocontrol agents in their areas of responsibility.

b. Conduct field surveys in the spring and fall of one growing season in the 10 southeastern states to observe the status of alligatorweed in over 50 locations where the biological agents were originally released in the United States (Table 1).

c. Compile the data into a document that would point out the effectiveness of the biocontrol agents, produce possible explanations for their effectiveness in certain areas, and suggest management plans for the utilization of the biocontrol agents more effectively.

Table 1
Alligatorweed Release and Sampling Sites

State	*Biocontrol Agent Release Sites 1959-1972*	*No. of Releases*	*Sites Visited 1982*
Louisiana	11	17	10
South Carolina	20	44	11
Alabama	10	13	6
Florida	42	48	17
Georgia	9	12	3
Texas	8	15	5
North Carolina	9	16	8
Mississippi	9	19	3
Arkansas	10	20	3
Tennessee	1	1	1

Results

The preliminary data thus far indicate that the southernmost range of alligatorweed along the Gulf Coast has no real problem with the aquatic form of alligatorweed. The biocontrol agents seem to be very effective in this area. There are a few agricultural areas where it is a problem, probably due to heavy usage of insecticides which limit the biocontrol agents. In the Carolinas, Tennessee Valley, and Arkansas, the effectiveness of the insects varies, which seems to be due to limiting climatic conditions. Texas has probably the most severe problems with alligatorweed due to a number of reasons, including severe water fluctuation, heavy use of insecticides, and low numbers of biocontrol agents. There are large amounts of alligatorweed in the terrestrial form throughout these 10 states (Table

1). Of the three introduced biocontrol agents, only the *Aminothrips* can attack the terrestrial form but it does not seem to be doing the job.

In general, alligatorweed is not the major problem that it once was. The northern areas need to conduct management programs using the biocontrol agents similar to the Tennessee Valley Authority program which has had success. This involves yearly releases of the appropriate agents in the early spring to manage particular problem areas. Guidance included in the APCRP's Instruction Report A-81-1 entitled, "The Use of Insects to Manage Alligatorweed," will prove very useful in formulating such a management plan. Assistance in obtaining biocontrol agents and added information on their uses can be obtained from Dr. Joe Joyce and Mr. Jim McGehee of the Army Corps of Engineers, Aquatic Plant Control Operations Support Center, Jacksonville District.

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

Microbiological Control of Eurasian Watermilfoil

by
Haim B. Gunner*

Microorganisms closely bound to Eurasian watermilfoil (*Myriophyllum spicatum*), and apparently species determined, have been selected for their ability to attack the pectin and cellulose tissues of the plant. The pectinolytic and cellulolytic capacities of the organisms are enhanced by passage through appropriate growth media. The enzyme-enriched cultures subsequently applied to the plant bring about accelerated necrosis and death within 21 days (Table 1).

Most recently, in an effort to compress the decay curve of treated plants and bring about more rapid decline, plants were mechanically injured prior to microbial inoculation. This process was designed to simulate:

- Insect damage—Injection by hypodermic.
- Mechanical harvesting—tissue maceration.
- Mechanical harvesting—tissue shearing.

Table 1
Acceleration of Decay of *Myriophyllum* spp. by Cellulolytic and Pectinolytic Microbial Isolates from *M. spicatum*

	Percent Nectrotic Plants*					
	*M. spicatum***			*M. heterophyllum***		
Treatment	*Day 7*	*Day 14*	*Day 21*	*Day 7*	*Day 14*	*Day 21*
Control untreated	0	0	0	0	0	0
Control 1% cellulose medium	0	70	80	10	40	40
Br-3	10	40	70	20	20	20
Br-4	20	30	70	0	0	0
P-3	10	20	80	30	30	30
P-4	0	40	90	40	30	30
P-6	20	80	90	10	10	10
P-7	60	80	100	0	10	10
P-8	10	70	100	10	10	20
Y-2	10	80	90	10	10	10
Y-4	10	70	100	10	20	40
Y-5	20	80	90	20	10	10

* Based on numerical scores, 1 = least decay, 10 = maximum decay.
** Number of plants observed, 10 per treatment.

METHODS AND MATERIALS

Healthy tip portions of the plants, ca. 15 to 20 cm in length, were separated and rinsed under running tap water. After 7 days of recovery, the plants were again washed and then soaked twice in distilled water. Two tips were selected at

* University of Massachusetts, Amherst, Massachusetts.

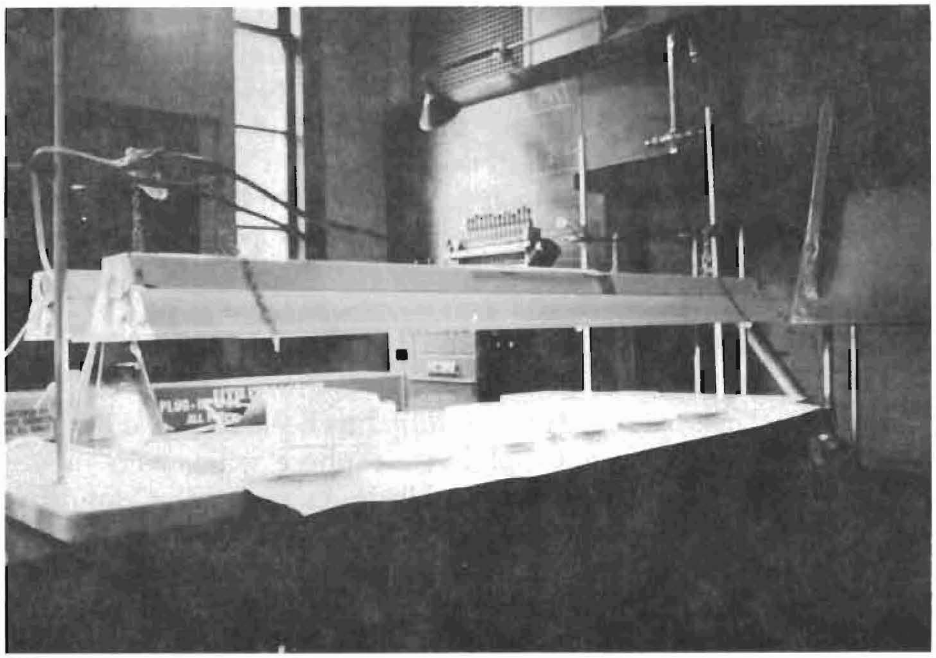


Figure 1. Experimental setup for studies in stress enhancement of microbial decomposition of *Myriophyllum* spp.

random for each treatment and submerged in a 14-cm-diam glass petri dish containing approximately 240 ml Angrosperm medium diluted thirtyfold. The dishes were placed under GE plant lights, Glo and Sho-F40-PL, which provided 55,000 lux at a distance of 15 cm (Figure 1).

At the initiation of the experiments, plants were stressed either by penetration with a B-D Yale Regular Point hypodermic needle, or by crushing or shearing with 30-cm forceps. Hypodermic needle penetration and tissue crushing were performed in respective treatments 4 cm from each end of the plant section; shearing of leaves and stem cutting were performed in the central portion of the section.

Bacterial inoculation of hypodermic-needle-stressed plants was simultaneous with the tissue-damaging penetration, and approximately 0.2 ml of each culture was injected into the site of wounding. The other treatments each received 2.0 ml of the inoculant added directly into the medium. Control plates received 2.0 ml of sterile nutrient broth. At the conclusion of the experiment, bacterial inoculants were successfully reisolated from the liquid medium and plant tissue by serial dilution, and the presence of pectin-utilizing bacteria was observed and enumerated on pectin agar medium.

RESULTS

As can be noted from Figure 2, even undamaged plants maintained in growth medium will succumb to attack from pectinolytic microorganisms deriving from their own ecosphere, with the *Erwinia* bringing about actual total decomposition. The uninoculated control on the other hand remains virtually unaltered and healthy. Further, there is an ascending order of plant decline paralleling the degree of plant injury. As shown in Figure 3, in all treatments except the control, even at 7 days there are indications of necrosis at the site of hypodermic injection. Similarly, in Figure 4 there is, with the unexplained exception of the *Erwinia*-treated section, enhanced die-back at the midsection where tissue has been crushed. Most notably, cutting and shearing as shown in Figure 5 bring about the virtual disintegration of the plant tissue when this injury was followed by inoculation and pectinolytic bacteria.

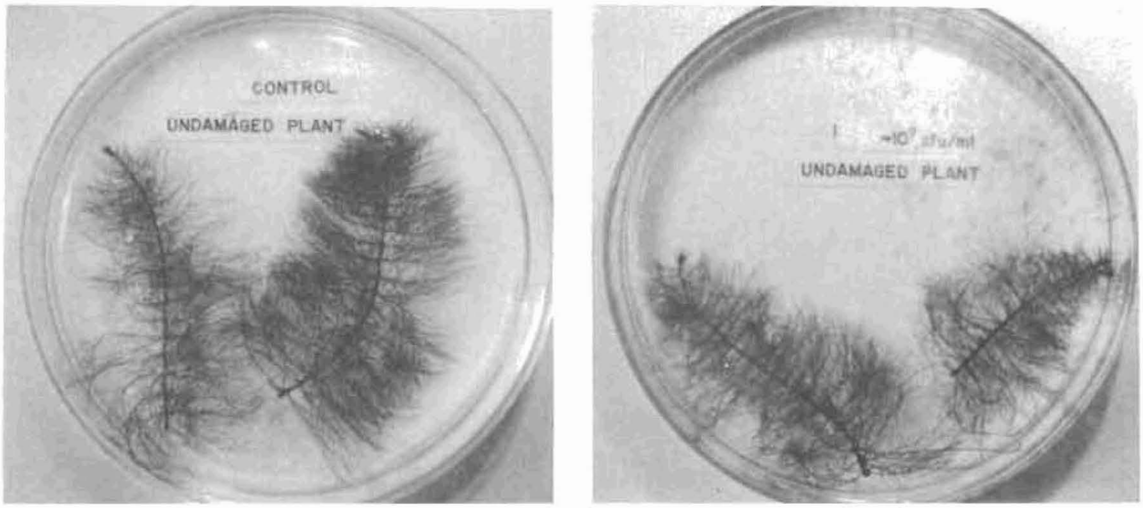
DISCUSSION AND CONCLUSIONS

Though accelerated necrosis of *Myriophyllum* has been obtained by inoculation with microorganisms isolated from the plant's ecosphere, which were subsequently induced to produce enhanced quantities of lytic enzymes, the rapidity of this process has been a matter of concern. The work described in the foregoing suggests that stressing the plants prior to inoculation may be a critical facilitating element in ensuring the most rapid infection and decay. It would indicate the merit of further investigation of stressing techniques by physiologically active agents as well as by mechanical means.

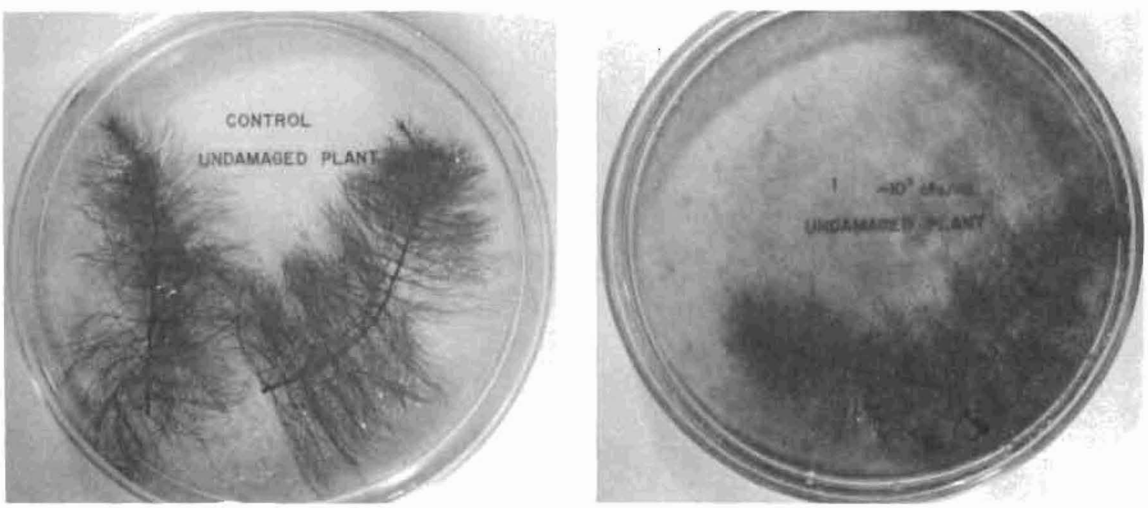
ACKNOWLEDGEMENT

The author wishes to acknowledge the participation of Yuthana Limpa-Amara and Beryl Bouchard.

Control	*Agrobacterium* sp. 01



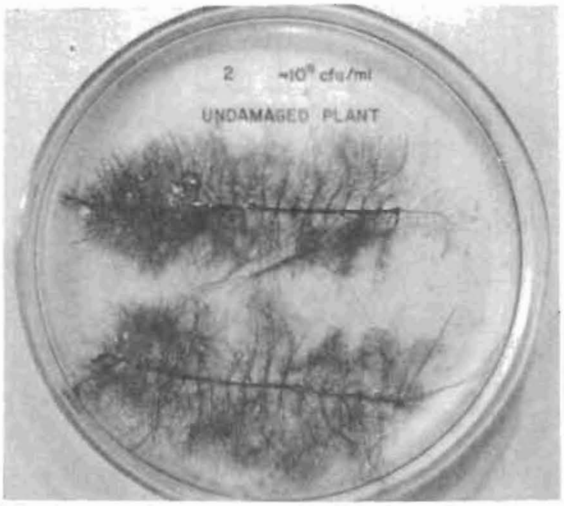
Incubation, 7 days

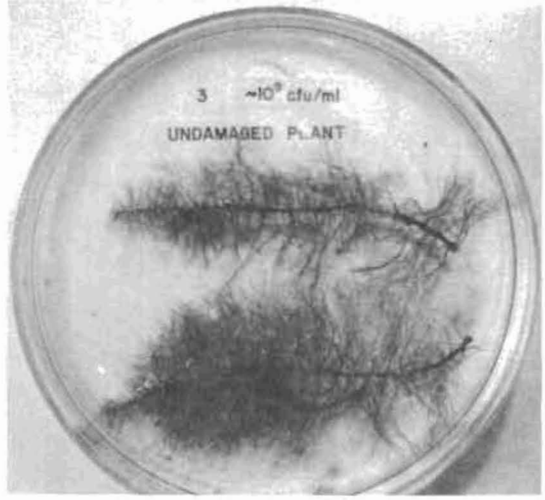


Incubation, 14 days

Figure 2. Accelerated decomposition of undamaged *Myriophyllum* sections inoculated with various pectinolytic bacteria (Sheet 1 of 3)

Agrobacterium sp. 02	*Xanthomonas* sp.

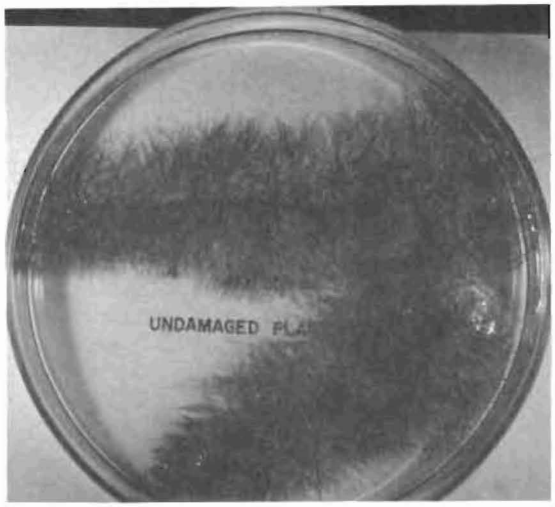




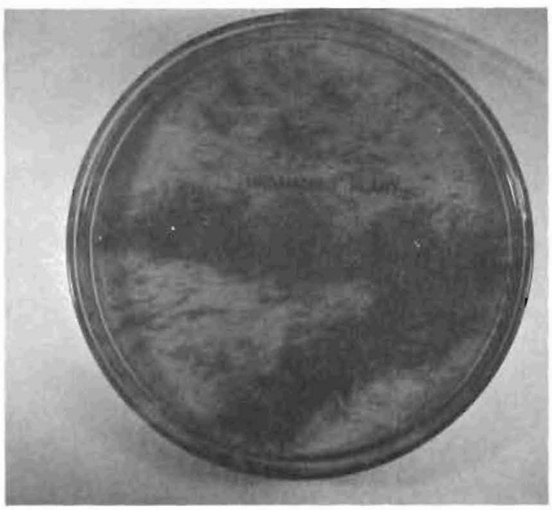
Incubation, 7 days

Incubation, 14 days

Figure 2. (Sheet 2 of 3)



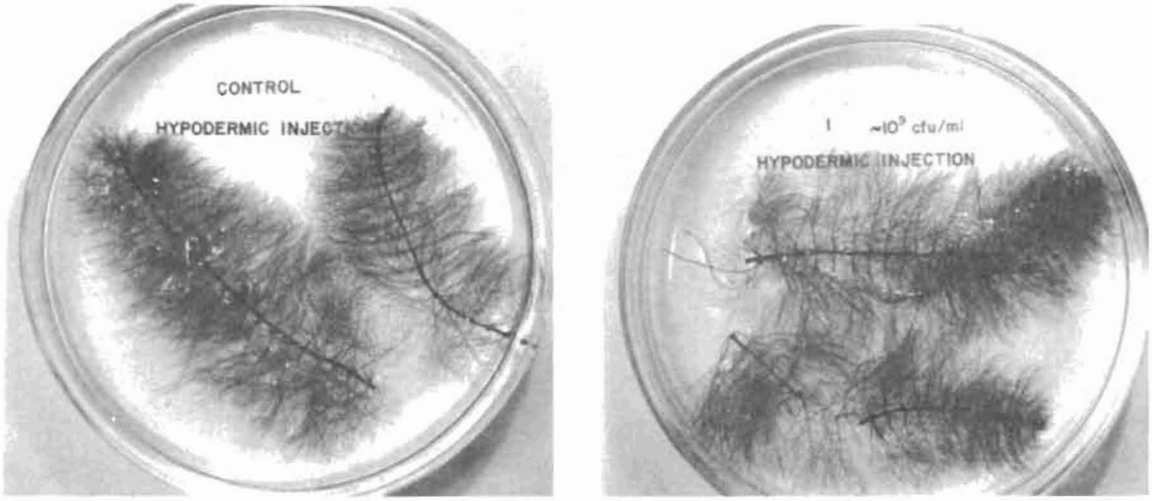
Incubation, 7 days



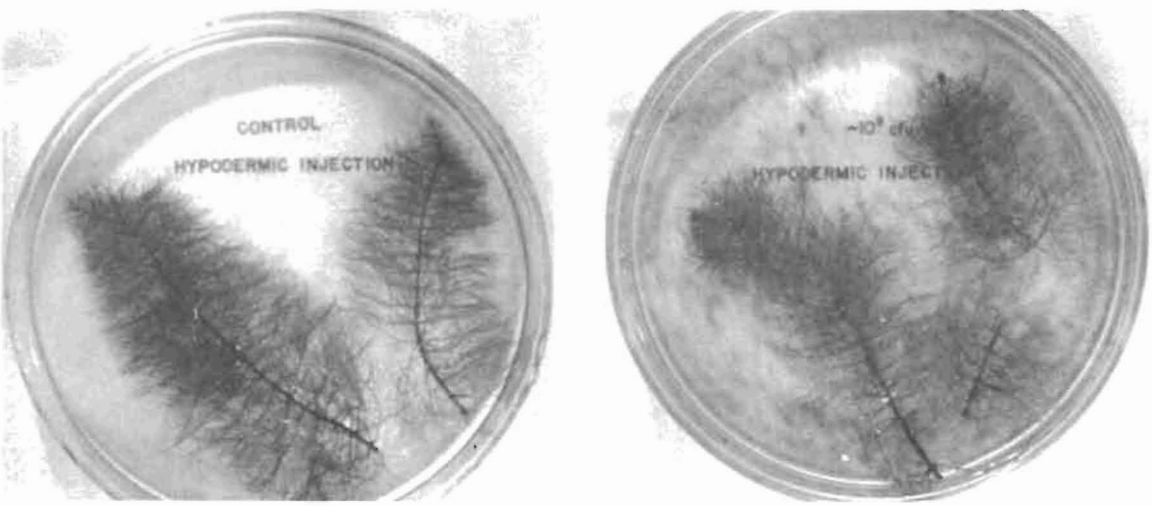
Incubation, 14 days

Figure 2. (Sheet 3 of 3)

Control	*Agrobacterium* sp. 01



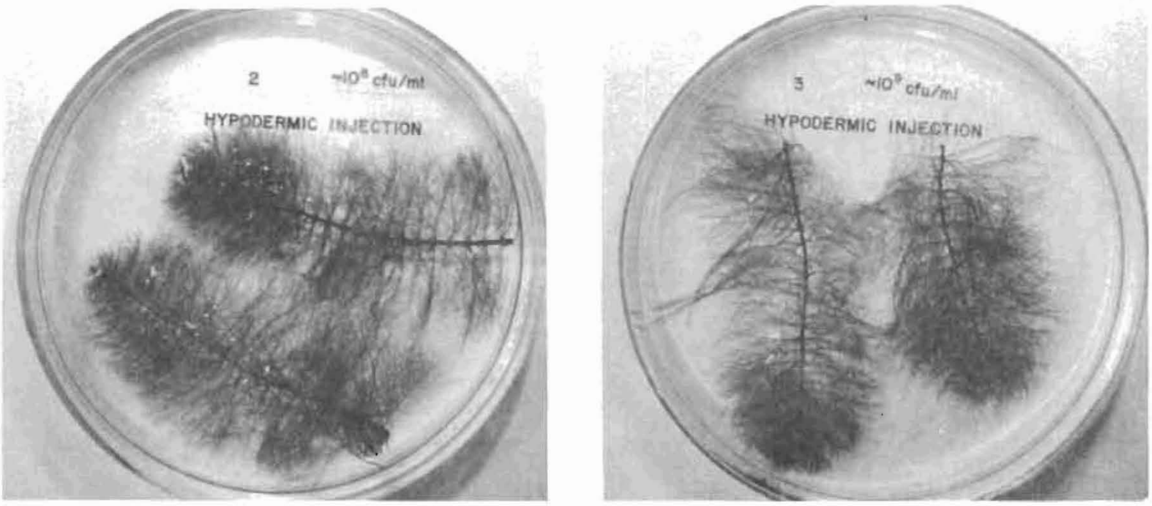
Incubation, 7 days



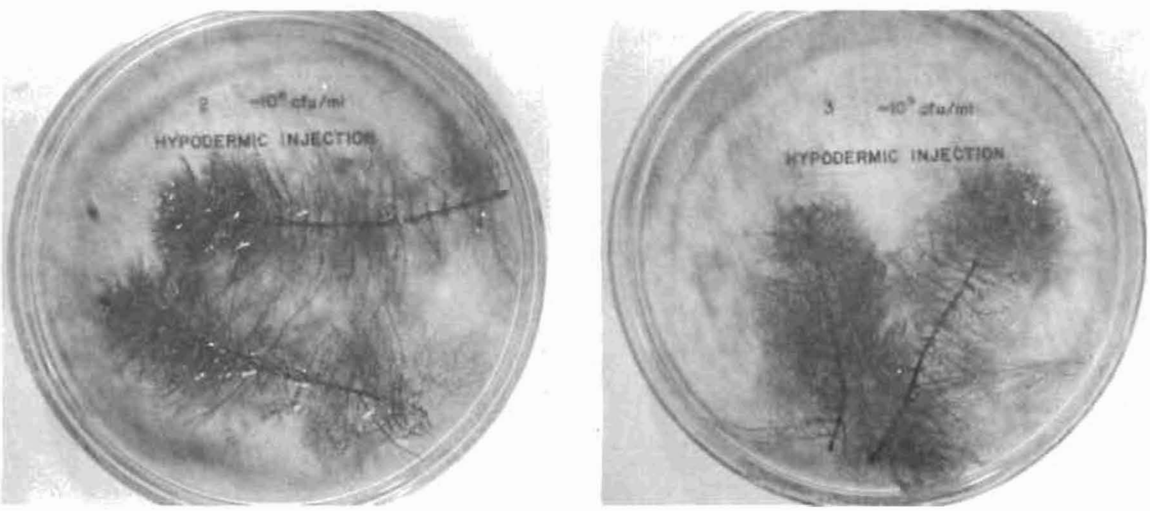
Incubation, 14 days

Figure 3. Accelerated decomposition of *Myriophyllum* sections stressed by hypodermic needle injection of various pectinolytic bacteria (Sheet 1 of 3)

Agrobacterium sp. 02	*Xanthomonas* sp.

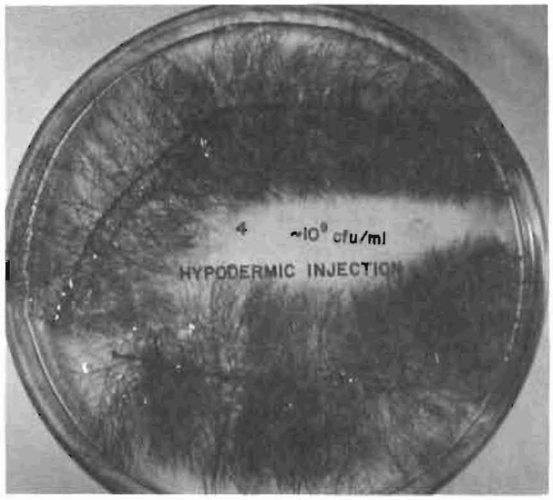


Incubation, 7 days

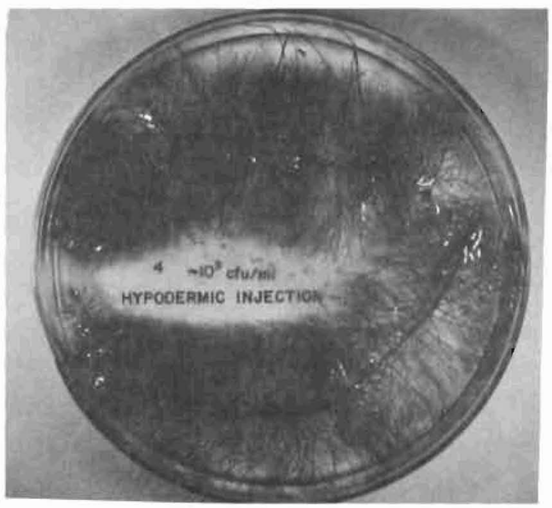


Incubation, 14 days

Figure 3. (Sheet 2 of 3)



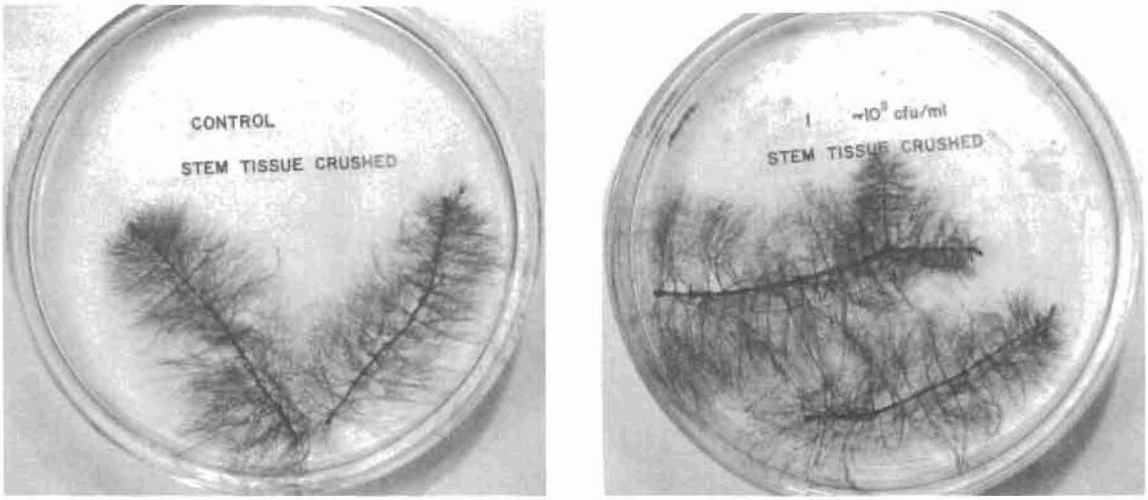
Incubation, 7 days



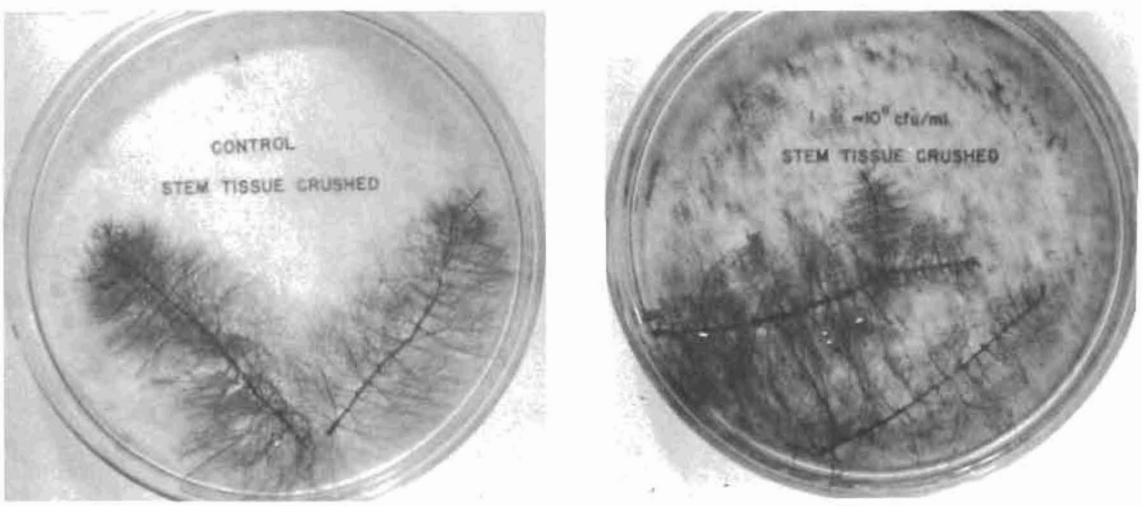
Incubation, 14 days

Figure 3. (Sheet 3 of 3)

Control	*Agrobacterium* sp. 01

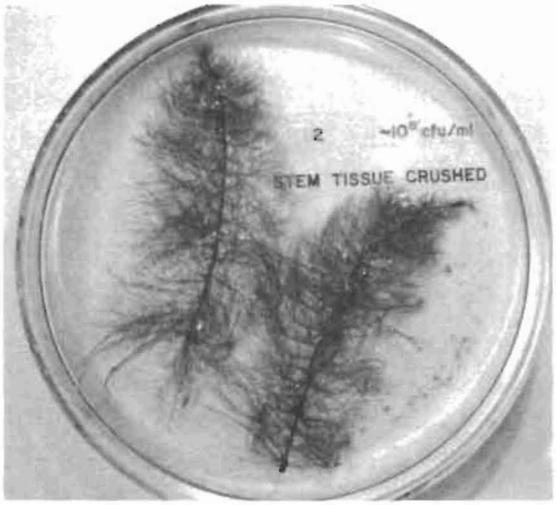
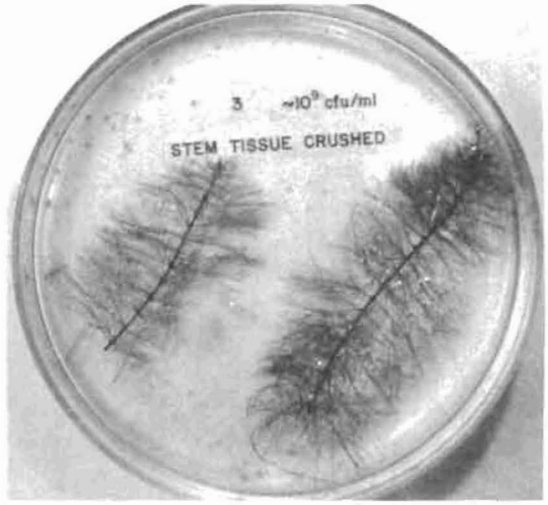


Incubation, 7 days

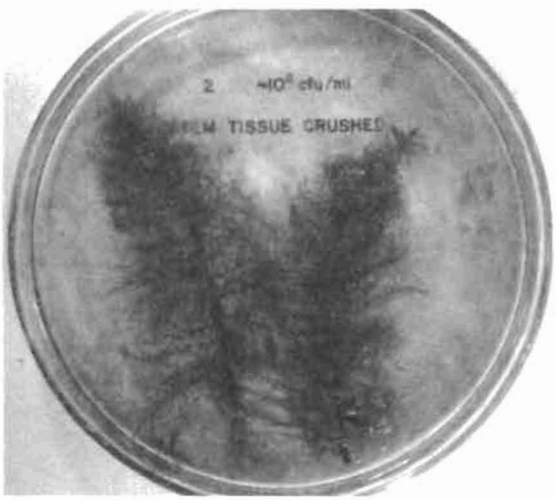
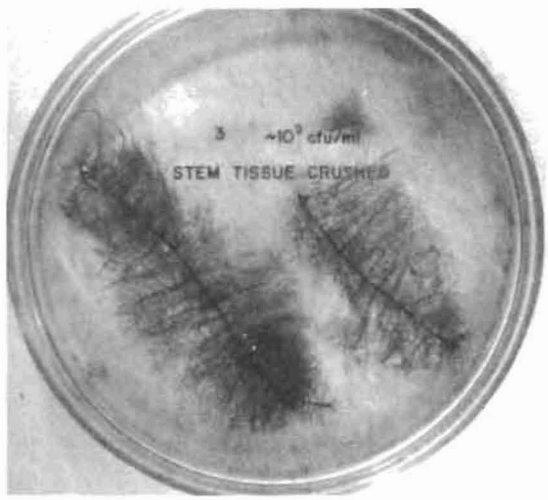


Incubation, 14 days

Figure 4. Accelerated decomposition of *Myriophyllum* sections stressed by crushing 4 cm from each end of the plant section and subsequently inoculated with various pectinolytic bacteria (Sheet 1 of 3)

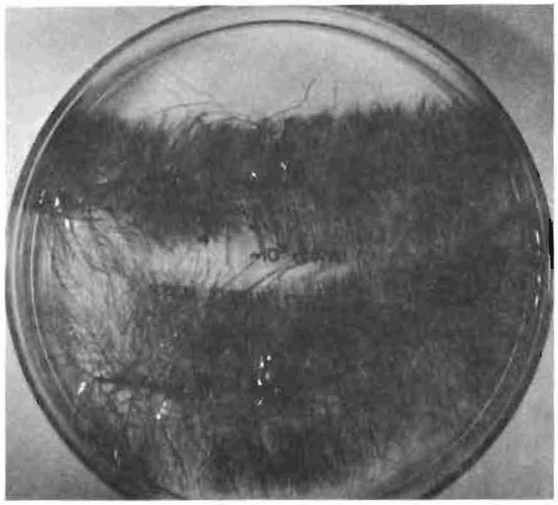
Agrobacterium sp. 02	*Xanthomonas* sp.
	

Incubation, 7 days

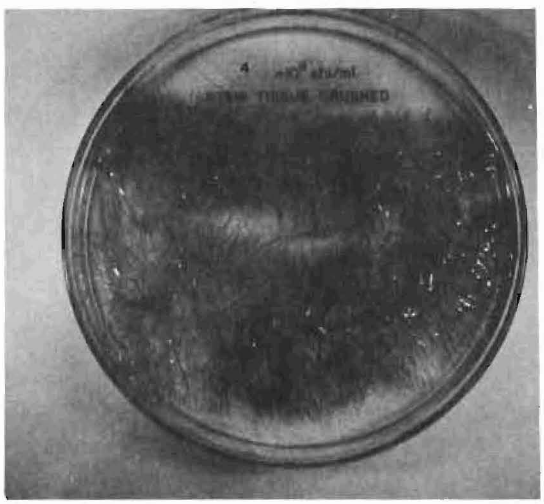
	

Incubation, 14 days

Figure 4. (Sheet 2 of 3)



Incubation, 7 days



Incubation, 14 days

Figure 4. (Sheet 3 of 3)

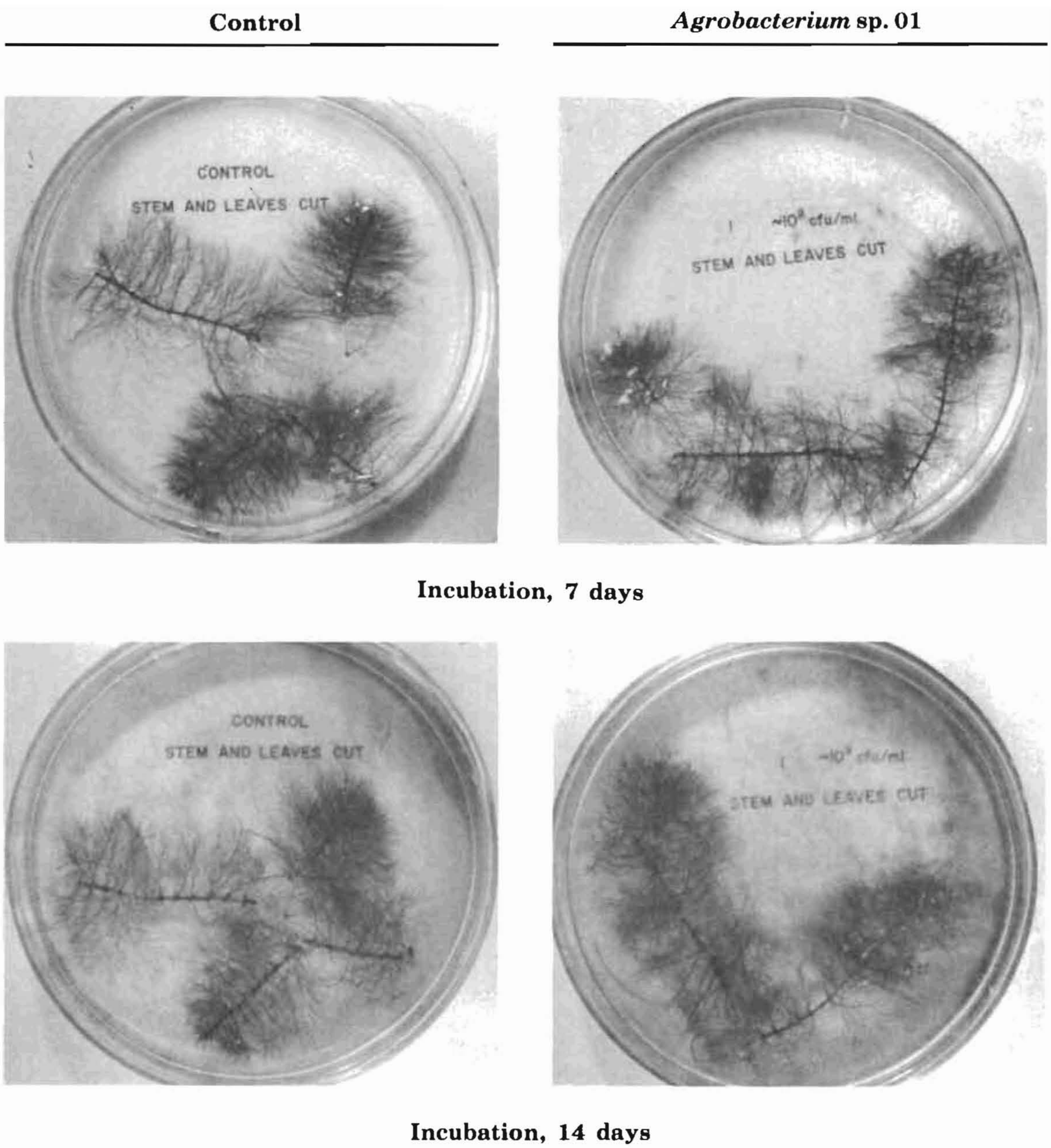
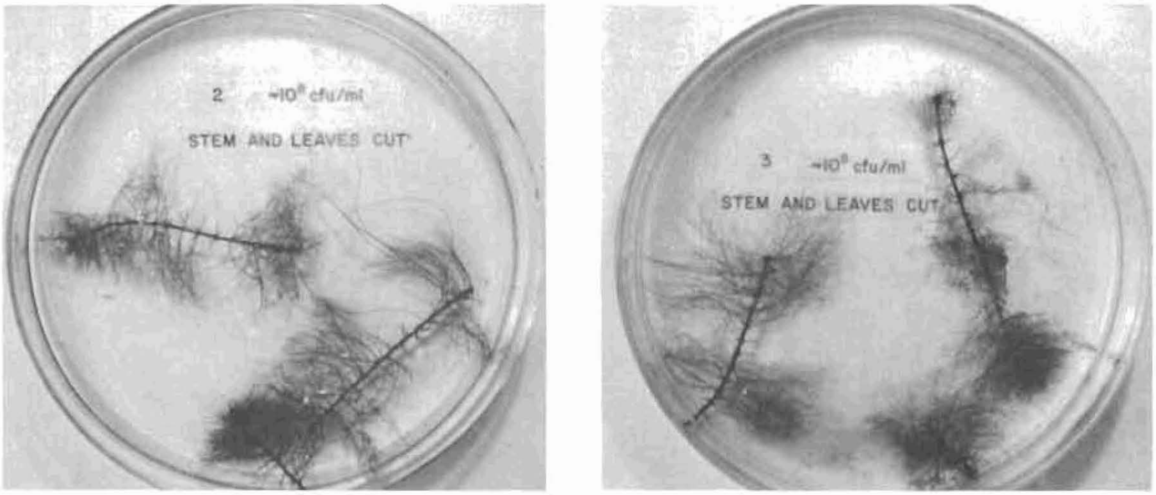
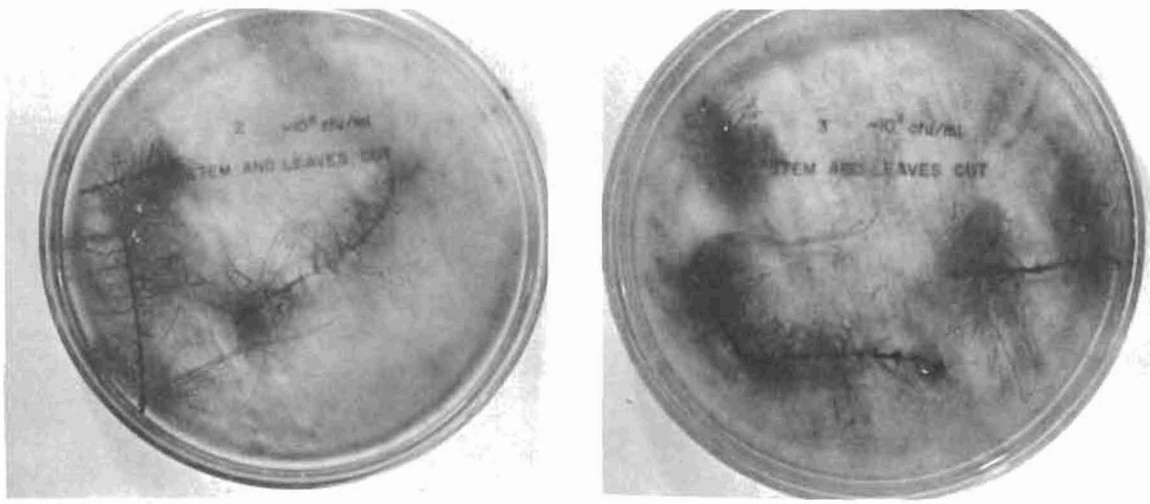


Figure 5. Accelerated decomposition of *Myriophyllum* sections stressed by cutting and tearing of leaves at section midpoint and subsequently inoculated with various pectinolytic bacteria (Sheet 1 of 3)

Agrobacterium sp. 02	*Xanthomonas* sp.

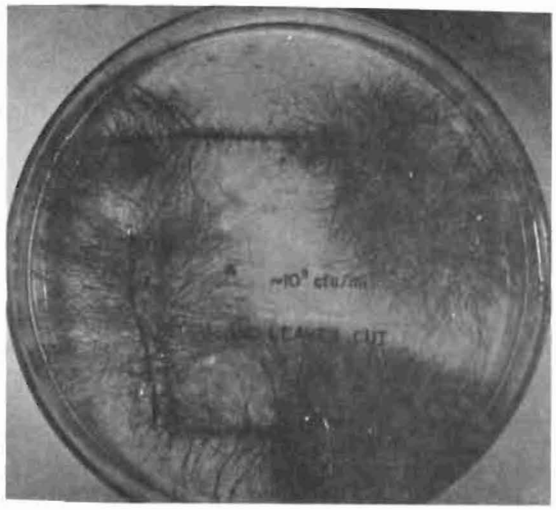


Incubation, 7 days

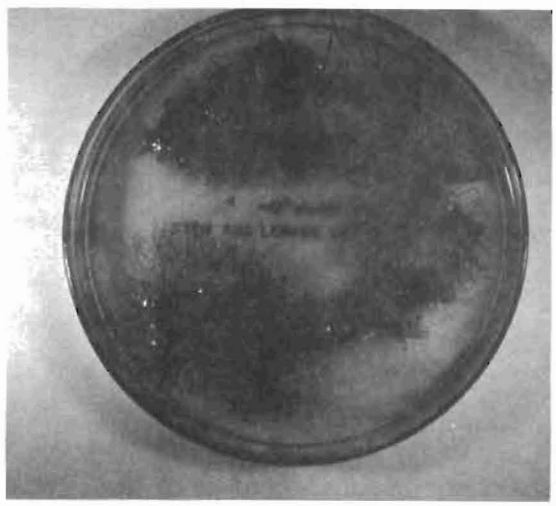


Incubation, 14 days

Figure 5. (Sheet 2 of 3)



Incubation, 7 days



Incubation, 14 days

Figure 5. (Sheet 3 of 3)

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

Control of Waterhyacinth with the Pyralid Moth *Sameodes albiguttalis*

by
Ted D. Center*

The weevils *Neochetina eichhorniae* and *N. bruchi* were released in 1972 and 1974, respectively, for the biological control of waterhyacinth. In 1977 the pyralid species, *Sameodes albiguttalis* (Warren), was released for the same purpose. Only one of the original three releases was successful, so insects were released at an additional 17 sites during 1978 and 1979. Ultimately, populations of this species were established at 16 sites, most of which were located in south Florida. It was learned that the morphological form of waterhyacinth is very important for successful establishment since the insects prefer the small, luxurient shoots with inflated leaf petioles typical of the colonizing form of the plant.

In February 1979 it was noticed that the populations of *S. albiguttalis* within the Everglades Conservation Areas in south Florida had begun to disperse northwards towards Lake Okeechobee. Careful monitoring demonstrated a continual expansion of populations through 1979 until, by the end of the year, *S. albiguttalis* was widespread throughout the peninsular portion of Florida from Lake George southwards. By July 1980 the range of *S. albiguttalis* had increased to the Georgia border ca. 528 km to the north. Dispersal occurred at an average rate of 29 km per month or nearly 1 km per day.

In the process of monitoring dispersal of *S. albiguttalis,* data were collected at sites on a transect line which extended the entire length of Florida. The data included morphological measurements of shoots and *S. albiguttalis* infestation rates. It was learned that dispersal rates were influenced by the relative representation of the proper plant morphotype in the waterhyacinth populations as well as by seasonal effects. Dispersal occurs most rapidly during cool, but not cold, periods, which is also when the preferred plant form is most abundant.

When it was determined that populations of *S. albiguttalis* had become established in the field, various efficacy studies were begun. The first of these began in September 1978; ultimately, data were collected at 15 sites throughout Florida. The objectives of these studies were to determine if *S. albiguttalis* would be persistent, if it could be augmented if it were not persistent, and if it had a significant impact upon waterhyacinth populations within the context of relative comparisons with other control agents and the plants' ability to recover from serious injury.

APPROACH

Although methods were diverse since 15 sites and nearly 5 years were involved, basically, the approach was aimed at deriving waterhyacinth leaf budgets. Debits

* U.S. Department of Agriculture, Fort Lauderdale, Florida.

to the budget involved leaf mortality caused by various factors including *S. albiguttalis* larvae, weevil adults and larvae, pickerelweed borer larvae, waterhyacinth mites, spider mites, various pathogens, frosts, drought, etc. The average contribution to leaf mortality by each of these was assessed for leaves of each age class as determined by stem position. In addition, the average survivorship of each leaf age class was determined. Credits to the leaf budget were represented by the average rate of leaf production per shoot. The resultant balance between leaf mortality and leaf production was represented by the number of live leaves per shoot. Hence, the relative effect of any given mortality agent could be measured by its impact on the number of live leaves per shoot, and the severity of injury could be gauged according to the ability of the plant to replace injured leaves. These data were collected both on tagged plants, which were periodically reexamined, as well as on randomly chosen nontagged plants, which were examined only once.

Other data collected at the sites included parameters such as standing crop, plant density, shoot height, proportion of shoots killed by *S. albiguttalis* larvae or other factors, leaf morphometric measurements, and root length.

CURRENT STATUS AND ACCOMPLISHMENTS

The project is now complete and a comprehensive project report has been prepared.

Data indicate that *S. albiguttalis* will, under certain conditions, be an effective biological control of waterhyacinth. This will generally be true only where the waterhyacinth population is in a predominantly colonizing mode. In these situations, the plants are small, luxuriently growing, have large inflated leaf petioles, and often do not exist as part of a continuous mat. Infestations are usually heaviest in areas where the plants have been killed by frost, drought, or herbicide and are regrowing, or along the developing fringe of a mat.

At a site near St. Petersburg, the waterhyacinth within a canal were periodically washed out by floods. As the plants began to recolonize the canal, the damage inflicted by *S. albiguttalis* infestation became intense. Later, the infestation only caused damage to shoots along the fringe of the growing mats. It is estimated that 70 percent of the shoots were injured at this site in the fall of 1979 and, by the spring, ca. 40 percent had been killed. This greatly retarded the rate at which the waterhyacinth plants covered the water surface and nearly 8 months were required for this to occur.

At sites in the Everglades Conservation Area 3A differing patterns of *S. albiguttalis* infestation were seen depending upon the characteristics of the sites. The shoots at a site in the main channel generally sustained persistently heavy injury (60-80 percent), whereas those in more impounded areas showed heavy injury only in the spring and fall. It is felt that this is due to either the physical or nutritional state of the plants or related to periods of active growth.

At a site in Lake Okeechobee, many shoots were infested by *S. albiguttalis* larvae just prior to a severe drought. As the area dried out, the shoots became stranded in wet mud and the *S. albiguttalis* injury increased. Leaf production was very slow so the shoots had difficulty replacing injured leaves. Shoots injured by *S. albiguttalis* desiccated rapidly and only those which were not injured were able to survive the drought. Thus, the combined effects of the larvae and environmental stress proved devastating to the plant population.

At two sites in Broward County, 100 shoots were tagged and their fate followed over relatively long periods of time. At one site, 31 percent were killed by *S. albiguttalis* larvae, 43 percent by weevil larvae, and only 25 percent survived for 1 year. At the second site, 78 percent were killed by *S. albiguttalis* larvae, 7 percent by weevil larvae, and only 14 percent survived.

Life table studies of waterhyacinth leaves show distinct spatial patterns. Only *S. albiguttalis* larvae, weevil adults, weevil larvae, and, occasionally, environmental factors affect the young leaves, injure the apical buds of the shoots, cause leaf production to cease, and effectively kill the shoots. Most other factors usually only cause superficial injury and usually only to older leaves, although sporadic outbreaks of any of these agents may temporarily cause severe shoot injury. Overall, generalizing from all sites, it is estimated that biological control by *S. albiguttalis* and the two species of waterhyacinth weevil results in a 34 percent reduction in waterhyacinth productivity. This is based upon the observed reduction to leaf longevity which is usually brought about by the early destruction of young leaves. Unfortunately, damage caused by *S. albiguttalis* larvae is sporadic and unpredictable.

At many sites, absolutely no damage to the plants resulted from *S. albiguttalis* infestation. This was even true when large supplemental releases were attempted. When data for such sites are reviewed, it is apparent that these are generally established waterhyacinth populations, the shoots are morphologically adapted to a competitive phase of growth, and observations indicate that the leaves have a generally tough, leathery texture. At sites where the populations grow into this phase, the *S. albiguttalis* population disappears, although a residual population may persist temporarily by feeding within the youngest, tenderest leaf petioles. Hence, in this situation, *S. albiguttalis* will probably never be effective.

CONCLUSIONS

Sameodes albiguttalis, more than either of the other two waterhyacinth insects, should fit comfortably into a management scheme. Its effectiveness may be maximized in a maintenance program where the waterhyacinth population is constantly perturbed and always in a colonizing mode. Many possible management strategies exist in which this insect and herbicidal or mechanical control could be integrated and experimentation along these lines should be given a high future priority.

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

Overseas Searches of Insects on Hydrilla

by
Joseph K. Balciunas*

This report presents some preliminary findings of a 6-month trip (13 April-24 October 1982) to Africa, India, Southeast Asia, and Australia (see Figure 1). This trip was the second in a series of overseas trips in search of natural enemies of hydrilla (*Hydrilla verticillata* Royle). These trips are intended to be preliminary surveys. The emphasis is on finding a great number of hydrilla-damaging insects species by collecting at as many hydrilla sites in different locations as time and circumstances permit. Evaluation of any particular insect species potential and host specificity will be done on subsequent trips, which will emphasize intensive, long-term studies at selected countries.

Specific locations visited were Egypt; Kenya; India; Sri Lanka (Ceylon); Burma; Thailand; Malaysia; in Indonesia, Sumatra, Java, South Sulawesi, Bali, and Lambok; and Northern Australia.

Figures 2-6 show stages of several of the most common insects collected on the trip.

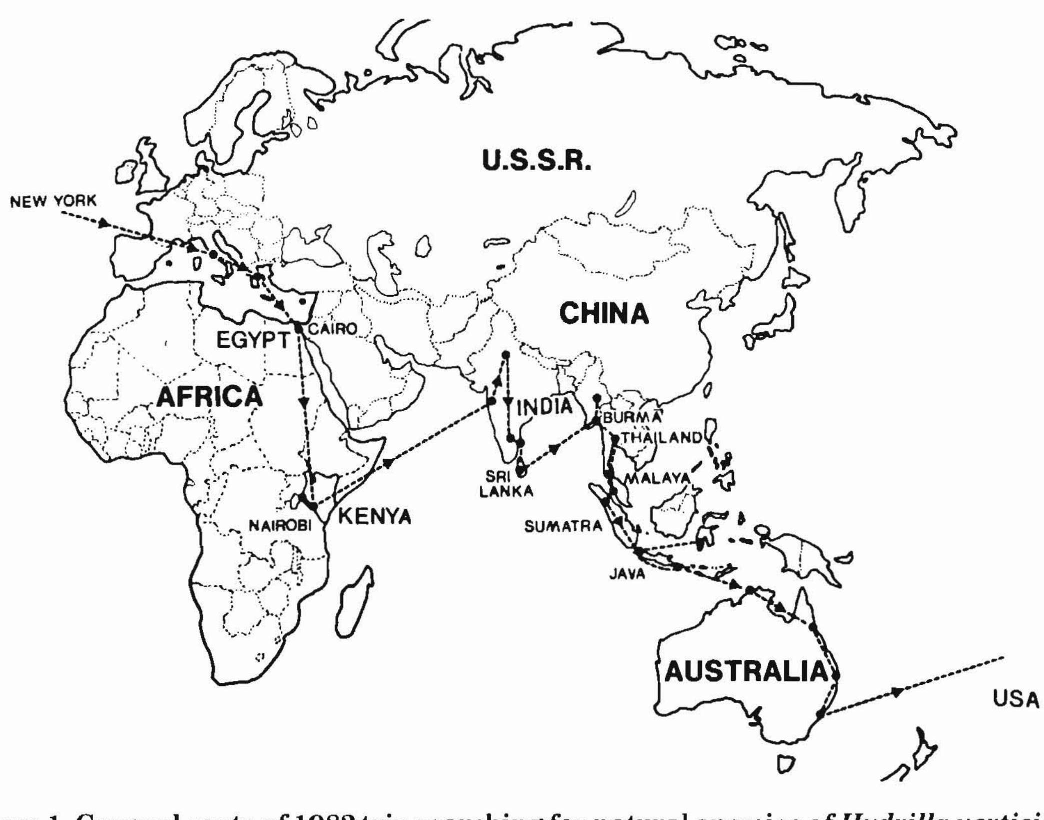


Figure 1. General route of 1982 trip searching for natural enemies of *Hydrilla verticillata*

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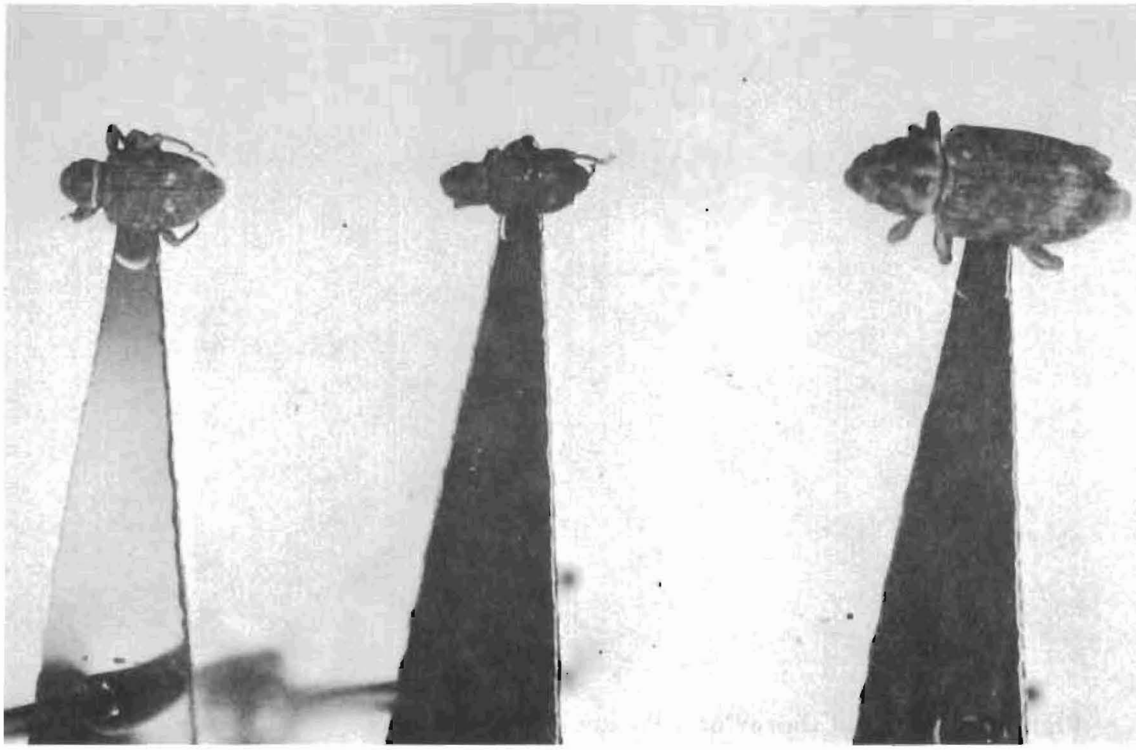

Figure 2. The three most commonly collected species of *Bagous* weevils collected near Bangalore, India. More than six species of *Bagous* weevil adults were found to feed on hydrilla in the laboratory. (It should be noted that the host specificity of adult weevils is generally much broader than that of the larvae.)

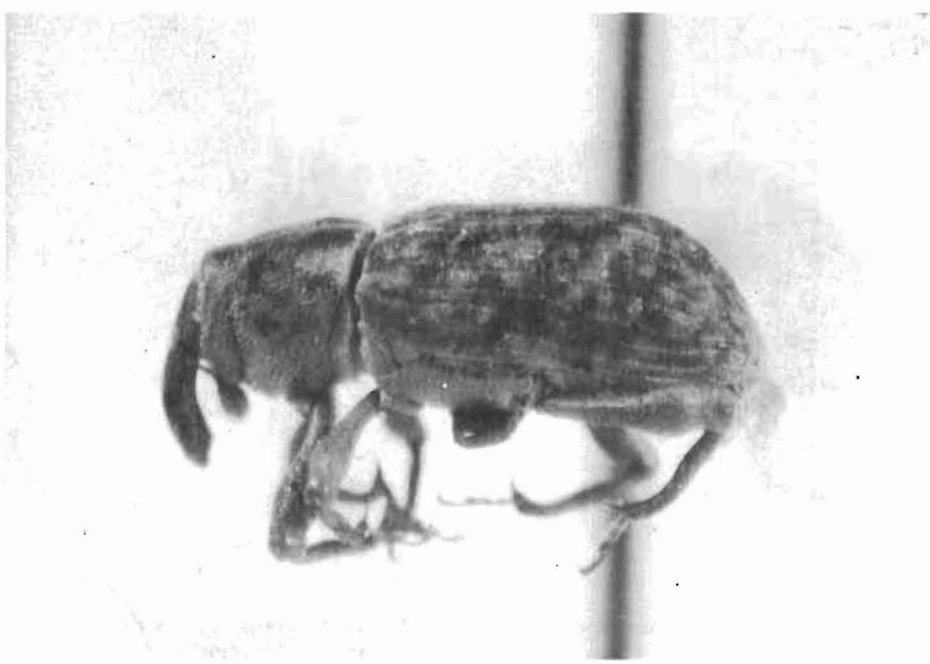

Figure 3. Close-up of *Bagous* species C weevil collected near Bangalore, India

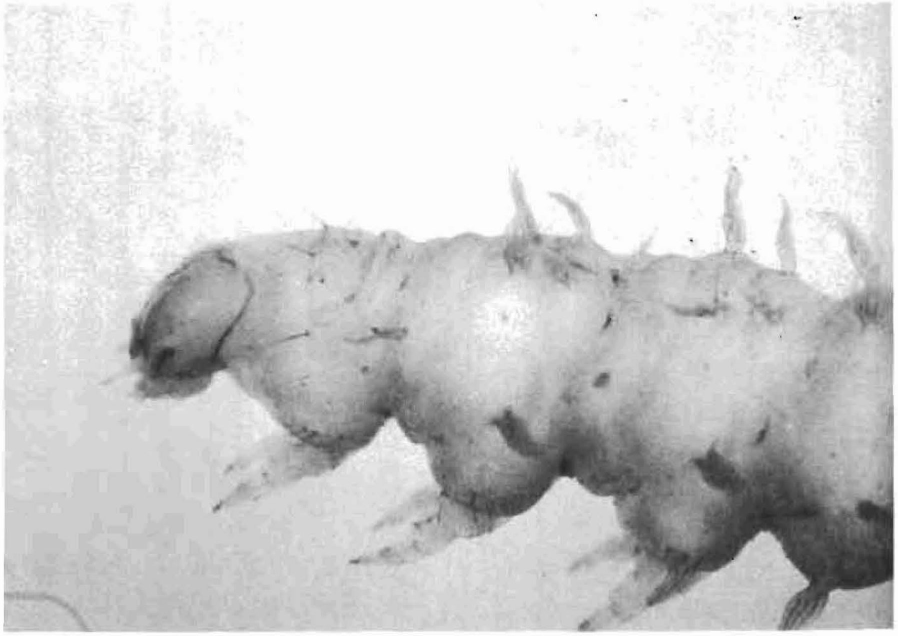

Figure 4. Head and thorax of a *Parapoynx* species moth larvae that feeds voraciously on hydrilla at Yellowwater Billabong, Northern Territory, Australia. This is *not* the larvae of *Parapoynx diminutalis,* the moth commonly found on hydrilla in many countries

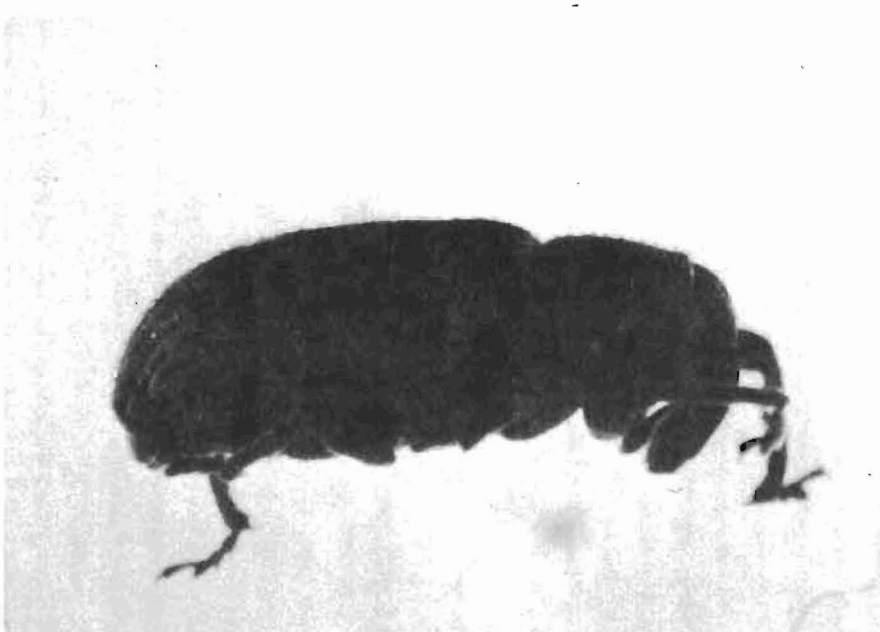

Figure 5. One of the *Bagous* species weevils found to feed on hydrilla at Yellowwater Billabong, Northern Territory, Australia

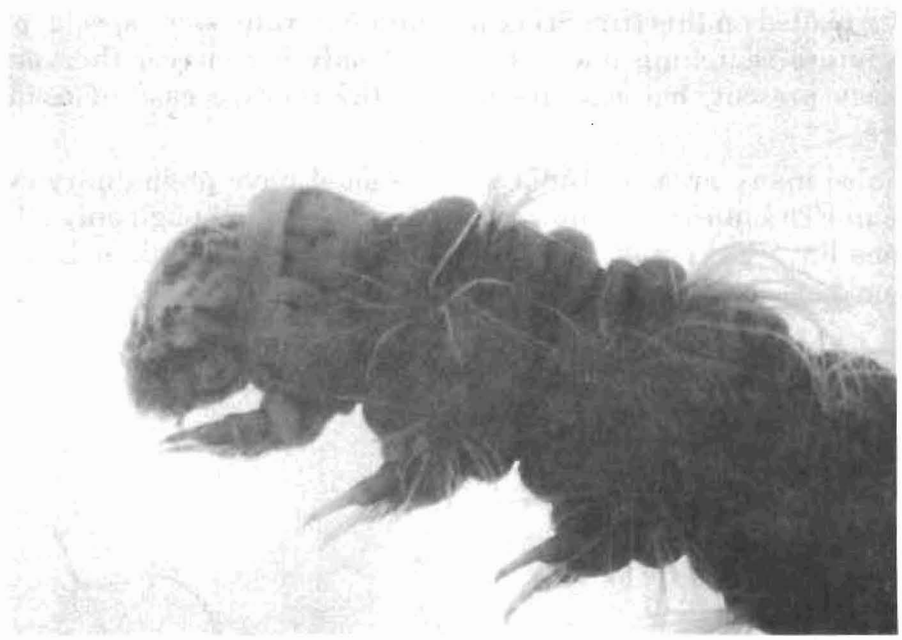

Figure 6. Head and prothorax of a moth larvae, similar to *Parargyractis*, collected on hydrilla at several locations in northern Queensland, Australia

CONCLUSIONS AND RECOMMENDATIONS

This extensive trip added many new insects to the growing list of insect species that should be tested for possible use as biological control agents on hydrilla in the United States. Table 1 presents a very preliminary compilation of the insects and other organisms collected on hydrilla during this trip. Many specimens, especially from the ultraviolet-light collections, remain to be sorted and identified.

I probably collected at least 15 species of *Bagous* weevils in Asia and Australia. Since *Bagous* weevils, especially the larvae, are frequently very host specific, there is a good possibility that some of these may prove to be useful as biological control agents on hydrilla. Only a few species of *Bagous* from India and Pakistan have been tested for host specificity thus far.

The moth species collected on hydrilla for the first time during this trip also deserve more intensive scrutiny. Since moth larvae are voracious feeders and the adults disperse readily, they would be excellent biocontrol agents if they are found to be host specific.

In order to visit as many hydrilla sites as possible, only a short time was spent at each location. More extensive testing will be undertaken at carefully selected sites once the bulk of these preliminary surveys are completed. Since almost all aquatic weevils and most aquatic moths feed on aquatic macrophytes, these have received most attention during my brief visits to each site. Insect groups, such as caddisflies and midges, with only a small proportion of species feeding on aquatic macrophytes, will be investigated more thoroughly during longer visits.

Of the areas visited on this trip, Sri Lanka and Australia show special promise for efficient future searching and testing, not only because of the variety of hydrilla insects present, but also because of the relative ease of conducting research there.

There are also many areas of India which should have preliminary surveys. Both Burma and Thailand have shown some promise even though only relatively few collections have been made there. The insect-pathogen link at Lake Toba, Sumatra, should also be investigated more thoroughly.

TABLE 1. INSECTS AND OTHER INVERTEBRATES COLLECTED ON HYDRILLA VERTICILLATA IN ASIA AND THE SOUTH PACIFIC (MAY - OCTOBER, 1983).

INSECTS:

ORDER COLEOPTERA (BEETLES)

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Curculionidae Bagous species	India	28	KAR82205, KAR82206, KAR82207
Dytiscidae	Australia	2	QLD82202, QLD82203
	India	5	KAR82202, KAR82205
	Malaysia	2	PEN82202, PEN82203
Hydrophilidae	Australia	2	QLD82202, QLD82203
	India	78	KAR82201, KAR82203, KAR82204, KAR82205, KAR82206, KAR82207
Undetermined Coleoptera	Burma	1	BUR82206
	India	10	KAR82203, KAR82205, KAR82206
	Malaysia	4	PEN82202
	TOTAL	82	

ORDER DIPTERA (TRUE FLIES)

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Ceratopogonidae	Burma	2	BUR82202
	India	1	KAR82202
	Indonesia	1	LOM82201
	Malaysia	3	PEN82203, PEN82204
Chironomidae	Australia	65	QLD82202, QLD82203, NTR82201, NTR82202
	Burma	6	BUR82202, BUR82203, BUR82204
	India	13	KAR82201, KAR82202, KAR82205, KAR82206
	Indonesia	78	LOM82201, SUL82201, SUL82202
	Malaysia	166	PEN82201, PEN82202, PEN82203, PEN82204, PRK82202, PRK82206, PRK82207, PRK82208, PRK82210, PRK82211, PRK82212
	Sri Lanka	3	LAN82201, LAN82202, LAN82204
Culicidae	Malaysia	24	PEN82202, PRK82210, PRK82211, PRK82212
Ephydridae	India	15	KAR82205, KAR82207
Stratiomyidae	India	1	KAR82206
	Indonesia	1	SUL82201
	TOTAL	379	

TABLE 1 CONTINUED.

ORDER EPHEMEROPTERA (MAYFLIES)

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Baetidae	Burma	1	BUR82205
	India	1	KAR82201
	Malaysia	10	PEN82203, PRK82206, PRK82211, PRK82212
	Sri Lanka	3	LAN82201, LAN82202, LAN82203
Caenidae	Australia	2	QLD82201, QLD82BL1
Caenis spp.	Malaysia	1	PRK82201
	Sri Lanka	2	LAN82204
Leptophlebiidae	Australia	3	QLD82202

	TOTAL	23	

ORDER HEMIPTERA (TRUE BUGS)

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Belostomatidae	India	1	KAR82201
Corixidae	Burma	3	BUR82205
	India	1	KAR82203
	Malaysia	42	PRK82210, PRK82211, PRK82212, PEN82205
Naucoridae	Burma	4	BUR82202
	India	9	KAR82201, KAR82202, KAR82203, KAR82204
	Indonesia	2	SUL82202
	Malaysia	3	PEN82203
	Sri Lanka	3	LAN82202, LAN82203
	Thailand	2	PHK82201
Nepidae	Australia	1	NTR82202
	Burma	1	BUR82205
	India	2	KAR82201
	Indonesia	3	PEN82203, PEN82205
	Sri Lanka	1	LAN82204
Pleidae	Burma	11	BUR82202, BUR82204, BUR82205
	India	45	KAR82201, KAR82202, KAR82203, KAR82206, KAR82207
	Malaysia	17	PEN82203, PRK82201, PRK82202, PRK82209
	Sri Lanka	2	LAN82204
	Thailand	1	PHK82201
Veliidae	India	17	KAR82201, KAR82203, KAR82204, KAR82205, KAR82206

	TOTAL	171	

TABLE 1 CONTINUED.

ORDER HOMOPTERA

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Aphididae	Malaysia	3	PEN82202

	TOTAL	3	

ORDER LEPIDOPTERA (BUTTERFLIES AND MOTHS)

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Pyralidae	Burma	14	BUR82201, BUR82204, BUR82205
Parapoynx diminutalis (Snellen)	India	56	KAR82201, KAR82202, KAR82204, KAR82205, KAR82206, KAR82207
	Indonesia	12	SUL82201, SUL82202
	Malaysia	1	PRK82202
	Sri Lanka	83	LAN82203, LAN82204
	Thailand	21	PHK82201
Parapoynx species	Australia	6	NTR82201, NTR82202
	Indonesia	2	LOM82201
Undetermined Pyralidae	Australia	29	QLD82202, QLD82203, NTR82203
	Burma	1	BUR82205
	India	1	KAR82202

	TOTAL	226	

ORDER ODONATA (DRAGONFLIES AND DAMSELFLIES)

SUBORDER ANISOPTERA (DRAGONFLIES)

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Aeschnidae	Burma	2	BUR82205
Gomphidae	India	1	KAR82202
	Malaysia	1	PEN82201
Libellulidae	Australia	1	QLD82204
	India	1	KAR82206
	Malaysia	1	PEN82203
	Sri Lanka	3	LAN82201, LAN82203, LAN82205
	Thailand	1	PHK82201

TABLE 1 CONTINUED.

SUBORDER ZYGOPTERA (DAMSELFLIES)

Coenagrionidae	Australia	9	QLD82202
	Burma	19	BUR82204, BUR82205
	India	6	KAR82202, KAR82203, KAR82207
	Indonesia	7	SUL82201
	Sri Lanka	17	LAN82201, LAN82202, LAN82203 LAN82204
	Malaysia	27	PEN82203, PRK82206, PRK82207, PRK82208, PRK82209, PRK82210, PRK82211, PRK82212
	Thailand	2	PHK82201

	TOTAL	98	

ORDER TRICHOPTERA (CADDISFLIES)

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Hydroptilidae	Australia	2	NTR82201
	Burma	5	BUR82203
	Indonesia	1	LOM82201
	Malaysia	1	PRK82208
Leptoceridae	Australia	3	NTR82201
	Burma	3	BUR82203, BUR82205
	Indonesia	3	SUL82201
	Sri Lanka	2	LAN82202
Polycentropodidae ?	Australia	5	QLD82203, NTR82202
	Malaysia	3	PRK82209, PRK82211
Undetermined Trichoptera	Australia	9	QLD82202, NTR82202, NTR82203
	India	3	KAR82202, KAR82206

	TOTAL	40	

UNDETERMINED INSECTS

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Insect Eggs	Indonesia	50	SUL82201
	Malaysia	4	PEN82202

	TOTAL	54	

TABLE 1 CONTINUED.

OTHER INVERTEBRATES:

CLASS ARACHNIDA

SUBCLASS ACARI (Mites)

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Aquatic Mites	Burma	18	BUR82205
	India	3	KAR82205, KAR82206
	Malaysia	2	PRK82203, PRK82208

	TOTAL	23	

CLASS CRUSTACEAE

NAME	COUNTRY	SPECIMENS	COLLECTIONS
ORDER AMPHIPODA (Scuds)	Australia	1	QLD82201
ORDER COPEPODA (Copepods)	Malaysia	1	PEN82203
ORDER CLADOCERA (Water Fleas)	Malaysia	6	PEN82203, PEN82204, PRK82210
	Sri Lanka	3	LAN82204
ORDER DECAPODA (Crayfish, Crabs, Shrimp)			
Shrimp	Australia	18	QLD82201, QLD82203, QLD82BL1
	Burma	14	BUR82204, BUR82205, BUR82206
	India	2	KAR82202
	Sri Lanka	4	LAN82204
Crabs	Australia	2	QLD82201, QLD82BL1
ORDER OSTRACODA (Seed Shrimps)	Indonesia	1	SUL82201
	Malaysia	2	PEN82203, PRK82211

	TOTAL	54	

CLASS HIRUDINEA

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Leeches	India	2	KAR82203
	Indonesia	1	LOM82201
	Malaysia	4	PEN82201, PRK82201
	Sri Lanka	3	LAN82202, LAN82204, LAN82205

	TOTAL	10	

TABLE 1 CONTINUED.

CLASS MOLLUSCA (Snails and Clams)

ORDER GASTROPODA (Snails)

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Ampullariidae (Apple Snails)			
	Burma	3	BUR82204
	Indonesia	1	PRK82205
Hydrobiidae	Burma	38	BUR82203, BUR82204, BUR82205, BUR82206
	India	36	KAR82201, KAR82202, KAR82203, KAR82205, KAR82206
	Sri Lanka	155	LAN82202, LAN82203, LAN82204
Lymnaeidae (Pond Snails)	Burma	18	BUR82201, BUR82202, BUR82204
	India	33	KAR82201, KAR82203, KAR82205, KAR82206
	Indonesia	12	SUL82202
	Sri Lanka	20	LAN82201, LAN82202
	Thailand	17	PHK82201
Planorbidae (Orb Snails)	Burma	2	BUR82202, BUR82206
Helisoma species	India	14	KAR82201, KAR82205
	Malaysia	13	PRK82201, PRK82204, PRK82205
	Sri Lanka	22	LAN82201, LAN82202, LAN82204, LAN82205
	Thailand	103	PHK82201
Undetermined	Burma	82	BUR82202, BUR82203, BUR82204, BUR82205, BUR82206
Planorbidae	India	16	KAR82201, KAR82206
	Indonesia	42	SUL82201, SUL82202
	Malaysia	28	PRK82201, PRK82202, PRK82204, PRK82209, PRK82210, PRK82211
	Sri Lanka	29	LAN82201, LAN82203, LAN82204, LAN82205
	Thailand	9	PHK82201
Physidae (Pouch Snails)	Australia	5	NTR82201, NTR82203, QLD82203
	India	14	KAR82201, KAR82203, KAR82206
	Malaysia	17	PEN82201, PEN82203, PEN82204, PRK82201
	Sri Lanka	44	LAN82202, LAN82204
	Thailand	31	PHK82201
Pleuroceridae (River Snails)	Australia	5	NTR82201, QLD82201
	Burma	9	BUR82201, BUR82206
	India	2	KAR82201
	Indonesia	5	LOM82201, SUL82202
	Malaysia	9	PRK82201, PRK82205
	Sri Lanka	2	LAN82205
	Thailand	2	PHK82201
Viviparidae	Burma	8	BUR82204, BUR82206
	India	4	KAR82201
	Malaysia	5	PRK82201, PRK82210
	Sri Lanka	5	LAN82201, LAN82202
	Thailand	2	PHK82201

	TOTAL	862	

CLASS OLIGOCHAETA

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Oligochaet Worms	India	1	KAR82206
	Malaysia	17	PEN82203, PRK82204

	TOTAL	18	

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

Status of *Cercospora rodmanii* and *Fusarium roseum* 'Culmorum' as Biocontrol Agents

by
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WATERHYACINTH

Cercospora rodmanii Conway, a leaf-spotting fungal pathogen, has been under consideration as a biocontrol agent for waterhyacinth (*Eichhornia crassipes* (Mart.) Solms). Abbott Laboratories, Chicago, Ill., has developed a wettable powder formulation of the fungus and has obtained an Environmental Protection Agency Experimental Use Permit (EUP) to evaluate it as a microbial herbicide. The question of whether *C. rodmanii* will be registered for commercial use will be answered largely by field efficacy data, which suggest that the fungus has a definite place among the control options, including herbicides, that are available now for waterhyacinth management. Field studies were, therefore, continued in 1982 and were planned such to include testing of the Abbott formulation as part of the EUP evaluations. The funding for this research was obtained through the Florida Department of Natural Resources.

Cercospora rodmanii has been evaluated in the past years in several locations in the southeastern United States (Addor 1977; Conway et al. 1978, 1979; Theriot et al. 1981a, b; Freeman et al. 1981). Theriot (1980, 1981) and Theriot et al. (1981a) have concluded that an Abbott formulation of *C. rodmanii,* which has since been slightly modified, was infectious when sprayed over large (1.8 to 2.5 ha) infestations of waterhyacinth by aerial applications and that significant reductions in waterhyacinth biomass were achieved in 2 years following the initial spraying. However, in previous studies (e.g. Conway 1976; Conway et al. 1979; Theriot 1981), the experimental design did not allow for the biocontrol effects of the fungus to be distinguished from those of the arthropod biocontrol agents that were present. Moreover, due to the absence of proper fungicide-treated controls, the results of the lack of a pathogen pressure on waterhyacinth growth and biomass could not be described, leading to a bias against the efficacy of *C. rodmanii* (Conway et al. 1979). Likewise, in the absence of insecticide-treated checks, the effects of the arthropods and the synergistic effects of the fungus and arthropods on waterhyacinth will not be evident. Our studies, therefore, included experiments designed to determine the effect of *C. rodmanii* alone and in combination with arthropods in relation to fungicide- and insecticide-treated controls.

Objectives

Specifically, the objectives of our studies were to determine the efficacy of: (1) the Abbott formulation, (2) *C. rodmanii* alone as a biocontrol agent, (3) the fungus

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and arthropod biocontrol agents (primarily *Neochetina* spp.), and (4) the fungus and low rates of two herbicides (diquat and 2,4-D).

Approach

Tests were conducted in small (2.5 m^2) field plots and later expanded to larger (100 m^2) field plots in which the combined actions of the fungus and arthropods are being studied. In addition, the in vitro compatibility of the fungus with diquat and 2,4-D was determined using petri plate cultures. The lowest diquat and 2,4-D rates that yielded a necrotic damage rating of 5 (on a scale of 0-9, developed by Conway et al. 1979) on the leaves were selected in greenhouse experiments. The combined effects of *C. rodmanii* and one low level of diquat or 2,4-D were also determined in another greenhouse experiment. Finally, a combination of the fungus and a herbicide was tested in 83.65-m^2 field plots. Some of the experiments are still incomplete; therefore, the results discussed here are preliminary at this time.

Results

The infectivity, virulence, and efficacy of *C. rodmanii* in the Abbott formulation were established. *Cercospora,* in combination with the arthropods, had a controlling effect on waterhyacinth in the small plot study. The arthropods alone had a significant impact in reducing the plant height. *Cercospora,* on the other hand, had only a slight affect in reducing the plant height, but its greatest impact was on leaf necrosis, debilitation, and death of arthropod-damaged plants. Plants treated with the fungus, which also had arthropods, were severely diseased and stressed. About 6 months after the first application of the fungus, these plants died, decayed, and sank, leading to open water within the frames. Seven months after the initial application, treatment with a combination of *C. rodmanii* and arthropods yielded 90 to 100 percent control of waterhyacinth (n = 10). Neither *Cercospora* nor the arthropods alone completely killed the plants in this study.

In vitro compatibility of *C. rodmanii* with herbicides was determined from the radial growth of the fungus on potato dextrose agar—yeast extract medium containing various concentrations of diquat or 2,4-D. The herbicides were tested at five concentration levels each, corresponding to 200, 100, 50, 25, 13, and 6.5 percent label rates. Roughly a 50 percent reduction in the radial growth of the fungus was evident at the highest herbicide concentrations, and, as the concentrations were reduced, the growth was comparable to that on the control plates. Even at the highest concentrations, the fungus was not killed; the herbicides were merely fungistatic.

Pigmentation and sporulation of *C. rodmanii* were affected by the herbicides, but not its virulence. At the two higher concentrations of 2,4-D, and all concentrations of diquat, the fungus lacked the typical purple-red pigment. The control plates and plates with 2,4-D concentrations of 50, 25, and 13 percent supported normal pigmentation. Sporulation was stimulated at 2,4-D concentrations of 100, 50, 25, and 13 percent; control plates had very few spores compared to the abundant sporulation at these concentrations. There was no sporulation in diquat plates. The stimulation of spore production by 2,4-D may prove to be an unexpected beneficial effect on the biocontrol efficacy of *C. rodmanii* since spores are important for plant infection.

By screening decreasing concentrations of the herbicides in a greenhouse experiment, a concentration of 2,4-D was selected that yielded a necrotic damage rating of 5 on the photosynthetic tissues of waterhyacinth. This concentration (154 ppm active ingredient) was equal to 6.4 percent of the recommended rate of 2,4-D for waterhyacinth control. A similar damage level (rating of 5) could not be established for diquat. Even at the lowest concentration tested (55 ppm; 3.3 percent recommended rate), diquat produced a foliar damage rating of 5. Therefore, this herbicide was tested in subsequent studies, arbitrarily at 5 ppm (0.3 percent rate) concentration.

The damage to waterhyacinth resulting from the combined actions of *C. rodmanii* and 2,4-D or diquat was evaluated in outdoor pools. Diquat and 2,4-D were tested, respectively, at 5 and 154 ppm rates. The treatments consisted of the fungus and herbicides sprayed singly (treatments 1, 2, and 3); simultaneously as *C. rodmanii* and 2,4-D or *C. rodmanii* and diquat combinations (treatments 6 and 9); the herbicides first, followed 1 week later by *C. rodmanii* (treatments 7 and 10); and *C. rodmanii* first, followed 3 weeks later by 2,4-D or diquat (treatments 8 and 11). Treatment 4 was a control without any sprays (as expected, natural cross-infection of *C. rodmanii* resulted on these plants), and treatment 5 was a fungicide-sprayed control. Treatment 8 (*C. rodmanii* followed by 2,4-D) was the most damaging to waterhyacinth (damage rating of 4.9 by the 49th day after the fungus application). This combination of *C. rodmanii* and 2,4-D is being evaluated on a large scale.

Based on these preliminary results, it is clear that (1) *C. rodmanii* in the Abbott formulation is infective and virulent; (2) *C. rodmanii* in combination with the arthropods can yield total control of waterhyacinth; (3) it is possible to use *C. rodmanii* and 2,4-D sequentially to achieve control of waterhyacinth; and (4) although the fungus is compatible in vitro with diquat and 2,4-D, the potential for integration of *C. rodmanii* is greater with 2,4-D than with diquat. Diquat being a contact herbicide, following its application there may not be sufficient living tissue left for subsequent infection by the fungus.

HYDRILLA

Fusarium roseum 'Culmorum', a fungus that was isolated from diseased *Stratiotes aloides* L. plants (Hydrocharitaceae) in Holland, has been under evaluation as a potential biocontrol agent for hydrilla (*Hydrilla verticillata* (L. fil.) Royle) (Charudattan and McKinney 1977, 1978). It was found to be a safe and desirable candidate for large-scale tests against hydrilla (Charudattan et al. 1980, 1981). Last year, while reporting the preliminary results of the large-scale pilot testing (LSPT), it was stated that, although the results were less satisfactory than anticipated, the potential of the fungus as a control agent for hydrilla still could not be discounted (Charudattan et al. 1982). Since then the efficacy of the fungus has been further evaluated in 1982 in a series of tests.

Approach

In each test, one of two matched pools (3 m in diameter), containing hydrilla or hydrilla and other submerged aquatic macrophytes that were maintained under conditions comparable to field conditions, was treated with the fungus. The other pool served as the uninoculated check. The type of inoculum, water pH, water temperature, CO_2 concentration in water, light intensity, and plant density varied in each test. After varying incubation periods following fungus treatment, the damage to hydrilla was rated and analyzed for significant differences due to the fungus.

Results

The fungus was applied as an aqueous suspension at a rate of 5×10^4 spores per millilitre of treated water from 7 January 1981 to 23 February 1981. Although no germination, penetration, or colonization could be confirmed, damage to hydrilla and naiad was apparent 1 week after treatment with the fungus. After 1 month, about 90 percent of the hydrilla and 100 percent of the naiad plants in the treated tank were moderately to severely chlorotic, whereas eelgrass, common arrowhead, coontail, and spatterdock were unaffected by the fungus. All six plant species in the control tank were healthy.

Less than 5 percent of the spores in the tank germinated. This was partly due to the high pH (9.08 to 9.87) of the water. Spores in deionized water in a companion tube test germinated at about 90 percent.

Hydrilla in the tubes turned chlorotic nine days after treatment with the fungus at levels of 1×10^5 and 2×10^5 spores per millilitre. By the twenty-second day, hydrilla plants at these inoculum levels were completely dead and decayed. Similar effects were not seen at the 5×10^4 inoculum level.

The mean damage ratings for 'Culmorum' are indicated below:

	Mean Damage Rating	
	Treated	***Control***
Test II	2.46*	2.32*
III	2.08***	2.68***
IV	1.97**	1.74**
V	2.01*	1.99*

NOTE: The differences between the treated and the control were significantly different, using the t-test, at 0.5 level (*); 0.02 level (**); and 0.001 level (***).

In summary, there was consistently more damage on the fungus-treated hydrilla when compared to the untreated control. However, although statistically significant, the difference was barely noticeable in each test. There was no perceptible reduction in the biomass of the fungus-treated hydrilla. Therefore, based on the results of the LSPT, *F. roseum* 'Culmorum' cannot be considered to be efficacious for practical use as a biocontrol agent for hydrilla. Research on this fungus will be continued to determine the cause of its lethal effects on hydrilla in small-scale tests.

CONCLUSIONS

The results of the 1982 field studies with the Abbott formulation of *Cercospora rodmanii* have been extremely successful. Registration and commercialization of *C. rodmanii* as a microbial herbicide for waterhyacinth is still a very good possibility.

Fusarium roseum 'Culmorum' was not efficacious in large-scale pilot tests on hydrilla. Its potential as a microbial herbicide is not good.

Both fungi must undergo further testing in 1983.

REFERENCES

Addor, E. E. 1977. "A Field Test of Selected Insects and Pathogens for Control of Waterhyacinth," Technical Report A-77-2, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Charudattan, R., and McKinney, D. E. 1977. "A *Fusarium* Disease of the Submerged Aquatic Weed, *Hydrilla verticillata,*" *Proc. Am. Phytopathol. Soc.,* Vol 4, p 222 (Abstr. S-5).

Charudattan, R., and McKinney, D. E. 1978. "A Dutch Isolate of *Fusarium roseum* 'Culmorum' May Control *Hydrilla verticillata* in Florida," *Proc. European Weed Res. Soc. Symp. on Aquatic Weeds,* pp 219-224, EWRS Secretariat, P.O. Box 14, Wageningen, The Netherlands.

Charudattan, R., et al. 1980. "Evaluation of *Fusarium roseum* 'Culmorum' as a Biological Control for *Hydrilla verticillata:* Safety," *Proc. V Int. Symp. Biol. Control of Weeds,* CSIRO, Australia, pp 307-323.

Charudattan, R., et al. 1981. "Evaluation of *Fusarium roseum* 'Culmorum' as a Biological Control for *Hydrilla verticillata,*" *Proceedings of the 15th Annual Meeting of the Aquatic Plant Control Research Planning and Operations Review, 17-20 November 1980, Savannah, Georgia,* Miscellaneous Paper A-81-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 165-171.

Charudattan, R., et al. 1982. "Preliminary Results of Large-Scale Pilot Testing of *Fusarium roseum* 'Culmorum' as a Biological Control Agent," *Proceedings of the 16th Annual Meeting of the Aquatic Plant Control Research Planning and Operations Review, 17-19 November 1981, St. Paul, Minnesota,* Miscellaneous Paper A-81-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 159-163.

Conway, K. E. 1976. "Evaluation of *Cercospora rodmanii* as a Biological Control of Waterhyacinth," *Phytopathlogy,* Vol 66, pp 914-917.

Conway, K. E., et al. 1978. "Development of *Cercospora rodmanii* as a Biological Control for *Eichhornia crassipes,*" *Proc. European Weed Res. Soc. Symp. on Aquatic Weeds,* pp 225-230, EWRS Secretariat, P.O. Box 14, Wageningen, The Netherlands.

Conway, K. E., et al. 1979. "Field Evaluation of *Cercospora rodmanii* as a Biological Control of Waterhyacinth. Inoculum rate studies," Miscellaneous Paper A-79-6, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Freeman, T. E., et al. 1981. "Biological Control of Aquatic Plants with Pathogenic Fungi," Technical Report A-81-1, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Theriot, E. A. 1980. "Large-Scale Operations Management Test of Insects and Pathogens for Control of Waterhyacinth in Louisiana. Preliminary Studies with *Cercospora rodmanii,*" *Proceedings of the 14th Annual Meeting of the Aquatic Plant Control Research Planning and Operations Review, 26-29 November 1979, Lake Eufaula, Oklahoma.* Miscellaneous Paper A-80-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 203-212.

Theriot, E. A. 1981. "Large-Scale Field Application of *Cercospora rodmanii*," *Proceedings of the 15th Annual Meeting of the Aquatic Plant Control Research Planning and Operations Review, 17-20 November 1980, Savannah, Georgia,* Miscellaneous Paper A-81-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 491-495.

Theriot, E. A., et al. 1981a. "Evaluation of the Infectivity of a *Cercospora rodmanii* Formulation Using Two Application Systems," Miscellaneous Paper A-81-2, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Theriot, E. A., et al. 1981b. "Evaluation of a Formulation of *Cercospora rodmanii* for Infectivity and Pathogenicity of Waterhyacinth," Technical Report A-81-5, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

An Overview

by
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Research conducted under the Chemical Control Technology Development element of the Aquatic Plant Control Research Program (APCRP) is directed toward accelerating the development and use of new herbicide formulations and improved application techniques. Successful completion of research under the auspices of this APCRP element should result in more environmentally compatible herbicides and safe and effective application techniques.

APPROACH

Seven research work units were identified for FY 83 that address specific needs in this APCRP element, including:

- I: Herbicide Evaluation Program
- II: Controlled-Release Fluridone for Aquatic Plant Control
- III: Controlled-Release Dichlobenil for Aquatic Plant Control
- IV: Herbicide/Adjuvant Evaluation in Flowing Water
- V: Aquatic Herbicide User Guide
- VI: Controlled-Release 2,4-D for Aquatic Plant Control
- VII: Naturally Occurring Plant Growth Regulators

Over the past year, the work unit (VI) involving the development of a controlled-release (CR) 2,4-D formulation was completed successfully. Dr. Frank Harris, Wright State University, will summarize his research in this work unit. Work Unit VII involves the isolation and identification of naturally occurring plant growth inhibitors from sediment. The research under the direction of Dr. Dean Martin, University of South Florida, accomplished its objective concerning isolation of the chemical inhibitor; however, the identity of the chemical was not determined. Priority research needs for FY 83 required that the latter work unit be delayed until additional funding is available.

Efficacy evaluation of new chemicals by the U.S. Department of Agriculture (USDA) Aquatic Plant Management Laboratory (APML) in Fort Lauderdale, Fla., under Work Unit I will be discussed by Dr. Thai Vann. Southern Research Institute (SRI) in Birmingham, Ala., is represented by Dr. Richard Dunn, who will discuss the research progress in FY 82 related to Work Unit II toward the development of a CR fluridone formulation. During FY 83, similar work is to be initiated by SRI using dichlobenil under Work Unit III. Plans were developed during FY 82 for Work Unit IV concerning the evaluation of herbicide/adjuvant mixtures in flowing water. The objective of Work Unit IV is to determine the water velocity range in which herbicide/adjuvant mixtures are most effective.

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IN-HOUSE RESEARCH

Most of the in-house research until FY 83 was assigned to Work Unit I, the Herbicide Evaluation Program. The diluter system, as described in last year's APCRP Proceedings, was used to estimate the threshold fluridone and dichlobenil concentrations required to control Eurasian watermilfoil and hydrilla. Results of these studies suggest that the minimum sustained fluridone concentration required to control watermilfoil and hydrilla growth on both natural and sand-peat substrates was between 10 and 20 μg/ℓ and 20 μg/ℓ, respectively. Preliminary results suggest that the threshold dichlobenil concentration required to control these plants was between 40 and 90 μg/ℓ for both watermilfoil and hydrilla. However, the growth of both target plants was essentially stopped at the 40-μg/ℓ sustained dichlobenil concentration. Neither the watermilfoil nor hydrilla changed in physical appearance within these aquaria over the 12-week study period.

A field evaluation of Garlon 3A (in cooperation with Dow Chemical Company) and a CR elastomeric formulation of 2,4-D butoxyethanol ester (BEE) was initiated in Lake Seminole, Georgia, during July. The target species, Eurasian watermilfoil, was very dense and covered the entire surface area of the plots. It was considered very late in the season to initiate these tests since the posttreatment evaluation would include the period normally associated with senescence.

Garlon 3A was applied to two 1-acre plots at 12 and 34 kg a.e./ha (1.0 and 2.5 mg a.e./ℓ), respectively; and, the CR 2,4-D (BEE) was applied to three 1-acre plots at 17, 45, and 90 kg a.e./ha, respectively. Water and sediment samples were collected from Garlon 3A plots through posttreatment day 56 and sent to Dow Chemical Co. for residue analysis. Similarly, water and sediment samples were collected and sent to the Tennessee Valley Authority's Analytical Laboratory in Chattanooga, Tenn., for 2,4-D and 2,4-dichlorophenol analyses. These samples have not been completely analyzed at this time.

Both herbicides were found to be efficacious toward watermilfoil. Within 28 days following treatment, the 1.0- and 2.5-mg-a.e./ℓ Garlon 3A plots exhibited 50 and 70 percent control, respectively. However, regrowth of Eurasian watermilfoil was observed by posttreatment day 56. Approximately 2 weeks elapsed following treatment prior to observing any physical effects of Garlon 3A on the watermilfoil. The CR 2,4-D (BEE) plots provided 65 to 85 percent control within 28 days. The response of watermilfoil toward this CR formulation was very similar to the response exhibited following treatment with the conventional formulation, Aqua-Kleen, on 25-acre plots during 1982.

PLANS FOR FY 83

During FY 83, in-house research will focus on field evaluation of CR poly-GMA/2,4-D and a CR formulation of fluridone. A cooperative field study is being planned with Dow Chemical Co. and Duphar Corp. to evaluate further Garlon 3A and dichlobenil against Eurasian watermilfoil. Morever, renovation of the existing 30-m-long, 1.8-m-wide, 0.7-m-deep flume at WES will be completed early in FY 83. The herbicide 2,4-D and two adjuvants, ASGROW 403 and Nalquatic, will be tested in this flume to determine flow velocities above which treatment of

Eurasian watermilfoil with each herbicide and adjuvant mixture is ineffective. Finally, planned development of an Aquatic Herbicide User Guide in FY 83 and publication in FY 84 has been cancelled since funds for completion and publication in FY 84 were not available. The FY 83 funds programmed for this guide will be reprogrammed to allow more thorough evaluations in the aforementioned field studies and herbicide/adjuvant research.

Contract research will include continued development of controlled-release fluridone and dichlobenil and the laboratory evaluation of new herbicides at USDA-APML. However, work on naturally occurring plant growth regulators will be postponed as previously discussed.

CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

Activity of Naturally Occurring Hydrilla Growth Inhibitors

by
John Barltrop* and Dean F. Martin*

A number of workers have called attention to certain lakes and waterways that do not support the growth of hydrilla or related plants (Martin, Doig, and Millard 1971; Martin, Victor, and Dooris 1976; Dooris and Martin 1980; Barko and Smart 1980; Barko 1982; Martin and Dooris 1983). Lakes that fail to support growth of hydrilla do, however, allow good growth of other macrophytes (Dooris and Martin 1982); thus, there is suggestive evidence and specific evidence for the natural products that serve as hydrilla growth inhibitors.

One lake that has been investigated is Lake Starvation, Hillsborough County, Florida. This lake is dark colored, and organic material from nearby stands of bald cypress (*Taxodium disticium*) comprises a significant component of the lake sediment, but aqueous extracts of branches and leaves of *T. disticium* do not inhibit the growth of hydrilla in laboratory tests (Dooris and Martin 1980).

Current efforts have been directed toward characterizing the nature of aqueous extracts of sediment from Lake Starvation. This research has indicated that these aqueous extracts inhibit the growth of hydrilla in the laboratory (Dooris and Martin 1980). The present efforts are directed toward (1) purifying larger quantities of the hydrilla inhibiting fraction(s) through high performance liquid chromatography (HPLC) and (2) characterizing the mechanisms of growth inhibition of these fractions.

Development of sufficient background information through establishment of these tasks would permit (1) monitoring lakes for hydrilla inhibitor concentration (through HPLC "fingerprinting") as well as (2) a better understanding of the factors that naturally limit the growth of hydrilla in certain lakes and waterways and (3) development of an additional hydrilla control agent.

EXPERIMENTAL

Isolation of lake sediment extracts

The procedures used previously (Dooris and Martin 1980) were followed with slight modifications: 300 g of sediment was treated with 600 mℓ of distilled water and autoclaved (110° C, 138 kPa) for 20 min. The cool extract was filtered, centrifuged (6,000 × g) for 10 min, and filtered through an 8-μm membrane filter in an all-glass filtering apparatus. The volume was reduced to 10 percent under reduced pressure using a rotary evaporator and keeping the bath temperature less than 35° C. The residue was passed over Bond-Elut by centrifuging for 3 to 5 min on a clinical centrifuge.

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Fractionation of active components by HPLC

The material that passed through a Bond-Elut column was injected into an Altex HPLC (Model 110) unit equipped with a solvent programmer attachment and a multi-wavelength detector and one of two columns: (1) a preparative scale (Zorbax) column, or (2) a semipreparative (LiChrosorb RP-18 10-μm column, 10 × 250 mm). A linear gradient was used with a 20-min run starting with 50 percent (v/v) methanol-water and finishing with 100 percent water. Under these conditions with the RP-18 column, two major fractions were obtained; essentially the same results were obtained using 50 percent (v/v) methanol-water in an isocratic mode (Figure 1). Two major fractions were also obtained with the preparative scale column.

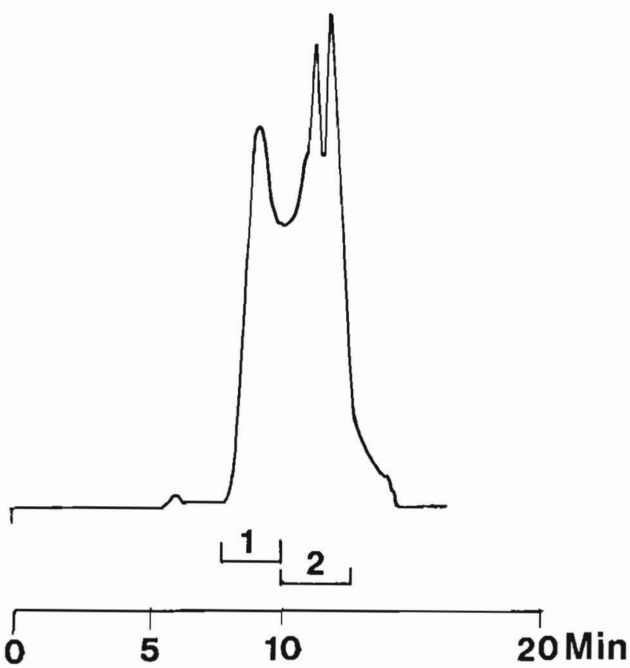

Figure 1. Typical HPLC chromatogram showing separation of hydrilla growth inhibitor into two fractions. Details for the isocratic mode using methanol-water are given in the text

Bioassays with lettuce seeds

Lettuce seeds (Dark Green Boston, Ferry Morse Seed Company) were sown on filter paper and placed in individual plastic weighing boats (S/P disPo). Each boat contained 10 seeds, and a known volume (0.2 mℓ) of aqueous extract was added to each boat. Previously described procedures (Moon and Martin 1981; Barltrop and Martin 1983) were followed in monitoring changes daily in the seed coat, hypocotyledon, and cotyledon.

Effect of sediment on photosynthesis and respiration of hydrilla

Hoagland's solution (5 mℓ supplemented with 400 mg of $NaHCO_3$ per litre) was pipetted into the outer annulus of Warburg flasks and leaves stripped from matched hydrilla stems were immersed in the solution. The central wells of the

Warburg flasks were equipped with filter paper strips, saturated with NaOH solution to absorb CO_2: the side arms contained the HPLC extracts, or water, in the case of control flasks. The atmosphere in the flasks was either N_2 for photosynthesis experiments or air for respiration studies.

The flasks were immersed in a water bath at 30.5° C and shaken manually. Illumination (60 $\mu E/m^2/sec$) was provided by fluorescent lamps. Manometer readings, measured as a function of time, were fitted to the best straight line by a least-square procedure. The gradients of the lines obtained are a measure, in arbitrary units, of photosynthesis/respiration rates.

The general form of the experiment was to measure the initial rate of respiration/photosynthesis, add the contents of the side arms to the suspension of the hydrilla leaves, incubate in the dark for a time at 30.5 ° C, and then repeat measurements of photosynthesis/respiration rates (Figure 2).

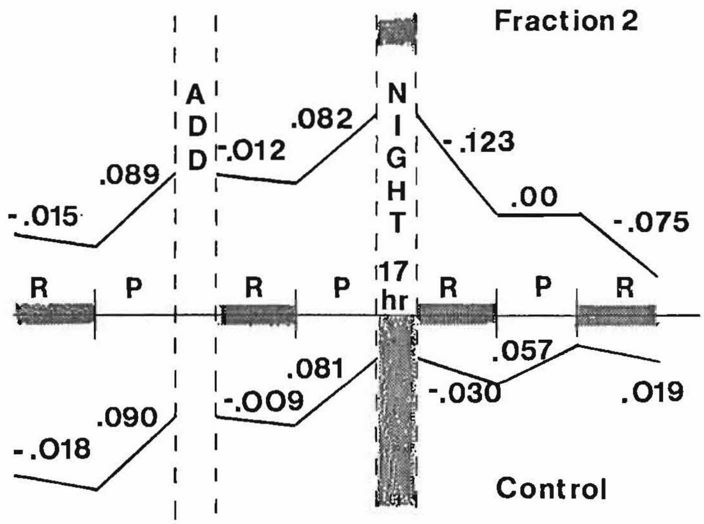

Figure 2. Schematic representation of the effect of hydrilla growth inhibiting material on relative rates of photosynthesis and respiration. The sequence shown indicates: (a) respiration, R, (b) photosynthesis, P, (c) addition of inhibitor, (d) respiration, (e) photosynthesis, (f) incubation overnight, 17 hr, (g) respiration, (h) photosynthesis, and (i) respiration. The effect of fraction 2 is compared with a control sample

RESULTS AND DISCUSSION

Bioassays with lettuce seeds

Lettuce seeds provide a convenient screening technique for evaluating herbicidal activity. In the present instance, the hydrilla growth inhibiting extract also was observed to inhibit the germination of lettuce seeds (Baltrop and Martin 1983). Several observations are pertinent: (1) the effect is concentration dependent; (2) the development of both hypocotyledons and dicotyledons is retarded, though no morphological changes were noted in comparison with control samples (in contrast with the results of other natural products; Moon and Martin 1981); (3) a photodynamic action is involved, i.e., the number of seeds developing cotyledons and hypocotyledons in a given time is significantly reduced for those samples exposed to light and the growth inhibitor, relative to control samples (exposed to inhibitor but maintained in the dark); and (4) singlet oxygen (O_2, $^1\Delta_g$) is presumably responsible for the observed photodynamic effect for sodium azide, a powerful quencher of singlet oxygen, and exercises a protecting effect.

On the basis of these observations and others, it seemed appropriate to investigate what components were responsible for growth inhibition and to obtain a better method for evaluating hydrilla response than simple growth.

Effect of HPLC-separated fractions on hydrilla photosynthesis and respiration

Two major fractions were separated by HPLC (see Figure 1), and both were tested for their effect on photosynthesis and respiration of hydrilla leaves. The results of the tests were summarized schematically in Figure 2, which indicates the changes in rates following specific events (e.g., addition of inhibitor, initiation of respiration, overnight incubation, initiation of photosynthesis, etc.).

One experiment compared fraction 1 with control sample, and it was evident that fraction 1 had little effect on the photosynthetic rate and no effect on the rate of respiration of hydrilla leaves. Any inhibiting effect on photosynthesis that may have been observed was small and was readily ascribable to the contamination of fraction 1 by fraction 2.

At first examination, the effect of adding fraction 2 was inhibition of photosynthesis by a notable amount, relative to initial value and in comparison with control samples. But diffusion to the active site of interaction was slow, and, after standing overnight, more pronounced effects were observed (Figure 2); e.g., respiration rate increased eightfold to tenfold, and the rate of photosynthesis dropped to zero. In comparison, the rate of respiration of control samples did not change, though the rate of photosynthesis decreased to 60 percent of the initial rate during the course of the experiment.

It is evident from considering the typical chromatogram (Figure 1) that, though a partial separation was effected, it was not a baseline separation of fractions 1 and 2. Moreover, fraction 2 contains at least two major components and probably one or two minor ones. Until fraction 2 is resolved into its components, we cannot distinguish between the possibilities: that one component affects both respiration and photosynthesis or that one component affects respiration and another affects photosynthesis.

CONCLUSIONS

The general mode of action of fraction 2 seems well enough defined: respiration is accelerated and photosynthesis is inhibited. Either process or both have a deleterious effect on hydrilla. The material that inhibits the growth of hydrilla did not adversely affect the growth of a common alga *Scenedesmus obliquus* (Dooris, Silver, and Martin 1982) at concentrations below 12 ppm as organic carbon. Thus, the action of the naturally occurring hydrilla growth inhibitor shows some degree of specificity. Finally, though the action of fraction 2 is effective for practical purposes, for a variety of reasons the components must be separated and characterized.

ACKNOWLEDGEMENTS

The financial support of the U.S. Army Engineer Waterways Experiment Station is gratefully acknowledged. The technical assistance of Mrs. Louise B. Worrell is appreciated. Finally, we are grateful to the President's Council (USF) for funds to purchase the preparative-scale HPLC column.

REFERENCES

Barko, J. W. 1982. "Influence of Potassium Source (Sediment vs. Open Water) and Sediment Composition on the Growth and Nutrition of a Submersed Freshwater Macrophyte," *Aquatic Botany,* Vol 12, pp 157-172.

Barko, J. W., and Smart, R. M. 1980. "Mobilization of Sediment Phosphorus by Submersed Macrophytes," *Freshwater Biology,* Vol 10, pp 229-238.

Barltrop, J., and Martin, D. F. 1983. "Evidence for Photodynamic Action by a Naturally Occurring Hydrilla-Growth Inhibitor," *Journal of Environmental Science and Health,* In press.

Dooris, P. M., and Martin, D. F. 1980. "Growth Inhibition of *Hydrilla verticillata* by Selected Lake Sediment Extracts," *Water Research Bulletin,* Vol 16, pp 112-117.

Dooris, P. M., Silver, W. S., and Martin, D. F. 1982. "Effects of Hydrilla-Growth Inhibiting Extracts Upon the Growth of *Scenedesmus obliquus,*" *Journal of Environmental Science and Health,* Vol 17A, pp 639-645.

Martin, D. F., Doig, M. T., III, and Millard, D. K. 1971. "Potential Control of Florida Elodea by Nutrient-Control Agents," *Hyacinth Control Journal,* Vol 9, pp 36-39.

Martin, D. F., and Dooris, P. M. 1983. "Hydrilla Growth-Inhibiting Substances from Aqueous Extracts of Lake Sediments, Effect of Temperature," *Journal of Environmental Science and Health,* Submitted.

Martin, D. F., Victor, D., and Dooris, P. M. 1976. "Effects of Artificially-Introduced Ground Water on the Chemical and Biochemical Characteristics of Six Hillsborough County (Florida) Lakes," *Water Research,* Vol 10, pp 65-69.

Moon, R. E., and Martin, D. F. 1981. "Assay of Diverse Biological Activities of Materials Elaborated by a Marine Blue-Green Alga, *Gomphosphaeria aponina,*" *Microbios Letters,* Vol 18, pp 103-110.

CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

Fiber Formulations for the Controlled Release of Aquatic Herbicides

by
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Several different systems have been developed for the controlled delivery of aquatic herbicides. Most of these systems consist of an aquatic herbicide either dispersed in a polymer matrix or chemically bound to polymers. These polymeric delivery systems are normally dispersed in the field as granules or pellets. The pellets either float at the surface of the water or sink. In flowing water systems, the floating pellets are carried downstream before they have a chance to release the herbicide. Those pellets that sink to the bottom may release the herbicide, but often at a reduced rate when covered by mud. Moreover, the herbicide may be deactivated by sorptive interactions with the soil. It was suspected that aquatic herbicide delivery systems in the form of fibers could be effective in controlling aquatic weeds. The fibers could entangle with the weeds and thus not be carried downstream in flowing water applications. The entanglement would also prevent them from sinking to the bottom and being covered with mud.

As part of the program to evaluate fibrous delivery systems for aquatic herbicides, we have developed fibers with controlled release of two aquatic herbicides. These are diquat manufactured by Chevron Chemical Company and fluridone marketed by Elanco. Both of the herbicides were incorporated into fibers prepared from polycaprolactone (PCL), a biodegradable polymer. After the herbicide is completely released, the polymer degrades within the water leaving no effect upon the environment. The PCL material is relatively inexpensive, and the melt-spinning process used to prepare the fibers is simple, noncontaminating, and easily adapted to large-scale production.

EXPERIMENTAL

Materials

An aqueous solution of diquat was purchased from Chevron Chemical Company. The herbicide was precipitated from the aqueous solution by the addition of ethanol. The precipitate was then recrystallized from ethanol to give a pure, dry form of diquat. Fluridone was obtained from Elanco as a solid, technical grade of 97 percent purity.

Two different samples of PCL were used in the studies. One sample of PCL was prepared in our laboratories by the ring-opening polymerization of ϵ-caprolactone. This material was of a high molecular weight with an inherent viscosity of 1.8 dl/g. The other sample was PCL 700 supplied by Union Carbide Corporation.

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Fiber preparation

Monolithic fibers of the herbicide/PCL mixtures were prepared with two different types of melt-spinning equipment. A melt indexer was used to prepare monolithic fibers having a low degree of fiber orientation. Fibers with more uniformity and higher orientation were produced on a ram extruder.

Fiber preparation with the melt indexer was straightforward. The melt indexer was preheated to the desired spinning temperature, the barrel was loaded with the herbicide/PCL mixture, and an extrusion ram with attached weights was placed in the top of the barrel. When the mixture had equilibrated at the spinning temperature, additional weights were added to the ram to force the molten material through the spinneret. As the molten material extruded, it cooled and formed a fiber which was collected in loose coils.

Fibers were prepared on the ram extruder by a similar process. The herbicide/PCL mixture was added to the electrically heated bore of the ram extruder. The polymer mixture was equilibrated at the spinning temperature, and the melt was forced at a constant rate through the spinneret. Some of the extruded fibers were cooled in air, and others were cooled or quenched in water. All fibers were wound on paper tubes with a surface-driven winder. The winding tension produced some slight orientation of the fibers. Additional orientation of these ram-extruded fibers and those produced on the melt indexer were obtained by our drawing the fibers at various ratios over a hot plate.

Coaxial or sheath/core fibers were also prepared by two methods. In the first procedure, monolithic fibers of herbicide/PCL were passed through an 18-gauge syringe needle which contained a concentrated solution of the sheath polymer. The fiber was drawn through the needle, and the solvent was evaporated. We passed the fibers through the solution two, three, and four times to obtain a variety of coating thicknesses. Cross sections of the thoroughly dried fibers were examined microscopically for sheath and core dimensions.

In the second procedure for preparing sheath/core fibers, we used the ram extruder and a coaxial spinneret. The coaxial spinneret has two concentric openings. The core material is melted in one electrically heated metal block and pumped through the center opening; the sheath polymers are melted in a separate block and pumped through the outer circle. As both polymer streams emerge from the spinneret, they cool to form the sheath/core fiber. The rate at which the two polymer streams are pumped to the coaxial spinneret determines the thickness of the sheath membrane and the size of the filament.

Herbicide release rates

Triplicate samples of each herbicide-loaded fiber were cut to the same length and weighed. The monolithic fibers were used with no changes, but the sheath/core fibers were sealed on the ends with polymer. With longer lengths of fiber, the sealing of the ends to make a complete reservoir system was not necessary. The fiber samples were then immersed in 25 or 50 mℓ of receiving fluid. Deionized water, 50 percent aqueous ethanol, and reconstituted hard water were used during the study as receiving fluids. The sealed containers with the fibers were agitated on an Eberbach shaker bath at approximately 22° C. We exchanged the receiving fluid periodically and assayed for herbicide content by measuring the ultraviolet (UV) absorbance on a Perkin-Elmer 575 spectrophotometer. The quantity of herbicide released was determined from Beer's Law plots of absorbance versus herbicide concentration.

RESULTS AND DISCUSSION

Diquat fibers

With diquat, we were able to prepare monolithic fibers containing from 5 to 30 percent of the herbicide. Because diquat does not melt at the extrusion temperature of PCL, it acts as a solid filler in the fiber. The mechanical properties of the fibers loaded with diquat and drawn to various lengths were quite good. These fibers had strengths comparable to commercial textile or industrial yarns. As we expected, the strengths of the fiber samples increased with the higher draw ratios, and the values of elongation decreased. Fibers cooled by air during spinning appeared to have better properties than those cooled or quenched in water. These results are presented below:

Sample No. A293-	*Draw Ratio*	*Tenacity, g/d**	*Elongation at Break, %*	*Tensile Factor*
3	0	-	-	-
3-1	2.1	2.5	75	20
3-2	3.1	3.1	90	30
3-3	4.1	5.0	53	38
5	0	-	-	-
5-1	3.0	1.7	40	11
5-2	4.0	2.4	24	12
5-3	5.0	3.4	37	21

* g/d = grams/denier

The release of diquat from the monolithic fibers was first-order as we had expected. In this type of system, there is a quick release or burst of herbicide initially followed by a gradually declining release. The fibers with the higher loadings of diquat gave the greatest burst effect and the quickest release of herbicide. These release characteristics suggest that dissolution of diquat rather than diffusion is the most probable mechanism by which release is controlled from the fibers. The release kinetics for this system in which the herbicide is dispersed as a solid rather than dissolved in the polymer matrix can be complex since dissolution of the herbicide and the formation of pores can be occurring simultaneously. In the case of pore formation, the higher the herbicide loading, the more pores generated and the higher the release rate. Thus, higher loadings gave higher release rates.

The more highly drawn or oriented monolithic fibers containing diquat gave slower release rates and smaller burst effects. These results can be explained with the same dispersed-agent model if we assume that the receiving fluid, water, has to penetrate the polymer to dissolve the diquat salt. The more crystalline polymer produced by drawing would exert an inhibitory effect upon water penetration and cause slower release. The nonoriented fibers produced on the melt indexer would allow both a more rapid rate of water permeation and a more rapid dissolution of the diquat salt with a resulting fast release of diquat.

None of the diquat monolithic fibers gave satisfactory release profiles. All had too great of a burst effect. To slow down the burst effect and prolong the release of diquat from the fibers, we prepared sheath/core fibers in which a herbicide-free polymer layer surrounded the herbicide. Both cellulose acetate (CA) and polycaprolactone (PCL) were used. The layer of CA had almost no effect on the rate of release of diquat. The layer of PCL did slow the release rate, but not enough to provide the long-term delivery of diquat desired. The thicker coating of PCL gave the slower release rate. These effects are shown in Figures 1 and 2. Apparently, the more hydrophilic cellulose acetate membrane formed around the monolithic fiber did not impede water penetration, and the release of diquat was not affected to any serious extent. The additional PCL simply formed a thicker noncrystalline membrane which slowed water penetration and salt dissolution only slightly.

Fluridone fibers

Monolithic fibers containing 10 to 60 percent of fluridone in PCL were prepared on both the melt indexer and ram extruder. These fibers spun much better than those prepared from diquat. We suspect this improved spinning performance was a result of fluridone dissolving in PCL and the lower melting point of fluridone compared to diquat. The fluridone fibers were strong and colorless indicating no degradation of the herbicide during melt spinning.

The release of fluridone from the monolithic fibers was first-order as predicted. However, the fibers did not have the enormous burst effects like those of the diquat-loaded fibers. In fact, the release of fluridone from these monolithic fibers was more nearly constant, and the release of fluridone could be extended from several days to over four months simply by controlling the loading of fluridone in the fibers. These effects are shown in Figure 3.

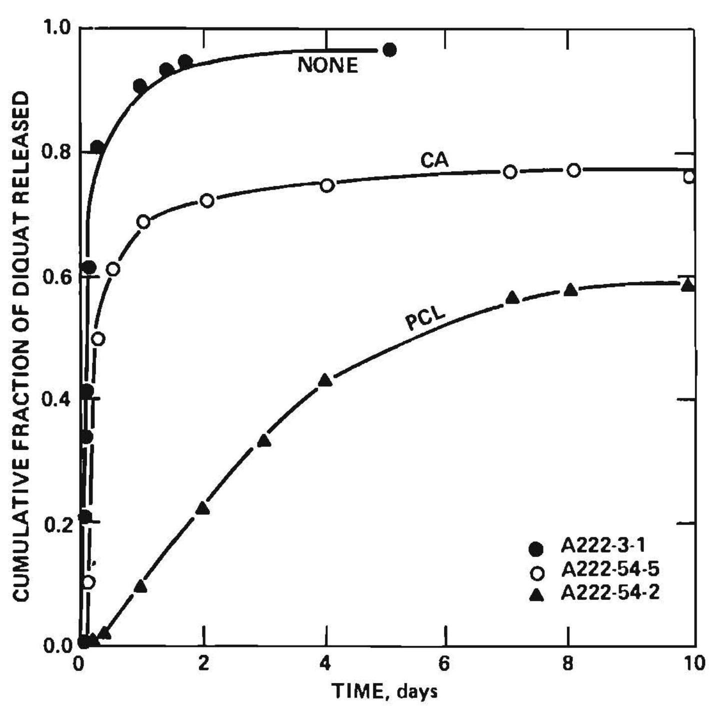

Figure 1. Effect of sheath polymer on release of diquat from monolithic fibers prepared on melt indexer

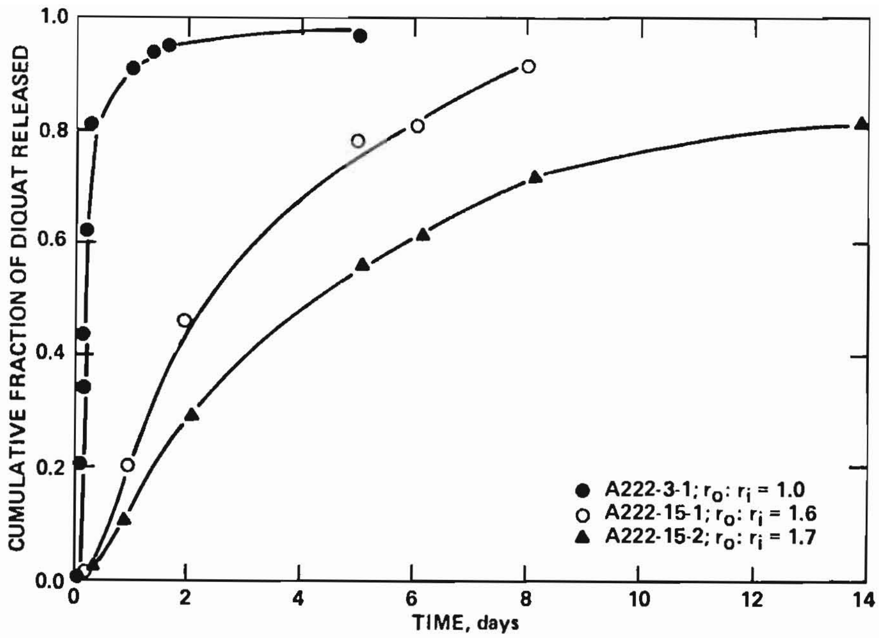

Figure 2. Effects of PCL coating on release of diquat from monolithic fibers prepared on melt indexer

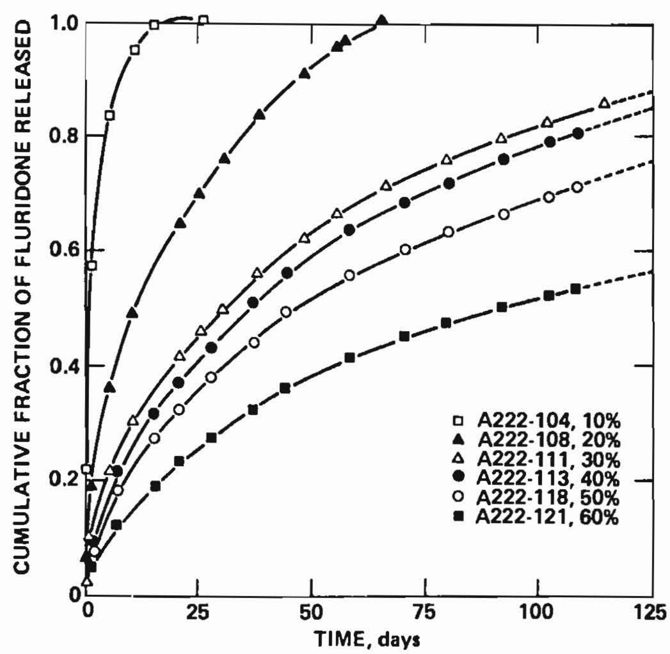

Figure 3. Cumulative fractional release of fluridone from PCL monolithic fibers into hard water: 0 to 110 days

The data plotted in Figure 3 also show that the release of fluridone from the PCL fibers is controlled by diffusion. In this type of system, the fractional rate of release is inversely proportional to the herbicide loading. Thus, the herbicide diffuses at a constant rate through the polymer matrix, and the higher the loading of herbicide, the longer the duration of release. Consequently, the mechanism of the fluridone release is quite different from that of diquat in PCL.

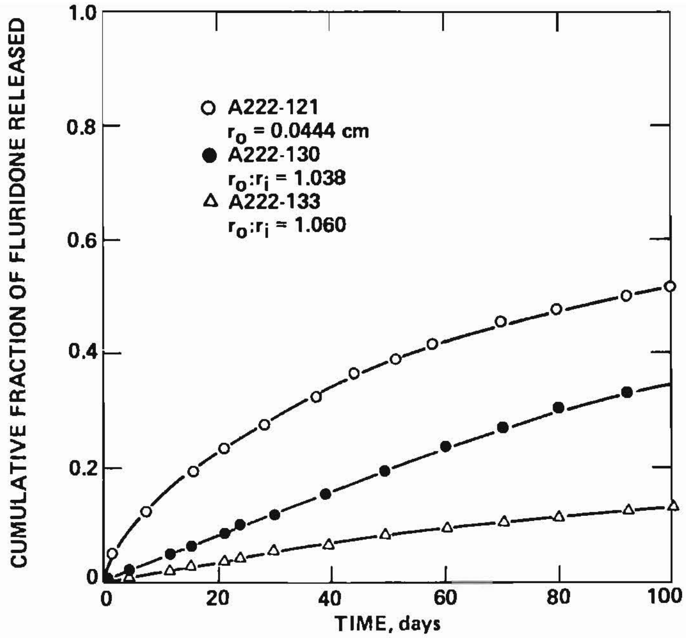

Figure 4. Cumulative fractional release of fluridone from 60-percent-loaded coaxial fibers into hard water

Although the monolithic fibers loaded with fluridone gave excellent release profiles, the release of herbicide from these fibers was not zero-order or constant because of the slight initial burst. We coated the monolithic fibers with additional PCL and obtained constant release of fluridone as shown in Figure 4. The data plotted in this figure show that thin layers of herbicide-free PCL on the monolithic fiber suppress the initial burst of fluridone and lead to a constant rate of release. In addition, the thickness of the coating as given by the ratio of r_o, the outer fiber radius, to r_i, the inner monolithic fiber radius, affects the release rate in a predictable manner. Based upon this behavior, we can design fibrous systems with fluridone to give either constant release or a slight burst. The fibrous systems can also be designed to deliver fluridone for times ranging from several days to years.

CONCLUSIONS AND RECOMMENDATIONS

From the results of the fibrous herbicide program thus far, the following conclusions can be drawn:

a. Diquat can be incorporated into fibrous PCL at relatively low levels.

b. PCL fibers containing diquat can be drawn to produce high strengths.

c. The release of diquat from PCL fibers is too fast for long-term use.

d. Fluridone can be incorporated into fibrous PCL at very high levels.

e. The release of fluridone from PCL fibers can be controlled to give various rates and duration of action.

The recommendations suggested by this study include the following:

a. Fluridone-loaded fibers should be evaluated in aquariums with flowing water.

b. Larger quantities of fluridone fibers should be prepared for field trials in both static and flowing-water systems.

ACKNOWLEDGMENTS

The assistance of Mr. Bernard J. Jenkins, Assistant Chemist, in spinning the fibers; Ms. Brenda H. Perkins, Assistant Biomathematician, Ms. Amelia G. Potter, Assistant Chemist, and Mr. Hai Nam Tran, Assistant Polymer Chemist, in conducting the release studies; and Dr. Donald R. Cowsar, Director, Applied Sciences Department, in interpreting the release data is most appreciated.

We also wish to thank Dr. Howard E. Westerdahl and Mr. Ronald E. Hoeppel, both of WES, for their suggestions during the course of the program, and appreciation is given to the U.S. Army Corps of Engineers Aquatic Plant Control Research Program for financial support of the project.

CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

Evaluation of Controlled Release Herbicides for Aquatic Weed Control

by
Thai K. Van* and Kerry K. Steward*

HERBICIDE EVALUATION

The evaluation of controlled release (CR) herbicide formulations has been one of the major objectives of our program during the last few years. The concept of CR formulations is to allow a prolonged exposure of the target plants to a sustained low concentration of a given herbicide. The effective use of CR herbicides appears to hold great potential for long-term management of aquatic plant growth with much less chemical required for the same period of activity.

One major problem encountered in controlling hydrilla (*Hydrilla verticillata* Royle) is the fast regrowth of the plant from vegetative propagules, i.e., tubers and turions. Hydrilla tubers are buried in the hydrosoil and are, therefore, immune to conventional control techniques. For extended hydrilla control, it would be necessary to find chemicals that are translocated to regenerative tissues and inhibit regrowth, or chemicals that could be applied before emergence and attack emerging new growth.

Dichlobenil (2,6-dichlorobenzonitrile) has been shown to have herbicidal activity toward germinating seedlings of many weed species. The effect of this herbicide on aquatic plants was first reported by Barnsley (1960) who found that *Salvinia auriculata* Aubl. exhibited severe sprout inhibition after treatment of 1 ppmw** dichlobenil. Later studies showed high activity of dichlobenil against many other aquatic species (Walker 1964; Hiltibran 1966; Weldon, De Rigo, and Blackburn 1968; Durden and Blackburn 1972). In recent field tests conducted by Steward (1980), hydrilla regrowth was controlled over 48 months in one of the three replicates treated with 11 kg/ha dichlobenil. Regrowth was associated with disappearance of the herbicide in the water. The studies reported here were conducted to evaluate the potential of various CR formulations of dichlobenil to maintain inhibitory levels of the chemical in water for long-term control of hydrilla regrowth from propagules.

Fluridone (1-methyl-3-phenyl-5-[3(trifluoromethyl) phenyl]-4(1H)-pyridinone) is a relatively new preemergence herbicide for use on cotton (Waldrep and Taylor 1976). The chemical was later found to possess high activity against new growth of hydrilla and other aquatic vascular plants at low application rates (Arnold 1979). Results of our studies with ^{14}C-fluridone, however, indicated a sigmoid-shape uptake curve by hydrilla, with very slow uptake rates during the first few days after treatment. The slow initial uptake may present a problem in the control of submersed aquatic plants with this herbicide in flowing waters, such as in

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** Parts per million in water.

irrigation and drainage canals. One logical approach to improving the uptake characteristics of fluridone is by incorporating the herbicide in a CR formulation. The CR formulation would be designed to provide adequate plant contact through timed release of the herbicide, thereby increasing the chances for plant uptake.

The evaluation of various CR formulations of 2,4-D for use on watermilfoil (*Myriophyllum spicatum* L.) has also been a high-priority item of our program. The uptake and translocation of 2,4-D in plants have been reviewed extensively (Richardson 1977). At relatively low doses, 2,4-D is translocated throughout the plant tissues and therefore able to kill the entire plant.

MATERIALS AND METHODS

Chemicals

Two CR formulations of 2,4-D were provided by Dr. Frank Harris, Wright State University, Dayton, Ohio. The formulations are of a second generation of the clay pellets Poly (GMA) 2,4-D (12.5 percent a.e.*) and designed to give constant release rates of 3.0 mg (Lot 2) and 1.5 mg 2,4-D/g polymer/day (Lot 3).

The clay-filled alginate granules containing dichlobenil (7.1 percent a.i.**) were developed by the Southern Regional Research Institute (SRRC), U.S. Department of Agriculture (USDA), New Orleans, La. The release profile of the formulation was previously determined in static reconstituted water by the SRRC. The results indicated that the duration of action of the system was about 150 days. Release appeared to be first-order with rates slowly declining with time. An average release of 0.45 mg dichlobenil/g granules/day was calculated for the system by averaging all rates over the 150-day activity of the formulation.

The monolithic fiber of fluridone (40 percent a.i.) was provided by Dr. Richard Dunn of the Southern Research Institute, Birmingham, Ala. The fiber formulation was expected to release all of its fluridone within approximately 1 month after treatment.

Determination of release rates in static water

Chemical release rates in static water were determined under controlled laboratory conditions at $28 \pm 2°$ C. Treatments of the CR formulations were made to 3.7 ℓ of water with amounts calculated to produce a given herbicide concentration based on the estimated release rate specified by the cooperating formulators. Treatments were replicated four times.

Natural water from a dug pond on the Fort Lauderdale Agricultural Research Center grounds was used. Water quality was monitored monthly. For inter-laboratory comparisons, release rate data were also determined in reconstituted distilled water at pH 8.0, containing 192 mg $NaHCO_3$, 120 mg $CaSO_4 \cdot 2H_20$, 120 mg $MgSO_4$, and 9 mg KCl per litre. Water samples were taken from each container at various times throughout the experiment for herbicide residue analyses.

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* a.e. = acid equivalent.

** a.i. = active ingredient.

Determination of release rates in flowing water

Treatments of the CR formulations to maintain various herbicide concentrations were made to 19 ℓ of flowing water in glass, flow-through culture vessels. Natural pond water was used and treatments were replicated four times.

Regulated flowing water provided by a multichannel tubing pump (Eldex Laboratories Inc., 3551 Haven Ave., Menlo Park, Calif.) was delivered to the bottom of individual culture vessels at a rate to provide one volume change in 24 hr. Water flow was checked at least once a week, and adjusted when necessary. Wastewater flowed out through side arms near the top of the vessels and was carried outside. Residual herbicide in solution was removed by passage of the wastewater through three series-connected containers filled with activated charcoal. Fifty-millilitre water samples were taken from each vessel at various times throughout the experiment. The samples were concentrated on SEP PAC® C_{18} cartridges and analyzed for herbicide residues.

Evaluation of efficacy against aquatic plants

Mature plants of watermilfoil were obtained from Lake Seminole, Ga. The plants were maintained as a stock culture in an outdoor pool until use. Tubers and mature plants of hydrilla were collected locally.

The two formulations of Poly (GMA) 2,4-D were evaluated for control of watermilfoil in the laboratory. Apical stem sections 15 cm long were planted in standard soil mix (70 percent sand and 30 percent organic peat) in 250-ml glass beakers. Five beakers, each containing three plant sections, were placed in the culture vessels and allowed to establish for 4 weeks before chemical treatment was applied. Culture vessels were subjected to 14-hr days of 150 $\mu E/m^2/sec$ from a combination of fluorescent and incandescent lamps. Temperature was maintained at 28° ± 2° C. Treatments were applied to vessels containing watermilfoil and to vessels without plants in order to determine the effect of plants and soil on herbicide concentrations. Culture vessels with plants to which treatments were not applied served as plant controls. Response of watermilfoil plants to chemical treatments under flowing water conditions was evaluated closely throughout the experiment. The plants were harvested 10 weeks after treatment and evaluated for percent survival. Stem lengths and plant weights were measured.

The CR formulations of dichlobenil and fluridone were evaluated for control of hydrilla regrowth from rootstocks and from germinating tubers. Hydrilla tubers were pregerminated in pond water in the laboratory. The new shoots emerging from tubers were selected for uniformity (3 cm long) and planted in 250-ml beakers. Three beakers each containing three germinating tubers were placed in the culture vessels, and regrowth was observed with or without CR herbicide treatments.

For studies of regrowth from rootstocks, apical stem sections of hydrilla were planted in 250-ml beakers and allowed to establish for 3 to 4 months in an outdoor pool. The plants were then clipped to 3 cm above the hydrosoil and the beakers transferred into the culture vessels 1 week before chemical treatment was applied.

Outdoor evaluation of CR 2,4-D

The outdoor evaluation of Poly (GMA) 2,4-D against watermilfoil was conducted from April through August 1982. A system of 24 concrete, flow-through aquaria was used. The dimensions of the aquaria were 77 cm wide by 219 cm long (1.7×10^{-4} ha) with depth varying from 50 to 56 cm. The normal volume of these containers after adding soil was 850 to 950 ℓ. A clear fiberglass shelter was constructed over the system to prevent rainwater from getting into the aquaria. The aquaria were filled with natural pond water. Uniform low water pressure was maintained by constant overflow in a standpipe, and flow to individual aquaria was regulated by small petcock valves to provide one volume change every 24 hr. Watermilfoil plants were established in 30- by 30- by 15-cm aluminum trays. Twelve trays were placed in each culture aquaria and allowed to grow for 6 months before chemical treatment was applied.

Residue analyses

Complete details of the analytical procedures used for determining herbicide residues have been discussed in a previous publication (Steward 1980). Briefly, 2,4-D was analyzed by high pressure liquid chromatography (HPLC) with a Perkin-Elmer series 3B HPLC, a Perkin-Elmer LC 75 detector (285 nm), and a Perkin-Elmer Sigma 10 integrator. The chromatographic column was HCODS SIL X (reversed phase). The mobile phase was acetonitrile: 1 percent acetic acid (35:65), and solvent flow rate 1.5 ml/mn. The detection limit was determined to be 50 ng 2,4-D.

Dichlobenil was partitioned into hexane from 9-ml water samples and analyzed with a Perkin-Elmer Model 3920 gas chromatograph equipped with a ^{63}Ni electron-capture detector. The column was 1.5 percent OV 17/11.95 percent QF-1 on 80/100 mesh Chromosorb Q. Chromatographic conditions: column (140°-195° C at 32 degrees/min), detector (275° C), injection port (230° C). The detection limit was determined to be 0.05 ng.

Fluridone was determined with a Perkin-Elmer high-pressure liquid chromatograph Model 3B, equipped with a PE/HS-5 C_{18} reversed phase column, and a LC 75 detector (238 nm). The mobile phase was acetonitrile: 1 percent acetic acid (50:50), and flow rate 2.1 ml/mn. The detection limit was determined to be 0.025 ng.

RESULTS

Clay pellets Poly (GMA) 2,4-D in static water

Figure 1 illustrates the cumulative release of 2,4-D from the two formulations of Poly (GMA) 2,4-D in static reconstituted water. The increasing levels of herbicide in the water with time indicated that release from the formulations had occurred. Release rates in both formulations appeared fairly constant, except that the rate probably slowed down a little in Lot 2 after 68 days, when approximately 70 percent of the chemical had been released. The rates of release in reconstituted water were estimated to be 5.4 mg and 0.9 mg 2,4-D per gram polymer per day for Lot 2 and Lot 3, respectively. Regression equations of the release rate data from

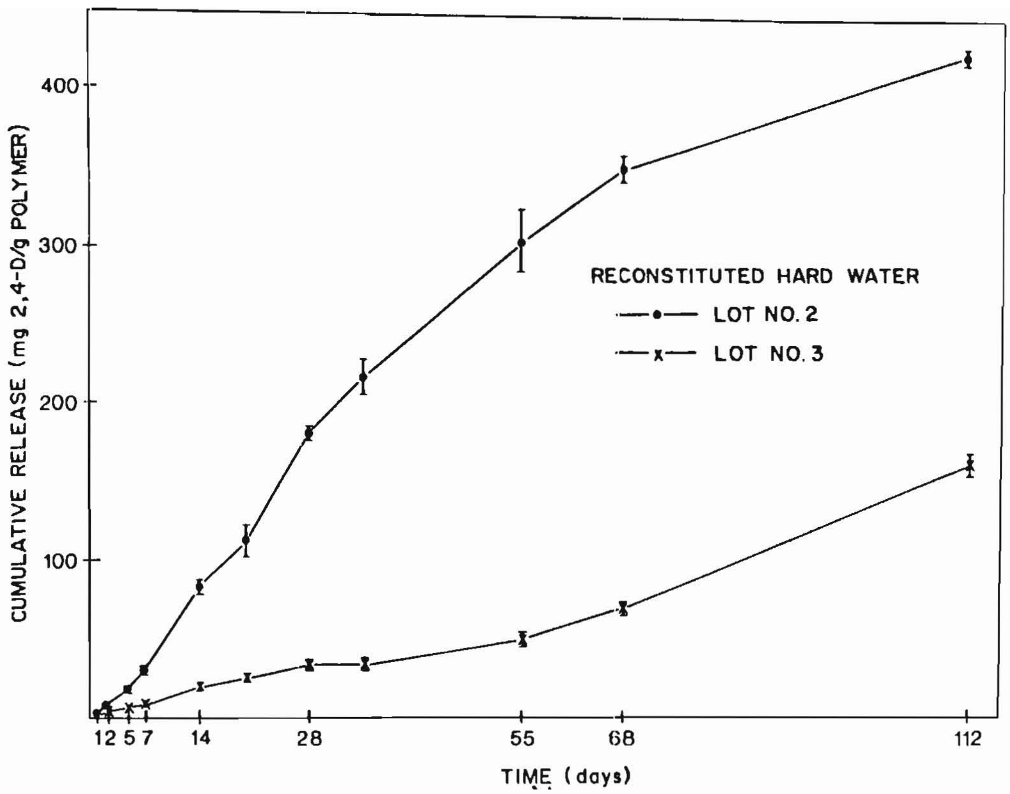

Figure 1. Release of 2,4-D from clay pellets of Poly (GMA) 2,4-D in static reconstituted water. Each point is the mean of four replicates ± S.E.

Day 0 to Day 112 were Y=3.6 + 5.4X, R=0.98 for Lot 2, and Y=4.5 + 0.9X, R=0.95 for Lot 3.

The results of cumulative 2,4-D release in natural pond water are presented in Table 1. Considerable variability among the replicated samples was observed. Between Day 14 and Day 20, levels of 2,4-D in treatments with both fomulations actually dropped as compared to levels from previous measurements, suggesting that some degradation of the released chemical had occurred.

A study of the accountability of 2,4-D in treatments with reconstituted water and natural pond water was conducted at the conclusion of the experiment on Day 112. The treatments were stirred vigorously to obtain a homogenous mixture, and two 100-ml samples taken immediately after stirring. Suspended particulate matter containing 2,4-D was collected by filtering the sample through a combination of Reeve-Angel® glass microfiber and Gelman Metrigard® filter (0.2 micron pore size). The portion of 2,4-D that had been hydrolyzed and adsorbed onto clay particles was recovered by first eluting with 10 ml ethanol (95 percent) and finally desorbing with another 10 ml ethanol (95 percent). The remaining 2,4-D polymer collected on the filter was then dissolved in acetone and subjected to complete hydrolysis at pH 2. However, no 2,4-D acid was recovered from the final acid hydrolysis step, suggesting that all 2,4-D had been released from the polymer in both treatments in reconstituted water and in natural water. The results of analyses for 2,4-D in the ethanol fractions and the aqueous filtrate are presented in Table 2.

Table 1
Release of 2,4-D from Clay Pellets Poly (GMA) 2,4-D in Static Natural Pond Water

	Days Posttreatment										
Treatment	*1*	*2*	*5*	*7*	*14*	*20*	*28*	*35*	*55*	*68*	*112*
Lot 2											
A	2.2	3.7	6.0	8.6	2.5*	2.2*	12.8	33.6	74.0	174.7	185.3
B	—	4.3	7.2	10.5	12.4	16.8	50.5	84.2	118.8	195.1	252.7
C	1.6	3.6	6.9	11.5	6.3*	1.4*	4.9	19.8	80.1	199.6	302.1
D	2.4	4.6	6.5	8.1	6.1*	2.4*	12.9	25.7	86.1	175.1	278.4
Average	2.1	4.1	6.7	9.7	6.8	5.7	20.3	40.8	89.8	186.1	254.6
Lot 3											
A	1.8	3.3	4.2	6.5	2.0*	2.5	0.6*	BDL	BDL	13.9	34.2
B	—	2.4	3.7	7.4	5.8*	0.8*	1.8	BDL	BDL	11.9	95.0
C	1.6	3.3	4.5	7.2	3.4*	3.3*	1.2*	BDL	BDL	13.9	131.1
D	—	4.0	4.9	7.4	0 *	2.2*	1.2*	BDL	BDL	11.9	142.5
Average	1.7	3.3	4.3	7.1	2.4	2.2	1.2	BDL	BDL	12.9	100.7

NOTE: Units in mg/g polymer.
* Degradation was evident.

Table 2
Accountability of 2,4-D Released in Static Reconstituted and Natural Water

Total 2,4-D Applied mg	*2,4-D Recovered 5 Months After Treatment, mg**				
	Aqueous Filtrate	*EtoH Eluent*	*EtoH Desorption*	*Total Recovery*	*Percent Recovery*
Reconstituted Water					
(187)	142.9 ±7.6	26.5 ±0.4	22.7 ±3.2	192.0 ±4.1	102
Natural Pond Water					
(187)	89.0 ±6.0	24.4 ±3.2	22.8 ±0.5	136.2 ±8.8	73

* Means of three replicates ± standard error.

It appears that all of the available 2,4-D was recovered from treatments in reconstituted water. About 76 percent was measured in the aqueous filtrate, 14 percent in the ethanol eluent, and 12 percent in the ethanol desorption mixture. On the other hand, total 2,4-D recovered from treatments made to natural water averaged only 73 percent. About 48 percent was recovered in the aqueous filtrate, 25 percent recovered from the ethanol fractions, and 27 percent was not accounted for. Higher microbial activity and algal growth were observed in treatments with natural pond water. These factors may have been partly responsible for the loss of the released 2,4-D in natural water.

Clay pellets Poly (GMA) 2,4-D in flowing natural water and efficacy against watermilfoil

Treatments of the two clay pellets Poly (GMA) 2,4-D were made to 19 ℓ of flowing water in glass, flow-through culture vessels with and without Eurasian watermilfoil. Rates of treatment were calculated to maintain 0.05 and 0.10-mg/ℓ

2,4-D concentrations in the culture vessels, based on the estimated release rates specified by the cooperating formulator (3.0 mg and 1.5 mg 2,4-D/g polymer/day for Lot 2 and Lot 3, respectively).

Results of measurements of 2,4-D concentrations in the flowing water at various sampling times after treatment are presented in Table 3. Based on these concentrations, release rates of 2,4-D from the formulations were calculated. During the first week after treatment, average release rates for Lot 2 were 5.6, 3.9, and 3.4 mg 2,4-D/g polymer/day on Day 1, 3, and 7, respectively. Corresponding values for Lot 3 were 4.0, 1.9, and 0.4 mg 2,4-D/g polymer/day.

Treatments with both Lot 2 and Lot 3 to maintain 0.10 mg/ℓ 2,4-D were applied to vessels containing watermilfoil and to vessels without plants in order to determine the effects of plants and soil on herbicide concentrations. In the absence of plants and soil, concentrations of 2,4-D appeared to be maintained around the expected level (0.10 mg/ℓ 2,4-D) until the end of the 63-day experiment (Table 3). In all treatments with watermilfoil, however, 2,4-D concentrations decreased rapidly and disappeared from the flowing water after 35 days posttreatment. Similar losses of 2,4-D were previously reported (Van and Steward 1981) and were probably due to the various components in the experimental system acting as sinks in taking up the released 2,4-D.

On 30 April and 1 May 1982, water flow through the experimental vessels was stopped because of power failure, resulting in exceedingly high levels of 2,4-D in the culture vessels, as reflected in results of residue analyses on Day 14.

These high residue levels in the flowing water were probably responsible for the severe plant injuries observed in all treatments after 14 days (Table 4). However, regrowth began as early as 42 days after treatment, and appeared to be much more vigorous in the treatment with Lot 3. All plants were harvested 10 weeks after treatment, and percent of surviving plants, stem length, and plant dry weights were measured (Table 5). The dry weights as well as growth in stem length were significantly inhibited in all treatments with the 2,4-D polymers.

Table 3

Release of 2,4-D from Clay Pellets Poly (GMA) 2,4-D Lot 2 and Lot 3 in Flowing Natural Water Under Controlled Laboratory Conditions

2,4-D Treatment	*Concentration of 2,4-D (mg/ℓ) at Days Posttreatment**							
	1	*3*	*7*	*14***	*21*	*35*	*49*	*63*
0.05 mg/ℓ, Lot 2 with plants	0.08 ±0.02	0.07 ±0.02	0.08 ±0.01	—	0.07 ±0.05	BDL	BDL	0
0.10 mg/ℓ, Lot 2 with plants	0.19 ±0.04	0.16 ±0.03	0.14 ±0.02	0.55 ±0.07	0.29 ±0.13	BDL	0	0
0.10 mg/ℓ, Lot 2 no plants	0.21 ±0.08	0.09 ±0.03	0.04 ±0.02	0.94 ±0.08	0.35 ±0.12	0.08 ±0.03	0.09 ±0.04	0.11 ±0.02
0.10 mg/ℓ, Lot 3 with plants	0.26 ±0.08	0.15 ±0.04	0.03 ±0.01	0.16 ±0.07	0.02 ±0.02	BDL	BDL	0
0.10 mg/ℓ, Lot 3 no plants	0.26 ±0.08	0.10 ±0.01	0.02 ±0.01	0.23 ±0.11	0.17 ±0.07	0.11 ±0.08	0.13 ±0.04	0.10 ±0.03

* Means of four replicates ± standard error.

** Power failure resulting in stop of flow.

Table 4
Phytotoxicity of 2,4-D Released from Clay Pellets Poly (GMA) 2,4-D Toward Watermilfoil in Flowing Water Under Controlled Laboratory Conditions

2,4-D Treatment	*Percent Injury at Days Posttreatment*					
	7	*14*	*28*	*42*	*56*	*70*
Control	0	0	5	8	11	15
0.05 mg/l, Lot 2	20	62	81	76**	55	38
0.10 mg/l, Lot 2	26	68	88	91*	74	78
0.10 mg/l, Lot 3	26	70	78	78***	58	30

NOTE: Average of four replicates.
* Indicates degrees of regrowth.

Table 5
Effect of 2,4-D Released from Clay Pellets Poly (GMA) 2,4-D on Watermilfoil after 10 Weeks in Flowing Water

2,4-D Treatment	*Percent Surviving Plants*	*Stem Length cm*	*Shoot Dry Weight g*	*Root Dry Weight g*
Control	95[a]	61.0[a]	1.10[a]	0.16[a]
0.05 mg/l, Lot 2	20[b]	11.5[bc]	0.06[bc]	0.03[b]
0.10 mg/l, Lot 2	12[b]	6.0[c]	0.02[c]	0.02[b]
0.10 mg/l, Lot 3	33[b]	17.4[b]	0.14[b]	0.03[b]

NOTE: Values in a column followed by the same letter are not significantly different at P = 0.05 as determined by Waller-Duncan Test. Each value is the mean of four replicates.

Outdoor evaluation of Poly (GMA) 2,4-D

Treatments of the two clay pellets Poly (GMA) 2,4-D were applied to maintain 0.05, 0.10, and 0.20 mg/l 2,4-D in outdoor aquaria previously established with watermilfoil. Results of 2,4-D analyses in the flowing water at various times during the experiment are presented in Table 6. After 7 days, the measured concentrations of 2,4-D in the flowing water were close to the expected levels. The 2,4-D concentrations then declined gradually in all treatments, and disappeared from the flowing water during the last several weeks of the experiment.

Because of several power failures resulting in chemical buildups in the aquaria around Day 3 posttreatment (Table 6), severe plant damage occurred in all treatments as observed in the 4-week evaluation (Table 7). Plant injury ratings 20 weeks after treatment, however, reflected the difference in regrowth in the various treatments. Treatments of Lot 2 to maintain 0.10 mg/l 2,4-D in the flowing water appeared adequate for control of regrowth in these tests. Lot 3 at the same treatment rates was much less effective, judging from the amounts of regrowth and plant dry weights at the end of the 20-week experiment (Table 8). Complete plant control was obtained, however, with treatment of Lot 3 calculated to maintain 0.02 mg/l 2,4-D in the flowing water.

Table 6

Release of 2,4-D from Clay Pellets Poly (GMA) 2,4-D in Flowing Natural Water in Outdoor Aquaria

Treat-ment No.	*2,4-D Treatment*	*Weight Pellets Applied g**	*Concentration of 2,4-D (mg/l) at Days Posttreatment***								
			1	*3†*	*7*	*14*	*21*	*35*	*49*	*83*	*120*
I	0.05 mg/l, Lot 2	60.2	0.06 ±0.03	0.26 ±0.06	0.06 ±0.03	0.12 ±0.03	0.01 ±0.01	0.01 ±0.01	0.01 ±0.01	0	0
II	0.10 mg/l, Lot 2	120.4	0.09 ±0.04	0.63 ±0.17	0.11 ±0.06	0.21 ±0.07	0.03 ±0.01	0.01 ±0.01	0.02 ±0.02	0	0
III	0.20 mg/l, Lot 2	240.8	0.21 ±0.06	0.64 ±0.18	0.20 ±0.01	0.23 ±0.08	0.01 ±0.01	0.04 ±0.02	0.02 ±0.02	0	0
IV	0.05 mg/l, Lot 3	120.4	0.07 ±0.00	0.09 ±0.02	0.02 ±0.02	0.03 ±0.02	0.02 ±0.01	0.01 ±0.02	0.01 ±0.01	0	0
V	0.10 mg/l, Lot 3	240.8	0.11 ±0.02	0.16 ±0.03	0.08 ±0.03	0.04 ±0.03	0.06 ±0.04	0.01 ±0.01	0.03 ±0.02	0	0
VI	0.20 mg/l, Lot 3	481.6	0.26 ±0.03	0.39 ±0.06	0.11 ±0.04	0.15 ±0.06	0.04 ±0.06	0.04 ±0.03	0.06 ±0.04	0.02 ±0.02	0

* Total treatment, assuming complete release, equals to: 8.2, 16.3, and 32.7 mg/l 2,4-D with Lot 2 in treatments I, II, III; and 16.3, 32.7, and 65.3 mg/l 2,4-D with Lot 3 in Treatments IV, V, and VI, respectively.

** Means of three replicates ± standard error.

† Power failure resulting in stop of flow.

Table 7

Phytotoxicity of 2,4-D Release from Clay Pellets Poly (GMA) 2,4-D on Watermilfoil in Flowing Water in Outdoor Aquaria

2,4-D Treatment	*Percent Injury at Weeks Posttreatment*								
	1	*2*	*4*	*6*	*8*	*10*	*12*	*16*	*20*
Control	0	2	0	2	2	2	3	5	7
0.05 mg/l, Lot 2	22	43	75	88	87	83*	80	72	60
0.10 mg/l, Lot 2	23	50	80	92	93	93	93	90	98
0.20 mg/l, Lot 2	13	37	82	92	93	88	88*	85	82
0.05 mg/l, Lot 3	20	27	70	63**	63	43	40	40	37
0.10 mg/l, Lot 3	15	35	65	60**	57	48	48	45	43
0.20 mg/l, Lot 3	23	50	85	90	90	90	90	88	93

NOTE: Mean values of three replicates; asterisks indicate degrees of growth.

Table 8

Effect of 2,4-D Released from Clay Pellets Poly (GMA) 2,4-D on Watermilfoil after 20 Weeks in Flowing Water in Outdoor Aquaria*

2,4-D Treatment	*Lot 2*		*Lot 3*	
	Shoot Dry Weight g	*Root Dry Weight g*	*Shoot Dry Weight g*	*Root Dry Weight g*
Control	227.3[a]	37.9[a]	227.3[a]	37.9[a]
0.05 mg/l	47.4[b]	11.5[b]	100.6[b]	17.9[ab]
0.10 mg/l	0.1[b]	12.0[b]	136.5[b]	16.7[ab]
0.20 mg/l	9.3[b]	10.7[b]	0.1[c]	3.3[b]

* Values in a column followed by the same letter are not significantly different at P = 0.05 as determined by Waller-Duncan Test. Each value is the mean of three replicates.

Clay-filled dichlobenil-alginate granules in flowing water and efficacy against hydrilla regrowth

Preliminary experiments have indicated that a threshold level of about 0.05 mg/ℓ dichlobenil is required for effective inhibition of hydrilla new growth emerging from tubers.

In these studies, the clay-filled alginate granules containing dichlobenil were evaluated for reliability of maintaining low levels of dichlobenil in flowing water to control hydrilla regrowth from germinating tubers and from rootstocks. Based on the average release rate of 0.45 mg dichlobenil/g granules/day previously observed in static water, treatments were made to maintain various levels of dichlobenil in culture vessels with or without hydrilla. Residue levels in the flowing water and efficacy of the formulation in controlling plant regrowth were determined.

Table 9 shows the actual dichlobenil concentrations in the flowing water at various times during the experiment. A gradual decline of the herbicide concentrations with time was observed in all treatments, with or without plants and soil, suggesting that release from the dichlobenil-alginate system was first-order, as it was previously shown in static water tests. No significant difference in herbicide concentrations was observed between treatments with and without plants and soil.

Table 9
Measured Release of Dichlobenil from Clay-Filled Alginate Granules in Flowing Water

Treatment No.	*Dichlobenil Treatment**	*Weight Granules g*	*Dichlobenil (mg/ℓ) at Days Posttreatment*** 7	21	28	42
I	0.01 mg/ℓ, with plants	0.3973	0.07 ±0.01	0.04 ±0.01	0.03 ±0.01	0.01 ±0.00
II	0.025 mg/ℓ, with plants	0.9911	0.16 ±0.01	0.12 ±0.01	0.08 ±0.01	0.04 ±0.02
III	0.05 mg/ℓ, with plants	1.9837	0.32 ±0.05	0.22 ±0.02	0.24 ±0.08	0.06 ±0.01
IV	0.10 mg/ℓ, with plants	3.9582	0.50 ±0.10	0.41 ±0.01	0.21 ±0.02	0.11 ±0.01
V	0.10 mg/ℓ, no plants	3.9608	0.39 ±0.11	0.34 ±0.02	0.23 ±0.03	0.13 ±0.08

* Total treatment, assuming complete chemical release, equals to 1.6, 4.0, 7.9, 15.8, and 14.9 mg/ℓ dichlobenil in treatments I, II, III, IV, and V, respectively.

** Means of four replicates ± standard error.

Regrowth from both germinating tubers and rootstocks (Table 10) was completely inhibited in treatments where dichlobenil concentrations in the flowing water were maintained at levels above 0.04 mg/ℓ. Regrowth was observed only at the lowest treatment rate where dichlobenil levels dropped to 0.03 and 0.01 mg/ℓ after 4 and 6 weeks posttreatment, respectively. Both shoot growth and root growth were affected by the dichlobenil treatments.

Table 10

Effect of Dichlobenil-Alginate Granules on Hydrilla Regrowth from Germinating Tubers and from Rootstocks after 6 weeks in Flowing Water*

	Regrowth from Tubers				*Regrowth from Rootstocks*			
Dichlobenil Treatment	*Shoot Length cm*	*Shoot Weight g*	*Root Weight g*	*Root/ Shoot Ratio*	*Shoot Length cm*	*Shoot Weight g*	*Root Weight g*	*Root/ Shoot Ratio*
Control	50^{a}	1.44^{a}	0.188^{a}	0.13^{a}	38^{a}	0.44^{a}	0.087^{a}	0.20
0.010 mg/l	18^{b}	0.20^{b}	0.024^{b}	0.12^{a}	17^{b}	0.18^{b}	0.036^{b}	0.20
0.025 mg/l	5^{c}	0.06^{c}	0.004^{c}	0.07^{b}	$5^{c}1$	0.16^{b}	0.024^{c}	0.14
0.050 mg/l	4^{c}	0.03^{c}	0.003^{c}	0.08^{b}	4^{c}	0.13^{b}	0.030^{bc}	0.23
0.100 mg/l	5^{c}	0.04^{c}	0.002^{c}	0.06^{b}	6^{c}	0.18^{b}	0.034^{bc}	0.19

* Values in a column followed by the same letter are not significantly different at P = 0.05 as determined by Waller-Duncan test. Each value is the mean of four replicates.

Monolithic fiber containing fluridone in static water

Figure 2 illustrates the cumulative release of the monolithic fiber containing fluridone in reconstituted water and natural pond water.

In reconstituted water, release rates appeared fairly constant during the first 3 weeks after treatment (Y = 18.2 + 9.0X, R = 0.97), but slowed down significantly during the next 7 weeks (Y = 134.8 + 3.3X, R = 0.95). About 60 percent of total fluridone in the formulation was released by 1 month after treatment, and another 30 percent released during the second month. No further release was observed after 70 days posttreatment when approximately 90 percent of total fluridone had been released.

Release rates appeared somewhat slower in natural pond water than in reconstituted water. However, the cumulative levels of fluridone were not significantly different until after 56 days posttreatment. Again, no further release was observed after 70 days when 84 percent of the fluridone had been released into natural pond water.

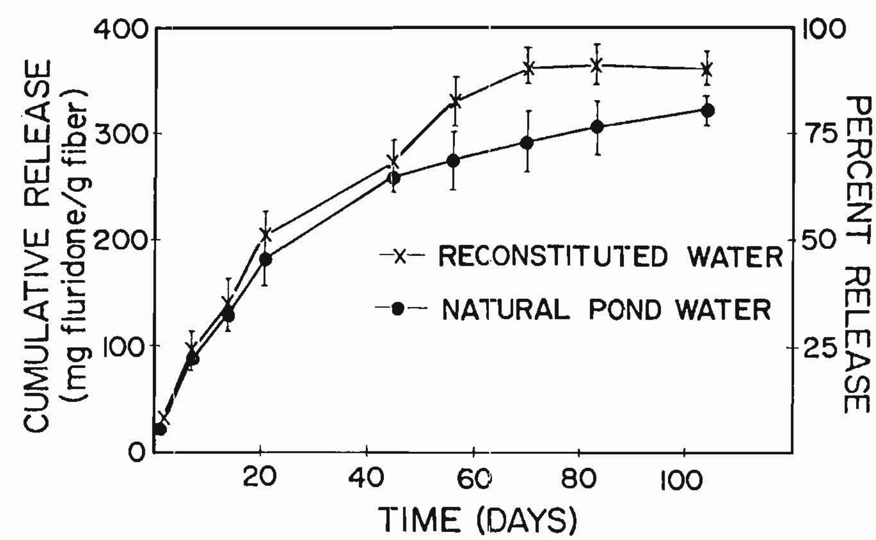

Figure 2. Release of fluridone from monolithic fiber formulation in static reconstituted water and in natural pond water. Each point is the mean of four replicates ± S.E.

The amounts of fluridone remaining in the fiber formulation at the end of the experiment on Day 104 were determined by extracting the fiber in methanol. A total recovery of 96 percent and 98 percent was obtained for treatments in reconstituted water and in natural water, respectively, indicating that degradation of fluridone was minimal under our experimental conditions. The amount of fluridone remaining in the fiber formulation was significantly higher in treatments with natural water (14 percent in treatments with natural water vs. 6 percent with reconstituted water), suggesting that the difference in release rates observed in the two types of water (Figure 2) may be real.

Fluridone fiber in flowing water and efficacy against hydrilla

An average release rate of 4.3 mg fluridone/g fiber/day was calculated for the fluridone formulation based on results of cumulative release in static tests (Figure 2). Treatments were then made to maintain levels from 0.01 to 0.10 mg/ℓ fluridone in the flowing water in culture vessels previously established with hydrilla. The experiment was conducted in a glass greenhouse under 80 percent sunlight.

Concentrations of fluridone in the flowing water stabilized around the desired treatment levels by 7 days posttreatment; however, levels continued to decline in later sampling periods (Table 11). By Day 42, fluridone concentrations were about half of the expected levels. The presence of plants and soil in the experimental system had no significant effect on the herbicide concentrations in the flowing water.

Typical discoloration of the hydrilla tips was observed as early as 3 days after fluridone treatment; however, mature plant tissues remained healthy and injury ratings stayed below 30 percent through the end of the 7-week experiment. Previous studies indicated that fluridone has slow activity, and weed control was not achieved until after 12 weeks posttreatment under our experimental conditions.

Table 11
Measured Release of Fluridone from Monolithic Fibers in Flowing Natural Water

Treatment No.	Fluridone Treatment*	Fluridone (mg/ℓ) at Days Posttreatment** 1	3	7	14	21	28	42
I	0.01 mg/ℓ, with plants	0.016 ±0.002	0.022 ±0.001	0.012 ±0.002	0.008 ±0.003	0.004 ±0.002	0.006 ±0.001	0.005 ±0.001
II	0.02 mg/ℓ, with plants	0.032 ±0.004	0.050 ±0.003	0.027 ±0.002	0.016 ±0.002	0.008 ±0.001	0.010 ±0.003	0.007 ±0.001
III	0.05 mg/ℓ, with plants	0.100 ±0.004	0.109 ±0.010	0.054 ±0.002	0.035 ±0.004	0.020 ±0.006	0.026 ±0.001	0.026 ±0.004
IV	0.10 mg/ℓ, with plants	0.202 ±0.012	0.293 ±0.052	0.105 ±0.005	0.073 ±0.007	0.041 ±0.005	0.043 ±0.006	0.054 ±0.018
V	0.10 mg/ℓ, no plants	0.197 ±0.028	0.283 ±0.014	0.118 ±0.005	0.057 ±0.002	0.028 ±0.003	0.035 ±0.004	0.049 ±0.006

* Total treatment, assuming complete chemical release, equals to 0.42, 0.82, 2.05, 4.07, and 3.81 mg/ℓ fluridone in treatments I, II, III, IV, and V, respectively.

** Means of four replicates ± standard error.

Table 12

Effect of Fluridone Released from Monolithic Fibers on Mature Hydrilla and on Regrowth from Rootstocks after 7 weeks in Flowing Water*

	Mature Plants				*Regrowth from Rootstocks*			
Fluridone Treatment	*Shoot Length cm*	*Shoot Weight g*	*Root Weight g*	*Root/ Shoot Ratio*	*Shoot Length cm*	*Shoot Weight g*	*Root Weight g*	*Root/ Shoot Ratio*
Control	65[a]	9.93[a]	0.41[a]	0.04	27[a]	1.06[a]	0.10[a]	0.10
0.01 mg/l	80[a]	5.86[b]	0.02[b]	0.03	18[ab]	0.44[b]	0.08[ab]	0.18
0.02 mg/l	99[a]	5.10[b]	0.23[b]	0.05	15[b]	0.42[b]	0.06[bc]	0.14
0.05 mg/l	63[a]	5.76[b]	0.15[b]	0.03	17[ab]	0.50[b]	0.06[abc]	0.12
0.10 mg/l	59[a]	5.86[c]	0.17[b]	0.03	4[c]	0.51[b]	0.05[c]	0.11

* Values in a column followed by the same letter are not significantly different at P = 0.05 as determined by Waller-Duncan test. Each value is the mean of four replicates.

Regrowth from rootstocks was observed in all treatments and the emerging shoots continued to elongate in vessels receiving low treatment rates (Table 12). However, the young shoots emerging from rootstocks never grew more than 4 cm long in treatments where fluridone concentrations were maintained at levels of 0.04 mg/l or higher. Significant reductions in both shoot and root dry weights were obtained after 7 weeks (Table 12); however, no differences in dry weights were observed among the different treatment rates.

REFERENCES

Arnold, W. R. 1979. "Fluridone—A New Aquatic Herbicide," *Journal of Aquatic Plant Management,* Vol 17, pp 30-33.

Barnsley, G. E. 1960. "An Assessment of the New Herbicide 2,6-dichlorobenzonitrile," *Proceedings, 5th British Weed Control Conference,* pp 597-616.

Durden, W. C., and Blackburn, R. D. 1972. "Control of Fragrant Waterlily (*Nymphaea adorata*)," *Hyacinth Control Journal,* Vol 10, pp 30-32.

Hiltibran, R. C. 1966. "Result of Pre-emergent Aquatic Herbicides in Illinois," *Abstracts of Weed Society of America Meeting,* Urbana, Ill., pp 100-101.

Richardson, R. G. 1977. "A Review of Foliar Absorption and Translocation of 2,4-D and 2,4,5-T," *Weed Research,* Vol 17, pp 259-272.

Steward, K. K. 1980. "Retardation of Hydrilla (*Hydrilla verticillata*) Regrowth Through Chemical Control of Vegetative Reproduction," *Weed Science,* Vol 28, pp 245-251.

Van, T. K., and Steward, K. K. 1981. "Evaluating Controlled Release Herbicides for Aquatic Weed Control," *Proceedings, 16th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 17-19 November 1980, St. Paul, Minnesota,* Miscellaneous Paper A-82-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 55-67.

Waldrep, T. W., and Taylor, H. M. 1976. "1-methyl-3-phenyl-5-[3-(trifluoromethyl) phenyl]-4(1H)-pyridinone, A New Herbicide," *Journal of Agriculture and Food Chemistry,* Vol 24, pp 1250-51.

Walker, C. R. 1964. "Dichlobenil as a Herbicide in Fish Habitat," *Weeds,* Vol 12, pp 267-269.

Weldon, L. W. L., De Rigo, H. T., and Blackburn, R. D. 1968. "Control of Alligatorweed with Dichlobenil," *Proceedings 21st Southern Weed Conference,* Fort Lauderdale, Fla., pp 287-291.

EFFECTS OF ORGANIC MATTER ADDITIONS TO SEDIMENT ON THE GROWTH OF *HYDRILLA VERTICILLATA*

by
John W. Barko, and R. Michael Smart*

BACKGROUND

Variations in the composition of bottom sediments appear to strongly influence the growth and distribution of freshwater macrophytes (e.g. Pearsall 1920; Misra 1938; Moyle 1945; Sand-Jensen and Søndergaard 1979). However, the underlying causes are obscure. Results of previous studies conducted in the U.S. Army Engineer Waterways Experiment Station (WES) Environmental Laboratory have suggested that the growth of aquatic macrophytes may be retarded on organic sediments (Barko 1982, 1983). An organic extract from the highly organic sediment of Lake Starvation, Florida, has been demonstrated to inhibit the growth of *Hydrilla verticillata* (Dooris and Martin 1980).

In view of the significance of these findings to the general question of how aquatic macrophytes might be affected by sediment composition, it is of interest to investigate further the relationship between sediment organic matter and macrophyte growth. Toward this end, the growth of *Hydrilla verticillata* (hereafter referred to as *Hydrilla*) is examined here on a sediment experimentally amended by additions of vegetative organic matter.

MATERIALS AND METHODS

This investigation was conducted in large white fiberglass tanks, housed in the Environmental Laboratory greenhouse facility (Barko and Smart 1981). Irradiance was reduced to 50 percent full sunlight beneath neutral density shade fabric. Water temperature was maintained at 25° ± 1° C. The solution used in the tanks was formulated by the addition of reagent-grade salts to deionized water (Barko, Hardin, and Matthews 1982).

Surficial sediment was obtained by dredging from Lake Washington, Washington State. After thorough mixing, the sediment was divided into six separate quantities, five of which were amended by additions of vegetative organic matter (Table 1). The remaining sediment was not amended, and served as an experimental control. Hereafter the nonamended sediment is referred to as NON, and amended sediments are referred to as ALG, MYR, CAT, OAK, and PIN in agreement with designations of specific amendment types (Table 1).

Sediment amendments were oven dried (100° C), ground in a Wiley mill to a particle size <0.7 mm, thoroughly mixed, and then rewet before addition to NON. Individual amendments were added to increase the organic content of NON from

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Table 1
Description of Organic Matter Amendments to Sediment

Amendment	*Form*	*Condition**	*Designation***
Filamentous green alga (*Rhizoclonium*)	Whole thalli	Living	ALG - Amend
Submersed macrophyte (*Myriophyllum*)	Leafy shoots	Living	MYR - Amend
Emergent macrophyte (*Typha*)	Leafy shoots	Dead (standing)	CAT - Amend
Hardwood tree (*Quercus*)	Leaves	Dead (litter)	OAK - Amend
Softwood tree (*Pinus*)	Needles	Dead (litter)	PIN - Amend

* Living materials were collected in a state of active growth in the spring. Dead materials, also collected in the spring, had overwintered in a moribund state.

** Designations are used throughout the text in referring to sediment amendments.

an initial value of ca. 10 percent to a final value of 15 percent (low-level amendment) and from an initial value of ca. 15 percent to a final value of 20, 25, and 30 percent (high-level amendments).

In two separate experiments, *Hydrilla* was grown for a period of 6 weeks on sediment amended 2 and 8 weeks previously. Differences in growth were determined from estimates of total dry-weight biomass (shoots + roots) according to procedures described elsewhere (Barko and Smart 1981).

RESULTS

The growth of *Hydrilla* on amended sediments at various levels of organic matter addition was inhibited relative to growth on NON in Experiment 1 (Figure 1). At the low level of amendment growth varied with amendment type; ALG, CAT, and PIN were more inhibitory than MYR and OAK. At higher levels of amendment, variations in *Hydrilla* growth, associated with amendment type, were negligible.

The possibility that the influence of amended sediments on the growth of *Hydrilla* might vary as sediments decreased in organic content with age was examined in Experiment 2, initiated 8 weeks after amendment at the low level of organic matter addition. Results of Experiments 1 and 2 are compared in Figure 2. Growth on sediments receiving refractory organic matter* (OAK, PIN, and CAT) did not differ with aging. In contrast, growth on sediments receiving labile organic matter* (ALG and MYR) was substantially greater after aging in Experiment 2. Rather than inhibiting growth as in Experiment 1, MYR sediment in Experiment 2 stimulated the growth of *Hydrilla*.

Various properties of the amended sediments were examined to elucidate possible relationships with *Hydrilla* growth (Barko and Smart 1983). Growth on all sediments with the exception of MYR, where high concentrations of dissolved

* Designations of refractory and labile organic matter are based on differences in structural and chemical composition (Barko and Smart 1983).

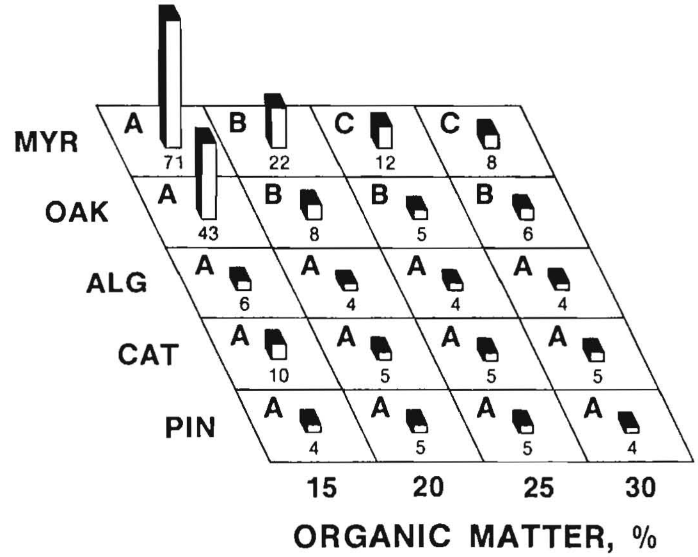

Figure 1. Relative growth (final dry weight) of *Hydrilla verticillata* on sediment receiving different levels of organic matter addition (Experiment 1). Mean values (n = 4) for growth are percentages of dry weight obtained on control sediment (NON). Means associated with different levels, within each type of organic matter, sharing the same letter do not differ at the 5 percent level of statistical significance (Duncan's Multiple Range Test)

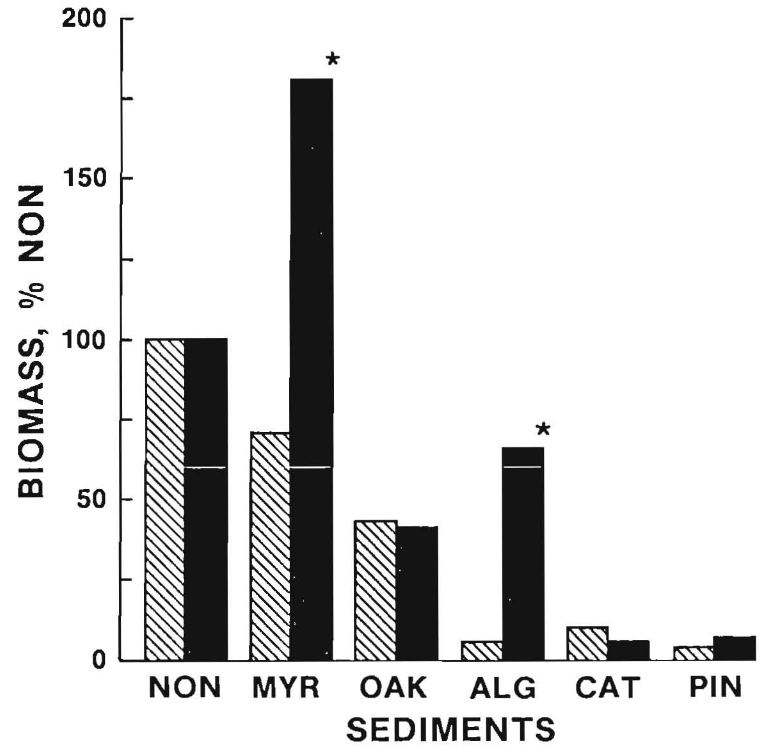

Figure 2. Comparison of relative growth (final dry weight) of *Hydrilla verticillata* on sediment receiving different types of organic matter before aging (Experiment 1, hatched bars) and after aging (Experiment 2, shaded bars). Mean values (n = 6) for growth are percentages of dry weight obtained on control sediment (NON). Asterisks indicate differences in growth between experiments at the 5 percent level of statistical significance (Students t-test)

inorganic carbon in the interstitial water may have augmented photosynthesis (Sand-Jensen and Søndergaard 1979), varied inversely with interstitial water dissolved organic carbon concentration. Iron, manganese, and phosphorus concentrations in the interstitial water were highly correlated with dissolved organic carbon concentration. However, from analyses of *Hydrilla* tissues, it was determined that these elements were unlikely to have affected growth (Barko and Smart 1983).

DISCUSSION

Sediment organic water can substantially inhibit the growth of *Hydrilla*. Other submersed species are similarly affected (Barko and Smart 1983). The inhibitory property of sediment organic matter here was associated either directly or indirectly with high concentrations of soluble organic compounds imparted to the interstitial water. Sediments amended by additions of refractory organic matter possessed macrophyte growth-inhibiting properties for a longer period than those receiving additions of labile organic matter. Thus, the extent of macrophyte growth inhibition appears to be determined by the type as well as the amount of organic matter incorporated into the sediment.

Macrophytes modify the sediment environment through both their passive reception of allochthonous materials and their direct contribution of autochthonous primary production to the sediment (Wetzel 1979; Carpenter 1981). During the ontogeny of lacustrine systems, increasing proportions of sediment organic matter are derived from structurally complex emergent vegetation (Wetzel 1979). The littoral zone retains both soluble and particulate organic inputs from the watershed (Wetzel and Allen 1972; Mickle and Wetzel 1978). Due partially to the refractory nature of these materials (Godshalk and Wetzel 1977) and to a decreasing availability of electron acceptors (Rich and Wetzel 1978), sediment organic matter accumulates at an increasing rate as lakes age.

It is intriguing to speculate that the development of unfavorable changes in sediment chemistry, associated with the presence of highly productive species such as *Hydrilla*, may contribute to the decline of such species. In this connection, the influence of sediment composition on the growth and distribution of rooted macrophytes, with emphasis on organic properties, deserves continued investigative attention.

ACKNOWLEDGMENTS

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REFERENCES

Barko, J. W. 1982. "Influence of Potassium Source (Sediment vs. Open Water) and Sediment Composition on the Growth and Nutrition of a Submersed Freshwater Macrophyte *(Hydrilla verticillata* (L. F.) Royle)," *Aquatic Botany*, Vol 12, pp 157-172.

Barko, J. W. 1983. "The Growth of *Myriophyllum spicatum* L. in Relation to Selected Characteristics of Sediment and Solution," *Aquatic Botany*, Vol 15, pp 91-103.

Barko, J. W., and Smart, R. M. 1981. "Comparative Influence of Light and Temperature on the Growth and Metabolism of Selected Submersed Freshwater Macrophytes," *Ecological Monographs*, Vol 51, pp 219-235.

Barko, J. W., and Smart, R. M. 1983. "Effects of Organic Matter Additions to Sediment on the Growth of Aquatic Plants," *Journal of Ecology*, Vol 71, pp 161-175.

Barko, J. W., Hardin, D. G., and Matthews, M. S. 1982. "Growth and Morphology of Submersed Freshwater Macrophytes in Relation to Light and Temperature," *Canadian Journal of Botany*, Vol 60, pp 877-887.

Carpenter, S. R. 1981. "Submersed Vegetation: An Internal Factor in Lake Ecosystem Succession," *The American Naturalist*, Vol 118, pp 372-383.

Dooris, P. M., and Martin, D. F. 1980. "Growth Inhibition of *Hydrilla verticillata* by Selected Lake Sediment Extracts," *Water Resources Bulletin*, Vol 16, pp 112-117.

Godshalk, G. L., and Wetzel, R. G. 1977. "Decomposition of Macrophytes and the Metabolism of Organic Matter in Sediments," *Interactions Between Sediments and Freshwater*, H. L. Golterman, ed., Dr. W. Junk B. V. Publishers, The Hague, pp 258-264.

Mickle, A. M., and Wetzel, R. G. 1978. "Effectiveness of Submersed Angiosperm-Epiphyte Complexes on Exchange of Nutrients and Organic Carbon in Littoral Systems; II, Dissolved Organic Carbon," *Aquatic Botany*, Vol 4, pp 317-329.

Misra, R. D. 1938. "Edaphic Factors in the Distribution of Aquatic Plants in the English Lakes," *Journal of Ecology*, Vol 26, pp 411-451.

Moyle, J. B. 1945. "Some Chemical Factors Influencing the Distribution of Aquatic Plants in Minnesota," *American Midland Naturalist*, Vol 34, pp 402-420.

Pearsall, W. H. 1920. "The Aquatic Vegetation of the English Lakes," *Journal of Ecology*, Vol 8, pp 163-199.

Sand-Jensen, K., and Søndergaard, M. 1979. "Distribution and Quantitative Development of Aquatic Macrophytes in Relation to Sediment Characteristics in Oligotrophic Lake Kalgaard, Denmark," *Freshwater Biology*, Vol 9, pp 1-11.

Rich, P. H., and Wetzel, R. G. 1978. "Detritus in the Lake Ecosystem," *The American Naturalist*, Vol 112, pp 57-71.

Wetzel, R. G. 1979. "The Role of the Littoral Zone and Detritus in Lake Metabolism," *Archiv fur Hydrobiologie*, Vol 13, pp 145-161.

Wetzel, R. G., and Allen, H. L. 1972. "Functions and Interactions of Dissolved Organic Matter and the Littoral Zone in Lake Metabolism and Eutrophication," *Productivity Problems of Freshwaters. Warszawa - Krakow*, Z. Kajak and A. Hillbricht-Ilkowska, eds., Proceedings of the IBP-UNESCO Symposium on Productivity Problems of Freshwaters 1970, Kazimierz Dolny, Poland, pp 333-347.

MECHANICAL CONTROL TECHNOLOGY DEVELOPMENT

An Overview

by
H. Wade West*

Mechanical control research will provide the technology base required to permit the Corps of Engineers (CE) to carry out its responsibilities in the control of aquatic plants by use of mechanical control methods and procedures. Coordination necessary to carry out this research has been maintained on a continuing basis with the various Corps Districts and Divisions so that the mechanical control research can be operational in a timely manner.

The objective of the mechanical control research work is to develop technology and design concepts and techniques to be used to develop improved mechanical equipment and operating procedures for controlling floating, submersed, and emergent aquatic plants in Corps waterways (rivers and lakes). The research presently includes: (1) development of analytical models, (2) experimental testing and evaluation of existing mechanical control equipment, (3) development of procedures and techniques for successful field deployment of mechanical control equipment, and (4) development of design specifications for new equipment. The U.S. Army Engineer Waterways Experiment Station (WES) research will provide practical methodology for effective deployment of mechanical systems in terms of environmental constraints.

DEVELOPMENT OF ANALYTICAL MODELS

Analytical computer models that aid in the evaluation of existing and proposed mechanical systems for harvesting aquatic plants are an important part of the mechanical control work area in the Aquatic Plant Control Research Program (APCRP). The WES analytical methodology is illustrated in Figure 1. It is noteworthy that mechanical control procedures may consist of four distinct operations: cutting, harvesting (collection of cut plant material), processing (chopping, dewatering, grinding, etc.), and disposal. Various combinations of these individual operations may be combined to form different mechanical control options as depicted in Figure 1. Up to the present time most of the mechanical control operations have been conducted using Option 2 (i.e., cutting, harvesting, and land disposal). Mechanical control using either Options 1 or 3 has been used only on a limited operational scale; therefore, data are needed to determine when and how these options should be used to provide effective control.

Through the development and use of analytical models, WES is simulating realistic mechanical control operations.* During 1983, the WES HARVEST model

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* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

** See the paper by Koerner and Sabol (pp 8-16) for an example of how a model can be used for planning a mechanical control operation.

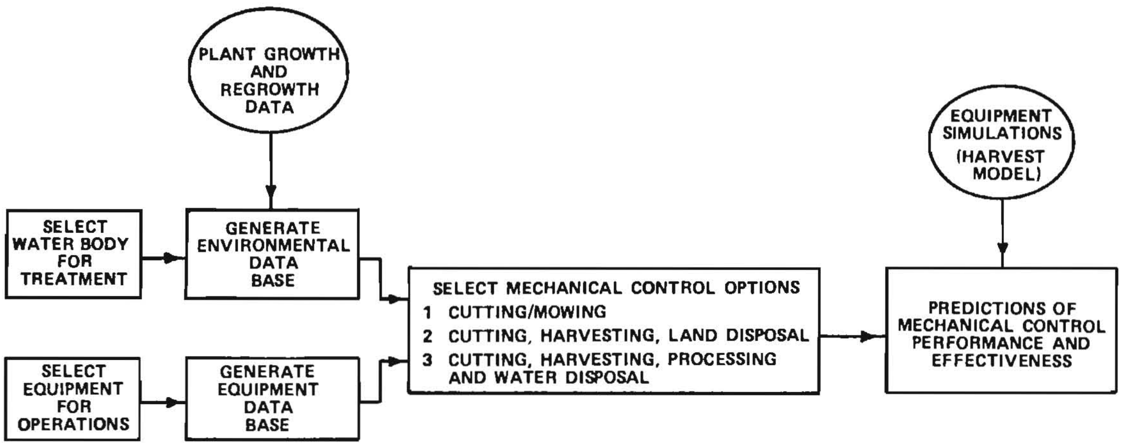

Figure 1. Conceptual analytical mechanical control methodology

will undergo modifications to allow for incorporation of new simulation algorithms for: (1) cutting operations, (2) upland disposal operations, (3) plant growth/regrowth, and (4) cost analyses. Each of these algorithms is discussed briefly below.

Cutting operations

Cutting or mowing operations have always been part of an overall mechanical control operation. Most plant cutting operations have been conducted at a time when submersed plants have reached a near "topped-out" condition. With this algorithm, cutting of the submersed plants can be simulated at any time during the growing season at a prescribed depth and then allowed to remain in the water. To develop this cutting algorithm, it will be necessary that data and relationships be developed on the effective use of the various sickle-bar cutter assemblies in different plant density conditions and for different plant species. The effectiveness of simulated mechanical cutting operation will be dependent upon the forward speed of the cutter machine, speed of the cutter knives, type and design of the cutter knife assembly, and velocity of the water currents.

Upland disposal operations

A second algorithm will be developed to determine the time and effort (man-hours) required to transport harvested plant material from the water/land interface site to a remote site for disposal. It will be assumed that transportation of harvested plant material will be via use of one or more dump trucks of various capacities and that movement of the trucks between the shore site and the remote site will be along paved or hard surface roads (i.e. roads with good soil strength conditions). Once the harvested plant material is delivered to the remote site, the material will be unloaded from the trucks and the trucks will return to the disposal site. This completed algorithm will provide predictions on man power, equipment, and time for this portion of the mechanical control operation.

Plant growth/regrowth

A routine is needed to realistically simulate regrowth of major nuisance aquatic plant species after mechanical control operations and also natural growth of aquatic plants such that future mechanical control operations can be planned. The forcing function behind the plant growth/regrowth routine will be the in situ conditions experienced by the plants, i.e. sediment conditions, water temperature, and light conditions as previously defined by Barko* as being the main factors that control plant growth. The rate of regrowth will be determined experimentally by conducting limited laboratory tests at WES wherein the important environmental conditions can be controlled. This algorithm will predict stem configuration and structure and unit weight, and will be used to derive plant biomass density by layer as a function of time.

Cost analyses

The cost of mechanical control operations is of the utmost concern to the operational manager. Therefore, a cost algorithm will be developed to provide an estimated cost of the mechanical control operations. It is important to understand that an operational manager can perform the control operation by contracting the complete mechanical control operation or by purchasing the equipment, training personnel, and using the equipment with the District's staff. To support this decision process, the cost algorithm will be developed and will include:

- Equipment price
- Cost of fuel
- Cost of operator labor
- Cost of maintenance labor
- Cost of repair parts
- Cost of insurance
- Cost of interests on the investment less the resale value of equipment at end of use, or
- Cost of equipment rental (dollars/hour)

The cost (dollars/acre) of the mechanical control operation will be based on the predicted times to perform the overall control operation as obtained by HARVEST.

MODEL CAPABILITY

Once the above four algorithms are developed and incorporated into the WES HARVEST model, the model will have the capability of predicting the following for all particular aquatic plant sites that require mechanical control:

- Total harvest time, hours
- Fuel costs, dollars
- Labor, dollars
- Plant material harvested, tons
- System productivity, tons/hour
- Areal production, acres/hour
- Total cost of control operation

* For an overview of this research, see: Barko, J. W. 1982. "Ecology of Submersed Macrophytes," Aquatic Plant Control Research Program Information Exchange Bulletin, Vol A-82-2, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

EVALUATION OF MECHANICAL CONTROL EQUIPMENT

In order to accurately predict the performance of the various mechanical control systems available, using the WES HARVEST model, it is necessary to have realistic performance specifications (as input to HARVEST) derived from field performance tests. Relatively little of the type of data needed to determine these specifications is presently available. Collection of field performance data is planned this year to determine performance specifications on the particular mechanical systems for which no data are presently available.

DEVELOPMENT OF PROCEDURES FOR FIELD DEPLOYMENT OF MECHANICAL CONTROL EQUIPMENT

Efficient deployment of mechanical control equipment is dependent on knowing several important things:

a. What harvesting schedule (how many times to harvest and when) will achieve the most cost-effective control.

b. What specific mechanical control option (Figure 1) is best suited to the particular site under consideration.

c. Which of the various mechanical control systems available would be most cost-effective for the particular control operation being planned.

Models developed and planned will be used to address these questions for various types of aquatic plant infested water bodies. General procedures and recommendations will be developed from this modeling exercise.

REDESIGN OF EQUIPMENT COMPONENTS AND CONCEPTS FOR NEW DESIGNS

Through the use of HARVEST, the effect of each specific operation on overall system production rates and efficiency can be examined, and operational bottlenecks can be identified. Specific mechanical subsystems that perform these operations will be examined in an attempt to improve the design and thus improve overall system performance. Several mechanical subsystems already identified as needing redesign include the sickle-bar cutter, to allow faster more efficient cutting operations, and the onboard chopper/processor, which reduces the volume of the plant material harvested.

EVALUATING THE EFFECTIVENESS OF AQUATIC PLANT TREATMENT METHODS

by
K. Jack Killgore*

A variety of treatment methods are available for aquatic plant management. To decide on the treatment method to use, information on the treatment effectiveness must be available. However, operational aquatic plant management personnel rarely collect this select type of information. As a result, aquatic plant management researchers must quantify and make available data that reflect this need. The Aquatic Plant Control Research Program (APCRP) of the U.S. Army Engineer Waterways Experiment Station is currently developing rapid and accurate field techniques to measure treatment effectiveness. These techniques have been used successfully in the field and are discussed as examples in this paper.

MEASUREMENT OF TREATMENT EFFECTIVENESS

Treatment effectiveness is considered a quantitative determination of the extent and duration of aquatic plant populations attributable to the use of a treatment method (i.e. chemical, mechanical, biological). Aquatic plant populations may increase, decrease, or remain at the same level. Changes in aquatic plant populations generally have been expressed in various measures such as (1) surface acres, (2) height profiles, (3) biomass, (4) stem density, or (5) other measures.

Biomass is a measure of horizontal and vertical distribution and is usually expressed in grams per square metre. Thus, one measure of treatment effectiveness is change in plant biomass. Treatment effectiveness or changes in plant populations can also be indicated by other methods. Depending on the plant species, changes in the areal distribution or height of an aquatic plant may be indicative of changes in its biomass. The APCRP has developed methods to quantify biomass, areal distribution, and height of an aquatic plant in the field over a period of time. These methods have been used in APCRP field studies to determine treatment effectiveness.

Biomass is determined using the WES Aquatic Biomass Sampler. Submersed aquatic plant height is measured with a fathometer (depth recorder) used with an electronic positioning and repositioning system (AGNAV System). The areal distribution of aquatic plants may be determined by aerial photography or with an electronic positioning system.

FIELD TECHNIQUES

Aerial photography

Low altitude aerial photography has been used to map the distribution of most problem populations of aquatic plants. By obtaining aerial photography before

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and after a treatment, changes in the areal distribution of the plant due to the treatment can be quantified. This method is applicable to large areas and when the aquatic plants are visible on or near the surface throughout the posttreatment monitoring.

Leonard and Payne (1983) outline four sequential tasks to complete an aerial photographic survey. The first task involves identifying which plant species and water bodies are to be the targets of a survey and when the survey is to be conducted. The survey should be conducted before and after treatment. The area surveyed should include treatment sites and a reference site for monitoring untreated plant growth. Secondly, the photomission design must be determined. This task requires the establishment of the desired scale, format, film type, image overlap, and image products. True color film is used for submerged plants with false color infrared film for emergent and floating species. The third task is to acquire ground truth data to be used as visual clues for the interpretation of the photographs and should be obtained at the same time as the photomission. This information includes those conditions on the ground which are to be visually extracted from the photographs such as water depth, plant species present, location of plant colonies, plant condition, and plant growth forms. The fourth task is a transparent base map constructed by tracing the shoreline of the target water body from the photographs onto a material such as mylar. Then the locations of plants are interpreted and traced onto the map (Figure 1).

Areal estimates of plant communities can be made using two methods (Dardeau 1983): a dot count method and a digitizer. The dot count method uses a Bruning Areagraphic Chart No. 4849, with a published accuracy of 97 percent, provided that map areas are 12-in. square or greater. The chart is divided into grids and

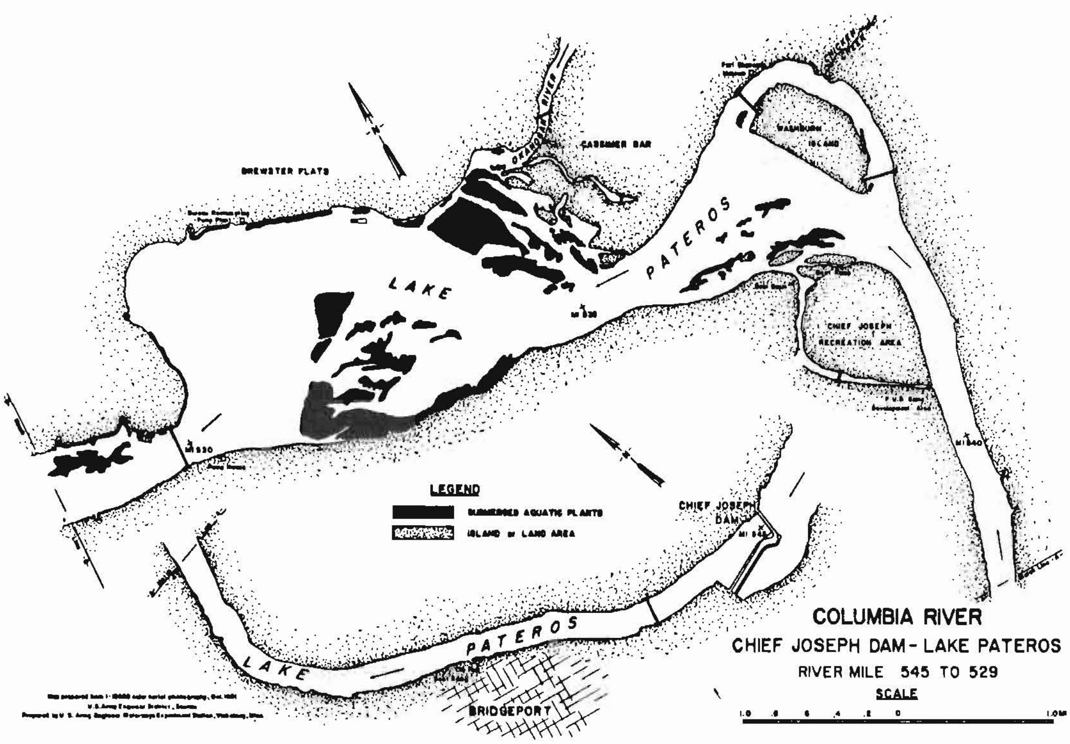

Figure 1. Base map showing the areal distribution of submerged aquatic plants

each grid contains a random distribution of dots. The chart is placed over the areas mapped as plants on the mylar and the dots are counted. The dots counted are converted to acreage using a published equation.

The digitizer method also estimates areal coverage of aquatic plants. A program was developed at the WES that computes areas of irregular shapes using a Tektronix terminal and Tektronix 4954 digitizer. The interpreted map is placed on a tablet. Under the surface of the tablet are two grids of magnetostrictive wires, one set for the X-axis and one set for the Y-axis. An acoustic wave is sent along these wires and detected by a cursor. As the operator traces the boundaries of the aquatic plants with the cursor, a change in magnetic field caused by the acoustic wave is detected. The detected signal is transmitted to the computer that converts the time between when the wave is sent and when it is received to digital information that directly relates to cursor position. This method maintains a 0.01-in. resolution and should be used when the area of aquatic plants on the map is less than 12 in. squared.

Positioning system

An electronic positioning system has been used to quantify areal distribution of plants (Killgore 1983). The Agricultural Navigator (AGNAV) is a relatively inexpensive, commercially available electronic positioning system designed to apply farm pesticides and fertilizers in straight, parallel, and evenly spaced paths. The WES has used the AGNAV to triangulate to two permanent shore locations, thus being able to position a boat or field equipment over the sampling sites during multiple visits to the same water body. The AGNAV system measures distances up to a mile and thus is appropriate for most aquatic research studies.

The AGNAV system consists of a mobile unit and two repeaters (A and B) (Figure 2). For aquatic use, the mobile unit is placed in a boat and the repeaters are placed at separate shoreline positions. The mobile unit consists of a computer-transmitter-receiver(c-t-r) with an antenna, range reader, control panel, and direction indicator display unit. The c-t-r transmits a short (0.002 sec) burst of high frequency radio signals 100 times each second. Both repeaters receive each signal burst and retransmit the signal back to the c-t-r. The c-t-r counts the number of 1/4 wavelengths transmitted by each repeater and computes and displays a number on the range reader. The number of AGNAV unit corresponds to the total number of 1/4 wavelengths between the c-t-r and a single repeater. One AGNAV unit for 154.6 MHz transmission equals 9.584 in. The range reader displays the AGNAV unit distances from the mobile unit to Repeater A, the mobile unit to Repeater B, and Repeater A to Repeater B (A, B, and P, respectively, as displayed on the range reader).*

The areal distribution of an aquatic plant colony can be delineated by moving the mobile unit along the boundary and recording the AGNAV A- and B-distance at successive points (Figure 3). More irregular boundaries require collection of additional AGNAV coordinates for accurate mapping. By positioning repeaters A and B at their original sites during successive sampling periods and following the

* In any triangle, if the locations of two vertices (the A and B repeaters) and the lengths of all three sides are known (distance A, B, and P), the location of the third vertex can be determined.

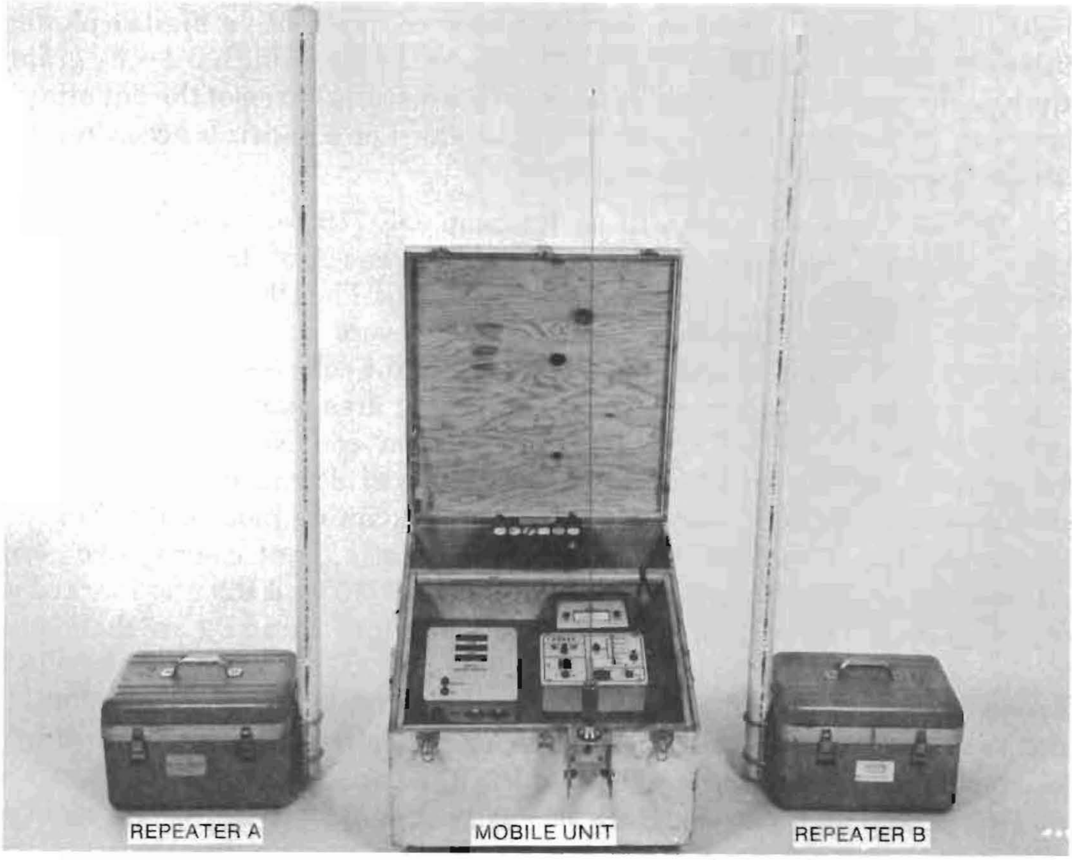

Figure 2. Components of the AGNAV positioning system

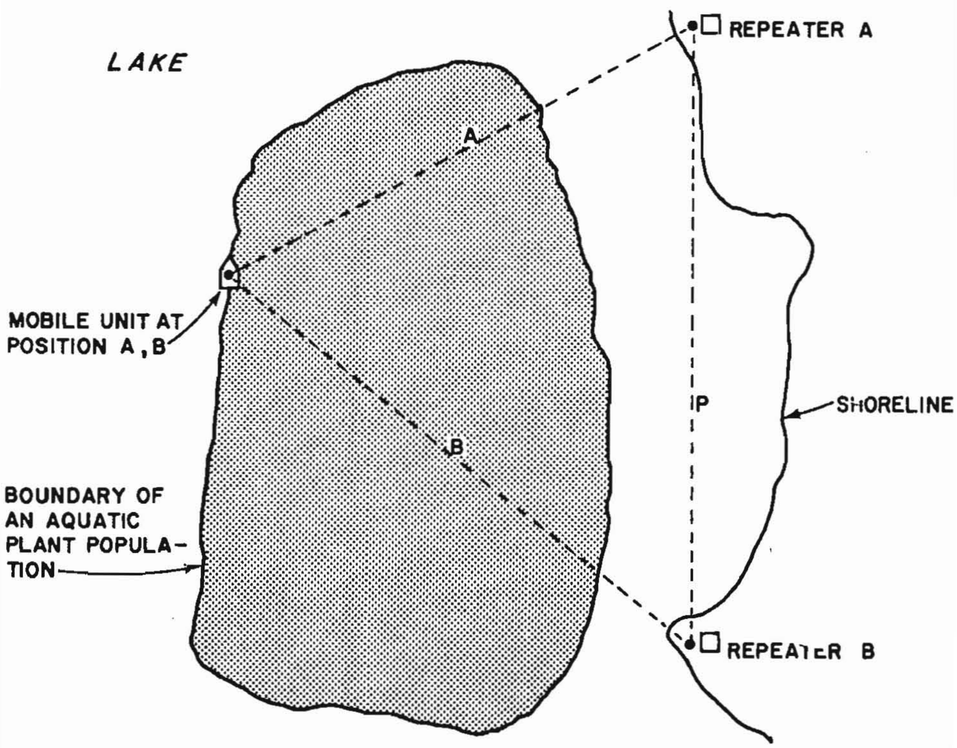

Figure 3. Delineating the boundary of an aquatic plant population

method described above, changes in the boundary of the aquatic plant colony can be quantified through time. A terminal and an interactive digital plotter or similar automated systems can be used to display and provide hard copy graphics of the aquatic plant colony relative to shoreline features. Area of the aquatic plant colony can be determined by an areagraphic chart or a digitizer according to the methods discussed for aerial photography.

The AGNAV system used with a Ratheon DE-719 fathometer can rapidly provide accurate indicator data on the effectiveness of treatment aimed at controlling the growth of submersed aquatic plants. The DE-719 fathometer is an echo depth sounder providing a permanent record of water depth, bottom topography, and height of submerged aquatic plant colonies. The first step is to establish an experimental plot over the treatment area using the AGNAV and a simple computer. The WES has used a system consisting of a pocket-size programmable calculator, a thermal printer, direct to alternating current inverter, and magnetic cards containing programs that facilitate plot establishment. To establish square or rectangular plots in an aquatic plant colony, two corners positioned diagonally from each other are selected (P1 and P2) and marked with floats (Figure 4). The AGNAV A and B distances for P1 and P2 are then entered into the calculator. The calculator computes the AGNAV location of the two unknown corners (P3 and P4), the dimensions, and the area of the plot, all of which are then printed on the thermal paper. The plot area is determined by the location of the diagonal corners (P1 and P2) and can range from less than 1 acre to 320 acres. The plot can be relocated easily if buoys are lost or are moved by positioning the repeaters at their original location and moving the mobile unit until the AGNAV values for each corner are located.

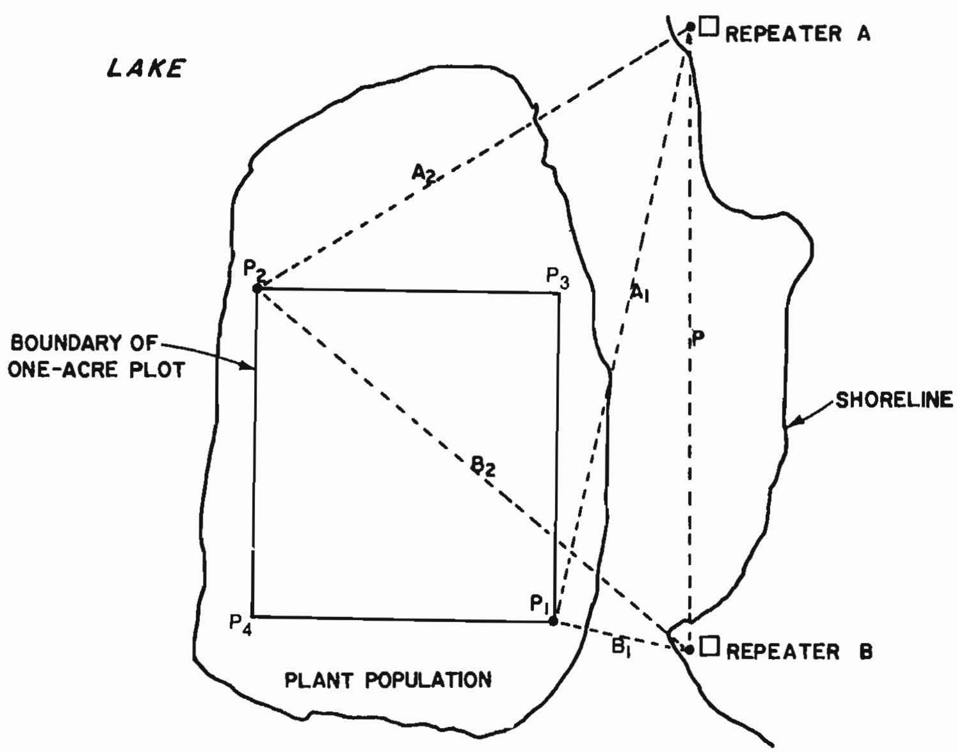

Figure 4. Establising 1-acre treatment plot

Once a plot has been designated, straight-line transects are positioned over the plot and the aquatic plant colony using the AGNAV transect positioning system. The AGNAV control panel allows the operator to select transect swath distances. Each transect is positioned perpendicular to the baseline and directed in a straight line using the AGNAV direction indicator display unit. While traveling over each transect, event marks are put on the fathometer paper at appropriate intervals and an AGNAV location corresponding to each event mark is recorded (Figure 5). By always positioning Repeaters A and B in the same location, plant height throughout the plot can be determined along the same transects at various times after the initial sampling period.

Computer-generated contour maps can be produced from the AGNAV/fathometer data. The AGNAV locations for each event mark along each transect are entered into a spatially arranged data base. Then the fathometer tracings are interpreted and digitized at each event mark for plant height and water depth using a terminal and an interactive digital plotter. A computer program has been written which interpolates plant height and water depth between digitized event marks, thus increasing the number of data points used for producing the maps. The computer mathematically manipulates the parallel sets of plant height (or water depth) to generate isoline drawings of the vertical and horizontal distribution of the submersed aquatic plant population.

Isoline drawings of Eurasian watermilfoil plant height were made for an experimental herbicide treatment plot as a visual measure of efficacy. Experimental treatment plots were established in Okanogan River, Washington, using the AGNAV (Killgore 1983). Plant height was determined before, 1 month, and 2 months after herbicide application using the AGNAV/fathometer method. Isoline

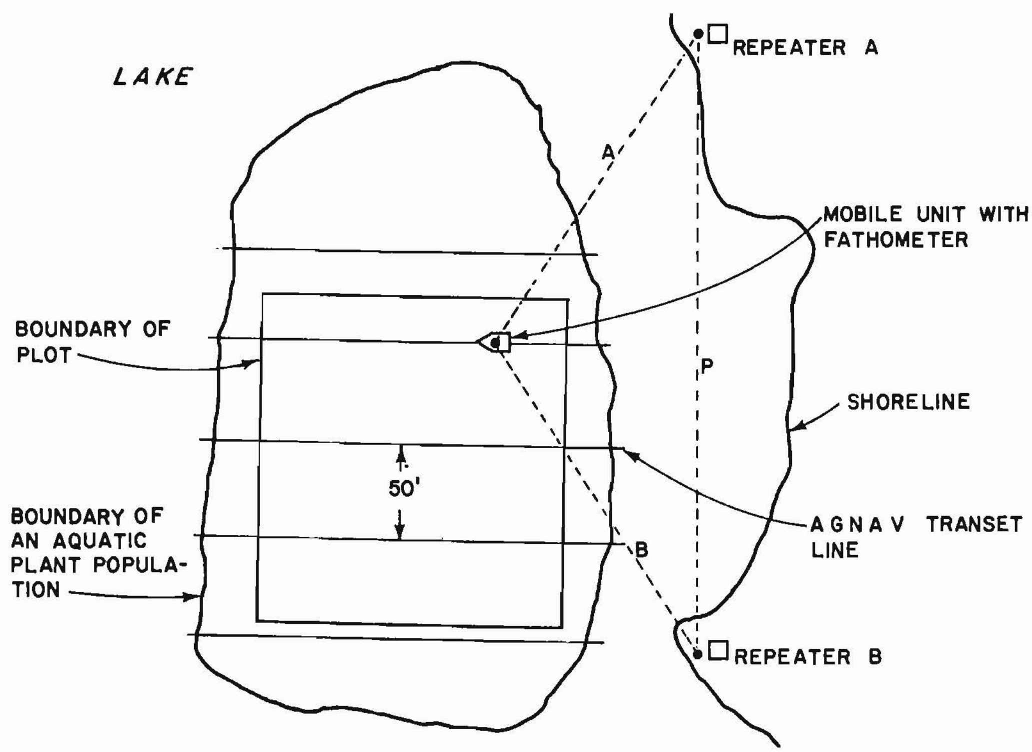

Figure 5. Positioning a fathometer over an aquatic plant population using the AGNAV transect subsystem

maps of submersed plant height before and 1 month after treatment are shown in Figure 6. Fathometer tracings were also manually interpreted to obtain an average plant height and water depth within a plot. Percent change in average height was determined by comparing the plant heights within a plot on different dates. These results are shown in Figure 7.

Biomass sampler

Biomass samples can also provide information on both the horizontal and vertical distribution of aquatic plants. The WES has used an Aquatic Biomass Sampler designed specifically to quantify biomass of submerged aquatic plants (Figure 8). Sabol (1983) describes the biomass sampler as a plant sampler head mounted on a pontoon boat equipped with hydraulic machinery to lift and operate the sampler head. The head is a large cylinder (approximately 0.6 m in diameter and 1.1 m tall) constructed of perforated stainless steel. The bottom has closing

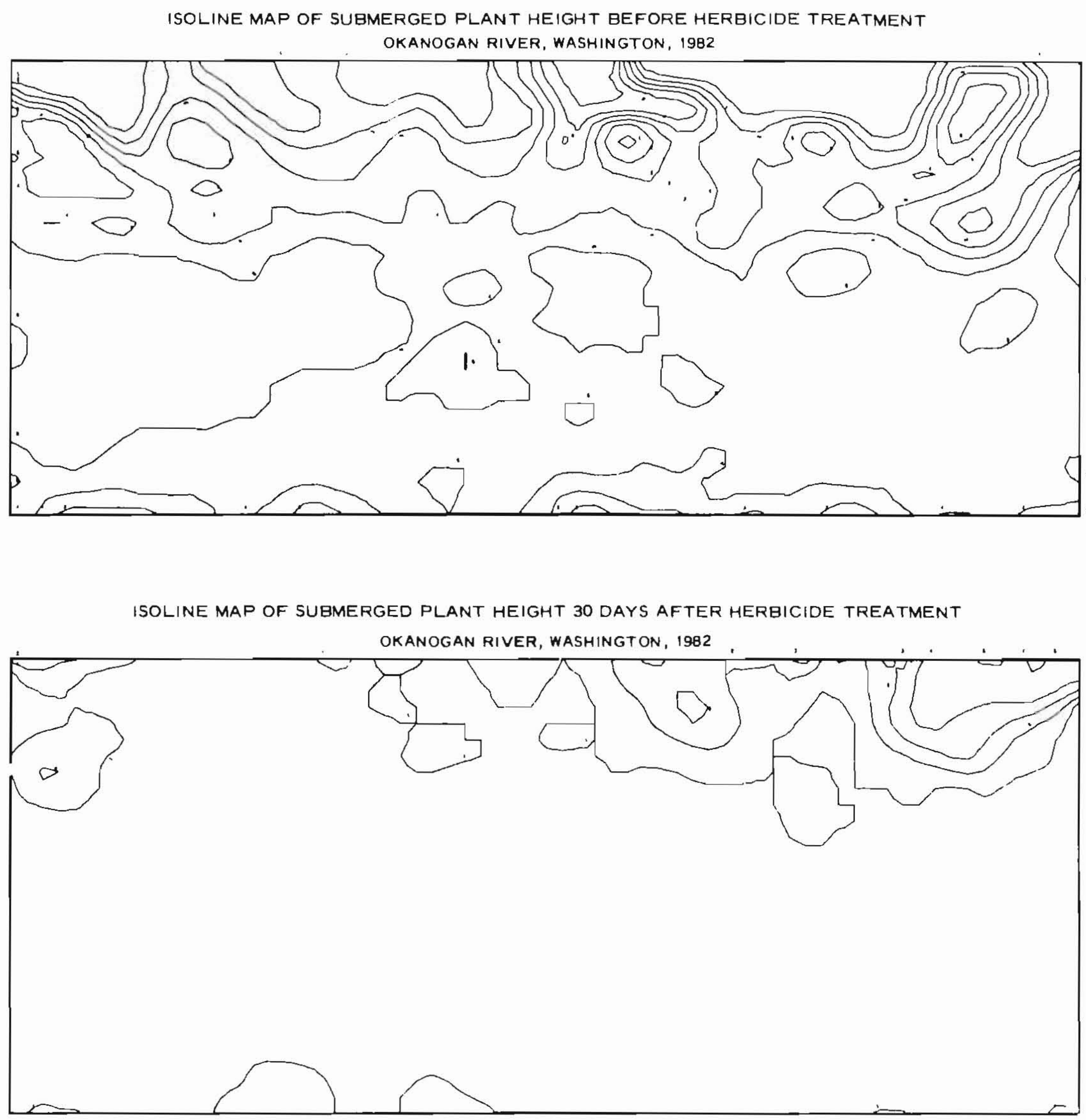

Figure 6. Isoline maps of an experimental herbicide treatment plot showing changes of submerged aquatic plant height over time

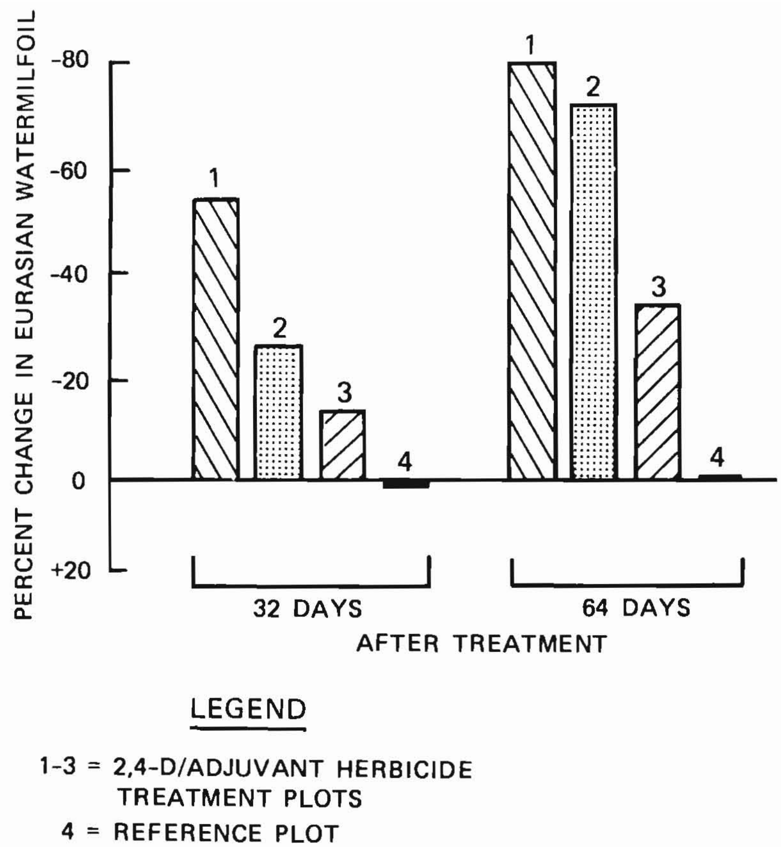

Figure 7. Percent change in Eurasian watermilfoil plant height following herbicide applications. Plant height was interpreted from fathometer tracings taken in the plots over time

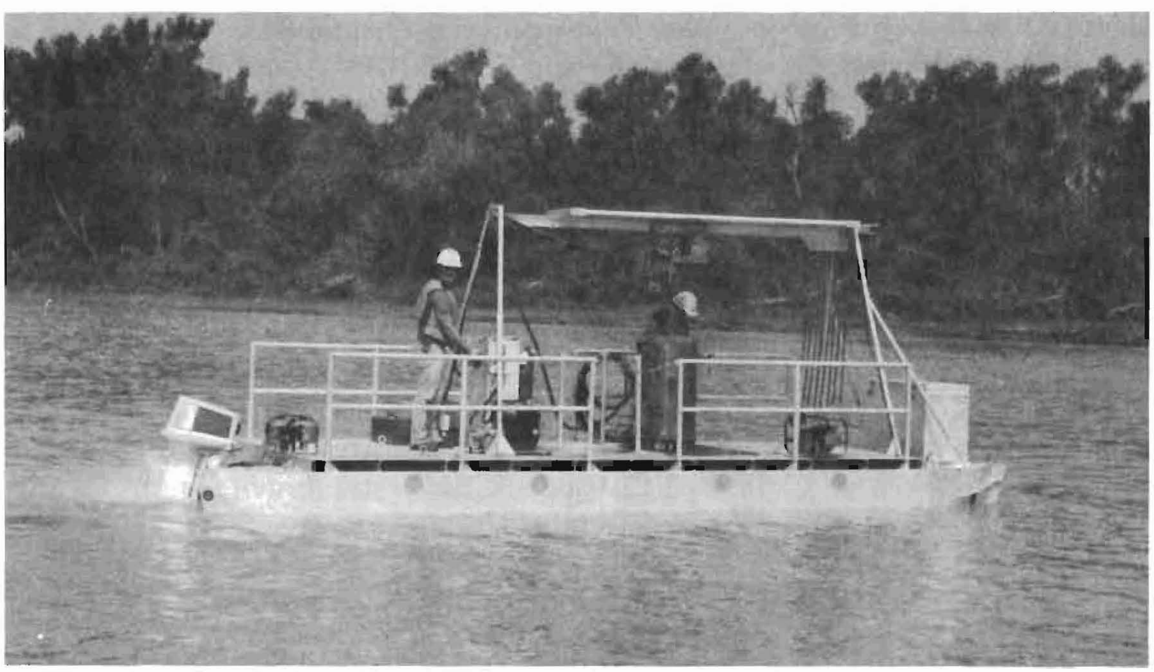

Figure 8. The WES Aquatic Biomass Sampler

doors which are open when the sampler is lowered and closed when it is raised; the bottom is encircled by revolving cutting blades. To operate, bottom closing doors are opened, the sampler is slowly lowered through the water while vertical cutting bars revolve, cutting a core of plant material in the water column. At the desired depth or bottom, the bottom doors are closed and the sampler is raised. Plant material is removed through a side door and its wet, dry, and ash-free dry weights are determined. Variations of biomass values in homogeneous plant growth have created speculation on the accuracy of the biomass sampler. As a result, different sampling head designs are being evaluated for overall accuracy (Sabol 1983). However, the biomass sampler can usually estimate relative changes in plant biomass, thus providing a measure of treatment effectiveness.

Sampling methods using the biomass sampler will vary according to the research objective. The WES has used two sampling methods to quantify changes in biomass over time attributable to a treatment method: random sampling and systematic sampling. Both methods require that an experimental plot be established over the aquatic plant colony and treatment site using the AGNAV. The first method involves random sampling within square or rectangular plots. The WES has used a programmable calculatory program that superimposes a grid over the plot. The size of an individual grid square is determined by the operator of the program. Each grid square is numbered beginning at plot corner location P2. Five grids are randomly selected by the calculator program and these grid numbers, with calculated AGNAV A and B values for the center of each grid, are printed on thermal paper. These randomly selected grids can then be located using the AGNAV's positioning system and marked with a buoy. The biomass sampler is then positioned over the buoy and a sample taken. Additional grid number and locations can be generated by the program in groups of five. The A and B values for a specified grid also can be requested.

In the second method, the AGNAV positioning system can be used to carry out systematic sampling within a plot. To systematically sample, the mobile unit is positioned at the desired sampling site and the AGNAV A and B distances are recorded. A buoy is placed to work the site and a biomass sample is taken. This unique site can be found during any subsequent sampling period as long as the original positions of Repeaters A and B were marked.

The biomass sampler was used in Lake Osoyoos, Washington, to quantify changes in Eurasian watermilfoil biomass due to herbicide treatments (Killgore 1981). Biomass sampling points were established over each herbicide treatment plot using a systematic approach. The biomass samples were taken over each point. The aquatic plants were separated according to species, and the wet, dry, and ash weight of the aquatic plants were taken. Each biomass sampling point was again located 1 month after treatment using the AGNAV, and the biomass samples were taken and analyzed the same as the pretreatment samples. Thus, changes in biomass over time were determined (Figure 9).

CONCLUSIONS AND RECOMMENDATIONS

A standard method of measuring treatment effectiveness is desirable in order for aquatic plant managers to compare and select the appropriate treatment

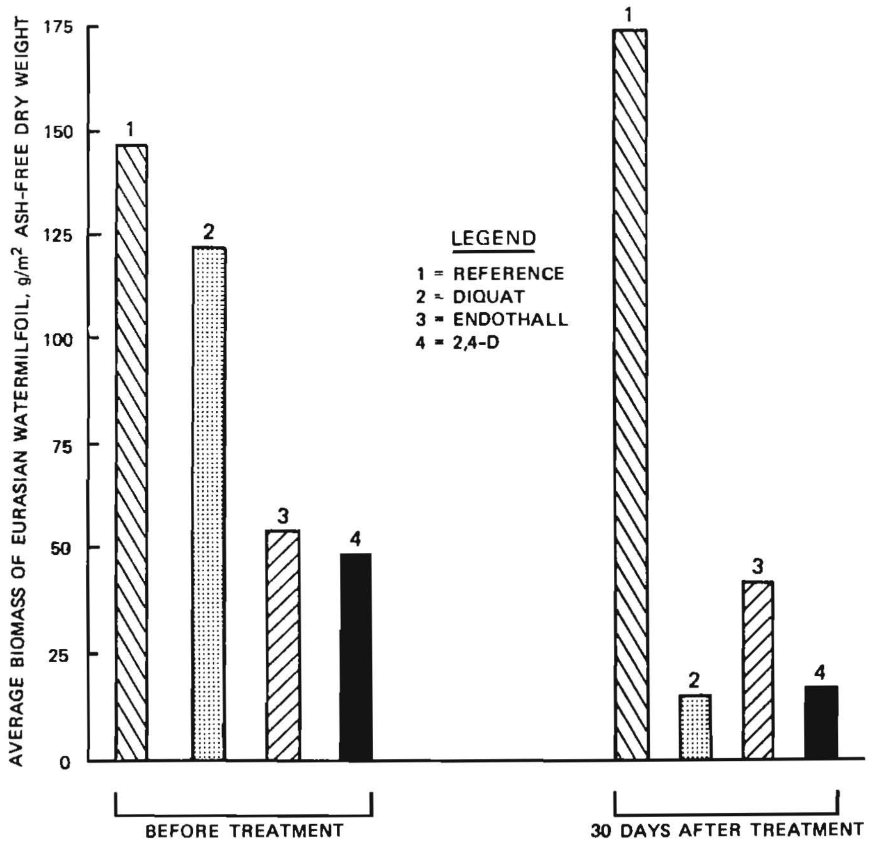

Figure 9. Changes in Eurasian watermilfoil biomass following herbicide treatments. Biomass was sampled using the WES Biomass Sampler

method. Biomass is considered one measure of the aquatic plant's vertical and horizontal distribution while the plant's areal distribution or height may be indicative of the plant's biomass. Thus, the effectiveness of a treatment can be expressed in terms of changes in biomass, plant height, or areal distribution. Aerial photography can be used to measure changes in the aquatic plant areal distribution over a relatively large area. An electronic positioning system coupled to a fathometer is a nondestructive, rapid method to chart plant height over time. Data are required to better relate the plant height or plant areal distribution to the biomass of the aquatic plant.

REFERENCES

Dardeau, E. A., Jr. 1983. "Aerial Survey Techniques to Map and Monitor Aquatic Plant Populations—Four Case Studies," Technical Report A-83-1, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Killgore, K. J. 1981. "Eurasian Watermilfoil Treatment with 2,4-D, Diquat, and Endothall at Reduced Application Rates," *Proceedings, 15th Annual Meeting Aquatic Plant Control Research Planning and Operation Review, 17-20 Nov 1980, Savannah, Ga.*, Miscellaneous Paper A-81-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Killgore, K. J. 1983. "Herbicide Evaluation Research for the Large-Scale Operations Management Test for Prevention Methodologies," Technical Report (in preparation), U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Leonard, J. M., and Payne, B. S. 1983. "Handbook for Obtaining and Using Aerial Photography to Map Aquatic Plant Distribution," Instruction Report (in preparation), U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Sabol, B. M., 1983. "Development and Use of a Hydraulically Operated Submerged Aquatic Plant Sampler," *Proceedings for Symposium of Ecological Assessment of Microphyton Collection,* Fort Lauderdale, Fla.