US Army Corps
of Engineers

**AQUATIC PLANT CONTROL
RESEARCH PROGRAM**

MISCELLANEOUS PAPER A-90-3

PROCEEDINGS, 24TH ANNUAL MEETING, AQUATIC PLANT CONTROL RESEARCH PROGRAM

13-16 NOVEMBER 1989
HUNTSVILLE, ALABAMA

June 1990
Final Report

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The 24th Annual Meeting of the US Army Corps of Engineers Aquatic Plant Control Research Program was held in Huntsville, Alabama, on 13-16 November 1989, to review current research activities and to afford an opportunity for presentation of operational needs. Papers presented at the meeting are included in this report.

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PREFACE

The 24th Annual Meeting of the US Army Corps of Engineers Aquatic Plant Control Research Program (APCRP) was held in Huntsville, Alabama, on 13-16 November 1989. The meeting is required by Engineer Regulation 1130-2-412, paragraph 4c, and was organized by personnel of the APCRP, which is managed under the Environmental Resources Research and Assistance Programs (ERRAP) of the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi.

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, ERRAP. Mr. Robert C. Gunkel, Assistant Program Manager, ERRAP, was responsible for planning the meeting. Mr. James W. Wolcott was Technical Monitor for the Headquarters, US Army Corps of Engineers.

Ms. Billie F. Skinner, Program Managers' Officer, EL, was responsible for coordinating the necessary activities leading to publication. The report was edited by Ms. Jessica S. Ruff of the Information Technology Laboratory, WES. Ms. Betty Watson, ITL, designed and composed the layout.

Commander and Director of WES was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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AGENDA

24th Annual Meeting
US Army Corps of Engineers
AQUATIC PLANT CONTROL RESEARCH PROGRAM

Huntsville, Alabama
13-16 November 1989

MONDAY, 13 NOVEMBER 1989

12:30 p.m. -5:00 p.m.	Registration (Indoor Pool Lobby)
3:00 p.m. -5:00 p.m.	Federal Aquatic Plant Management Working Group (42nd Street)
6:30 p.m. -8:00 p.m.	Reception (Madison Avenue)

TUESDAY, 14 NOVEMBER 1989
General Session, Grand Ballroom
(5th Avenue/Times Square)

7:30 a.m. -9:00 a.m.	Registration Continued (Indoor Pool Lobby)
8:00 a.m.	Call to Order and Announcements — J. L. Decell, Manager, Environmental Resources Research and Assistance Programs Waterways Experiment Station (WES), Vicksburg, Mississippi
8:15 a.m.	Welcome to Nashville District — COL James P. King, Commander, USAE District, Nashville; Nashville, Tennessee
8:30 a.m.	— James W. Wolcott, Technical Monitor Office, Chief of Engineers (OCE) Washington, DC
8:45 a.m.	Billy Bond — Vice President of River Basin Operations Tennessee Valley Authority (TVA) Knoxville, Tennessee
9:00 a.m.	Impacts of 1988 FIFRA Amendments on Herbicide Testing and Registration for Aquatic Use — T. Adamczyk, US Environmental Protection Agency (EPA) Washington, DC
NOTE:	Computer model demonstrations and posters/displays (Wall Street) 9:00 a.m. - 4:00 p.m., Tuesday, 14 Nov 9:00 a.m. - noon, Wednesday, 15 Nov

9:30 a.m.	Valuation of Aquatic Plant Economic Benefits (WU 740-2) – J. E. Henderson, WES
9:45 a.m.	Evaluation of Expert Systems for Use in Aquatic Plant Management – L. Lawrence, WES
10:00 a.m.	BREAK

Biological Control of Aquatic Plants
– A. Cofrancesco, WES, Presiding

10:15 a.m.	Overview – A. Cofrancesco, WES
10:30 a.m.	Foreign Exploration for Insect Biocontrol Agents of Eurasian Watermilfoil and Hydrilla for Use in Temperate Portions of the United States (WU 740-3) – J. Balciunas, US Department of Agriculture (USDA) Fort Lauderdale, Florida
10:45 a.m.	Host Range Test for Insect Biocontrol Agents: History and Comparison – G. Buckingham, USDA, Gainesville, Florida
11:00 a.m.	Release, Establishment, and Evaluation of Insect Biocontrol Agents for Aquatic Weed Control (WU 32406 & 31799) – T. Center, USDA, Fort Lauderdale, Florida
11:15 a.m.	Changes in Population Levels of Waterhyacinth and the Reproductive Status of an Associated Biological Agent, *Neochetina eichhorniae* – M. Grodowitz, WES
11:30 a.m.	Effects of Herbicides on *Neochetina eichhorniae*, a Biocontrol Agent of Waterhyacinth (WU 32442) – A. Cofrancesco, WES
11:45 a.m.	Biological Control of Hydrilla with Plant Pathogens (WU 32200) – G. Joye, WES
12:00 noon	LUNCH
1:00 p.m.	Microbiological Control of Eurasian Watermilfoil (WU 32202) – L. Winfield, WES
1:15 p.m	Development of a Commercial Microbiological Control for Eurasian Watermilfoil (WU 32202) – J. Stack, EcoScience Amherst, Massachusetts
1:30 p.m.	Inhibition of Hydrilla Growth by Aquatic Plant Extracts and Secondary Compounds (WU 32408) – C. Smith, WES
1:45 p.m.	Attachment of Plant Pathogens to Submersed Aquatic Plants (WU 32388) – S. Kees, WES
2:00 p.m. -4:30 p.m.	USAE Division/District Working Session (Madison Avenue)

WEDNESDAY, 15 NOVEMBER 1989
General Session - Grand Ballroom
(5th Avenue/Times Square)

Chemical Control Technology
— K. Getsinger, WES, Presiding

8:00 a.m.	Overview — K. Getsinger, WES
8:15 a.m.	Herbicide Concentration/Exposure Time Studies (WU 32352) — M. Netherland, Purdue University West Lafayette, Indiana
8:30 a.m.	PGR Research for Improving Aquatic Plant Management (WU 32578) — L. Nelson, WES
8:45 a.m.	Plant Growth Regulator Effects on Submersed Aquatic Plants (WU 32578) — C. Lembi, Purdue University West Lafayette, Indiana
9:00 a.m.	Coordination of Control Tactics with Phenological Events of Aquatic Plants (WU 32441) — K. Getsinger, WES
9:15 a.m.	Evaluation of Application Techniques in Flowing Water (WU 32354) — K. Getsinger, WES
9:30 a.m.	Dye Studies in Submersed Plant Stands of Florida — A. Fox, IFAS, Center for Aquatic Plants University of Florida, Gainesville, Florida
9:45 a.m.	BREAK

Special Session - Guntersville Reservoir
— A. L. Bates, TVA, Presiding

10:00 a.m.	History of Aquatic Plant Management, Guntersville Reservoir — A. L. Bates, TVA Muscle Shoals, Alabama
10:15 a.m.	Herbicide Control, Guntersville Reservoir — E. R. Burns, TVA Muscle Shoals, Alabama
10:30 a.m.	Drawdowns and Grass Carp for Aquatic Weed Control, Guntersville Reservoir — D. H. Webb, TVA Muscle Shoals, Alabama
10:45 a.m.	Aquatic Weeds - Mosquito Production, Guntersville Reservoir — J. C. Cooney, TVA Muscle Shoals, Alabama

11:00 a.m. Fisheries Investigations, Guntersville Reservoir
— B. Wrenn, TVA
Muscle Shoals, Alabama

11:15 a.m. TVA-USACE Joint Agency Plan for Aquatic Plant Management, Guntersville Reservoir
— A. L. Bates, TVA

11:30 a.m. LUNCH

12:30 p.m. Field Trip to Guntersville Reservoir

THURSDAY, 16 NOVEMBER 1989
General Session - Grand Ballroom
(5th Avenue/Times Square)

Ecology of Submersed Aquatic Plant Species
— J. W. Barko, WES, Presiding

8:15 a.m. An Overview of Ecological Studies
— J. W. Barko, WES

8:30 a.m. Monotypic Response of Submersed Macrophytes to Sediment Fertility at Different Levels of Plant Density (WU 32351)
— D. G. McFarland, WES

8:45 a.m. Influences of Plant Density and Sediment Fertility on Interactions Between Submersed Macrophyte Species (WU 32351)
— N. J. McCreary, WES

9:00 a.m. Seasonal and Spatial Variability in Patterns of Sedimentation in Macrophyte Beds in the Potomac River (WU 32405)
— H. L. Eakin, WES

9:15 a.m. The Habitat Value of Aquatic Macrophytes: A Comparison Between Lentic and Lotic Sites (WU 32505)
— A. C. Miller, WES

9:30 a.m. The Value of Aquatic Macrophytes for Fishes: Studies at Lake Marion, South Carolina (WU 32505)
— K. J. Killgore, WES

9:45 a.m. An Overview of the Lewisville Pond Facility and Plant Competition Studies (WU 32577)
— R. M. Smart, WES

10:00 a.m. BREAK

10:15 a.m. Environmental Factors Influencing Gas Evolution Beneath a Benthic Barrier (WU 32579)
— D. Gunnison, WES

10:30 a.m. Convective Exchange in the Littoral Region of Eau Galle Reservoir (WU 32405)
— J. W. Barko, WES

Computer-Aided Simulation Procedures
— R. M. Stewart, WES, Presiding

10:45 a.m.	Computer-Aided Simulation Procedures: An Overview — R. M. Stewart, WES
11:00 a.m.	Plant Growth Models for Hydrilla and Eurasian Watermilfoil (WU 32440) — J. W. Wooten, Department of Biological Sciences, University of Southern Mississippi, Hattiesburg, Mississippi
11:15 a.m.	Preliminary Evaluation of Triploid White Amur Stocking Rates in Guntersville Reservoir, Alabama, Using AMUR/STOCK Version 1.5 (WU 32438) — W. A. Boyd and R. M. Stewart, WES
11:30 a.m.	Field Validation of HERBICIDE Version 1.0 (WU 32439) — P. A. Clifford, Department of Biology, University of North Texas, Denton, Texas
11:45 a.m.	Environmental Digital Database Design and Applications: Guntersville Reservoir, Alabama (WU 32506) — M. R. Kress, WES
12:00 noon	LUNCH
1:00 p.m.	Report on Tuesday's Division/District Working Session
1:30 p.m.	Adjourn 24th Annual Meeting
1:45 p.m.	FY91 Civil Works R&D Program Review, Directorate of R&D, OCE (Madison Avenue - Corps of Engineers Representatives Only)

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24th Annual Meeting
US Army Corps of Engineers
AQUATIC PLANT CONTROL RESEARCH PROGRAM

Huntsville, Alabama
13-16 November 1989

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
feet	0.3048	metres
gallons (US liquid)	3.785412	cubic decimeters
inches	2.54	centimeters
miles (US statute)	1.609347	kilometers
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square meters
tons (mass) per acre	0.22	kilograms per square meter
tons (2,000 pounds, mass)	907.1847	kilograms
torrs (mm Hg, 0° C)	133.322	pascals

24th Annual Meeting
US Army Corps of Engineers

AQUATIC PLANT CONTROL RESEARCH PROGRAM

INTRODUCTION

The Corps of Engineers (CE) Aquatic Plant Control Research Program (APCRP) requires that a meeting be held each year to provide for professional presentation of current research projects and to 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 Headquarters, US Army Corps of Engineers; the Program Manager, APCRP; and representatives of the operations elements of various CE Division and District 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, US Army Engineer Waterways Experiment Station, each year in the form of quarterly progress reports and a final technical report. Each technical report is distributed widely in order to transfer 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, Engineer Circulars, and Engineer Manuals. 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 nationwide operational needs.

The contents of this report include the presentations of the 24th Annual Meeting held in Huntsville, Alabama, 13-16 November 1989.

Welcoming Remarks

by
COL James P. King*

Thanks, Lewis [Decell]. Why is it that everytime I talk to you it's "watermilfoil this or hydrilla that"? Since leaving the "Puzzle Palace" and the theater nuclear policy business in July, my association with Lewis has taught me an entirely new language, words such as "Eurasian watermilfoil, alligatorweed, hydrilla, waterhyacinth, waterlettuce," and--not foreign invasion but--"aquatic invasion!" Since I've gotten to know Lewis, I have found he has a secret weapon to control aquatic plants--he can talk them to death!

Seriously, I am especially pleased that Nashville District was selected to host the 24th Annual Aquatic Plant Control Research Meeting. Huntsville is a very appropriate city in which to convene such a group of researchers, and now is a particularly opportune time for this meeting to be held.

I want to express my appreciation to our friends at the Waterways Experiment Station for their efforts in arranging this meeting. Lewis Decell and Bob Gunkel, ably assisted by Billie Skinner, have done a superb job over the years in putting these meetings together. In looking over the agenda, I can see this year will be no exception. I know a great deal of thought, preparation, and time have gone into the topics being covered the next 3 days, and I am certain that each attendee will take back a considerable amount of information for application to your particular situation.

I also want to thank the Tennessee Valley Authority and particularly Mr. Leon Bates and Dr. David Webb for the assistance they have provided in making sure the meeting and the field trip tomorrow to Guntersville Lake are a success. I can only hope that Mother Nature will cooperate in producing some nice weather. I encourage each of you to follow the progress of the joint project for aquatic plant management that TVA, Waterways Experiment Station, and the Nashville District are beginning at Guntersville Lake.

At the Reservoir, you will see significant populations of aquatic plants which have been in the reservoirs of the Tennessee River System for more than 25 years. These plants have resulted in many changes to the lakes and to the uses of these lakes. During this same 25-year period, TVA has managed the aquatic plants with various techniques. The strategy now in effect is called a "Priority Treatment Strategy," which means that treatment efforts are focused in areas which provide the greatest benefits in terms of reducing conflicts with reservoir uses. Guntersville Lake now has the most extensive infestation of aquatic plants on the entire Tennessee River system.

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*Commander, US Army Engineer District, Nashville; Nashville, Tennessee.

However, aquatic plants have not had only negative effects. Positive benefits have resulted, particularly to certain fisheries and waterfowl resources. This fact was pointed out to me--in no uncertain terms--by all the bass fishermen who came to a public meeting I hosted at Guntersville in late August. Of course, all the homeowners present from the "Save Our Lake" clubs didn't share that view. Recognizing the potential for increasing benefits while reducing use conflicts at Guntersville, the Tennessee Valley Authority has teamed up with the Waterways Experiment Station and Nashville District to develop a long-range plan that seeks to bring conventional technologies with new research findings to optimize benefits and reduce conflicts.

I believe we can all benefit from what is to be learned through the Guntersville experience. Through the planning and public involvement processes we can work together to demonstrate the best methods and achieve the desired outcome of maximizing the multipurpose uses intended for Guntersville and other lakes.

In the Cumberland River Basin, where I manage the reservoirs, we have also had populations of aquatic plants for several years. Most of these have been native plant species, and we have been fortunate that use conflicts have been minimal.

In 1987, however, Eurasian watermilfoil was discovered in Lake Barkley, the most downstream lake on the Cumberland River. Since then, milfoil has spread to occupy approximately 100 acres* in Lake Barkley and has now invaded Old Hickory Lake, where approximately 75 acres are colonized.

We are beginning to develop aquatic plant management programs for our Cumberland River projects and will be incorporating what is learned at Guntersville and other places into our plans. We will seek to do the best job possible in integrating aquatic plant management with other natural resource, recreation, and environmental quality objectives at our lakes to ensure that multipurpose uses are maintained.

Again, I welcome everyone to the Nashville District, to Huntsville, and to the 24th Annual Aquatic Plant Control Research Meeting. It is indeed an honor and a privilege to serve as host for this gathering, and I am grateful for the opportunity to welcome this distinguished gathering.

At this time, then, I will return the podium to our friend--"Aquatic Plantman" himself--Lewis Decell.

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*A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page xvii.

TVA's Aquatic Plant Management Program

by
Billy J. Bond*

Some of you from outside the region may not be familiar with the Tennessee Valley Authority (TVA) and its relation to natural resources. Briefly, TVA is an independent corporate agency of the Federal Government; that is, it is not part of any cabinet department, and in some ways it operates more like a private corporation than like a Government agency, especially in regard to its self-supporting power program. However, electric power generation is only one of TVA's functions. Congress charged TVA to develop, conserve, and manage the full range of the Tennessee Valley region's resources--natural, economic, and social. One of TVA's greatest responsibilities is managing the water resources of the Tennessee River and its tributaries and the series of dams and reservoirs that now comprise the TVA water control system. That includes managing aquatic vegetation, which--depending upon where it grows and in what quantities--can either increase or decrease the usefulness of those water resources for various purposes.

About a year ago, TVA reorganized its resource programs into a Resource Development Group that includes River Basin Operations. Somewhat like the District offices of the US Army Corps of Engineers and their resource management activities, River Basin Operations is responsible for stewardship of TVA waters and lands. The water resources program is a part of River Basin Operations and includes the Aquatic Biology Department, which conducts TVA's aquatic plant management activities.

For more than 50 years, TVA has acted as a catalyst for improvements in resource use and conservation, productivity, economic growth, and overall quality of life. As a regional agency, TVA has been able to transcend state and local political boundaries within the seven-state region to help accomplish some resource development and management goals that otherwise might never have been realized. However, TVA has not worked alone but in concert with other Federal agencies, state and local agencies, cities and industries, and the people of the Valley. It is this cooperative effort that deserves much of the credit for the good things that have happened in the Tennessee Valley during the last half century.

TVA has long enjoyed a partnership with the Nashville District, Corps of Engineers. The Interconnected Inland Waterway extends 650 miles up the Tennessee River and 380 miles up the Cumberland River. The Tennessee and Cumberland river systems have operated as a unit since 1966, when a navigation canal was opened connecting TVA's Kentucky Reservoir and the Corps' Lake Barkley. Both drainages now have aquatic plant problems. Although those in the TVA system are more extensive than those in the Corps system, the presence of Eurasian watermilfoil and the threat of

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*Tennessee Valley Authority, Vice President, River Basin Operations, Knoxville, Tennessee.

hydrilla are reasons for mutual concern. We now share a new interest in the management of aquatic vegetation because the interconnected Tennessee and Cumberland River navigation systems are also linked to the Tombigbee River system by way of the Tennessee-Tombigbee Waterway, which extends navigation--and the potential for spread of aquatic plants--all the way to and from the Gulf of Mexico.

From its beginning, TVA has been involved in control of aquatic plants. During initial planning for the agency, it was realized that the proposed series of impoundments could increase breeding habitat for the malaria mosquito. Early cooperative research by TVA, the US Public Health Service, the Corps of Engineers, and state health agencies indicated the malaria mosquito could be controlled effectively and economically by controlling aquatic plants--at that time, primarily native emergent species--through a combination of water-level management and supplemental chemical or mechanical techniques.

TVA entered a new era of aquatic plant problems when the submersed species Eurasian watermilfoil was introduced in the late 1950s. As often happens when nonnative species enter new environments, populations expanded rapidly. Within a decade it had colonized 25,000 acres in eight TVA reservoirs from east Tennessee to north Alabama. It is now established in all nine mainstream reservoirs and in two tributary reservoirs. It is considered inextricable. There is no practical or ecologically acceptable eradication strategy. Our present management strategy is to reduce overly abundant populations of this and other problem species in designated priority areas where they interfere with one or more uses of water resources.

Although aquatic plant control has been practiced for several hundred years, aquatic plant management is a relatively new concept. It requires integrating information from several traditional disciplines. It also requires understanding the relationships among the various components of the water resource and the various uses of those components that must be accommodated. If we are going to manage--not just control--aquatic plants, we need to expand both our data bases and our understanding of the relationships among water resources and their uses. These are needs that aquatic plant scientists and managers can--must--help fill.

The shallow-water zone is a magnet for many types of resource use--especially for many types of recreation. In the Tennessee Valley as elsewhere, however, this same zone also produces the greatest concentration of aquatic vegetation. Vegetation can benefit waterfowl hunting and certain kinds of fishing, but excessive amounts of vegetation can limit the potential for many other kinds of recreation and other types of resource use and development.

Controversy exists about how much vegetation growth is needed for effective management and recreational use of waterfowl and fisheries resources as opposed to how much vegetation control is needed for effective management of the broad range of other reservoir resources and other resource uses, including other types of recreation. We are developing a better understanding of how aquatic plants influence and interact with the waterfowl and fishery components of the water resource system. Now we must develop better management plans and techniques to provide optimum compatibility and balance among the various uses of these and other reservoir resource components.

One of the other difficult issues is the urgent need to control the spread of undesirable species. Potentially troublesome species occur in almost every region. There is almost unanimous agreement among specialists that many such species are being transported from one region to another, either intentionally or accidentally. Those considered ornamental are frequently transported by an unsuspecting public. There is strong evidence that tournament fishermen transport aquatic plants long distances on boating equipment. All of this underscores the importance of educating the public about the ecological hazards of aquatic plants.

In the Tennessee Valley, this problem has been exemplified by the introduction of Eurasian watermilfoil and several other exotic species, the most recent of which has been hydrilla. Since its discovery in 1982, hydrilla has expanded to more than 3,000 acres in parts of four reservoirs. The situation is likely to get worse before it gets better. We estimate that the reservoir system contains more than 100,000 acres of potential habitat.

The central pervasive issue that confronts water resource managers is exotic introductions. Aquatic plant scientists are confronted every growing season with new introductions of nonnative species, each potentially a problem species when it reaches a new ecological region. Some are still so "new" that life histories and ecological requirements are poorly understood, making control difficult or impossible. Very likely, others are growing still undetected, like concealed biological time bombs.

Another issue is the public controversy about use of herbicides and pesticides in general. The use of aquatic herbicides has been--and should continue to be--closely scrutinized to ensure human and environmental safety. There is ample scientific evidence to support continued, careful use of a number of effective aquatic herbicides. However, it would be a tremendous loss if this entire control technology were unnecessarily restricted because aquatic plant managers were unprepared to respond effectively to unsubstantiated claims of effects on public health or the environment. Other issues, such as the use of grass carp and other biological controls, have stimulated nationwide press coverage and a great deal of interest, especially among sports fishermen. Congress has asked TVA, the Aquatic Plant Control Research Program of the Waterways Experiment Station, and the Nashville District to work together to test and demonstrate innovative management techniques and control technologies, including use of the grass carp, and to incorporate the most effective of these into a comprehensive aquatic plant management plan for Guntersville Reservoir in northeast Alabama. Technology arising from this joint project is expected to be applicable to other reservoir systems in the Southeast and throughout the United States.

We see this as an excellent opportunity for the agencies to work together in the spirit of cooperation, as they have so often in the past, to achieve a common goal. All lake users--both now and in future generations--have a big stake in how well we do our job. We are eager to get started.

Valuation of Aquatic Plant Economic Benefits

by
Jim E. Henderson*

INTRODUCTION

The purpose of the valuation work is to develop guidance for economic valuation to be used by project, District, and cost-sharing sponsors. The work will follow the Plan of Study presented at the 23rd Annual Meeting in West Palm Beach, FL (Henderson 1989). The work will be implemented along with the field demonstrations at Guntersville Lake. The research on economic valuation is intended to provide methods to:

a. Evaluate the economic benefits and costs of proposed control programs.

b. Provide information on public uses and perceptions about aquatic plants, and perceptions and preferences on different control strategies.

c. Determine the optimal benefits and trade-offs relating to alternative control strategies.

The overall purpose of economic valuation is to provide information that can be used by managers to make better decisions on aquatic plant control through consideration of all the benefits and costs.

ECONOMICS AND AQUATIC PLANTS

It has been suggested that economic incentives played a part in the initial infestations of aquatic plants (Wunderlich 1968). Desires to find cheap sources of cattle feed and inexpensive ornamental plants are purported to be the reason behind rapid spread of species such as waterhyacinth. The initial research and development of control mechanisms focused on effectiveness and safety of the technologies. For development of control technologies, the costs in time and research were viewed as an investment and were acknowledged as part of the research and development effort to attain control benefits. As control technologies have become better established, long-range management becomes possible to attain efficiencies of operation and to optimize and balance the public uses, habitat benefits, and navigation and other project purposes.

In examining the existing information on benefits and costs, there is more information on costs because of the need to account for, and therefore document, expenditures. A 1986 study compared the economic efficiency of alternative control methods by comparing the costs per hectare for controlling hydrilla in identical test

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*US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

plots (Shireman, Colle, and Canfield 1986). The study compared control by mechanical harvesting, herbicide control, and biological control, i.e., grass carp. The costs over the 4-year study are as follows:

Control Method	*Cost/Hectare/Year*
Mechanical harvesting	$2,587
Biological	$159-248
Herbicide	$417-1,339

An earlier study compared control costs of grass carp, herbicides, and a herbicide/grass carp combination (Osborne 1982). The cost comparison, based on biomass removed, is as follows:

Control Method	*Cost (per metric ton)*
Grass carp	$69.75
Herbicide	$127
Herbicide and carp	$143

Costs for the herbicide and carp combination were somewhat higher than the herbicide alone, but twice as costly as the carp alone. The herbicide and carp combination showed that biomass is reduced between years when herbicide is used, but the distribution and regrowth of hydrilla remained the same year after year. This required that the same acreage be treated annually. In considering the benefits and costs of aquatic plant control, consideration of such parameters as distribution and regrowth patterns is important with regard to the effects on fishery habitat. The cost for control methods must be viewed in light of all the effects on the resources. That is, effects on fishery benefits should be considered along with costs per metric ton, when comparing alternative control strategies.

The economic benefits from natural resource management arise from willingness-to-pay for the goods and services provided for or supported by aquatic plant control. The total economic value of an aquatic plant control program is the sum of increased value of services resulting from plant control. The services resulting from aquatic plant control include:

-Navigation
-Flood control
-Recreation
-Water supply
-Hydropower
-Irrigation
-Intangibles

Most of these services listed are readily recognized as project or authorizing purposes. The last service listed, Intangibles, includes such things as aesthetics, recreation, and preservation values. These intangible benefits may be valued, and the public may express a willingness-to-pay although the public is not required to pay to enjoy or to acquire the service.

The benefits from authorized project purposes are only part of the project benefits. Aesthetics, preservation, and other intangible values represent indirect or secondary benefits that are produced through control of aquatic plants. Just as there are indirect benefits, there are also indirect costs of aquatic plant control. These are the opportunity costs of using public monies in aquatic plant control rather than for a different mix of benefits.

ECONOMIC VALUATION WORK UNIT

The purpose of this discussion is to present the work that is being performed under the Economic Valuation of Aquatic Plants Work Unit. This work will be performed as part of the Guntersville Lake demonstration work, under the Aquatic Plant Control Research Program. The purpose of the work unit is to provide methods that can be used by District; Division; Headquarters, US Army Corps of Engineers; or cost-sharing personnel to better evaluate the economic benefits and costs of aquatic plant control. This work is organized into four phases, described below.

Phase I - Literature review

The initial work is a literature review and synthesis of existing documentation on the economics of aquatic plant control. The purpose of the literature review is to identify and evaluate the relevant literature on valuation of aquatic plant control, and identify what data on costs and benefits are normally available for use by Planning and Operations personnel. The emphasis on identifying information that is normally available is so that the recommended valuation methods can readily fit in ongoing Planning and Operations activities. This literature review is being performed by Dr. Eric Thunberg of the University of Florida.

The literature on aquatic plant control falls in two categories: control technology documentation and the economic valuation literature. The control technology documentation documents the costs, benefits, and effectiveness of the different control technologies. The documentation is in the form of technical reports, plant management literature, General Design Memoranda, and annual work plans. The data from the studies cited above is the type of information available from the control documentation. Data on direct outlays for labor and equipment costs are normally documented without including appropriate opportunity costs. For example, the benefits to fish habitat discussed above may be documented, but not quantified or without considering the trade-offs of habitat value and additional cost of treatment. As control technologies become more effective and benefits better defined, then trade-offs can be identified between costs and the different benefits, e.g. habitat, recreation, and flood control.

The economic valuation literature contains valuation methods that could be used to value aquatic plant services. Natural resource valuation literature contains the methods used to determine the willingness-to-pay for natural resource amenities and experiences. Willingness-to-pay values have been determined for such things as recreation experience, on a trip, day, or annual basis; improved water quality conditions;

improved fishery habitat; avoidance of congestion at recreation sites; and aesthetics. These types of valuation efforts could be applied to the impacts of aquatic plant infestations and control efforts.

Phase II - Determining impacts and public perceptions

The emphasis of work in Phase II is to determine the impacts and public perceptions of aquatic plants and aquatic plant control. In determining the benefits and costs of aquatic plant control, it is apparent that all the impacts of aquatic plants and aquatic plant control efforts should be considered. To value aquatic plant efforts, it is necessary to determine the benefits and costs of all of the services provided by or resulting from control efforts. The primary project purposes impacted by plant infestations, e.g., navigation, may not turn out to be the greatest or most highly valued of the project purposes by the public. That is, the indirect benefits, e.g., recreation or water quality, may be of higher importance to the public. Similarly, with a decision not to treat an area or reduce the extent of treatment, there are indirect costs in terms of such things as displacement of recreation use, loss of access to lake areas, and fish and wildlife habitat losses that are not accounted in just looking at level of navigation or flood control benefits (Henderson 1989).

Lake Guntersville is now in a near-precontrol state so that the navigation, recreation, and other uses currently occurring will be documented. Homeowner and recreators will be asked about their reaction to the aquatic plants, and perhaps a monitoring system will be established to determine the changes in use as the aquatic plants are controlled.

Identifying all the impacts of aquatic plants is a case of tracing out the natural resource and human responses to aquatic plant infestations. Recreational fishers can go to another site, another lake, or choose not to fish. That is, the recreation benefits may be transferred to a substitute site or lost altogether because of the aquatic plants. Homeowners with private boat docks made impassable by aquatic plants are similarly limited. They can move their boat to another part of the lake or not boat at all, again with a change or loss in recreation benefits.

With the ability to identify and quantify not only effects of infestations but also the human response, different management strategies can be proposed. The public can evaluate their willingness-to-pay for different levels of aquatic plant control. Members of the public may perceive plant problems differently than agencies. Different user groups may prefer different levels of plant biomass. Typically, fishing interests want a level of plant biomass that provides what they perceive as good fish habitat. Homeowners may prefer a more extensive clearing of plants.

Just as there are different perceptions of desirable plant levels, there are different public perceptions of alternative control technologies. Public perceptions and understanding of mechanical, biological, and chemical control technologies result in different levels of acceptability. Preferences for different control technologies by the public affect the willingness-to-pay for control efforts. Public perceptions of the implementation and the long- and short-term impacts, e.g., the closing of recreation areas for herbicide treatment, affect the public support and, in some cases, the cooperation by the general public and those local agencies responsible for cost sharing. Public perceptions of control technologies are acquired by a number of means involving questionnaires. Respondents indicate preference, acceptability, and willingness-to-pay for different technologies.

Phase III - Valuation methods for aquatic plant control

Phase III involves identification and evaluation of market and nonmarket valuation methods for the impact or benefits identified in Phase II. Emphasis will be on methods that are conceptually valid and that have the greatest potential for use in decision making. Aquatic plant control results in economic changes in both market (e.g. land values) and nonmarket (e.g. recreation) goods and services; thus, both market and nonmarket valuation methods will be examined (Henderson 1989).

Market methods are used to value changes in goods and services where well-developed markets exist, that is, where the price for use or consumption is responsive to supply and demand of the good or service. Nonmarket methods are used for goods and services that are not exchanged in a market environment. The services are consumed, but a price is not necessarily required for consumption. Alternately, the price paid may be arbitrary, such as an entrance fee, or bears no relation to the supply or demand for the service. The consumer may be willing to pay far more than is required for the license, entrance fee, or expenditures in tackle or other goods required to enjoy the recreation or other service. This additional amount of willingness-to-pay is known as the consumer surplus; it is this surplus that nonmarket methods are intended to measure.

Market valuation. Market valuation of natural resources is usually limited to increases in project benefits such as navigation, water supply, and flood control. The impact of natural resources on market values of such things as real estate is often evidenced in controversies such as those involving wetland development. Obviously, the natural resources characteristics (e.g., water frontage) make the wetland development site of a higher value, as shown by the market price of the lots (Henderson 1989).

Recently, efforts have been made to incorporate or measure the value attributable to natural resources that is a component of the market value of land developments. A market-based method called the Hedonic Approach or Hedonic Price Approach has been used to determine the value that natural resource characteristics contribute to land sale prices. This approach is being considered for use at Lake Guntersville to determine the impact of aquatic plant infestations on value of homes in the numerous subdivisions around the lake. Sales or appraisal values will be collected and related to historic infestation of aquatic plants.

The Hedonic Approach has been used in other land value applications, notably to determine wetland development values. Batie and Mabbs-Zeno (1985) used the Hedonic Approach for valuation of a proposed subdivision in a coastal wetland in Virginia. Using the characteristics and sale price of the lots, a regression equation was developed to show the influence or contribution of the different characteristics to the sale price. This analysis determined, for instance, that consumers were willing to pay

$4,180 for a lot on a canal but $7,410 for a lot on open water. Lots adjacent to wetlands were valued at $1,120 less than lots not adjacent to wetlands. At Lake Guntersville, the characteristics would likely be based on lakefront lot or off-the-lake lot, or other measures showing proximity to the aquatic plant infestations.

Nonmarket valuation. Recreation is the only nonmarket value usually included in water resources evaluations, due to the extensive water-based recreation opportunities available at rivers and lakes. Recreation benefits are measured by willingness-to-pay for the recreation services (Headquarters, Department of the Army 1983). The methods used to estimate willingness-to-pay for recreation are (a) Unit Day Value, an administrative or judgment-based method that assigns a dollar value or dollar range to recreation activities or facilities; (b) Travel Cost Method, which uses the cost of travel and time of the recreator as a proxy for willingness-to-pay; and (c) Contingent Valuation Method (CVM), which establishes a hypothetical market for recreation and elicits a direct measure of willingness-to-pay for alternative recreation experiences (Henderson 1989).

Milon, Yingling, and Reynolds (1986) used a CVM study to evaluate recreation benefits resulting from different levels of aquatic plant control at two lakes in Florida. This is the only identified study that valued recreation benefits related to aquatic plant control. At Lake Guntersville, a recreation use survey will be undertaken to determine existing levels of use and perceptions of aquatic plant problems. It is anticipated that the survey of lake users will provide a sample for a mail-back CVM questionnaire. The use survey will be conducted during fiscal years 1990-91, with the CVM survey to be implemented in FY 1991. The CVM questionnaire will be used to determine the willingness-to-pay for different levels of aquatic plant control at Lake Guntersville.

Evaluation of the methods. Use of the Hedonic Approach, CVM, or other valuation methods at Lake Guntersville will be evaluated in terms of ability of the methods to reliably determine the value of aquatic plants in a manner that can be used for decisionmaking. Valuation methods used for other natural resources or natural resource services may not be suitable for aquatic plant work because of characteristics of aquatic plants or aquatic plant control (Henderson 1989). Although the resources and natural resource attributes may be similar, use of a specific technique for aquatic plant valuation may require adaptation or extreme care. Particular methods or parts of methods may require adaptation or modification for application to aquatic plant valuation. The conclusions from Phase III will be presented in a report identifying the methods or adaptations that should be used in aquatic plant valuation.

Phase IV - Development of field guidance

Phase IV entails development of field guidance in the form of a User's Manual. The User's Manual will explain how to use the economic valuation methods for aquatic plant management. Changes to the methods, as identified by the Lake Guntersville work, will be incorporated into the field guidance. A Draft Manual will be prepared for review. This document will incorporate the revisions to the methods based on Lake Guntersville and any other field testing, guidance on implementation of the methods, and guidance on the use of public preference and economic information in evaluation of aquatic plant plans. The Draft Manual will be revised based on the review, published, and distributed.

REFERENCES

Batie, Sandra S., and Mabbs-Zeno, Carl C. 1985. "Opportunity Cost of Preserving Coastal Wetlands: A Case Study of a Recreational Housing Development," *Land Economics*, Vol 61, No. 1, pp 1-9.

Headquarters, Department of the Army. 1983. "Economic Considerations," Engineer Regulation 1105-2-40, Washington, DC.

Henderson, Jim E. 1989. "Plan of Study for Determining Economic Values of Aquatic Plant Management," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 11-18.

Milon, J. Walter, Yingling, Jay, and Reynolds, John E. 1986. "An Economic Analysis of the Benefits of Aquatic Weed Control in North-Central Florida," Economics Report 113, Food and Resource Economics Department, University of Florida, Gainsville, FL.

Osborne, John A. 1982. "Herbicide vs. Grass Carp," *Aquatics*, Vol 4, No. 2, pp. 13-14.

Shireman, Jerome V., Colle, Douglas E., and Canfield, Daniel E., Jr. 1986. "Efficacy and Cost of Aquatic Weed Control in Small Ponds," *Water Resources Bulletin*, Vol 22, No. 1, pp 43-48.

Wunderlich, William E. 1968. "Aquatic Plant Control and the Dollar," *Hyacinth Control Journal*, Vol 7, pp 28-29.

Feasibility of Using Expert Systems in Aquatic Plant Control

by
Larry R. Lawrence* and Hal Lemmon**

INTRODUCTION

Twenty years ago the concept of artificial intelligence was introduced. Computer scientists felt that it was possible to develop computer programs with the knowledge or intelligence to provide answers to questions when asked. They found that too often the questions were too complex to be addressed and realized that the computers of that day were not capable of holding the large amounts of information needed. The scope of areas or domains to be addressed have been narrowed with the development of the concept of expert systems. This has corresponded with the development of desktop and laptop microcomputers. More and more people are now using them and have found they are not nearly as difficult to use as first thought. The microcomputers have evolved to the point at which they have as much computing power and storage as mainframes of the past. For these reasons, expert systems have become the solutions to the management of many voluminous information data sets.

An expert system is defined as a computer system that has a wide base of knowledge in a restricted domain, and uses complex inferential reasoning in the development of solutions. The key here is a wide base of knowledge in a restricted domain. This has reduced the size of the knowledge base, and therefore the computer can store all of it. The expert system consists of three basic units: the knowledge base (facts and rules), the inference engine (control of the use of rules), and the user interface (user/expert system interaction). The knowledge base contains facts and expertise about the domain. The inference engine decides the order of rule execution and makes inferences based on the knowledge base and input from the user. The user interface is the mechanism whereby the user can interact with the expert system (McGraw and Harbison-Briggs 1989).

The process of building an expert system is often referred to as knowledge engineering. It involves an interaction between the expert system builder, referred to as the knowledge engineer, and one or more human experts in some problem area. The knowledge engineer extracts from the human experts their procedures, strategies, and rules of thumb for problem solving and builds this knowledge into the expert system, as illustrated in Figure 1 (Waterman 1968).

An Expert Systems Workshop was held at the US Army Engineer Waterways Experiment Station (WES) on 15 February 1989. The objective of the workshop was

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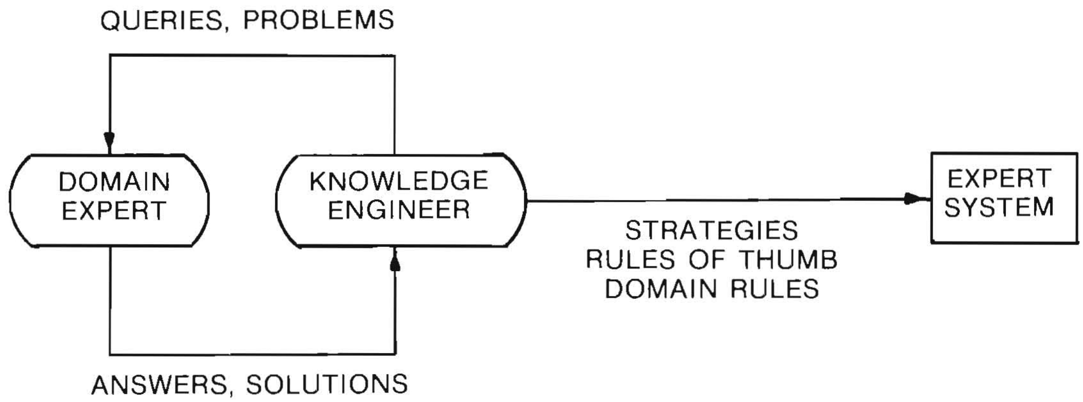

Figure 1. Process of constructing an expert system

to determine if expert systems can be used to assimilate the knowledge and reasoning required to control aquatic plants. Workshop participants included field users of aquatic plant control technology, researchers in the discipline, and expert system developers.

The workshop discussions identified a number of areas in which an expert system could assist in aquatic plant control. These include control applications technology, regulatory considerations, use of new control methods, orientation of new personnel, and dissemination of research findings.

CONTROL APPLICATIONS TECHNOLOGY

When a program manager attempts to assess an aquatic plant control problem, the amount of information available on a given control, say a chemical herbicide, is overwhelming. There are newsletters, journal articles, knowledgeable personnel, books, and manuals from which relevant information is available. When a manager requests a literature search, he can be overwhelmed simply by the number of articles available, without even attempting to read or understand them. What the manager needs is an expeditious answer regarding the application of a control to a specific problem, without being inundated with information from which he can glean little knowledge. The purpose of an expert system is to convert information into knowledge that can be used in the field. The expert system can use input from the user to have the computer sift through all of the information available and identify relevant solutions to the problem.

REGULATORY CONSIDERATIONS

The use of virtually all aquatic plant controls is regulated to some extent, and regulations are constantly changing. A control may be legal for application one year and illegal the following year. Laws governing a treatment often vary by State. It is difficult for a manager faced with an aquatic plant problem to have a full grasp of the meaning of a regulation, and how it applies to his problem in a particular State. Workshop participants determined that an expert system could provide the manager with current information regarding the regulation of controls.

The expert system could contain knowledge about the regulations which are appropriate to aquatic plant control. For example, if the use of a certain chemical is illegal in California but legal elsewhere, the expert system asks the user to input the State in which the application is to be made. If it is California, then that chemical would be ruled out as a potential control agent. If the manager notices that a chemical used last year is not recommended by the expert system, the expert system can be queried as to why the chemical was not recommended. The expert system would respond that use of this chemical is no longer allowed in the manager's area. The expert system could also contain considerations of impacts on endangered species. There are sometimes problems with different institutions having different lists. The expert system would search its data base containing all lists and inform the user of proper considerations.

NEW PRODUCTS

Field personnel pointed out that when a new method is approved for the control of aquatic plants there is usually a deficiency of both knowledge and experience about the product. The manager has innumerable questions about the method's effectiveness and use for the specific waterways for which he is responsible. The information available is often sketchy and too general or, conversely, too voluminous to find the information appropriate to the application. A current, accurate, well-managed expert system provides the knowledge in a form specifically useful to the aquatic plant manager. The expert system asks the manager questions about the plants to be controlled, as well as specific details about the site, such as water temperature, depth of water, or other environmental factors. If the new product is appropriate, the expert system automatically recommends it with instructions on how it should be applied for the local conditions.

ORIENTATION OF NEW PERSONNEL

It was noted that there is a continuous flow of new personnel into aquatic plant management positions as people are transferred, retire, or accept other positions. Considerable time and training are required before a new manager can be expected to be knowledgeable in available control methods and their proper use. An expert system allows a new employee to benefit from the accumulated knowledge. Thus, the expert system reduces training requirements for new personnel and allows them to be productive in a shorter time frame.

RESEARCH FINDINGS

It is extremely difficult for the manager to remain knowledgeable of the latest research developments. Participants pointed out that WES and other organizations conduct research and accumulate experience on methods of control. Technology transfer of the knowledge may be delayed or may be ineffective. For example, research may develop treatment schedules and methods that are superior to the original documented recommendations. A specific treatment method that a manager needs may be contained in a technical report or article that addresses a large number of new technologies, thereby escaping the manager's attention. The field application of aquatic plant controls can be thought of as an extension of research, with more experience and knowledge gained by the managers each year. A superior method of using a control may be identified by persons in the field actually doing the work. From experience, a manager may learn that certain techniques that should work do not work under his particular conditions. However, it is extremely difficult to disseminate this kind of knowledge. An aquatic plant expert system would be under constant development, and the latest research and experience would be incorporated. By accessing the expert system, the manager has the best chance of making full use of research results. The workshop participants emphasized that District personnel could not keep the expert system updated. They suggested that a formal procedure be established to evaluate and update information concerning successes and failures during field activities.

SUMMARY

It was the consensus of the workshop group that building an expert system for aquatic plant management and control is both desirable and feasible. A further recommendation made by the group is that it would not be wise to attempt to address the overall expert system initially. A more prudent approach would be to build a small prototype expert system. This would give users the opportunity to evaluate the capabilities of an expert system and to demonstrate its effectiveness. Workshop participants determined that an excellent prototype would be the knowledge contained in the manual "Aquatic Plant Identification and Herbicide Use Guide; Volume II: Aquatic Plants and Susceptibility to Herbicides" (Westerdahl and Getsinger 1988).

In summary, the workshop participants suggested several areas in the aquatic plant program that could be improved with the development of expert systems. An expert system for aquatic plant control would provide a single source for knowledge, thus eliminating lengthy searches and conflicting information. An expert system would provide a ready means for field personnel to capture knowledge and pass it forward to other persons in the field. The knowledge should still be verified by the appropriate experts, however. By placing the new knowledge into an expert system, this knowledge becomes available to other field personnel, increasing their effectiveness. Participants determined that an updated expert system would provide the manager with current information regarding the regulation of controls. Aquatic plant control knowledge contained in an expert system would reduce the training requirements for new personnel and allow them to be productive in a shorter time frame. An aquatic plant expert system would be under constant development and would incorporate the latest research results.

ACKNOWLEDGMENTS

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REFERENCES

McGraw, Karen L., and Harbison-Briggs, Karen. 1989. *Knowledge Acquisition: Principles and Guidelines*, Prentice-Hall, Englewood Cliffs, NJ.

Waterman, D. A. 1986. *A Guide to Expert Systems*, Addison-Wesley, Menlo Park, CA.

Westerdahl, H. E., and Getsinger, K. D. 1988. "Aquatic Plant Identification and Herbicide Use Guide," Technical Report A-88-9 (2 vols), US Army Engineer Waterways Experiment Station, Vicksburg, MS.

BIOLOGICAL CONTROL OF AQUATIC PLANTS

Biological Control Technology Development: An Overview

by
Alfred F. Cofrancesco, Jr.*

DIRECT ALLOTTED RESEARCH FOR FISCAL YEAR 1989

The FY 89 direct allotted biological research was apportioned among nine work units, which are described below.

- *Biological Control of Hydrilla Using Insects.* Approval for release of *Hydrellia* n. sp. (*balciunasi*) in the United States was received from the US Department of Agriculture Technical Advisory Group (USDA-TAG). Additional information was requested from the USDA-TAG on the petition to release *Bagous* n. sp. Release sites are still being monitored for *Hydrellia pakistanae*; however, some difficulties in recapturing the insect have occurred. Requests have been submitted to have one of the moths from Australia introduced into US quarantine facilities.
- *Biological Control of Eurasian Watermilfoil Using Plant Pathogens.* Two field tests of a commercial formulation of *Mycoleptodiscus* were conducted. Reductions in biomass were noted at the WES pond facility in Lewisville, Texas, and the pond studies in Amherst, Massachusetts. An Environmental Use Permit will be requested from the US Environmental Protection Agency in FY 90 so that larger field applications can be conducted.
- *Biological Control of Hydrilla Using Plant Pathogens.* The second small-scale replicated field test was conducted in Texas to verify the results that were reported last year. Significant reductions in biomass were again recorded 4 weeks after treatment. In FY 90, formulation development will begin.
- *Biological Control of Waterlettuce with Insects.* The USDA-TAG requested additional information on *Namangana pectinicornis*. This information has been submitted, and we expect to have this insect released in FY 90.
- *Management of Submersed Aquatic Plants with Genetically Engineered Microorganisms.* A rapid screening process for microorganisms has been developed. In FY 90 researchers will complete the screening of all microorganisms and the determination of which are host specific.
- *Management of Waterhyacinth Using Insects and Herbicides.* Weevil feeding studies of herbicide-treated plant material have been completed, and results show changes in feeding preference. A field study was completed in Louisiana, and insect populations were observed to move from treated to untreated sites. In

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addition, wing muscle development occurred in insects exposed to herbicides. In FY 90 a final report will be produced.

- *Determining Feasible Integrated Control Combinations for Aquatic Plant Management Using Expert Systems.* The second-generation system was completed, and new criteria for prioritizing combinations have been added. In FY 90 a report will be produced on how the system operates.

- *Temperate Biocontrol Insects for Eurasian Watermilfoil and Hydrilla.* This was a new start in FY 89. Overseas contacts were established, and USDA personnel made their first collection trip. Numerous insects were found feeding on the target plants. Surveys will continue during FY 90.

- *Biological Management of Aquatic Plants with Allelopathic and Competitive Species.* This was a new start in FY 89. A screening method was developed to test allelopathic materials, and a wide range of test plants have been collected. Research in FY 90 will center on screening these test plant to determine which exhibit allelopathic characteristics.

SUPPORT PROJECTS FOR FISCAL YEAR 1989

Two projects were addressed in support of Corps of Engineers Districts:

- *Biocontrol of Waterlettuce.* The 1987 release of *Neohydronomus pulchellus* at Kramer Island has produced a complete dropout of waterlettuce plants at the release and control sites. Extensive weevil damage can be seen at many of the *N. pulchellus* release sites. The weevil is now established at over 50 sites in Florida.

- *Texas Waterhyacinth Study.* This research has presented information on the changing nutritional status of the plants and correlated it with changes in the reproductive condition of the insect. This type of information is critical in the development of a functional model.

Biocontrol Agents From Temperate Areas of Asia

by
Joseph K. Balciunas*

INTRODUCTION

Insects from India and Australia appear promising for controlling hydrilla in the southern United States. However, the continued northward expansion of hydrilla's range is increasing the need for insects to control this noxious weed in more temperate locations. Insects to control Eurasian watermilfoil, a serious aquatic weed throughout most of continental United States, are not presently available. Accordingly, the US Army Corps of Engineers (CE) has agreed to financially assist a USDA-ARS effort to locate and test potential control agents for these two weeds. This research will be based at the newly established ARS-Chinese Academy of Agricultural Sciences cooperative biological control laboratory. The personnel involved in this new project appear enthusiastic, and the facilities, which are already adequate, should improve markedly as funds become available over the next few years. Dr. Wang Ren, Director of the new Sino-American Biological Control Laboratory (SABCL), has excellent contacts with a network of scientists and officials across China, and this should allow sampling in almost any portion of this vast country.

My examinations of herbarium specimens, coupled with conversations with various botanists and weed scientists, demonstrated that both hydrilla and milfoil are widespread throughout most of China. However, my collecting in Beijing and in Szechwan and Hunan Provinces showed that hydrilla is usually more abundant, at least in these areas. My preliminary surveys, although extremely limited, indicated a promising assortment of potential biological control agents for hydrilla. These included an aquatic weevil, two species of aquatic pyralid moths, two species (probably *Hydrellia* spp.) of ephydrid flies, chironomid midge larvae, and caddisfly larvae.

The prospect of finding biological control agents in China for these two aquatic weeds appears promising. However, until the Chinese cooperators become more familiar with the collection, rearing, and testing of aquatic plant herbivores, progress will be highly dependent on the amount of time I can personally spend in China. Thus, overseas training, either in Australia or Florida, for the principal Chinese assistant is highly recommended. Likewise, an intensive Chinese language course for myself would make future trips more productive.

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PURPOSE

The goals for my first trip to China were (a) to familiarize myself with the facilities and personnel at the recently established SABCL in Beijing, (b) initiate the training of the Chinese assistant cooperating on the Biological Control of Temperate Aquatic Weeds (TAW) Project, (c) learn the distribution and abundance in China of the two primary target plants (hydrilla, *Hydrilla verticillata*, and Eurasian watermilfoil, *Myriophyllum spicatum*), (d) meet with scientists and officials in other provinces who might act as local cooperators, (e) meet taxonomists who might assist in the project, (f) collect natural enemies of hydrilla and milfoil in Beijing and in Szechwan and Hunan Provinces, and (g) plan next year's research in conjunction with the Director of the SABCL.

TRAVEL DETAILS

Beijing (1-6 September)

Originally, I had planned to make two trips to China this year, each lasting about one month. Due to tensions surrounding the quelling of the Beijing student unrest in June, the US State Department did not allow official visits until late August. After hurried preparations, I departed on 31 August and arrived in Beijing on Friday evening, 1 September. Dr. Ren met me at the airport, accompanied by Mr. Wang Yuan, the research entomologist who would accompany me throughout my visit. During my stay in Beijing I found this city of 8 million to be very quiet. The most noticeable sign of martial law was the presence of heavily armed soldiers stationed at most major intersections. Access to some areas of Beijing, such as Tiananmen Square, was also restricted, and I was advised to always have a staff member from SABCL with me while collecting or traveling in the city.

Saturday morning, Dr. Ren gave me a tour of the SABCL facilities. These are located inside the Biological Control Laboratory (BCL), which is situated on the campus-like grounds of the Chinese Academy of Agricultural Sciences (CAAS). The SABCL has been allocated three rooms, each about 15 by 25 ft, on the bottom floor of the BCL Building. Twenty large Berlese funnels for extracting herbivores from aquatic weed samples had already been constructed and were available for use by the TAW project. Additional rearing and preparation rooms are available on the same floor, which also houses the quarantine. About the same size as the Gainesville, Florida, quarantine (though lacking Gainesville's attached greenhouses), this quarantine is thoughtfully laid out and reasonably well-equipped. It even includes three modern photomicroscopes. The four-story BCL is located inside its own small, walled compound, which also contains a very crowded greenhouse, experimental gardens, and staff housing.

My discussions with Dr. Ren concentrated on the fiscal aspects of the project. He and his supervisors were especially concerned that funds from the USDA had not yet arrived. I promised to check on the TAW Project funds. Afterwards I met the Deputy Directors of the CAAS Biological Control Laboratory, Professors Wang Bao-yi and Ye Zhengchu. With Dr. Ren translating, I discussed the biological control of aquatic plants, emphasizing the successes of USDA and the historically beneficial association of the USDA and the CE. I also explained the goals and potential benefits of the new TAW Project.

Later I met Dr. Luca Fornasari, an entomologist from the USDA Rome Lab, and Dr. Sam Yang, a USDA pathologist from the Frederick Maryland Lab. Both are working on the biological control of leafy spurge, a serious rangeland plant in the United States. That afternoon, I also had the privilege of meeting the founder and Director Emeritus of the BCL, Professor Qui Shi-Bang.

Sunday morning was primarily devoted to sightseeing in Beijing with Drs. Ren, Yang, and Fornasari. Dr. Ren and I continued our planning discussions, until the three of them departed for the airport for their trip to Inner Mongolia and northwestern China. They would collect natural enemies of leafy spurge in these provinces and return on 28 September.

Monday was spent purchasing equipment for my trip to the provinces and sightseeing with Mr. Yuan. Tuesday morning we spent several hours at the herbarium of the Academia Sinica, located at the Beijing Botanical Gardens. The herbarium was large, well maintained, and air-conditioned (the only air-conditioned government building I encountered). Mr. Yuan translated the labels of the hydrilla specimens, allowing us to obtain information on distribution, phenology, and habitat. Specimens of hydrilla were present from most of China's 30 provinces.

Later, I went to the American Embassy, where I discussed my project with Mr. Jonathan Gressel, the Agricultural Trade Officer, and picked up a USDA check for Dr. Ren, a portion of the funds he had been awaiting.

Wednesday was spent packing our field equipment, making final arrangements for our trip to the provinces, and sending faxes to the United States and Australia. In the afternoon, Mr. Yuan and I boarded our 2-hr flight to Chengtu.

Chengtu, Szechwan Province (6-10 September)

At 8 p.m. we arrived in Chengtu, the capital city (population approximately 2.5 million) of the southwestern province of Szechwan. Even at that late hour, a delegation from the Szechwan Academy of Agricultural Science (SAAC) was there to greet us. Among those welcoming us were Professor Wang Tin Quan, Director of the Weeds Laboratory and several officers from the Foreign Affairs Office of the SAAC.

At SAAC the next morning (Thursday, 7 September), Mrs. Jinrong Xie, the Deputy Director, formally welcomed me and explained the organization and role of SAAC. The Academy consists of 14 divisions and employs 2,500 staff, including 200 associate professors and 500 research assistants. Director of the Institute of Plant Protection (IPP), Mrs. Ki Qun, explained that the IPP is a very important division of SAAC, since Szechwan is one of the major rice-producing regions of China. Professor Quan then explained his recently completed 3-year survey of aquatic plants in Szechwan Province. The results were especially interesting--589 species belonging to 80 families. Almost half a million acres of Szechwan are treated annually with herbicides, an enormous cost for a developing nation. Alligatorweed is one of the most important nuisance plants, especially in rice-growing areas. The alligatorweed insects the USDA is providing for China were of very great interest, although Chengtu may prove to be too cool for the *Agasicles* beetle, the most damaging insect.

That afternoon I gave a lecture to several dozen IPP researchers and administrators, along with several professors and their students from Szechwan University. Translated by Mr. Yuan, I spoke about the biological control of aquatic plants, the successes of the USDA in this field, and the goals of my new projects. Mr. Yuan, who has been working with the alligatorweed insects received from USDA, then briefly updated this project.

Friday morning, Professor Quan and other IPP support staff drove Mr. Yuan and me to Shuangliu County Agricultural Bureau, about 45 minutes north of Chengtu. There, we were joined by a large contingent of Bureau personnel, including three deputy directors of the Bureau. Our large field party, occupying two buses, then drove to a rice-growing area 30 min distant, where after walking a kilometer across the paddy fields, we arrived at a small pond, which unfortunately contained only a few sprigs of hydrilla. However, on our return to the Bureau, hydrilla was noted in a roadside canal. I instructed Mr. Yuan in the proper methods of collecting a sample and completing the field data sheet. At the Bureau Headquarters, I gave a shortened version of the previous day's lecture to an audience of approximately 30 Bureau personnel. I also met the Bureau Director, Zhao Shungqun. Using a Bureau laboratory, Mr. Yuan and I spent more than 2 hr searching the collection for natural enemies and preserved three moth larvae. On later inspection, these appeared to resemble *Parapoynx diminutalis*, the Asiatic pyralid moth that is already present in the United States.

We arrived at Chengtu's Szechwan University at 5 p.m. and met Professor Fu, who guided us to aquatic sites in Chengtu that he knew had contained milfoil or hydrilla. Several hours of searching the various sites proved fruitless, probably due to increased turbidity from recent rains.

Saturday morning, Professor Quan and his assistants drove us north to Pi County, where we collected hydrilla at a small farm pond. We continued 150 km north to Dujiang Dam, a scenic and historical area. Built over 2,500 years ago, this dam is one of mankind's earliest feats of civil engineering and the first to tame a major river. The refurbished structure still provides flood protection and irrigation for a large portion of Szechwan Province. The Min River, because it drains the mountainous areas of western Szechwan, was very cold and swift and did not contain any aquatic vegetation. Returning to the IPP laboratory in Chengtu that evening, we processed the sample from Pi County. Only one natural enemy was found, but this moth larva was distinctly different from those found the previous day.

Sunday was spent sightseeing and resting. Late that night we departed on the overnight train to Chongqing.

Chungking, Szechwan Province (11-14 September)

Chungking, "The Mountain City," lies at the confluence of the mighty Yangtze and Chia-ling Rivers. With a population of 4 million, Chungking is Szechwan's largest city and the largest industrial center in southwest China. On arriving at the Chungking railway station Monday morning (11 September) we were met by Mr. Zhang Yuwen, a lecturer from Yuzhou University. After checking into our hotel and briefly reviewing our Chungking itinerary, Mr. Yuwen and Mr. Yuan departed to meet Professor Diao Zhengsu, the aquatic botanist from Yuzhou University. Professor Diao was returning early from a field trip in far northwest China, just to meet with me! Over 70 years old, Professor Diao has numerous publications on Chinese aquatic plants, including a book with over 200 illustrations that he personally drew. Professor Diao assured me that hydrilla and milfoil were frequently found in the vicinity of Chungking. A reservoir, Chang Sho Lake, 200 km north, should contain both species in abundance.

Before dawn the next morning, Messrs. Yuwen and Yuan and I set off in a rented car for the reservoir. It took over five bone-jarring hours to cover the twisting 220 km. However, no aquatic vegetation was visible in Chang Sho Lake. We did find small amounts (not enough for a sample) of hydrilla in some nearby streams. Eventually, we located a large bed of milfoil in a nearby river and collected a sample. We immediately examined this at a laboratory provided by Chang Sho Lake Fisheries Department. The only insect damage observed was caused by caddisfly (Trichoptera) larvae. The return trip was equally grueling, and we did not return to our hotel until nearly midnight.

Wednesday morning, Mr. Yuan and I drove to the town of Bei Bei to meet Professor Diao. While only 35 km away, the drive took over 2 hr because Chungking's few roads cannot cope with all the traffic of this industrial city. Professor Diao took us to Bei Bei Botanical Gardens, where several ornamental ponds contained hydrilla. After making a collection, we had lunch, then drove to Yuzhou University where I was greeted by the senior administrators. These included Vice Presidents Chen Dapeng and Dai Hongmin; Dr. Zhang Decao, Chairman of the Biology Department; and Mr. Wang Xiaocheng, the Foreign Affairs Officer. I arrived over 90 min late for my scheduled lecture, but the room was packed with over 100 students and staff. My translated lecture on biological control of aquatic weeds was well received, and numerous questions ensued. After the lecture, I met with the administrators and discussed my research. Professor Diao showed some herbarium specimens and presented me with some of his reprints. Then Mr. Yuan and I, assisted by four students, processed our sample from the Botanical Gardens. Two moth larvae, similar to *Parapoynx diminutalis*, were found and preserved.

On Thursday morning, Mr. Yuwen and Mr. Xiaocheng took us to the harbor to see us off on our 2-day trip down the Yangtze River to Dong Ting Lake.

Yangtze River (14-15 September)

Our trip down the Yangtze River was pleasant, relaxing, and frequently scenic, although the toilets left much to be desired. No aquatic vegetation was observed in the extremely swift and turbid water.

Dong Ting Lake, Hunan Province (16-18 September)

On our arrival Saturday morning at Yue Yang, one of the major cities on Dong Ting Lake, we were met by Professor Li Hongke from the Hunan Academy of Agricultural Science (HAAS). He had brought a car and driver from the Academy, located in Chang-sha, 6 hr distant by a terrible road. In Yue Yang, I was welcomed by the Director of the Dong Ting Lake Management Bureau (DTLMB), Mr. Li Yiju. Dong Ting Lake is huge, the second largest in China, and its fisheries and agriculture are of immense importance to China. The Bureau manages this vast resource and many of the industries located on its shores. I met Mr. Yan Jianyong, the Director of the Bureau's Reeds Research Unit. The marsh reeds growing in and near the lake are farmed and harvested for a variety of uses, including fuel, baskets, and mats. These reed products are worth 2 billion yuan ($540 million US) annually.

The next morning, Professor Hongke, Mr. Yiju, Mr. Jianyong, and I crossed a portion of the lake by ferry and then drove along the north shore to the Yi Meng Zha Irrigation and Electricity Station. There we boarded a large boat, from which we surveyed West Small Lake, a large embayment of Dong Ting Lake. Wave action had fragmented most of the submersed aquatic plants, but milfoil, *Ceratophyllum*, *Potamogeton*, and *Najas* were readily observed. We collected milfoil fragments from the shore as well as making several collections of hydrilla from a marsh and a farm pond.

During lunch, I learned that blood fever (*Schistosomiasis japonicum*) was endemic to Dong Ting Lake and that virtually all the locals were infected. Coupled with the chlorogin-resistant malaria that occurs here, visiting this part of Hunan Province is quite unhealthy, especially for foreigners.

After lunch, I presented my usual seminar on biological control of weeds to an audience of about 24 Bureau staff. The rest of the afternoon was spent processing our three collections, assisted by numerous station staff. Amazingly, none of these samples produced any natural enemies.

On Monday morning (18 September), Professor Li Hongke, Mr. Yiju, Mr. Jianyong, and Mr. Yuan joined me on a large DTLMB vessel. After a 2-hour journey across Dong Ting Lake, we arrived at Bei Zhou Reeds Farm on the southern shore of the lake. There, we transferred to a smaller boat, then surveyed some of the canals in the vicinity. The only submersed plant I observed was *Ceratophyllum*. After lunch, we did collect hydrilla from a pond beside the farm. During the boat trip back to Yue Yang, we processed this sample. Besides several small moth larvae, two adult weevils, similar to ***Bagous***, were found. These I set up on a sprig of hydrilla, on which they fed readily.

Early Tuesday, Mr. W. Yuan, Professor Li Hongke, the driver, and I left for Chang-sha in the HAAS minibus.

Chang-sha, Hunan Province (19-21 September)

The 250-km trip to Chang-sha, the capital of Hunan Province, took almost 6 hr. Entering the outskirts of the city we stopped at numerous aquatic sites and examined them for hydrilla and milfoil. That evening, we returned to a small pond where hydrilla was the most common plant and set up the black (ultraviolet, UV) light beside a white sheet hanging on our minivan. The number and variety of insects attracted was disappointing, although I did collect a single *Parapoynx* (very similar to *P. diminutalis*) and some *Hydrellia*-like flies.

The next morning we went back to one of the ponds that had contained hydrilla the day before. Now it was almost gone! Two young men in waders were "harvesting" the hydrilla to feed to pigs and fish. We convinced one of them to share his harvest with us. We then went to the Plant Protection Institute (PPI) of HAAS. There I met the Director of PPI, Mr. Ji-Rong Tian. An entomologist who had studied in Imperial Valley, California, he was the only scientist I met during this trip, apart from Dr. Ren, who readily understood English!

I also met Professor Xia Shong Ling, head of the Biological Control Lab at HAAS. Almost 80 years old, he is considered the father of biological control in China. He had read some of my publications, which we discussed. Then, we visited Professor Hongke's greenhouse where he was growing some hydrilla. He also has been cooperating with Dr. Ren and Mr. Yuan in releasing *Agasicles* in Hunan Province, and he showed me his colony of this chrysomelid beetle. That afternoon we processed the hydrilla sample collected in the morning. Only one small *Parapoynx* larva was found.

On Thursday morning, Mr. Yuan and I boarded our flight back to Beijing.

Beijing (21 September-2 October)

The remainder of my trip was spent in Beijing, intensively training Mr. Yuan to identify aquatic plants and to collect, identify, and preserve aquatic plant herbivores. During this period, we examined various aquatic sites in Beijing and made collections at three locations. A wide, shallow canal with concrete walls, near the White Peacock Department Store, was choked with a dozen different submersed aquatic plants, including milfoil and hydrilla. We collected the latter, and not only manually searched the sample but also used the new Berlese funnels to extract insects. Larvae of the leaf-mining *Hydrellia* fly were found, especially in the Berlese sample. At another canal, this one in southwest Beijing, 1 kg of hydrilla (wet weight) produced over 200 larvae of *Hydrellia*. This sample also contained numerous chironomid larvae, which burrow into hydrilla stems. On Wednesday evening (27 September) we returned to this canal and collected more of these insects by attracting them with our UV light.

Milfoil was present at many locations in Beijing, but was usually too sparse for efficient collecting. Finally, we were able to locate vast beds of milfoil at the lake at the Summer Palace. Unfortunately, the milfoil was no longer reaching the surface, and not surprisingly, this sample did not produce any herbivores.

Mr. Yuan soon grasped the basics of collecting and processing aquatic plant samples. He came to understand which field and laboratory data were required, and how they should be recorded. Teaching him to identify aquatic insects proved to be a problem because he was unfamiliar with specialized entomological terms. Many long hours were spent with an English-Chinese entomological dictionary and in making crude drawings of important insect characteristics. A course in entomology at an Australian or an American university, coupled with training in the rearing and testing of aquatic biocontrol agents, would prove exceptionally beneficial to Mr. Yuan and our project. I will also try to have some appropriate texts, especially on the taxonomy of aquatic insects, sent to SABCL.

On Saturday (23 September), shortly after my return to Beijing, while I was at SABCL, I had the opportunity to meet Dr. R. D. Plowman, Director of ARS, and Dr. E. B. Knipling, Director of the Beltsville Research Center, who were visiting the Academy. I briefly discussed with them my project, my findings on my recent trip to the provinces, and my impressions of SABCL.

On Tuesday morning Mr. Yuan and I returned to the Beijing Herbarium, where I met Professor Chen Yao-Dong. He is probably China's most active and eminent aquatic botanist. His numerous taxonomic publications indicate his productivity and his awareness of the relevant taxonomic research in other countries. His interest in the ecological requirements of aquatic plants is evidenced by his publications comparing aquatic plant distributions in different areas of China. He agreed to identify our plant specimens from Beijing and the provinces. He also agreed to cooperate in our future research, including, if feasible, accompanying us on one of our collecting trips to the provinces.

On Thursday evening (28 September), CAAS hosted a reception for the foreign experts visiting the Academy. Here I met some of the top administrators from the Ministry of Agriculture and the CAAS. These included Wang Lianzheng, Vice Minister of the Ministry of Agriculture; Liu Congmeng, Director of the Department of International Cooperation at the Ministry; Professors Liu Geng-Ling and Liu Zhicheng, both Vice Presidents of CAAS; Professor Chen Wanjin, Deputy Secretary General of CAAS; Professor Huang Jizhang, Deputy Director of CAAS; and Zhang Cuiping, Project Officer of the Foreign Affairs Division of CAAS.

I spent Friday and Saturday (29 and 30 September) with Dr. Ren, discussing the results of my visit and planning the research for 1990. Dr. Ren agreed to accompany me on my next visit to China, in July 1990, when we would most likely visit Inner Mongolia. During my second trip in mid-September I would review the accomplishments of 1990 and I would most likely revisit some of the more promising sites from my 1989 trip. We agreed that the chief Chinese assistant for the aquatic weed project (probably Mr. Yuan) should, if possible, go to Australia for training and instruction. Likewise, to better understand and supervise this project, Dr. Ren would like to visit our Florida laboratories in Gainesville and Fort Lauderdale and receive instruction in the rearing and testing of aquatic biological control agents.

Sunday, 1 October, was the 40th anniversary of the founding of the People's Republic of China. In honor of this occasion, on Friday evening, the Chinese Government hosted an immense reception for 1,300 foreign experts in the Great Hall of the People at Tiananmen Square. We three USDA experts visiting the Academy, as well as some foreign teachers at the Academy, were accompanied to the Great Hall by two staff members from the CAAS's Division of International Cooperation and Exchange, Director Han Lin and Project Officer Mrs. Zhang Ferong. The diversity of dignitaries present, the delectable Chinese appetizers, and the majestic splendor of the Great Hall were quite memorable. The politicians' speeches were relatively brief.

On Monday (2 October), I reviewed with Mr. Yuan and Dr. Ren which specimens and data were to be shipped to Fort Lauderdale at the end of the month. At noon, both accompanied me to the airport, and I departed for Australia.

Quarantine Laboratory: Research for Hydrilla Control

by
Gary R. Buckingham*

INTRODUCTION

The hydrilla quarantine research project completed studies during 1989 with two Australian insects. Permission was received for release of a leaf-mining fly, and a request for release from quarantine of a stem-boring weevil was submitted to the federal Technical Advisory Group (TAG). Rearing of both the Indian and Australian leaf-mining flies was increased to aid the field release effort of the USDA/ARS Fort Lauderdale program. The Indian hydrilla tuber weevil was temporarily established in a field experiment during a lake drawdown. Unpublished reports and publications were surveyed for information about host range tests with previously released and rejected agents for biocontrol of aquatic weeds. A summary of the initial results of this survey is presented.

AUSTRALIAN LEAF-MINING FLY

A summary of the biology and host range studies of this leaf-mining fly, *Hydrellia* n. sp. A, was included in my presentation last year at the 23rd Annual Meeting.** Permission to release this fly from quarantine was obtained from Federal and state officials in May 1989. Shipments were sent to Dr. Ted Center in Fort Lauderdale during May for establishment of his colony. When Dr. Center began field releases in late summer, we increased our rearing program to provide him with additional material for release. We also reared and shipped the Indian leaf-mining fly, *H. pakistanae* Deonier, to Dr. Center.

In November 1989 Dr. Balciunas sent us a small shipment of *Hydrellia* n. sp. A larvae from Australia. The progeny of the adults obtained from these larvae were scheduled to be sent to Fort Lauderdale for immediate field release to increase the genetic base of the field flies. Unfortunately, most larvae were parasitized by a small wasp, so the few flies that emerged were used to establish a colony. Shipments to Fort Lauderdale are scheduled for the second or third generation.

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**G. R. Buckingham. 1989. "Quarantine Work--Insect Biocontrol for Hydrilla," Proceedings, *23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, pp 28-33.

AUSTRALIAN STEM WEEVIL

Host range tests were completed with this stem-boring weevil, *Bagous* n. sp. Z, and a request for permission to release it from quarantine was submitted to the federal TAG. It will probably be early 1990 before we receive a response from them. Females oviposit in submersed hydrilla stems, which break apart due to adult feeding and float to shore carrying the developing larvae inside.* This species has a wider laboratory host range than either the Indian or the Australian flies, but it also appears potentially to be more rapidly destructive to hydrilla than the flies. Fly populations might be more destructive if they reach enormous numbers after many generations, but individual fly larvae are not as destructive as individual weevils. This weevil might thus be more amenable to mass release type programs than would the flies.

At least one generation was produced in the laboratory upon four species in the hydrilla family, Hydrocharitaceae, and upon three species in other families. These other species were *Ceratophyllum demersum* (1 adult), *Potamogeton perfoliatus* (8 adults) and *Najas guadalupensis* (10 adults). Because this nonhydrilla feeding was observed during the early stages of the project, Dr. Balciunas intensively collected hydrilla and its relatives in Australia for three years. Noticeable numbers of weevil larvae emerged from a few collections of *Vallisneria* and *Najas*, but the overwhelming numbers were from hydrilla. The nonhydrilla infestations were primarily during droughts after the hydrilla had been destroyed. Even though this weevil attacked a few native plants in our small laboratory cages, we do not believe it would present a risk to field populations.

For larvae to complete development, adults must cut the stems of the host plant so the broken pieces can float to shore. The most important larval feeding in the laboratory was on *Vallisneria americana* and *Elodea canadensis*. *Vallisneria* leaves were rarely cut by adults in the laboratory because they were too wide. Thus, any larvae in them would not complete development. *Elodea* stems were heavily cut, but the plant is primarily a northern species of greatest abundance outside the expected range of importance of this weevil. *Najas* produced very few adults in the second generation, indicating that it is not an adequate host.

INDIAN TUBER WEEVIL

The Indian tuber weevil, *Bagous affinis* Hustache, was first released in Florida in 1987. Because its life cycle has evolved with cyclical drought periods, it is poorly adapted to Florida's climate. Larvae only attack hydrilla tubers in nonsaturated soil. A winter-spring drawdown at Rodman Reservoir near Palatka, Putnam County, Florida, provided an opportunity to test methods for establishment of this weevil. Although we believed that the cool season and the short drawdown duration of several months would not allow permanent establishment of the weevils, we hoped that we could establish them temporarily to at least demonstrate that it was possible.

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*Ibid.

Releases were made at four adjacent sites near Kenwood Boat Ramp after the draw-down was at maximum low-water level. Distances among the sites were not measured, but the greatest distance was about 600 m. Initial releases were made in January. Single releases were made at Site 1 (adults), Site 2 (eggs), and Site 4 (larvae and pupae). Three releases of adults were made at Site 3 from January to March. Small pieces of wood containing uncounted numbers of eggs and clay pots containing uncounted larvae and pupae were buried, and the locations were marked with small flags. Adults were released under small piles of hydrilla pulled from the water, but the locations were not marked.

Tuber samples were collected at the egg site in February and April and at the larval site in April and May by washing soil through a screen using a gas-operated water pump. Damaged tubers were recovered at the egg site on both dates, but only one damaged tuber was recovered in March at the larval site. Few larvae were found in the damaged tubers. We believe that the relatively low soil temperatures prevented the larvae from developing. Larvae collected in tubers in February completed development in our 27° C temperature cabinets, and fresh tubers collected in April produced adults in our colony. This suggested that the tubers were not completely resistant to attack, although a proportion might have been resistant.

During late April/early May, tubers were sampled at the two adult release sites. Surprisingly, we found the greatest number of attacked tubers at Site 1 where we made only a single release. We found only a couple of attacked tubers at Site 3 where adults were released three times. We believe that the principal reason for this difference is that we were fortunate to find the exact release location at Site 1. At Site 3 the piles of hydrilla beneath which the weevils were released had blown away. The locations had not been marked because we believed that the adults would disperse widely within a few days. A possible alternate explanation is that attack is greatest in heavy soils. Both Site 1 and Site 2 (egg release) had extensive clay, whereas Sites 3 and 4 were primarily sandy. Site 3, however, had provided much of the soil we used through the years for our laboratory colonies.

Because we found both mature larvae and first stage larvae at Site 1 three months after adults were released, we believe that these weevils were temporarily established at Rodman Reservoir. Unfortunately the water rose within a few days of our sampling, ending our tests and destroying the immatures. Adults might have survived for a short period, but they could not reproduce without exposed tubers.

HOST RANGE TESTING: HISTORY AND COMPARISON

Recently I began a literature survey of host range testing conducted during previous aquatic weed projects. Although I have not completed the survey, I would like to summarize some of the information that I have compiled. Four projects in the United States resulted in introductions of control agents. These projects, in chronological order, were against alligatorweed, waterhyacinth, hydrilla, and waterlettuce. Ten species of insects in eight genera were introduced after host range tests demonstrated they were safe. A few additional species were either rejected or found to occur already in the United States.

Surprisingly, the range of years that it took to test each of the various agents during each project was relatively constant. Two to three years were needed to complete tests with most species (range 1 to 4). The complexity of the testing program, however, has not remained constant. More and more plant species in a wider variety of families have been tested with each new project (Figure 1). This increase in the testing effort has occurred in spite of the absence of any biocontrol "mistakes."

Data for the following insects were used to represent the plant projects summarized in Figure 1: *Agasicles hygrophila* Selman and Vogt (alligatorweed), *Neochetina bruchi* Hustache (waterhyacinth), *Bagous* n. sp. Z (hydrilla), and *Namangana pectinicornis* Hampson (waterlettuce).

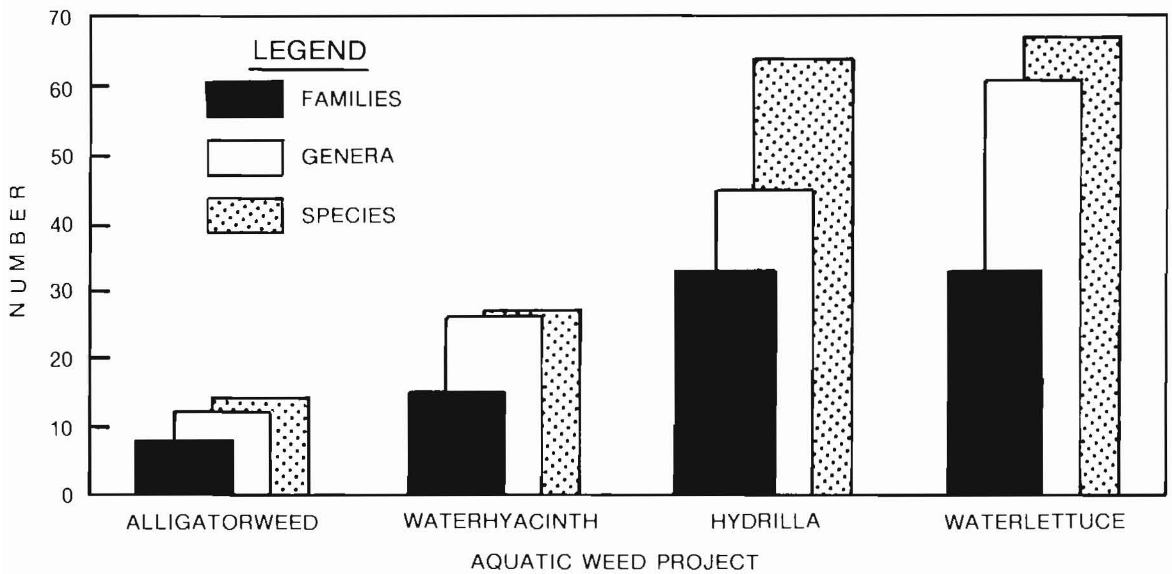

Figure 1. Comparison of the number of plants tested with representative insects during four aquatic weed projects. See text for the insect species representing each project

The increase in the testing effort has been followed by a decrease in laboratory host plant specificity. The three insects released against alligatorweed were tested against 14 to 30 species in six to eight families. Most of the species were ornamental or crop species in families related to alligatorweed. No development was noted on any of the test plants. A fourth alligatorweed insect, *Disonycha argentinensis* Jacoby, was tested against 54 species in 19 families. It developed on two test plant species and was rejected for introduction into the United States.

The two waterhyacinth weevils were tested against 26 and 27 species in 14 and 15 families. One weevil species developed on one test plant species. The last waterhyacinth insect introduced, the moth *Sameodes albiguttalis* (Warren), was tested against 56 species in 23 families and developed on two test plant species.

The three introduced hydrilla insects were tested against 41 to 51 species in 18 to 27 families. Development occurred on one to six species in one to three families. The waterlettuce weevil was tested against 37 species in 27 families, but there was no development on any test plants. Although some of these insect species developed in the laboratory on a few test plant species, the percentages developing were small and were not considered to be a threat to native plant populations.

It appears from these studies that hydrilla insects have a broader laboratory host range than do alligatorweed insects, although both groups are perfectly safe agents. These differences might be real, but they might be due to the increased number of plant species tested with hydrilla insects, to the increased testing of closely related aquatic plants instead of crop plants, or to the increased number of insects tested. A total of only 75 larvae and 75 adult alligatorweed fleabeetles were tested compared with a total of 5,252 larvae and 1,706 adult hydrilla tuber weevils.

My evaluation of previous host range testing programs is still incomplete, but it appears that we have greatly increased the scope of the programs, possibly without just scientific cause. Much of this was apparently done to satisfy increased expectations by the Federal committee. Continued inflation of the testing programs is probably not justified. Perhaps a test program that includes 30 to 50 plant species and 1,000 to 1,500 insects of each damaging stage would be a reasonable goal.

FUTURE STUDIES

We plan to continue rearing the two species of hydrilla leaf-mining flies until they are well established and no longer needed in Fort Lauderdale. This includes importation of new field-collected flies from Australia and Pakistan or India to increase our genetic base. When a response is obtained from the Technical Advisory Group concerning the Australian stem weevil, we will either ship it to Fort Lauderdale or continue studies with it if so directed by the TAG. Additional insects that might be imported for study, if available, include a stream-dwelling moth from Australia, a stem tip-mining midge from Africa, and temperate climate insects from China.

Release, Establishment, and Evaluation of Insect Biocontrol Agents for Aquatic Plant Control

by

Ted D. Center* and F. Allen Dray, Jr.**

INTRODUCTION

Projects employing nonnative insects against alligatorweed and waterhyacinth in the United States have demonstrated the effectiveness of "classical" biocontrol technology in aquatic ecosystems (Buckingham 1984). The success of these projects encouraged development of biocontrol programs addressing other aquatic weeds. As a result, the US Department of Agriculture, collaborating with the US Army Corps of Engineers, established several biocontrol projects, two of which are included in this report.

Hydrilla research

Hydrilla verticillata L. (hydrilla) is one of the most severe aquatic weed problems in the southern United States, infesting 57,000 acres in Florida alone (Schardt and Nall 1988). Worldwide faunal inventories initiated in 1981 resulted in the selection of several promising hydrilla herbivores for introduction into US quarantine (Balciunas 1982, 1983, 1984, 1985). The first insects selected were a tuber-feeding weevil, *Bagous affinis*, and a leaf-mining fly, *Hydrellia pakistanae*, from India. Host range tests confirmed that the diet of these insects is restricted to hydrilla (Buckingham 1988, 1989), and both have been released at field sites in Florida (Center 1989).

The worldwide faunal surveys were followed by more detailed studies in Australia, during which five candidate species were evaluated (Balciunas 1987; Balciunas and Center 1988; Balciunas, Center, and Dray 1989). Two of these, the leaf-mining fly *Hydrellia* n. sp. A and the stem-boring weevil *Bagous* n. sp. Z, were exported to US quarantine for more testing (Balciunas 1987, Balciunas and Center 1988). Another, the moth *Strepsinoma repititalis*, was eliminated from further consideration (Balciunas, Center and Dray 1989).

Bagous affinis was first released in April 1987 at Lake Tohopekaliga in central Florida (Center 1989). Nearly 6,600 adults and an unknown number of eggs had been released at 15 sites in Florida by the end of 1988 (Center 1989). No extensive postrelease studies have been undertaken, so we have been unable to confirm establishment at any of the release sites.

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Hydrellia pakistanae was first released at Lake Patrick in Polk County, Florida, during October 1987. Six additional releases--totaling about 22,000 eggs, 3,600 larvae, and 600 adults--were made through 1988 (Center 1989). Adult *H. pakistanae* were recovered from Everglades Holiday Park (in Broward County) 2 months after the flies' initial release there. Unfortunately, funding constraints have limited efforts to verify establishment of this insect.

Waterlettuce research

Pistia stratiotes L. (waterlettuce), while not as severe a problem as hydrilla, is still a substantial nuisance in southern Florida. The South American weevil *Neohydronomus affinis* Hustache (previously known as *N. pulchellus*) had been successfully applied against waterlettuce in Australia (Harley et al. 1984). So this weevil was imported to the United States in 1985 for host testing (Habeck et al. 1987). Subsequent studies confirmed that *N. affinis* was monophagous (Habeck et al. 1989), and it was approved for use in the United States.

In April 1987, 727 adult weevils were released at Kreamer Island in Lake Okeechobee, Florida (Habeck et al. 1988; Dray et al., in press). Between April 1987 and July 1988, over 7,500 laboratory-bred weevils were released at seven sites in southern Florida (Dray et al., in press). Self-perpetuating weevil populations had become established at several of these sites by October 1988 (Habeck et al. 1989; Dray et al., in press).

The moth *Namangana pectinicornis* is a common insect on waterlettuce throughout much of tropical Asia. Larval *N. pectinicornis*, particularly later instars (there are seven), are voracious feeders on waterlettuce. Napompeth (1982) reported that this moth achieved complete control of two infestations, measuring 4.5 and 10 km^2, within 6 to 10 weeks. Such an agent could supplement damage by *N. affinis* and native herbivores, providing control in areas where the weevil is ineffective.

Several researchers reported that *N. pectinicornis* larvae feed exclusively on *Pistia* (Sankaran and Ramaseshiah 1974, Suasa-Ard and Napompeth 1978, Mangoendihardjo et al. 1977). Based on this information, the moth was imported to US quarantine during 1986 and 1987 (Habeck et al. 1988). Host range studies confirmed that *N. pectinicornis* successfully completes its life cycle only on waterlettuce (Habeck et al. 1989), and permission to release this moth in Florida has been requested.

RESULTS AND DISCUSSION

Hydrilla bioagents

Table 1 lists the release sites and numbers of *Bagous affinis* released from April 1987 to September 1989. We conducted 11 releases during 1989, consisting of 4,125 adult weevils. Some of these releases also included egg-infested wood and larval-infested hydrilla tubers. Nearly 9,800 weevils have been reared (a very labor-intensive task) and released since this project's inception, despite the availability of only token funding.

Table 1
Releases of Hydrilla Tuber Weevil (*Bagous affinis*) in Florida During the Period April 1987 to September 1989.

Site	*Date*	*Number/Stage Released*
Lake Tohopekaliga, Osceola County	30 Apr 1987 20 May 1987	1,117 adults 370 adults
Sunshine Parkway, Exit 28, west side Palm Beach County	22 Jun 1987	250 adults
St. Johns River at S.R. 46, Volusia County	8 Jul 1987	110 adults + eggs
Lake Okeechobee Harney Pond Canal, Glades County	4 Sep 1987 5 Sep 1989	101 adults 125 adults
Conservation Area 3A, L-68A Canal, Broward County	30 Sep 1987	100 adults
Sunshine Parkway, Exit 28, east side Palm Beach County	7 Oct 1987	203 adults
Lake Osborne and Lake Worth, Palm Beach County	18 Nov 1987	200 adults
St. Johns River near S.R. 46, Hattbill Park, Brevard/Volusia Counties	2 Jun 1988	250 adults + eggs
Lake Harney, near S.R. 46, Seminole County	22 Jun 1988 24 Jun 1988 8 Jul 1988	435 adults 618 adults 990 adults
West side of US 27, 3 miles north of US 27/I-78 intersection	14 Oct 1988 21 Oct 1988 8 Nov 1988 10 Jan 1989	1,060 adults + eggs 465 adults 301 adults 510 adults

(Continued)

Table 1 (Concluded)

Site	*Date*	*Number/Stage Released*
West side of US 27 (Continued)	13 Jan 1989	500 adults
	20 Jan 1989	226 adults
	31 Jan 1989	257 adults
	2 Feb 1989	374 adults
	7 Mar 1989	282 adults
	29 Mar 1989	250 adults
Rodman Reservoir, Putnam County	26 Jan 1989	700 adults + eggs and infested tubers
	14 Feb 1989	426 adults
	29 Mar 1989	475 adults
Statewide total	26 releases	10,695 adults + eggs and infested tubers

In a separate article, Buckingham (1990) describes the establishment of *B. affinis* at Rodman Reservoir, Florida, when water levels were temporarily lowered as part of their aquatic plant management program. Unfortunately, the lake was restored to normal water levels soon after Buckingham made his observations, and the weevil population was most likely lost. This weevil appears to be of limited utility in Florida and is probably better suited to regions with a more pronounced wet-dry seasonality (e.g., portions of California). (See Buckingham for a more detailed discussion of this issue.)

Thirteen releases of *Hydrellia pakistanae* took place during 1989 (Table 2). Nearly 45,000 *H. pakistanae* eggs and 5,000 larvae have been released since this project was initiated (Table 2). However, we have been unable to confirm establishment at any of the release sites. This is partially because funding levels have, until FY 90, been insufficient to support a program to monitor these release sites, many of which are quite distant from our laboratory. Also, we suspect that the number of flies released at each site has been inadequate to ensure population establishment. As a result, we recently decided to postpone sporadic release efforts at more distant sites in favor of intensive releases at a few local sites. Once we have confirmed population establishment at several local sites, we can then use these sites as nursery areas from which to transport infested hydrilla to more distant sites.

During 1989, the Technical Advisory Group granted permission to release a new hydrilla agent, the fly *Hydrellia* n. sp., in the United States. Larvae of this new species were first released on a pond at the Orangebrook Golf Course in Hollywood, Florida, on 1 September 1989. At least 7,000 larvae have been liberated at this site

Table 2
Releases of Hydrilla Leaf-Mining Fly (*Hydrellia pakistanae*) in Florida During the Period October 1987 to November 1989

Site	*Date*	*Number/Stage Released*
Lake Patrick (Lenore) near Frostproof, Polk County	29 Oct 1987	600 adults
		2,600 larvae
		6,000 eggs
Rodman Reservoir Spike Club, Marion County	9 Nov 1987	1,000 larvae
Conservation Area 3-A, Broward County	26 Feb 1988	4,035 eggs
	28 Jun 1988	2,142 eggs
Lake Hicpochee, Glades County	17 Mar 1988	4,505 eggs
	16 Mar 1989	588 eggs
	8 May 1989	550 larvae
Lake Osborne and Lake Worth, Palm Beach County	23 May 1988	3,870 eggs
Lake Okeechobee, 26°59.14' N/80°58.72' W Glades County	18 Nov 1988	1,368 eggs
	6 Jan 1989	1,000 eggs
	20 Jan 1989	3,401 eggs
	23 Jan 1989	1,830 eggs
	31 Jan 1989	2,150 eggs
		215 larvae
	7 Mar 1989	387 eggs
North New River Canal SR 84 and Pine Island Road, Broward County	23 Jan 1989	Exhausted cultures
Lake Tohopekaliga,	1 Mar 1989	
28°12.04' N/81°24.76' W		3,227 eggs
28°11.11' N/81°20.05' W		143 larvae
		12 pupae
Sears Lake, Polk County	2 Mar 1989	948 eggs
	28 Mar 1989	2,583 eggs
US 27 & S.R.78 26°49.76' N/81°11.18' W Glades County	28 Apr 1989	410 eggs
		119 larvae

Table 2 (Concluded)

Site	*Date*	*Number/Stage Released*
Palm Beach Int. Airport, Southern Blvd. at Butler Aviation, Palm Beach County	3 Nov 1989	5,306 eggs
Statewide total	20 releases	43,749 eggs
		4,627 larvae
		600 adults
		12 pupae

thus far (Table 3). As with *H. pakistanae*, we plan to continue with frequent releases at just a few sites until population establishment can be confirmed.

Waterlettuce bioagents

The weevil population at Kreamer Island expanded dramatically during early 1989 (Figure 1). The waterlettuce population, estimated at 50 acres in January 1989, was reduced to less than 5 acres by May when the site held approximately 45 million weevils (Table 4).

Table 3
Releases of Hydrilla Leaf-Mining Fly (*Hydrellia* n. sp.) in Florida During the Period September to November 1989

Site	*Date*	*Number of Large Released*
Orangebrook Golf Course, Hollywood, Broward County	1 Sep 1989	5,745
	6 Sep 1989	348
	22 Sep 1989	278
	4 Oct 1989	*
	6 Oct 1989	*
	19 Oct 1989	669
	8 Nov 1989	186
Statewide total	7 releases	7,226+

*Uncounted.

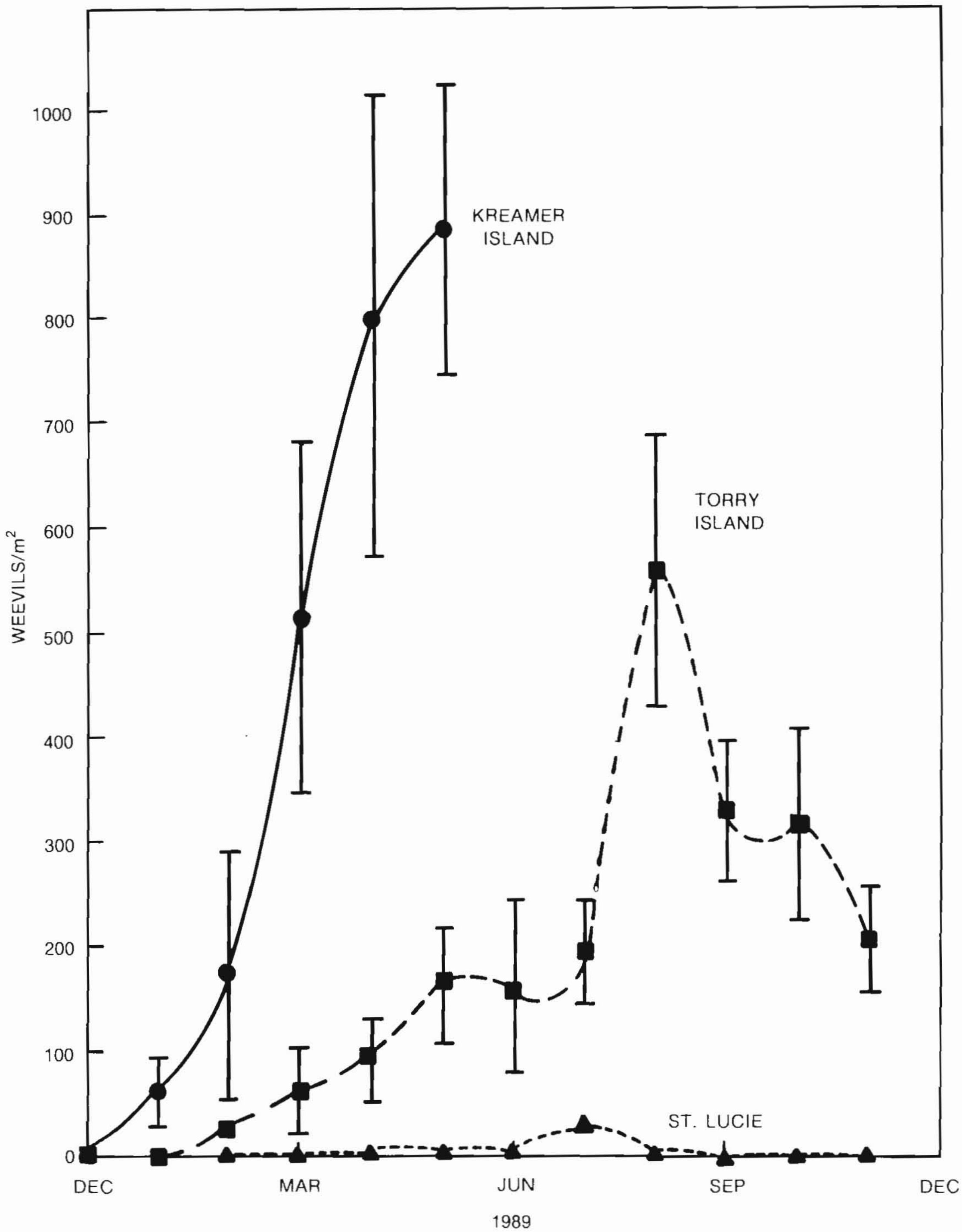

Figure 1. ***Neohydronomus affinis*** **population growth at three sites in southern Florida, December 1988-November 1989**

Table 4
***Neohydronomus affinis* Population Estimates for Three Sites in Florida, September 1987-September 1989**

Date	Kreamer Island	Torry Island	Port St. Lucie
Sep 1987	0	0	0
Jan 1988	0	0	0
May 1988	60,705	1,629	6,576
Sep 1988	331,854	67,505	1,956
Jan 1989	7,512,851	1,344	0
May 1989	44,764,373	6,622,295	83,664
Sep 1989	--	13,442,464	10,440

By June, the few plants that remained were destroyed by drought. The *N. affinis* population at a borrow pit on Torry Island in Lake Okeechobee is showing similar growth (Table 4, Figure 1), although destruction of the mat is, as yet, incomplete. Unfortunately, the weevils appear to be having little impact on plants at a third site, the Monterey Avenue canal in Port St. Lucie. *Neohydronomus* has been established there for over a year, but weevil abundance has failed to increase to levels found at the two other sites (Table 4, Figure 1).

Successful control of the waterlettuce infestation at Kreamer Island by *N. affinis* encouraged us to accelerate the pace of additional releases. With the assistance of cooperating agencies, *N. affinis* has now been released at over 80 sites in Florida (Figure 2). A task force has been created to coordinate the activities of USDA-ARS and the Corps with the Florida Department of Natural Resources and other state agencies. Members of this task force will collaborate to facilitate additional releases throughout Florida.

The failure of *N. affinis* populations to increase at the Port St. Lucie site suggests that this weevil may not control all waterlettuce infestations. Fortunately, the moth *Namangana pectinicornis* appears to be highly specific to waterlettuce. Observations made during the quarantine studies support earlier reports that these larvae can inflict extensive damage upon waterlettuce populations. Dr. Dale Habeck of the University of Florida has submitted a request to the Technical Advisory Group for permission to release *N. pectinicornis* in Florida. As soon as this moth becomes available, we will shift the emphasis of our waterlettuce biocontrol project to the culture, release, and establishment of *Namangana pectinicornis*.

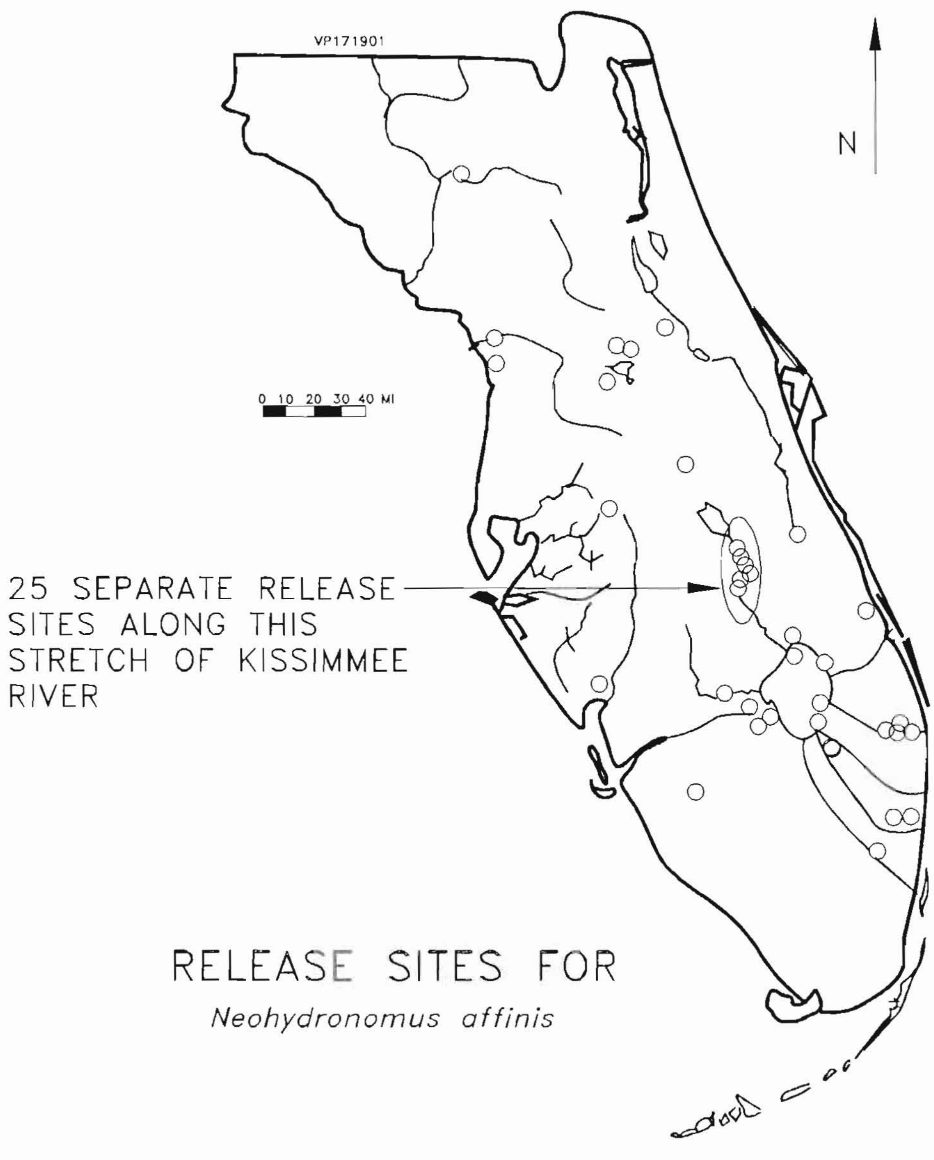

Figure 2. ***Neohydronomus affinis*** **release sites in Florida 1987-1989**

REFERENCES

Balciunas, J. K. 1982. "Overseas Searches for Insects for Control of Aquatic Plants," *Proceedings, 16th Annual Aquatic Plant Control Research Program and Operations Review, St. Paul, Minnesota*, Miscellaneous Paper A-82-3, US Army Engineer Waterways Experiment Station, Vicksburg, Miss., pp 141-154.

Balciunas, J. K. 1983. "Overseas Searches for Insects on Hydrilla in Southeast Asia and Australia," *Proceedings, 17th Annual Aquatic Plant Control Research Program and Operations Review, Sacramento, California*, Miscellaneous Paper A-83-9, US Army Engineer Waterways Experiment Station, Vicksburg, Miss., pp 104-114.

Balciunas, J. K. 1984. "Overseas Surveys of Biocontrol Agents for Hydrilla," *Proceedings, 18th Annual Meeting, Aquatic Plant Control Research Program, Raleigh, North Carolina.* Miscellaneous Paper A-84-4, US Army Engineer Waterways Experiment Station, Vicksburg, Miss., pp 76-84.

Balciunas, Joseph K. 1985. "Final Report on the Overseas Surveys (1981-1983) for Insects to Control Hydrilla," Technical Report A-85-4, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Balciunas, Joe K. 1987. "Australian Insects to Control Hydrilla," *Proceedings, 21st Annual Meeting, Aquatic Plant Control Research Program Mobile, Alabama*, Miscellaneous Paper A-87-2, US Army Engineer Waterways Experiment Station, Vicksburg, Miss., pp 57-66.

Balciunas, Joe K., and Center, Ted. 1988. "Australian Insects to Control Hydrilla, An Update," *Proceedings, 22nd Annual Meeting, Aquatic Plant Control Research Program, Portland, Oregon*, Miscellaneous Paper A-88-5, US Army Engineer Waterways Experiment Station, Vicksburg, Miss., pp 312-319.

Balciunas, Joseph K., Center, Ted D., and Dray, F. Allen, Jr. 1989. "Testing Suitability of Australian Bioagents for Control of *Hydrilla verticillata*," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program, West Palm Beach, Florida*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, Miss., pp 24-27.

Buckingham, G. R. 1984. "Biological Control of Weeds by Insects," *Journal of the Georgia Entomological Society*, Vol 19, No. 3, pp 62-78.

Buckingham, G. R. 1988. "Quarantine Research Program - Hydrilla Insects," *Proceedings, 22nd Annual Meeting, Aquatic Plant Control Research Program, Portland, Oregon*, Miscellaneous Paper A-88-5, US Army Engineer Waterways Experiment Station, Vicksburg, Miss., pp 307-311.

Buckingham, G. R. 1989. "Quarantine Work - Insect Biocontrol for Hydrilla," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program, West Palm Beach, Florida*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, Miss., pp 28-33.

Buckingham, G. R. 1990. See pp 34-38 in this proceedings.

Center, T. D. 1989. "Release and Establishment of Insect Biocontrol on Hydrilla," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program, West Palm Beach, Florida*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, Miss., pp 34-40.

Dray, F. A., Jr., Center, T. D., Habeck, D. H., Thompson, C. R., Cofrancesco, A. F., and Balciunas, J. K. "Release and Establishment in the Southeastern US of *Neohydronomus affinis* (Coleoptera:Curculionidae), An Herbivore of Waterlettuce (*Pistia stratiotes*)," *Environmental Entomology* (in press).

Habeck, Dale H., Thompson, Catherine R., Dray, F. Allen, Center, Ted D., and Balciunas, Joe K. 1987. "Biological Control of Waterlettuce," *Proceedings, 21st Annual Meeting, Aquatic Plant Control Research Program, Mobile, Alabama,* Miscellaneous Paper A-87-2, US Army Engineer Waterways Experiment Station, Vicksburg, Miss., pp 108-114.

Habeck, D. H., Thompson, C. R., Dray, F. A., Center, T. D., and Balciunas, J. K. 1988. "Biological Control of Waterlettuce," *Proceedings, 22nd Annual Meeting, Aquatic Plant Control Research Program, Portland, Oregon,* Miscellaneous Paper A-88-5, US Army Engineer Waterways Experiment Station, Vicksburg, Miss., pp 320-323.

Habeck, D. H., Thompson, C. R., Dray, F. A., Center, T. D., and Balciunas, J. K. 1989. "Update on Biological Control of Waterlettuce," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program, West Palm Beach, Florida*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, Miss., pp 59-63.

Harley, K. L. S., Forno, I. W., Kassulke, R. C., and Sands, D. P. A. 1984. "Biological Control of Waterlettuce," *Journal of Aquatic Plant Management,* Vol 22, pp 101-102.

Mangoendihardjo, S., Setyawati, O., Syed, R. A., and Sosromarsono, S. 1977. "Insects and Fungi Associated with Some Aquatic Weeds in Indonesia," *Proceedings, 6th Asian-Pacific Weed Science Society Conference*, Vol 2, pp 440-446.

Napompeth, B. 1982. "Biological Control Research and Development in Thailand," *Proceedings, International Conference on Plant Protection in the Tropics*, pp 301-323.

Sankaran, T., and Ramaseshiah, G. 1974. "Prospects for Biological Control of Some Major Aquatic Weeds in South-East Asia," Report, Commonwealth Institute of Biological Control, Indian Station.

Schardt, J. D., and Nall, L. E. 1989. "Florida Aquatic Plant Survey," Technical Report 89-CGA, Florida Department of Natural Resources, Tallahassee, FL.

Suasa-Ard, W., and Napompeth, B. 1976. "Ecological Investigation on *Namangana pectinicornis* Hampson (Lepidoptera:Noctuidae) As a Potential Biological Control Agent of Waterlettuce," Technical Bulletin 3, National Biological Control Research Center, Kasetsart University, Bangkok, Thailand.

Relationships Between Population Dynamics and Nutritional Profile of Waterhyacinth and *Neochetina eichhorniae* Population Dynamics and Reproductive Condition

by

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INTRODUCTION

The mottled waterhyacinth weevil, *Neochetina eichhorniae*, is an exotic biocontrol agent of waterhyacinth. It was introduced from Argentina in 1972 by the US Department of Agriculture, Agricultural Research Service, and the US Army Corps of Engineers (Bennett and Zwolfer 1968; Perkins 1973, 1974; DeLoach and Cordo 1976; Center 1982) and is distributed throughout the United States waterhyacinth range.** *Neochetina eichhorniae* has been shown to be effective in reducing populations of waterhyacinth in many areas, including Louisiana, Texas, and Florida (Center 1982; Goyer and Stark 1984; Cofrancesco, Stewart, and Sanders 1985; Center and Durden 1986; Center 1987; Grodowitz, Stewart, and Cofrancesco, in press;). These reductions have ranged from total dropout of the floating mat to only minor decreases in population size. Use of the biocontrol agent *N. eichhorniae* is viewed by many researchers and aquatic plant managers as an effective alternative to more traditional methods of waterhyacinth management, including chemical applications.

There is increasing evidence that *N. eichhorniae* may not be effective under certain circumstances, however. For example, in areas where chemical applications are used continually, numbers of *N. eichhorniae* are substantially reduced (see Grodowitz and Cofrancesco 1990). The reduction is believed to be caused, indirectly, by the use of herbicides (Haag 1986a,b; Grodowitz and Pellessier 1989). This occurs because of the relatively rapid degradation of the plants leading to subsequent destruction of the waterhyacinth mat, thereby leaving little, if any, harborage for escaping adults. Chemical applications also cause, indirectly, significant mortality of the immatures, which are relatively immobile and cannot easily escape the plant degradation. These effects have been documented by both laboratory experimentation and field investigations (Haag 1986a,b; Grodowitz and Pellessier 1989; Grodowitz and Cofrancesco 1990). In addition, waterhyacinth infestations have been observed to persist even under heavy insect herbivory and in the absence of chemical use.† Hence, it is becoming important to understand more specific aspects of *N. eichhorniae* basic biology in order to explain these apparent anomalies in *N. eichhorniae* effectiveness.

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†Unpublished data, Ted D. Center.

The majority of research on *N. eichhorniae* has concentrated on population dynamics and specific insect damages to its host plant (Center and Spencer 1981, Center 1982, Center and Durden 1986). More recently, information has become available describing the influence *N. eichhorniae* has on waterhyacinth leaf dynamics and phytochemistry (Center and Van 1989). However, limited information is available to characterize changes in the insect's reproductive status, especially under field conditions. Toward this goal, experiments were designed to quantify changes in the reproductive condition of *N. eichhorniae* in relation to both insect and plant population dynamics, as well as the nutritional profile of waterhyacinth. This research was initiated as a preliminary step in understanding what factors influence reproductive status and thereby effectiveness.

MATERIALS AND METHODS

Study sites

The study sites were located within a US Army Corps of Engineers facility, 40 miles east of Houston in Wallisville, Texas. Two sites were chosen based on past and present plant characteristics. The first site (LD) was situated within an unfinished lock and dam structure with water depths approaching 20 ft. Waterhyacinth was observed to completely cover the site toward the end of the preceding active growing season. The plants were tall and typically had numerous feeding scars by *Neochetina* spp.; however, characteristic stunting and hardening of the plant cuticle were not observed. Plants were first observed at site LD in 1983. The second site (OLD) was a borrow pit situated directly off the Trinity River. Plants at this site covered approximately 80 percent of the area during the active growing season. However, plants appeared to be heavily pressured by *Neochetina* spp., as indicated by very high numbers of feeding scars, plant cuticular hardening, and obvious plant stunting.

Quantitative plant and insect sampling

Plants were collected using a 0.25-m^2 sampling frame constructed of polyvinyl chloride pipe. The frame was positioned within the site randomly, and all plants 50 percent or more within the frame were removed and placed into plastic bags. The first 10 plants were bagged separately for insect counts. A total of four samples were taken monthly at each site beginning in October 1988 and continuing through September 1989.

For all samples, biomass was partitioned into that living plant material located above and below the waterline. Total dead plant material was also quantified. Dead plant material was determined by estimating the total amount of green living material present on the lamina and petiole. Leaves with 50 percent or less green material were considered dead. All plant estimates were transformed to a square meter basis for final analysis.

The total number of adults was determined by carefully examining the first 10 plants collected for each sample. Total number of adults was also transformed to a square meter basis for analysis.

Physiological age structure

Female *N. eichhorniae* used for determining physiological age were collected by randomly examining waterhyacinth from each site for adults. Females were held until dissection in plastic containers filled with fresh waterhyacinth leaves. Number of insects ranged from 50 to 65 individuals per sampling. The time to dissection never exceeded 48 hr.

The physiological age of female *N. eichhorniae* was determined using an age-grading system that divides the continuum of ovarian development into two broad categories, nulliparous and parous (Grodowitz and Stewart 1989). Nulliparous individuals were indicated if the reproductive system contained no eggs in the lateral or common oviducts and no follicular relics were present at the ovariole base. The reproductive system in parous individuals had eggs present in the oviducts and/or follicular relics present. Follicular relics were present in a large majority of parous individuals. Numbers of developing follicles and ovulated eggs were also quantified.

Information on the status of the insect's relative reproductive health was determined. In this case, individuals were classified as either nonfunctioning, i.e., having a limited number of developing follicles and obvious disruption of internal cellular material within the follicles, or functioning, i.e., higher number of developing follicles and no obvious disruption of cellular material within the follicles.

Nutritional profile

The nutritional profile of waterhyacinth wrapper leaves was also determined. This was quantified by using a proximate analysis that include determination of the percentages of dry matter, ash, crude fiber, crude protein, lipids, and nitrogen-free extract. These analyses have commonly been used for the nutritional analysis of animal feeds and grains (Williams 1984).

Samples of wrapper leaves used for proximate analysis were frozen on dry ice and shipped to the Aquatic Plant Management Laboratory, Fort Lauderdale, Florida, for analysis. Determination of dry matter was accomplished by weighing the frozen samples and subsequently lyophilizing at -90° C and 20 mtorr. After complete drying, the samples were again weighed to determine percent dry matter.

The dried samples were subsequently ground in a Wiley mill (40 mesh). Total ash was determined for 0.25 g dried material after combustion in a muffle furnace at 500° C for 3 hr (Allen et al. 1974).

Crude protein content was determined by methods modified by the American Public Health Association (1985). Dried 0.20-g samples were refluxed with H_2SO_4:H_2O_2 (5:4) and two selenized hengar granules on a Technicon digestion block for 3 hr at 400° C. Subsequently, the digestates were diluted to 100 ml with boiled, deionized water.

Total lipids were extracted from 0.25 g of dried material using a chloroform:methanol:water mixture (1.0:2.0:0.8). The mixture was then passed through a glass filter, rinsed with chloroform, and finally with water. The resulting chloroform layer was transferred to a tared boiling flask (30 ml), and the chloroform was removed under vacuum at 40° C. The remaining residue was dried overnight in a vacuum desiccator and subsequently weighed for total lipid determination.

A portion of the residue extracted for lipids (0.5 g) was used to determine crude fiber. The residue was refluxed for 0.5 hr with 50 ml 1.25-percent H_2SO_4. The acid was removed by suction through a No. 2 sinter stick. This was accomplished by washing the residue/acid mixture three times with 25 ml of boiling water and sintering each time. Fifty milliliters of boiling 1.25-percent NaOH was added, and the mixture was boiled for an additional 30 min. The alkali was subsequently removed by sintering. The remaining material was washed with 12 ml of a 1.25-percent H_2SO_4 solution. The sample was again washed with 25 ml of boiling water to remove impurities and subsequently sintered. The resulting mixture was transferred to a tared No. 2 glass sintered crucible and washed with 15 ml of mineral spirits. The crucible was then dried for 3 hr at 105° C. After cooling, the crucible and contents were weighed. This procedure is an AOCS-AOAC method modified by Allen et al. (1974).

Nitrogen-free extracts (NFE) were determined by subtracting the total of the percentages of ash, lipids, crude fiber, and crude protein from 100 percent. The NFE value provides a crude estimate of total soluble carbohydrates.

Statistical analyses

Differences between a given date and between sites were determined by analysis of variance (ANOVA) using PROC GLM contained within the Statistical Analysis System (SAS Institute 1982). Mean comparisons were made using a least significant difference (LSD) test based on the pooled mean square error from the ANOVA. Differences in physiological age distributions were determined using a chi-square row by column contingency analysis (Snedecor and Cochran 1980).

RESULTS

Plant dynamics

Significant ($P < 0.05$) changes in above-water biomass occurred that were qualitatively similar for both sites. Generally, lower above-water biomass was associated with the period beginning in October 1988 and ending April 1989 (Figure 1). Following this date, significant increases occurred for both sites (ca. fourfold). While similar trends in above-water biomass were noted for the sampled sites, overall lower values occurred for site OLD.

Decreasing below-water biomass was noted for both sites during the end of the active growing season, which began in October 1988 and continued through May 1989 (Figure 1). Below-water biomass subsequently increased approximately twofold at both sites. Limited differences in below-water biomass were noted between site LD and site OLD.

Highest dead biomass occurred during the inactive growth periods (October 1988-February 1989) for both sites and were subsequently followed by rapid decreases through May 1989 (Figure 1). Following May 1989, dead biomass increased approximately fourfold. Significantly ($P < 0.05$) higher dead material was found for site LD

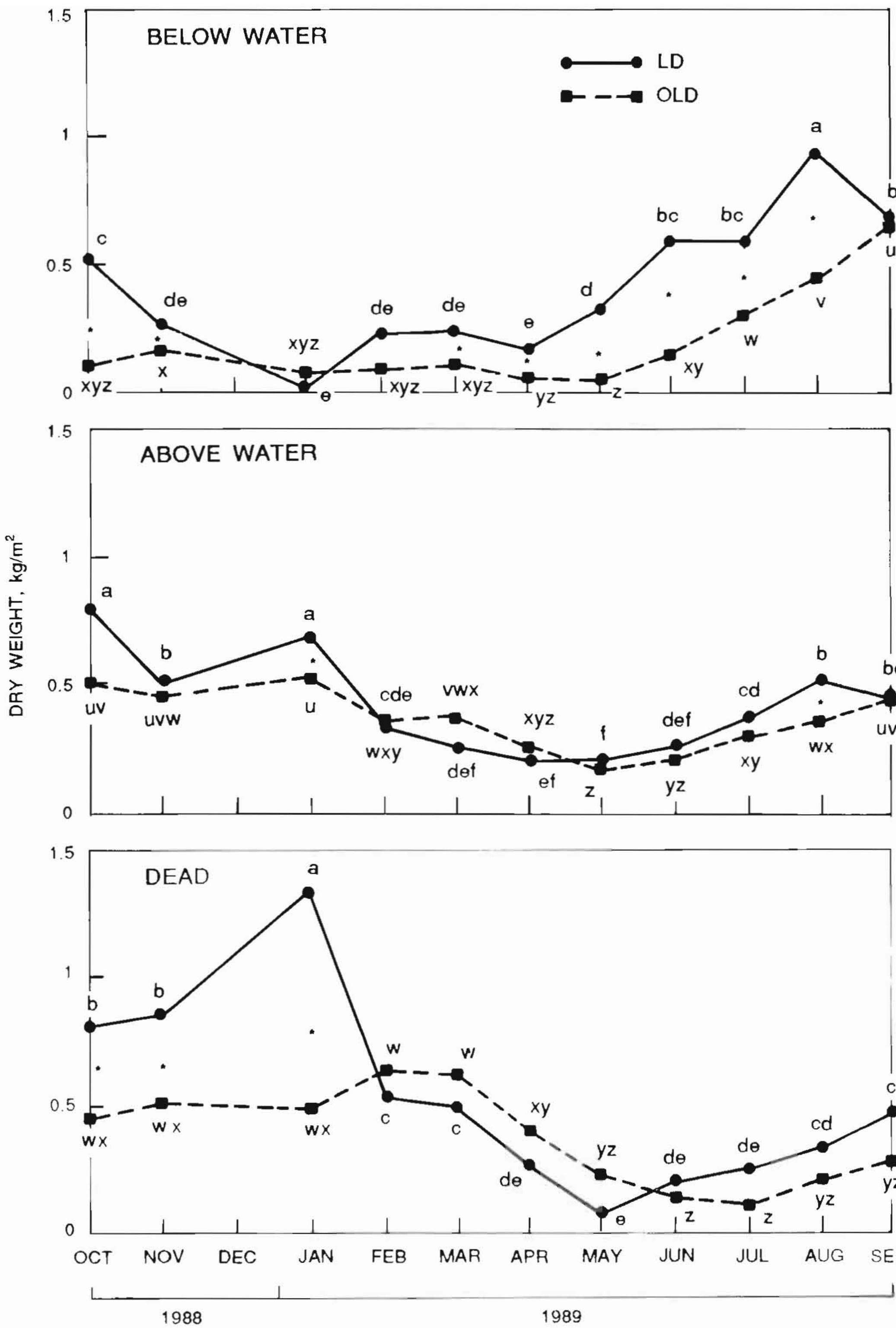

Figure 1. Above-water, below-water, and total dead biomass on a dry weight basis (kg/m^2) for waterhyacinth collected from Wallisville during 1988-1989 for sites LD and OLD. Means for sites separated with an asterisk are significantly different at $P \leq 0.05$ for a given date. Means followed by the same letter are not significantly different ($P \leq 0.05$) for a given site across time. The letters a-f are used for site LD, while u-z are used for site OLD. The LSD mean separation test was used

in comparison to site OLD during the winter months. This difference was approximately twofold.

Insect dynamics

Numbers of adult *Neochetina eichhorniae* remained relatively constant at about 25 individuals/m^2 for both sites until June 1989 (Figure 2). However, small increases were noted in February 1989 for both sexes. Adult numbers at site LD increased rapidly following June 1989, with highest values occurring in July 1989 for females (i.e., a ninefold increase) and in August 1989 for males (i.e., a sixfold increase). No significant increases occurred for site OLD throughout the sampling period.

Physiological age structure

Changes in the percentage of nulliparous and parous individuals showed distinct trends that were similar for each site (Figure 3). Major decreases in the percentage of nulliparous individuals occurred for both sites during the months of February, March, and April 1989. This reduction represented a nearly 40-percent difference. Fluctuations in the percentage of nulliparous and parous individuals were noted for the remaining months, although they remained relatively consistent at a ratio of 7.5 parous to 2.5 nulliparous individuals on any given date.

Changes in the percentage of nonfunctioning and functioning individuals also exhibited distinct trends similar to what was observed for the percentage of nulliparous and parous categories (Figure 4). Percentage of nonfunctioning individuals was ca. 70 percent during the months of October 1988 through January 1989. Following this month, substantial reductions of about 60 percent were noted in nonfunctioning individuals (ca. 99 percent). These low values continued until June 1989 when a fivefold increase in nonfunctioning individuals occurred for site LD. Percentages of nonfunctioning individuals continued low for site OLD until September 1989 when values approached those observed for site LD.

The number of follicles per ovariole and the number of ovulated eggs also exhibited significant changes which began on or around January 1989 (Figure 5). Beginning in January 1989 gradual increases occurred in both parameters, with highest values occurring in April 1989. On this date, significantly ($P < 0.05$) higher values were noted for site LD, i.e., a difference of 2.6 follicles per ovariole. Number of follicles per ovariole decreased following this date for both sites. However, higher values for number of follicles per ovariole were noted for site OLD during the months of July and August, and during the months of June, July, and August for the number of ovulated eggs.

Nutritional profile

Significant changes were observed in the nutritional profile established for waterhyacinth wrapper leaves (Figure 6). These included significant ($P < 0.05$) shifts in the percentage of crude fiber, crude protein, lipids, and NFE. Limited fluctuations were observed in dry matter and ash content. In most cases, observed changes were similar for each site with only quantitative differences noted. For example, significant ($P < 0.05$) increases (ca. 10 percent) in percent crude protein occurred during the

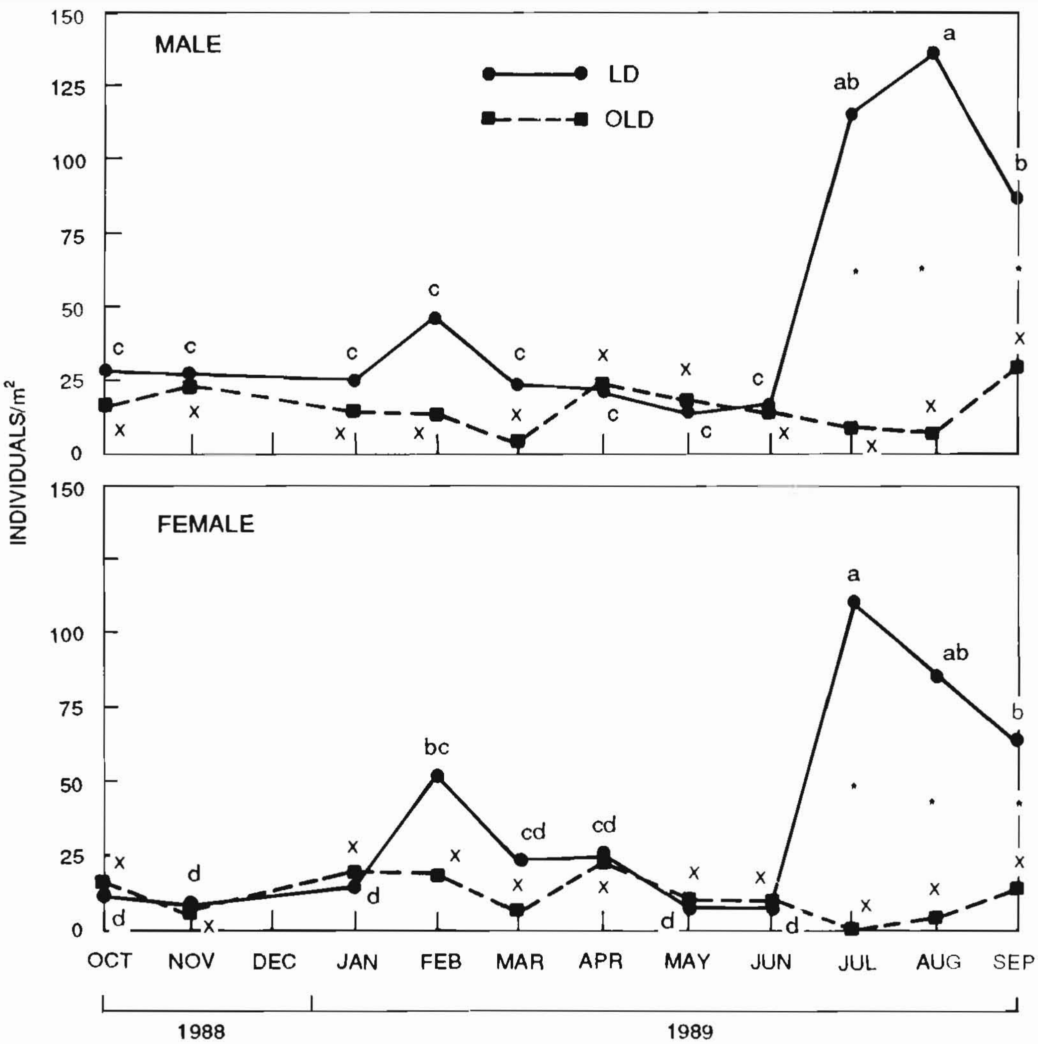

Figure 2. Total number of male and female *N. eichhorniae* (number/m^2) for waterhyacinth collected from Wallisville during 1988-1989 for sites LD and OLD. Means for sites separated with an asterisk are significantly different at $P \leq 0.05$ for a given date. Means followed by the same letter are not significantly different ($P \leq 0.05$) for a given site across time. The letters a-f are used for site LD, while u-z are used for site OLD. The LSD mean separation test was used

months of February, March, April, and May 1989. Following this period, crude protein values returned to levels comparable to those observed during the months of October 1988 through January 1989 (ca. 12 percent). On most sampling dates nitrogen content was significantly lower for site OLD, except during the months of July and August 1989.

Percent lipids also followed a similar trend to that observed for crude protein (Figure 6). Peak values of approximately 20 percent occurred in March 1989, which was preceded by a gradual increase of values beginning in January 1989. Lipid concentration decreased after March 1989, with lowest values (ca. 5 percent) noted in September 1989. Limited differences were noted between sites.

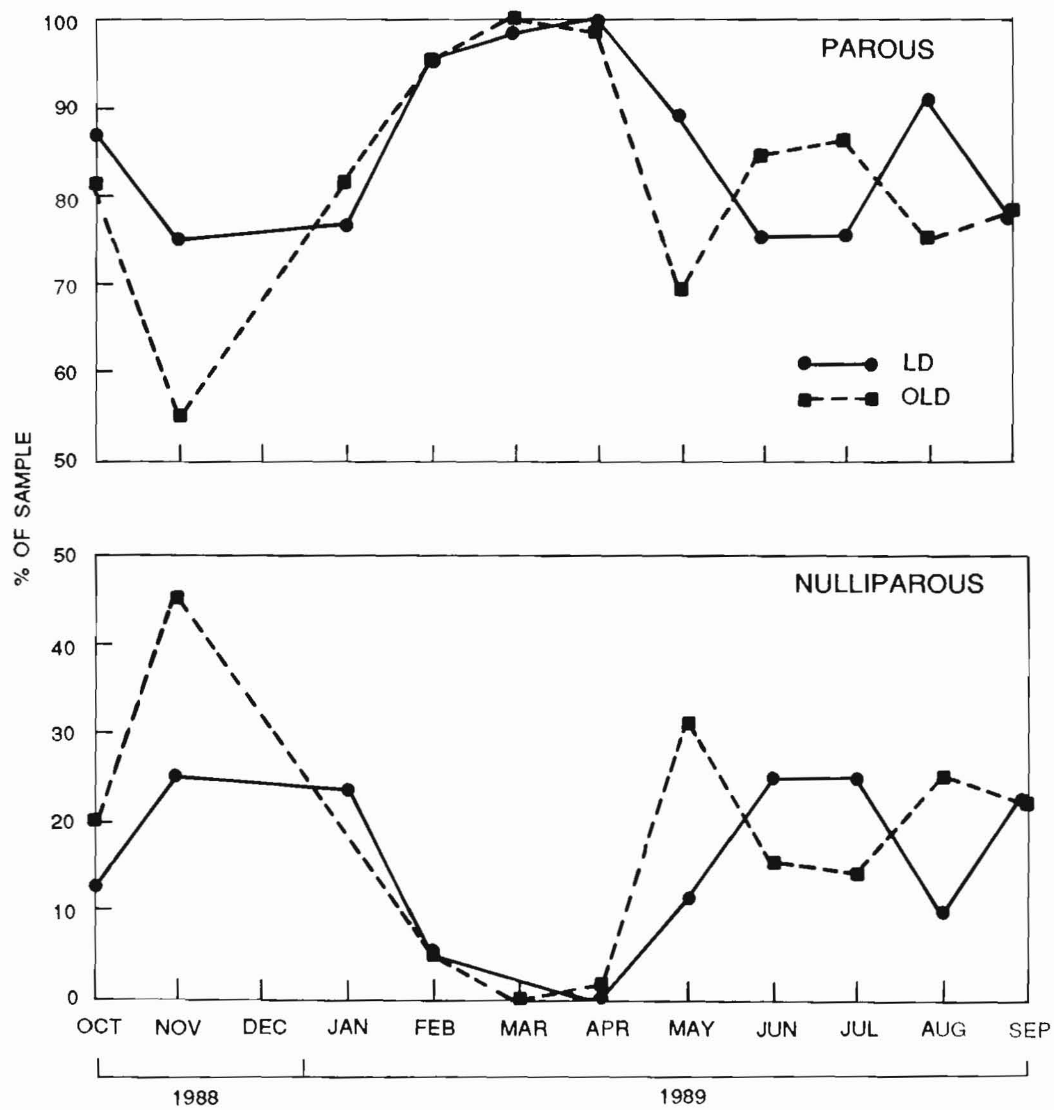

Figure 3. Percentage of nulliparous and parous *N. eichhorniae* females collected through time from Wallisville during 1988 and 1989 for sites LD and OLD

Crude fiber percentages exhibited two distinct peaks for site LD, while gradual increasing fiber percentages occurred for site OLD (Figure 6). Peaks of ca. 30 percent were observed for site LD in January and July 1989. Before and after these dates, crude fiber values were reduced to ca. 20 percent. This is in contrast to what was observed for site OLD. For this site, crude fiber values remained relatively constant at ca. 22 percent for the period beginning in October 1988 and ending in April 1989. Then, crude fiber values increased nearly linearly, with highest values recorded in August 1989.

Similar trends in percent NFE occurred for both sites; however, lower overall values were noted for site LD in almost every sampling period. Lowest values for percent NFE (a crude measure of water-soluble carbohydrates) occurred during the period February through March 1989. Preceding this period, NFE was relatively constant for

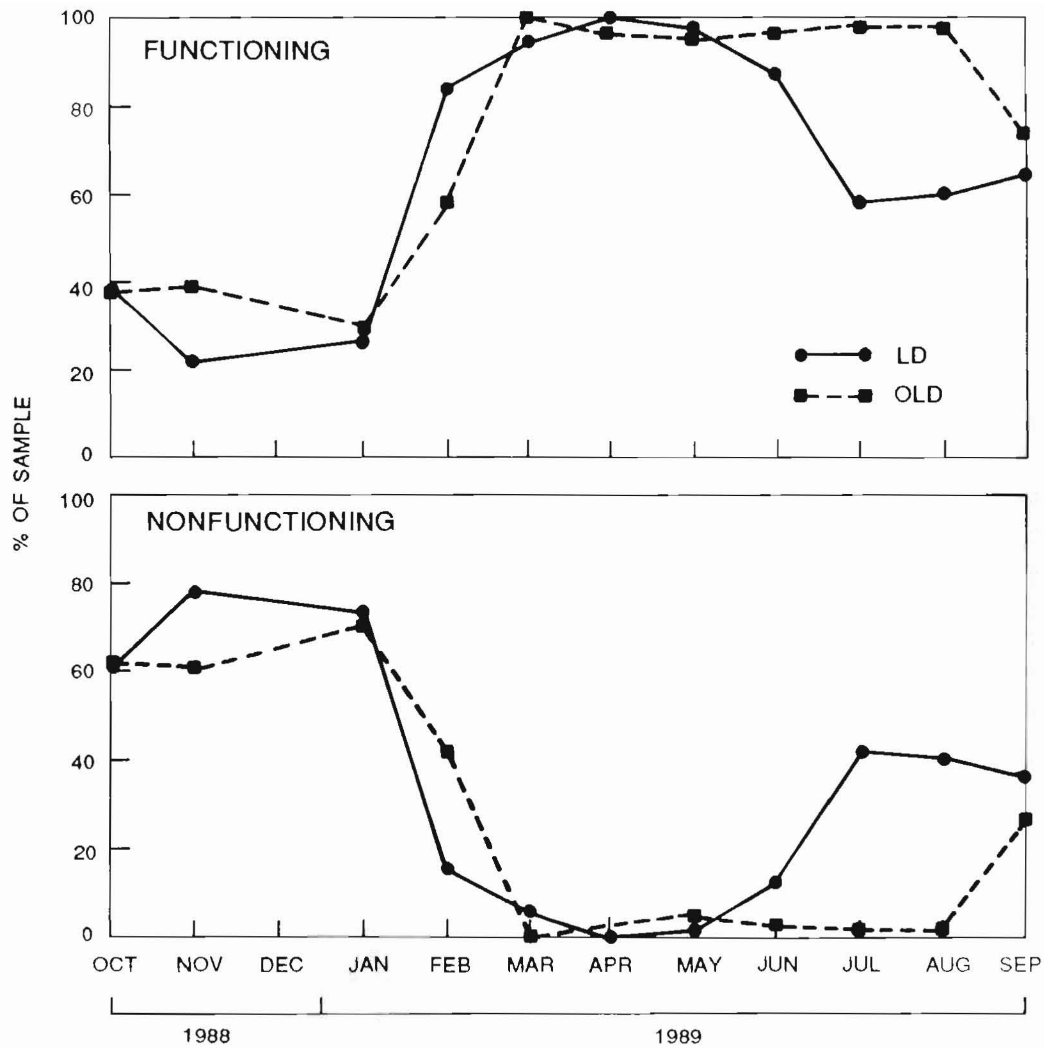

Figure 4. Percentage of *N. eichhorniae* females having functioning and nonfunctioning reproductive systems, collected from Wallisville during 1988 and 1989 for sites LD and OLD

both sites at ca. 40 percent for site OLD and 30 percent for site LD. Following April, NFE fluctuated at about 35 to 40 percent.

DISCUSSION

This research represents a first step in understanding relationships between waterhyacinth and *N. eichhorniae* population dynamics, the insect's reproductive condition, and the plant's nutritional status. The study was initiated to identify potential future research directions toward the goal of understanding the importance of such relationships. Along this line the presented research has identified several areas of study that appear to be important. This includes the plant's phenology and its relationship to *N. eichhorniae* reproductive status.

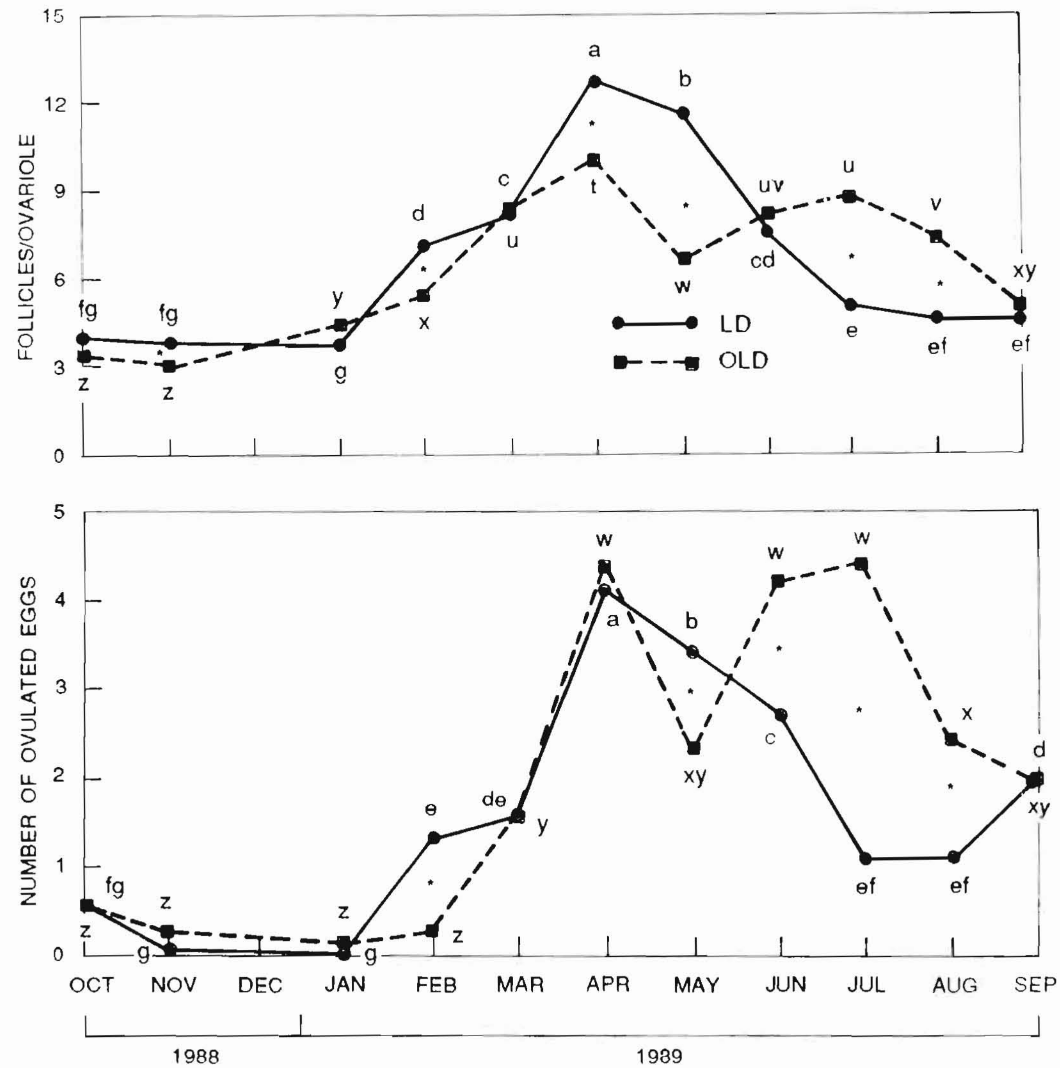

Figure 5. Number of follicles per ovariole and number of ovulated eggs present in parous *N. eichhorniae* females collected from Wallisville during 1988 and 1989 for sites LD and OLD

There are definitive shifts in the nutritional profile of waterhyacinth. These tend to occur during periods when temperature, light intensity, and photoperiod are increasing. During the period of February to April/May, changes in several nutritional parameters were noted, including significant increases in crude protein and lipid concentrations and decreases in crude fiber and NFE. Coincidentally, the changes in the nutritional profile were associated with increases in temperature, light intensity (as indicated by data collected from Wallisville during 1987-1988), and photoperiod. This period apparently represents the beginning of the active growth period for waterhyacinth. More favorable abiotic factors have returned, and the plant appears to be mobilizing stored food reserves in response to the more favorable conditions. There is also a reduced respiratory cost associated with this phenological stage because a majority of the above-water biomass was reduced during the late fall and early winter months.

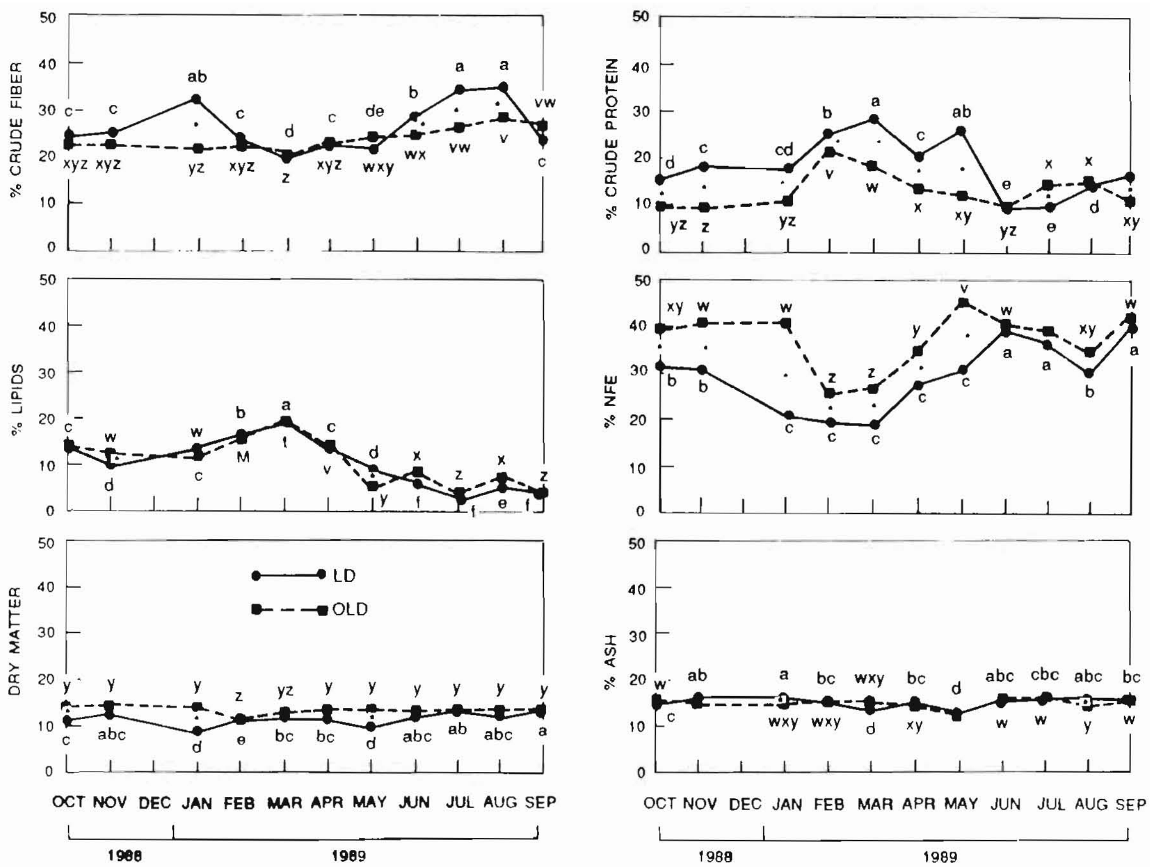

Figure 6. Overall nutritional profile (percentage crude fiber, crude protein, lipids, nitrogen-free extract, dry matter, and ash content on a dry weight basis) through time for waterhyacinth wrapper leaves collected from Wallisville during 1988 and 1989 for sites LD and OLD. Means for sites separated with an asterisk are significantly different at $P \leq 0.05$ for a given date. Means followed by the same letter are not significantly different ($P \leq 0.05$) for a given site across time. The letters a-f are used for site LD, while u-z are used for site OLD. The LSD mean separation test was used based on the mean square error taken from the ANOVA

With the increases in light parameters and temperature, the plant can also begin manufacturing other compounds required for adequate growth.

After this early growth period the plant enters the active growth phase where there are substantial increases in biomass (ca. fourfold). This phase begins in April and continues through August/September. During this active growth phase the plants have significant decreases in crude protein and lipids with corresponding increases in fiber content and NFE concentrations. The noted changes may be caused by decreases in the nutritional status of the site associated with the high nutrient uptake by waterhyacinth (Gopal 1987).

Following the active growth phase, the plant enters a preparation period for winter dormancy. This period is characterized by plants with reduced lipid and protein concentrations and increased fiber and NFE content. Associated with these changes are decreases in light intensity, photoperiod, and temperature.

The above-mentioned nutritional shifts appear to be similar for both sites, with differences occurring in magnitude only and not overall trends. Because of the similarity between sites and association to shifts in abiotic factors, the measured phenological changes appear to be caused mainly by seasonal factors and not site-to-site variation. Additional information is needed to more fully describe the dynamics of nutritional factors in waterhyacinth in relation to seasonal changes in various abiotic factors.

The shifts in abiotic factors and the nutritional profile for waterhyacinth are also associated with significant changes in *N. eichhorniae* reproductive condition. The early growth phase (i.e., February through April/May) is characterized by increasing percentages of individuals in the parous state and increases in the proportion of individuals with functioning reproductive systems. Such changes indicate that the insects are apparently shifting from reproductive dormancy during the winter months to a period of active reproductive condition. Another indication of such a shift is the increase in the numbers of developing follicles and ovulated eggs. The increases in the percentage of parous individuals and those with functioning ovaries, follicle numbers, and ovulated eggs suggest a higher relative reproductive health for *N. eichhorniae* individuals.

During the active growth phase, numbers of parous individuals decreased at both sites. However, the percentage of individuals with functioning reproductive systems declined for site LD only, with the percentage remaining high for those collected at site OLD. Similarly, numbers of developing follicles and ovulated eggs in the oviducts declined for site LD but remained high for site OLD during the active growth stage.

While the changes in reproductive condition were associated with shifts in abiotic factors, a more likely explanation for the reproductive changes can be attributed to the nutritional profile. Since no true diapause can be detected in *N. eichhorniae*, changes in light regime should have only minor impact to reproductive condition (Chapman 1971). Similarly, insect reproduction in the absence of a true diapause should be influenced by temperature only to a minor extent. Therefore, the changes in the plant's nutritional profile appear to be the most important reason for the measured changes in reproductive condition. However, it is important that additional experimentation be conducted to verify these relationships.

Some evidence is available which suggests that the insects may be influencing the plant's nutritional status. This is indicated because one of the major differences between the two sites was the higher number of insects at site LD during the active growing season. During this period, plants at site LD had significantly higher quantities of fiber and lower quantities of crude protein in their wrapper leaves. *Neochetina eichhorniae* has been found to influence nitrogenous content of waterhyacinth leaves (Center and Van 1989). More controlled experimental data are needed to substantiate this effect.

In summary, this study quantified changes in the insect and waterhyacinth population dynamics relative to changes in the plant's nutritional status and the reproductive condition of the weevils. Major trends in nutritional status were associated with changes in abiotic factors such as temperature, light intensity, and photoperiod. The shifts in nutritional profile apparently influenced the weevils' reproductive condition. This was especially strong in the early growth phase beginning in February and ending April/May. The weevils may have influenced the nutritional status of the plants, including lowered nitrogen levels and higher crude fiber content, when weevil populations were high. More research is needed to substantiate these relationships.

The information generated from such research is important for various modeling efforts, for elucidating the reasons for successes and failures of this biocontrol agent, and for timing of herbicide applications to reduce suspected noncompatibility between the two technologies (Grodowitz and Pellessier 1989).

REFERENCES

Allen, S. E., Grimshaw, H. M., Parkinson, J. A., and Quarby, C. 1974. *Chemical Analysis of Ecological Materials*," John Wiley and Sons, New York.

American Public Health Association. 1985. *Standard Methods for the Examination of Water and Wastewater*, Washington, DC.

Bennett, F. D., and Zwolfer, H. 1968. "Exploration for Natural Enemies of the Waterhyacinth in Northern South America and Trinidad," *Hyacinth Control Journal*, Vol 7, pp 44-52.

Center, T. D. 1982. "The Waterhyacinth Weevils *Neochetina eichhorniae* and *N. bruchi*," *Aquatics*, Vol 4, pp 8-19.

Center, T. D. 1987. "Insects, Mites, and Plant Pathogens As Agents of Waterhyacinth (*Eichhornia crassipes* (Mart.) Solms) Leaf and Ramet Mortality," *Lake and Reservoir Management*, Vol 3, pp 285-293.

Center, T. D., and Durden, W. C. 1986. "Variation in Waterhyacinth/Weevil Interactions Resulting from Temporal Differences in Weed Control Efforts," *Journal of Aquatic Plant Management*, Vol 24, pp 28-38.

Center, T. D., and Spencer, N. R. 1981. "The Phenology and Growth of Waterhyacinth (*Eichhornia crassipes* (Mart.) Solms) in a Eutrophic North-central Florida Lake," *Aquatic Botany*, Vol 10, pp 1-32.

Center, T. D., and Van, T. K. 1989. "Alteration of Waterhyacinth (*Eichhornia crassipes* (Mart.) Solms) Leaf Dynamics and Phytochemistry by Insect Damage and Plant Density," *Aquatic Botany*, Vol 35, pp 181-195.

Chapman, R. F. 1971. *The Insects: Structure and Function*, Elsevier, New York.

Cofrancesco, A. F., Jr., Stewart, R. M., and Sanders, D. R., Sr. 1985. "The Impact of *Neochetina eichhorniae* (Coleoptera:Curculionidae) on Waterhyacinth in Louisiana," *Proceedings, VI International Symposium on Biological Control of Weeds*, E. S. Delfosse, ed., Agriculture Canada, Vancouver, BC, Canada.

DeLoach, C. J., and Cordo, H. A. 1976. "Ecological Studies of *Neochetina bruchi* and *N. eichhorniae* on Waterhyacinth in Argentina," *Journal of Aquatic Plant Management*, Vol 14, pp 53-59.

Gopal, G. 1987. *Waterhyacinth*, Elsevier, New York.

Goyer, R. A., and Stark, J. D. 1984. "The Impact of *Neochetina eichhorniae* on Waterhyacinth in Southern Louisiana," *Journal of Aquatic Plant Management*, Vol 22, pp 57-61.

Grodowitz, M. J., and Cofrancesco, A. F., Jr. 1990. See pp 65-74 in this proceedings.

Grodowitz, M. J., and Pellessier, D. C. 1989. "Effects of Chemical Applications on the Biological Control Agents of Waterhyacinth," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 71-84.

Grodowitz, M. J., and Stewart, R. M. 1989. "Validation Studies in Texas for the Model INSECT," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 257-273.

Grodowitz, M. J., Stewart, R. M., and Cofrancesco, A. F. "Population Dynamics of Waterhyacinth and the Biological Control Agent *Neochetina eichhorniae* (Coleoptera:Curculionidae) in Southeast Texas," *Environmental Entomology* (in press).

Haag, K. H. 1986a. "Effective Control of Waterhyacinth Using *Neochetina* and Limited Herbicide Application," *Journal of Aquatic Plant Management*, Vol 24, pp 70-75.

Haag, K. H. 1986b. "Effects of Herbicide Application on Mortality and Dispersive Behavior of Waterhyacinth Weevils, *Neochetina eichhorniae* and *Neochetina bruchi* (Coleoptera:Curculionidae)," *Environmental Entomology*, Vol 15, pp 1192-1198.

Perkins, B. D. 1973. "Release in the United States of *Neochetina eichhorniae* Warner, An Enemy of Waterhyacinth," *Proceedings, Annual Meeting, Southern Weed Science Society*, Vol 26, p 368.

Perkins, B. D. 1974. "Arthropods That Stress Waterhyacinth," *Pesticide Articles News Summary*, Vol 20, pp 304-314.

Snedecor, G. W., and Cochran, W. G. 1980. *Statistical Methods*, The Iowa State University Press, Ames, IA.

Statistical Analysis Systems Institute. 1982. "SAS Users Guide: Statistics," Cary, NC, pp 139-200.

Williams, S. 1984. *Official Methods of Analysis of the Association of Official Analytical Chemists*, 14th ed., AOAC, Inc., Arlington, VA.

Effects of Herbicides on *Neochetina eichhorniae*, A Biocontrol Agent of Waterhyacinth

by

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INTRODUCTION

The use of herbicides to control waterhyacinth is common. Information from various US Army Corps of Engineers Districts indicates that >100,000 acres of waterhyacinth were treated with the herbicides 2,4-D, diquat, or glyphosate during 1988. By far the most prevalent herbicide used is 2,4-D (Aquatic Plant Control Operations Support Center, Aquatic Plant Survey, Jacksonville, Florida, 1988). While chemical control methods are a rapid way of managing problem aquatic plants, including waterhyacinth, chemical applications offer only a short-term solution (Gopal 1987).

Another viable control method for waterhyacinth is through biocontrol efforts. Beginning in 1972, three exotic insect herbivors of waterhyacinth were released in the United States from Argentina (Bennett and Zwolfer 1968, Perkins 1974, DeLoach and Cordo 1976). These included two weevil species, *Neochetina eichhorniae* and *Neochetina bruchi*, and the lepidopteran *Sameodes albiguttalis* (Perkins 1973; Perkins and Maddox 1976; Center and Durden 1981; Center 1982; Center, Durden, and Corman 1984; Sanders, Theriot, and Perfetti 1985). The *Neochetina* spp. have been shown to be the more effective agents (Cofrancesco 1985). While dramatic control was observed after their introduction in many areas, including Louisiana, Texas, and Florida (Center 1982; Goyer and Stark 1984; Cofrancesco, Stewart, and Sanders 1985; Center and Durden 1986; Grodowitz, Stewart, and Cofrancesco, in press), serious waterhyacinth infestations still persist.

The reasons for only limited success with biocontrol are not clear; however, there is increasing evidence that use of chemical applications for waterhyacinth control may be a factor (Haag 1986a,b; Grodowitz and Pellessier 1989). With the large expansion of the biocontrol agents' distribution and continued use of chemicals for waterhyacinth control, it is obvious that any negative effects due to chemical use should be manifested. For several years researchers have indicated that chemical use may be detrimental to existing populations of waterhyacinth biocontrol agents (Center 1982). Suggestions for biocontrol agent conservation included leaving untreated waterhyacinth to act as harborage for escaping adults and to spray at those times when the insect population numbers were high. Unfortunately, limited information was available that adequately characterized what effects chemicals have on these organisms.

Recently, several researchers have quantified the influence chemical applications have on the more important biocontrol agents of waterhyacinth. For example, several researchers (Haag 1986a,b; Pellessier 1988; Grodowitz and Pellessier 1989)

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documented the direct toxicity of several commonly used herbicides and adjuvants. Significant mortality from the herbicides was found for only a few tested compounds, most of which are used relatively infrequently (i.e., I'VOD) (Haag 1986a) or for which the mortality was manifested under unusual environmental conditions (i.e., Diquat and X-77 under very dry environments) (Pellessier 1988, Grodowitz and Pellessier 1989).

However, this research has indicated that chemical application may cause significant indirect effects. These include reductions in feeding activity (Pellessier 1988, Grodowitz and Pellessier 1989), which subsequently lead to increased movement away from treated plants (Haag 1986a,b; Pellessier 1988; Grodowitz and Pellessier 1989). Reductions in feeding may have been triggered by changes in phytochemistry, including decreases in ether-soluble compounds (i.e., lipids). Apparently, reduction in plant quality induces the adult insects to forage for better quality food sources farther from the area treated (Grodowitz and Pellessier 1989). In addition to the observed behavioral changes, these researchers indicated that significant indirect mortality could be expected after chemical application. This mortality occurs because of the total plant and mat destruction that is commonly observed after herbicide use. Since the immature stages (i.e., eggs, larvae, and pupae) are relatively immobile and completely dependent on the plant for survival, destruction of the plant mat indirectly causes significant mortality. This mortality has been hypothesized to be extreme; e.g., for a 5-acre pond with 25 percent adults, a total of 1.5 million immature stages would be lost (Table 1).

The mortality could be reduced if chemicals were applied at those times when the proportion of adults to immatures was high and the reproductive status of the moving adults was active. If, for the above-mentioned example, the proportion of adults was 75 percent instead of 25 percent, the resulting loss would be reduced to only 500,000 immatures (Table 1). In addition, the number of viable recolonizing females is dependent on the percentage of individuals in an active reproductive condition (Table 1). Such shifts in population structure and reproductive condition have been shown to occur in native populations of *Neochetina* sp. (see Grodowitz and Freedman 1990).

However, more information is needed to describe the effects that chemical applications have on biocontrol agents of waterhyacinth under field conditions. Most of this research was done under controlled laboratory conditions (Pellessier 1988, Grodowitz and Pellessier 1989) or unusual field situations (Haag 1986b). Toward this goal, we initiated a series of small field experiments designed to quantify chemical effects during typical chemical applications.

MATERIALS AND METHODS

Texas survey

A total of 12 sites with heavy waterhyacinth infestations were sampled during September 1989 to quantify and qualify the presence and damage of waterhyacinth biocontrol agents. The sites were categorized based on the degree of chemical management used over the last 3 years. If a site was treated with chemicals over each of

Table 1
Hypothetical Mortality and Potential Reproductive Colonizers for Waterhyacinth Infestations Treated with Herbicides for Biocontrol Agents with Varying Population Structures

Parameter	*Value*
Hypothetical Mortality	
Population structure (% adults/% immatures)	Immature mortality (loss, million/5 acres)
25/75	1.5
50/50	1.0
75/25	0.5
Reproductive Colonizers	
Reproductive status (% fecund/% nonfecund)	Potential recolonizers (million/5 acres)
25/75	0.25
50/50	0.50
75/25	0.75

Notes: The numbers for mortality are based on a 5-acre treated area, 100 individuals collected/m^2, 100-percent mortality for immatures, and no mortality for adults. Number of reproductive colonizers is based on 50 females/m^2.

the last 3 years, the site was considered to be heavily managed. The sites were located throughout the southeastern portion of Texas. A total of six heavily managed and six nonmanaged sites were sampled. One of the nonmanaged sites was eliminated from the analysis because of unusually low numbers of weevils collected on a per-square meter basis in comparison to high numbers collected on a per-hour basis. This left a total of five nonmanaged and six managed sites.

The insects were sampled by randomly placing a 0.25-m^2 polyvinyl choloride frame within the waterhyacinth canopy. All plants 50 percent or more within the frame were removed, and all adult biocontrol agents were quantified on the first 10 plants. In addition, biocontrol agents were collected for 1 hr, and the number of individuals collected per hour was quantified. This was done to check the accuracy of the per-square meter samples and to quantify sex ratio. Statistical differences were determined using analysis of variance (ANOVA) on the Statistical Analysis System (SAS 1982). Pair-wise comparisons were determined using a Least Squares Difference (LSD) analysis based on the pooled mean square error calculated from the ANOVA.

Chemical effects field study

The effects that typical chemical applications have on *Neochetina* sp. populations were quantified in a small study located on Lake Bouef, near the town of Raceland, Louisiana. The study was conducted beginning in July and ending August 1989. For this study, six relatively isolated waterhyacinth infestations in Lake Bouef or surrounding canals were selected. Three of the study sites were randomly chosen to be used as controls while the remaining three were randomly chosen as treated sites. Each site was divided in half by an imaginary line for separation of chemical applications and sampling. Thirty-five days prior to chemical application, all six sites were sampled as described in the previous section. In addition, the number of larvae was also quantified. Weevils collected from each site were also dissected, and flight muscle development was determined. The method for determining flight muscle development was similar to that described by Buckingham and Passoa (1985).

On day 0, sampling for insect numbers was accomplished prior to chemical application. The herbicide 2,4-D and the adjuvant Spreader/Sticker were applied on day 0 to the three sites chosen for treatment. For each site, only half of the total area was treated with chemicals. Application rates were 0.5 percent 2, 4-D mixed with 8.4 ℓ Spreader/Sticker per 100 ℓ water. Numbers of insects were determined 9 and 21 days after chemical application, as described previously. Similarly, statistical analysis was done as described for the Texas survey. Differences in the percentage of females with flight muscle development were determined using a chi-square analysis.

RESULTS AND DISCUSSION

Texas survey

The predominant species collected was *N. eichhorniae* for this survey. *Neochetina bruchi* was collected from only one site in Wallisville, Texas, and represented 14.3 percent of the total number of weevils collected at that site and 4.8 percent of the total number of insects collected from the entire survey. While no *S. albiguttalis* were collected, several sites contained plants with obvious damage from this species. *Tetranychus* spp., or spider mites, were observed in a majority of the sites sampled. At some locations spider mite infestations were considered to be high, although no attempt was made to quantify these infestations. In all, a total of 420 biocontrol agents were collected from all sites, not including those collected for sex ratio purposes.

A distinct difference in plant appearance was noted for sites with chemical application history (i.e., managed sites). Greater than 80 percent of the managed sites had plant populations in the incipient or colonizing phenotype. The plants had a lush green vegetation and only limited damage by biocontrol agents. The epidermis was obviously less tough and thickened than that observed for plants at sites with no application history. There was an apparent difference in the amount of feeding damage and associated browning and curling of the plant lamina. Such changes in leaf appearance are typically associated with plants subjected to sustained insect herbivory (Center and Durden 1981). Sites with a history of continual chemical applications had only minimal browning and curling of the leaves.

Lower numbers of *N. eichhorniae* were collected from sites with a past history of continual chemical applications (Table 2). This reduction was approximately

Table 2

Mean Number of Adult *Neochetina eichhorniae* Collected (per m^2) and Number of Weevils Collected (per hour) from Sites with a History of Chemical Management and Those with No Recent History of Chemical Application

Management Type	*Total Adults/m²**	*Weevils/Hour***
No chemicals	56.0 a†	141.4 a
Chemicals	23.3 b	42.9 b

*F-statistic = 4.89; df = 1, 9; P = 0.0543 for weevils/m^2.
**F-statistic = 4.10; df = 1, 9; P = 0.0736 for weevils/hr.
†Means followed by the same letter are not significantly different at P > 0.10 using a LSD analysis.

58 percent for number of weevils collected per square meter. Lower numbers of *N. eichhorniae*/m^2 (i.e., >50 percent) were also found at sites with similar chemical histories in south Florida during 1989.* Reductions also occurred for another quantitative estimate, numbers of weevils collected per hour (>69 percent).

While this survey was relatively small, it does indicate that factors associated with chemical application apparently have a decided impact on weevil numbers. Reasons for such large reductions are unknown, but several hypotheses can be offered. One of the more plausible is that the indirect effects speculated by various researchers are indeed causing significant reductions in population numbers. With continual applications of chemicals, large proportions of the biocontrol agent populations are removed by both mortality of the immatures and movement by the adults toward untreated sites. With the destruction of the waterhyacinth mat by chemical application, large areas of the water body become open for subsequent reinfestation by waterhyacinth. The reinfestation can occur by plants floating in from nearby areas or from regrowth from small pockets of plants that were missed by the original applications. Growth from dormant seeds could also be expected.

This situation creates the optimum environment for rapid growth and reestablishment of waterhyacinth. The plants change morphotype and begin producing large numbers of ramets asexually, which can quickly cover open water. With the disruption of the biocontrol populations, little if any natural control is achieved, and waterhyacinth population numbers increase dramatically. Establishment of the biocontrol agents requires time. After a period of several months the biocontrol agents begin to reestablish, and another chemical application is performed, starting the cycle over. The occurrence of such effects due to herbicide action was first postulated by Wright and Center (1984).

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Chemical effects field study

This study was a preliminary step toward understanding the effects that field applications of herbicides have on populations of *N. eichhorniae*. The 2,4-D applications produced degradation of the plant material relatively quickly. Nine days post-treatment, limited quantities of living plant material were found. Geniculation of the petioles was common. At 21 days after herbicide application, the plants were essentially dead. Little if any green plant material was remaining, and most of the leaves were prostrate on the water surface and could be separated easily from the stem and root material. Open water was beginning to occur due to sinking of the mat. In comparison, plants at nontreated sites were healthy, with damage occurring only due to insect feeding and tunneling.

No significant differences were found in insect numbers until day 21. On day 21, borderline significant differences ($P < 0.10$) occurred in total numbers of adults (Table 3). For example, >20-fold increases were noted in numbers of adults in areas adjacent to those treated with chemical applications. Significantly lower numbers of *N. eichhorniae* were collected from control sites relative to those treated with herbicides (>3-fold). No differences could be detected for sites adjacent to treated areas and control sites, even though there was a 6.7-fold difference. This was due to the large variation in numbers of insects of all life stages. Future studies need additional sampling efforts to minimize such variability.

Table 3
Mean Number of Adults and Larvae (per m^2) Collected from Sites on Lake Bouef with No Treatment (Control), with 2,4-D (Treated), and Adjacent to Treated Areas (Near Treated) 21 days After 2,4-D Application

Treatment Type	*Total Larvae/m^2**	*Total Adults/m^2***
Control	21.9 a†	110.6 b
Near treated	35.6 a	341.4 a
Treated	13.7 a	16.4 b

*F-statistic = 1.50, df = 2, 11, and $P = 0.2742$ for larvae/m^2.
**F-statistic = 3.85, df = 2, 11, and $P = 0.0619$ for adults/m^2.
†Means followed by the same letter are not significantly different at $P > 0.10$ using a LSD analysis.

This was in contrast to numbers of larvae/m^2, where no significant differences were documented for any sites. There was a trend for mean numbers to be lower in the actual treated areas (ca. 2.5-fold relative to sites adjacent to treated areas). The presence of living larvae in such degraded plant material was surprising. However, the larvae did not appear to be as healthy as those found in nontreated areas. This was indicated by limited food material in the alimentary canal of larvae collected from treated areas. There is little doubt that if sampling continued, no larvae would have been collected from treated sites.

This study begins to confirm what was found in the laboratory and more controlled field experiments. First of all, adults tend to move from treated to untreated plant material relatively quickly. However, not all adults migrate even though the plant material was essentially dead. This was evidenced by the 16.4 adults/m^2 collected in treated areas. This translates to almost 70,000 adults/acre. Movement from treated to untreated areas is presumed to be accomplished by walking, since flight muscle development is rare in *N. eichhorniae*. However, there was a significant increase in the percentage of females with flight muscles in treated and adjacent areas (ca. 5-fold; Figure 1).

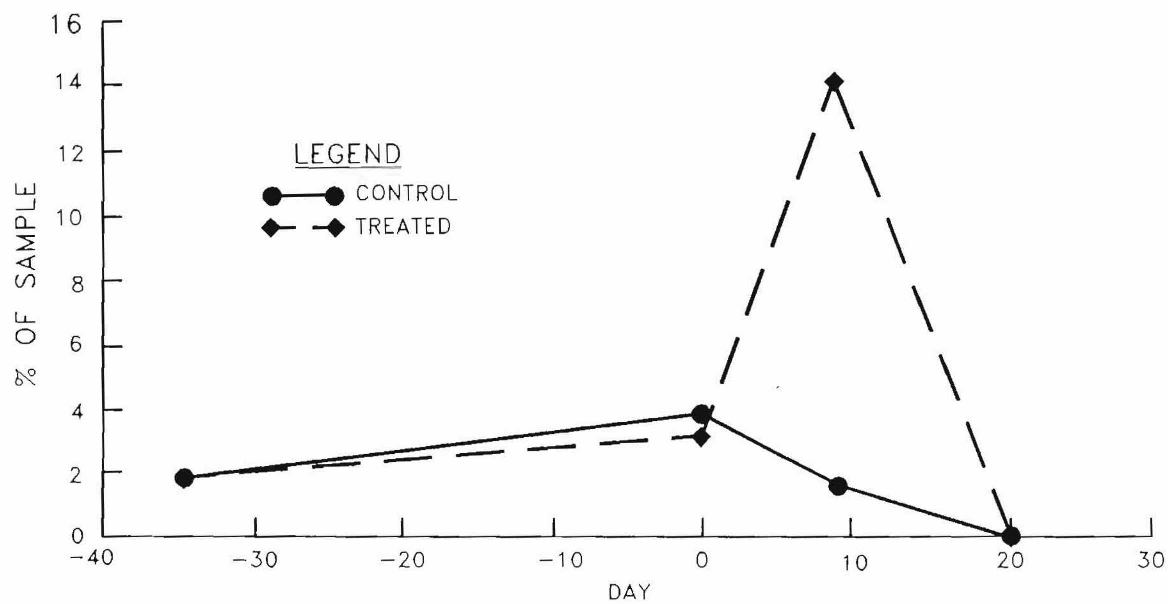

Figure 1. Percentage of females with flight muscle development at various times before (as indicated by negative numbers) and after 2,4-D application at sites on Lake Bouef near Raceland. Herbicide was applied on day 0. Means from both control and herbicide-treated areas are presented. Significant difference was detected using a chi-square row-by-column contingency analysis ($P < 0.005$)

Reasons for flight muscle development are unknown (Buckingham and Passoa 1985), but researchers have postulated that rapid changes in plant quality, such as what occurs during herbicide applications, may be an important factor (Haag 1986a,b). More information is needed to understand this phenomenon. In addition, larvae appear to live longer than was expected. Living larvae were collected from treated plant material even 21 days posttreatment. However, the larvae could not be expected to live without an adequate food source, which was eliminated by herbicide action. Hence, significant numbers of immatures are apparently lost during application of herbicides.

In summary, there appear to be significant negative effects on existing biocontrol agent populations due to the application of chemicals for controlling waterhyacinth.

This has been documented in the present study and other laboratory (Haag 1986a,b; Pellessier 1988; Grodowitz and Pellessier 1989) and field experimentation (Haag 1986a,b). These effects include loss of immatures and movement of adults toward untreated plant material. An overall decrease in biocontrol agent numbers is associated with waterhyacinth infestations that are continually treated with chemicals. Such effects have been postulated for several years (Center 1982, Wright and Center 1984).

More information is needed so that effective methods can be developed to minimize the observed negative effects that chemical applications have on existing populations of waterhyacinth biocontrol agents. This includes research designed to characterize what happens to *N. eichhorniae* before and after chemical application. This should be quantified at various population compositions (i.e., proportion of adults to immatures) and insect reproductive conditions, in order to determine if timing herbicide applications would be an effective method of reducing the present noncompatibility between chemical and biological control. If such efforts prove to be effective in reducing the observed noncompatibility, other studies need to be initiated to determine if they can be practically incorporated into existing aquatic plant management programs. Such research has been proposed previously (Center 1982; Haag 1986a,b; Grodowitz and Pellessier 1989).

REFERENCES

Bennett, F. D., and Zwolfer, H. 1968. "Exploration for Natural Enemies of the Waterhyacinth in Northern South America and Trinidad," *Hyacinth Control Journal*, Vol 7, pp 44-52.

Buckingham, G., and Passoa, S. 1985. "Flight Muscle and Egg Development in Waterhyacinth Weevils," *Proceedings, VI International Symposium on Biological Control of Weeds*, E. S. Delfosse, ed., Agriculture Canada, Vancouver, BC, Canada, pp 497-510.

Center, T. D. 1982. "The Waterhyacinth Weevils *Neochetina eichhorniae* and *N. bruchi*," *Aquatics*, Vol 4, pp 8-19.

Center, T. D., and Durden, W. C. 1981. "Release and Establishment of *Sameodes albiguttalis* for the Biological Control of Waterhyacinth," *Environmental Entomology*, Vol 10, pp 75-80.

Center, T. D. and Durden, W. C. 1986. "Variation in Waterhyacinth/Weevil Interactions Resulting from Temporal Differences in Weed Control Efforts," *Journal of Aquatic Plant Management*, Vol 24, pp 28-38.

Center, T. D., Durden, W. C., and Corman, D. A. 1984. "Efficacy of *Sameodes albiguttalis* As a Biocontrol of Waterhyacinth," Technical Report A-84-2, US Army Engineer, Waterways Experiment Station, Vicksburg, MS.

Cofrancesco, A. F. 1985. "The Release, Establishment, and Dispersal of *Sameodes albiguttalis* (Warren) in Louisiana," *Entomological Society of America, Annual Meeting*, Hollywood, FL.

Cofrancesco, A. F., Jr., Stewart, R. M., and Sanders, D. R., Sr. 1985. "The Impact of *Neochetina eichhorniae* (Coleoptera:Curculionidae) on Waterhyacinth in Louisiana," *Proceedings, VI International Symposium on Biological Control of Weeds*, E. S. Delfosse, ed., Agriculture Canada, Vancouver, BC, Canada.

DeLoach, C. J., and Cordo, H. A. 1976. "Ecological Studies of *Neochetina bruchi* and *N. eichhorniae* on Waterhyacinth in Argentina," *Journal of Aquatic Plant Management*, Vol 14, pp 53-59.

Gopal, G. 1987. *Waterhyacinth*, Elsevier, New York.

Goyer, R. A., and Stark, J. D. 1984. "The Impact of *Neochetina eichhorniae* on Waterhyacinth in Southern Louisiana," *Journal of Aquatic Plant Management*, Vol 22, pp 57-61.

Grodowitz, M. J., and Freedman, J. 1990. See pp 50-64 in this proceedings.

Grodowitz, M. J., and Pellessier, D. 1989. "Effects of Chemical Applications on the Biological Control Agents of Waterhyacinth," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Waterways Experiment Station, Vicksburg, MS.

Grodowitz, M. J., Stewart, R. M., and Cofrancesco A. F. "Population Dynamics of Waterhyacinth and the Biological Control Agent *Neochetina eichhorniae* (Coleoptera:Curculionidae) in Southeast Texas," *Environmental Entomology* (in press).

Haag, K. H. 1986a. "Effective Control of Waterhyacinth Using *Neochetina* and Limited Herbicide Application," *Journal of Aquatic Plant Management*, Vol 24, pp 70-75.

Haag, K. H. 1986b. "Effects of Herbicide Application on Mortality and Dispersive Behavior of Waterhyacinth Weevils, *Neochetina eichhorniae* and *Neochetina bruchi* (Coleoptera:Curculionidae)," *Environmental Entomology*, Vol 15, pp 1192-1198.

Pellessier, D. 1988. "Effects of Herbicides and Associated Adjuvants on *Neochetina eichhorniae*, the Mottled Waterhyacinth Weevil," Master's thesis, University of Southwestern Louisiana, Lafayette, LA.

Perkins, B. D. 1973. "Release in the United States of *Neochetina eichhorniae* Warner, an Enemy of Waterhyacinth," *Proceedings, Annual Meeting, Southern Weed Science Society*, Vol 26, p 368.

Perkins, B. D. 1974. "Arthropods That Stress Waterhyacinth," *Pesticide Articles News Summary*, Vol 20, pp 304-314.

Perkins, B. D., and Maddox, D. M. 1976. "Host Specificity of *Neochetina eichhorniae* Hustache (Coleoptera:Curculionidae), a Biological Control Agent for Waterhyacinth," *Journal of Aquatic Plant Management*, Vol 14, pp 59-64.

Sanders, D. A., Sr., Theriot, E. A., and Perfetti, P. 1985. "Large-Scale Operations Management Test (LSOMT) of Insects and Pathogens for Control of Waterhyacinth in Louisiana; Vol I," Technical Report A-85-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Statistical Analysis Systems Institute. 1982. "SAS Users Guide: Statistics," Cary, NC, pp 139-200.

Wright, A. D., and Center, T. D. 1984. "Biological Control: Its Place in the Management of Waterhyacinth," *Proceedings, International Conference on Water Hyacinth*, G. Thyagarajan, ed., UN Environmental Program, Nairobi, India.

Biological Control of Hydrilla with an Endemic Plant Pathogen

by
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INTRODUCTION

In 1988, an isolate of the fungus *Macrophomina phaseolina* (Tassi) Goid., previously identified as *Rhizoctonia* sp., was found to be pathogenic to hydrilla (Joye 1988, 1989). In laboratory, greenhouse, and field experiments this pathogen was able to incite a severe blight that rapidly destroyed hydrilla test plants. Results from those experiments have shown that this pathogen could potentially be used as a biocontrol agent of hydrilla. In 1989, greenhouse and field experiments were repeated to verify the stability of this isolate of *M. phaseolina* with regard to its pathogenicity and host range.

MATERIALS AND METHODS

Greenhouse tests

In a greenhouse test as previously described (Joye 1989), *Macrophomina phaseolina* was tested at three rates of 1×10^6, 1×10^7, and 1×10^8 colony forming units (cfu) per milliliter. Clear plastic tubes (150×13.75 cm) were used for culture of test hydrilla plants. Unsterilized lake sediment was planted in the bottom of each tube and overlain with 7.5 cm of fine sand. Three 15-cm sprigs of fresh hydrilla were planted in each tube, after which 16 ℓ of nutrient solution (Joye 1989) was added. The hydrilla tubes were maintained at 25° C under normal greenhouse lighted conditions.

The inoculum was grown in a 15-ℓ New Brunswick fermenter. The medium used for culture was V8 broth. Hydrilla plants receiving treatment were inoculated when the plants had grown to the top of the water column (100 cm). Treatments were replicated five times. Biomass samples were taken 3 weeks after inoculation. The biomass samples were dried at 100° C for 3 days. Data were subjected to an analysis of variance, and mean comparisons were made using Tukey's Test (Steel and Torrie 1980).

Host specificity

Historically, isolates of *M. phaseolina* have been the causal agent of a disease commonly known as charcoal rot. Many plant species (Farr et al. 1989), especially members of the family Fabaceae, are susceptible to this disease. For this reason, previously tested species (Joye 1989) in this family were retested. Species tested were *Glycine max*, varieties Bedford, Braxton, Coker 368, Davis, Forrest, Hartz 8112,

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H6385, and H7110; *Medicago sativa*, variety Pioneer; *Trifolium pratense*; and *Phaseolus vulgarus*, variety Kentucky wonder.

Seeds were planted in 90-ml styrofoam cups filled with a commercial potting mix. Because isolates of this fungus are known to cause greater damage when plants are under extreme stress (Sinclair 1982), the potted plants were placed on a greenhouse bench and watered as needed until they had grown to a height of about 30 cm, after which the plants were maintained under a drought stress condition by reducing the available water.

Plants were inoculated by impregnating to stem approximately 2 cm from the soil line with a toothpick that had been infiltrated by the fungus (Dhingra and Sinclair 1985). This was done to give the fungus an optimum portal of entry into the plant. The plants were observed daily for 14 days for any disease symptoms caused by this pathogen. Control plants were pierced with a sterile toothpick.

Field test

A small-scale field test was conducted in a hydrilla mat at the Sheldon Reservoir, Texas. This test was similar to that conducted at the same location in 1988 (Joye 1989). Plots ($1 \times 1 \times 1.3$ m) constructed of polyvinyl chloride tubing and polyethylene were secured in sediment as previously described (Joye 1989). Plots were established 1 month prior to inoculation to allow the plants to naturalize the plots. On 10 October, plots were inoculated with a concentrated inoculum (1×10^9 cfu/ml) which after dilution was 1×10^4 cfu/ml. Plots were observed 2 and 4 weeks after inoculation. Biomass was collected at 4 weeks. Treated and untreated plots were replicated five times. Data were subjected to a t-test.

RESULTS

Greenhouse test

Within 14 days after treatment, hydrilla plants were nearly completely destroyed by the fungus. There were no significant differences between inoculum rates; however, all treatments were significantly different from the control ($P = 0.05$). Mean dry weights for plants treated with 1×10^8, 1×10^7, and 1×10^6 were 0.13, 0.62, and 0.39 g, respectively. Mean dry weight for the untreated plants was 7.6 g.

Host specificity

None of the test plants were susceptible to *M. phaseolina*. Plants impregnated with the fungus-infiltrated toothpick responded by exhibiting a hypersensitive reaction that may be defined as an acute reaction of the plant to attack by a pathogen resulting in the prompt death of the invaded tissue, thus preventing further spread of the infection (Federation of British Plant Pathologists 1973). Plants impregnated with a sterile toothpick exhibited no reaction other than the production of callus tissue around the site of penetration.

Field test

The results of the 1989 field test were similar to those results reported for 1988 (Joye 1989). There was a significant difference ($P > t = 0.02$, $df = 4$) between the treated and nontreated plots. Biomass of treated plots (mean dry weight = 106.91 g) was 59 percent less than nontreated plots (mean dry weight = 258.80 g).

DISCUSSION

Results of these experiments indicate that an isolate (FHyl8) of the endemic fungal plant pathogen *Macrophomina phaseolina*, may satisfy the requirements for a biocontrol agent of hydrilla. It can be produced in abundance (mycelium and microsclerotia) on artificial media, it has shown a high level of host specificity, and prepared inoculum of the pathogen was able to rapidly destroy hydrilla within 4 weeks after inoculation.

The effects of application of large quantities of this fungus to an aquatic environment are not well understood. In general, biological control agents tend to have little effect on the area being treated or on nontarget plants. However, the application of this pathogen may result in an effect similar to that seen with more traditional control agents, resulting from the rapid killing of the targeted weed; i.e., the rapid decay of organic matter will likely promote eutrophication and decrease oxygen levels, which may have a temporary effect on the local fauna within the treated area. Nevertheless, the long-term effects on the environment would be practically nonexistent. There would be no persistence of harmful residues in the tissues of aquatic animals, plants, water, or the sediment. The disadvantage of using this pathogen as a biocontrol agent is that it will likely be sensitive to environmental conditions, which may prevent widespread use. However, this may be remedied through proper timing of application and selection of more cold-tolerant strains.

Future research plans will focus on several areas, as outlined below.

a. Experiments will be conducted as required for the acquisition of an Experimental Use Permit (EUP) from the US Environmental Protection Agency. The EUP will be necessary to satisfy required environmental safety precautions outlined in the Code of Federal Regulations (40 CFR) before any large-scale testing will be permitted.

b. Experiments will be conducted to study the epidemiology of the disease caused by this fungus to hydrilla. From these experiments, basic environmental conditions optimum for disease development will be determined.

c. Selection for cold-tolerant strains and increased virulence of this pathogen will make its application within more northern latitudes possible for biocontrol of hydrilla. Increased virulence may be accomplished through enhancement of cellulytic enzyme production, thus increasing the pathogen's ability to penetrate the host tissue.

d. The development of an appropriate delivery system will provide for a practical means of application for large-scale testing and demonstrations.

REFERENCES

Dhingra, O. D., and Sinclair, J. B. 1985. *Basic Plant Pathology Methods*, CRC Press, Boca Raton, FL.

Farr, D. F., Bills, G. F., Chamuris, G. F., and Rossman, A. Y. 1989. *Fungi on Plants and Plant Products in the United States*, APS Press, St. Paul, MN.

Federation of British Plant Pathologists. 1973. "A Guide to the Use of Terms in Plant Pathology," Phytopathology Paper No. 17, Commonwealth Agricultural Bureau, Kew, England.

Joye, G. F. 1988. "Biological Control of *Hydrilla verticillata* (L.f.) Royle Using an Endemic Fungal Plant Pathogen," *Phytopathology*, Vol 78, p 1593 (Abstract A642).

Joye, G. F. 1989. "Biological Control of *Hydrilla verticillata* (L.f.) Royle Using an Endemic Plant Pathogen," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 41-50.

Sinclair, J. B. 1982. *Compendium of Soybean Diseases*, American Phytopathological Society, St. Paul, MN.

Steel, R. G. D., and Torrie, J. H. 1980. *Principles and Procedures of Statistics*, McGraw-Hill, New York.

Biological Control of Eurasian Watermilfoil

by
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INTRODUCTION

This work unit deals with efforts to use biological means to control Eurasian watermilfoil. Last year we narrowed our focus for a plant pathogen to the fungus *Mycoleptodiscus terrestris* (Winfield 1988). We are currently involved in establishing the optimum shelf life for our formulations and determining what amendments will improve its viability. In addition, we have been conducting tests to establish the optimum level of inoculum needed for biocontrol of Eurasian watermilfoil and discovering more about the mode of action of this pathogen.

VIABILITY STUDIES

It is important that we first establish the optimum shelf life for our formulations to ensure that we can produce adequate amounts of inoculum for field applications. We designed the viability studies to find out which amendments would enhance our alginate formulation of *Mycoleptodiscus terrestris (M. t.)*. It has been noted in the literature that sodium alginate is an effective carrier of mycoherbicides (Walker and Connick 1983, Lewis et al. 1985).

All alginate formulations were tested with the same protocol. Immediately after the pellets were formed and allowed to air dry, half were stored at 25° C and half at 4° C. Pellets were placed on water agar plates beginning at day 0 and on a weekly basis thereafter. The plates were incubated for 3 days at 25° C and then checked for viability (indicated by growth).

We began to test for the effects of adding various dry amendments to an alginate mixture of *M. t.* in 1988 and concluded those tests this year. This portion of the test was allowed to run for 12 weeks. Next, we started to test for the effects of adding liquid amendments (oils) to an alginate mixture. The alginate mixture consisted of a broth culture of *M. t.*, a food source, an inert clay carrier, and sodium alginate. The carbohydrate food sources and the oils used are listed below.

Carbohydrates	*Clay Carriers*	*Oils*
Corn meal	Kaolin	Mazola
Rice flour	Bentonite	Crisco
Potato flour	Atta gel	Peanut
	Montmorillonite	Sunflower
	No clay	Safflower
		Olive

*US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

The results from the first part of this experiment are shown in Figure 1. Although this experiment was conducted for 12 weeks, other researchers have obtained viabilities for period of 6 to 8 months when using alginate formulations (Walker and Connick 1983).

Regardless of the clay or food source used, those pellets stored at 4° C remained viable about 40 percent longer than those stored at 25° C. This information about storage requirements will permit us to more accurately estimate the cost involved in formulation production. The increased viability of those pellets stored at 40° C will also provide a 3- to 4-week window when scheduling fieldwork; this can enhance the chances for successful field studies and provides greater flexibility with logistics.

The second part of the experiment involved the addition of the six oils tabulated above. The end point of this experiment occurred when viability dropped to 50 percent. A similar protocol was followed for plating out pellets and testing for viability.

Those pellets amended with oils and stored at 25° C had a mean viability of 19 days. Pellets stored at 4° C were viable about 42 percent longer, with a mean of 33 days. Regardless of the clay, oil, or temperature used, those pellets utilizing potato flour as the food source had the longest viabilities (20 percent longer). Generally, it appears that one of the better characteristics of oils for the manufacture of alginate formulations is their ability to affect the buoyancy or positioning of the pellets in the water column.

TITER TEST

The optimum level of inoculum has to be determined for each formulation. To accomplish this we conducted titer tests on a wet-pack formulation of *M. t.* This formulation was prepared for us by the Ecoscience Laboratories in Amherst, Massachusetts.

Our test unit consisted of three meristematic sprigs of Eurasian watermilfoil grown in sterilized lake sediment. The plants had been grown in plastic starter pots for 10 days in aerated aquaria. The plants were then placed into clear liter-sized glass jars and acclimated in an environmental chamber for 24 hr prior to inoculation. Four rates of inoculum were used: 1, 5, 10, and 15 g. Controls and treatments were replicated 10 times.

To be consistent with previous studies, we used a 16:8-hr photoperiod and 18° C temperature during these tests. Figure 2 shows representative plants at the conclusion of the tests. The test period lasted for 21 days. Dry weight biomass tests were done on all plants at the conclusion of the titer tests.

The graph in Figure 3 depicts the results of the titer tests. The maximum decrease in biomass occurs between the 1- and 5-g treatments. Very little additional decrease in biomass can be seen with increasing amounts of inoculum. This indicates that the optimum level of inoculum is between 1 and 5 g.

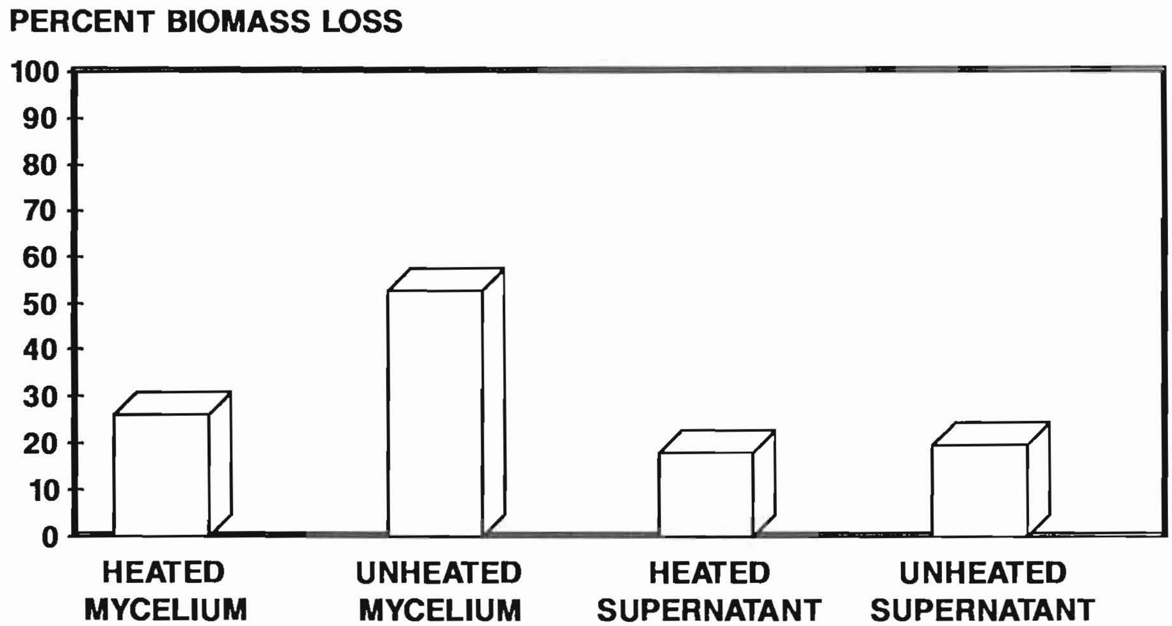

Figure 1. Percent biomass loss at completion of toxin study

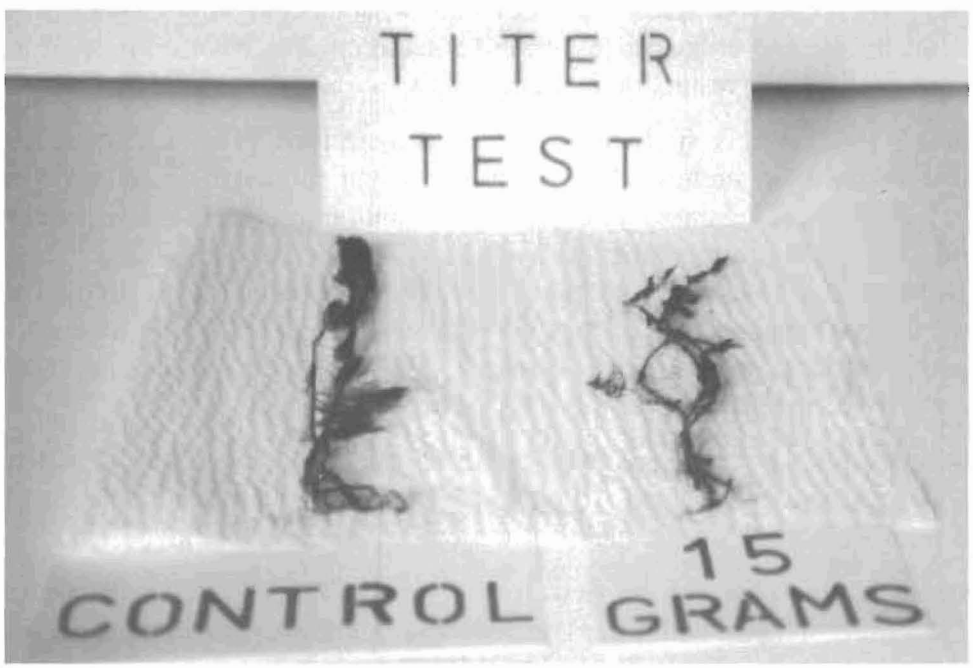

Figure 2. Plants at conclusion of titer test

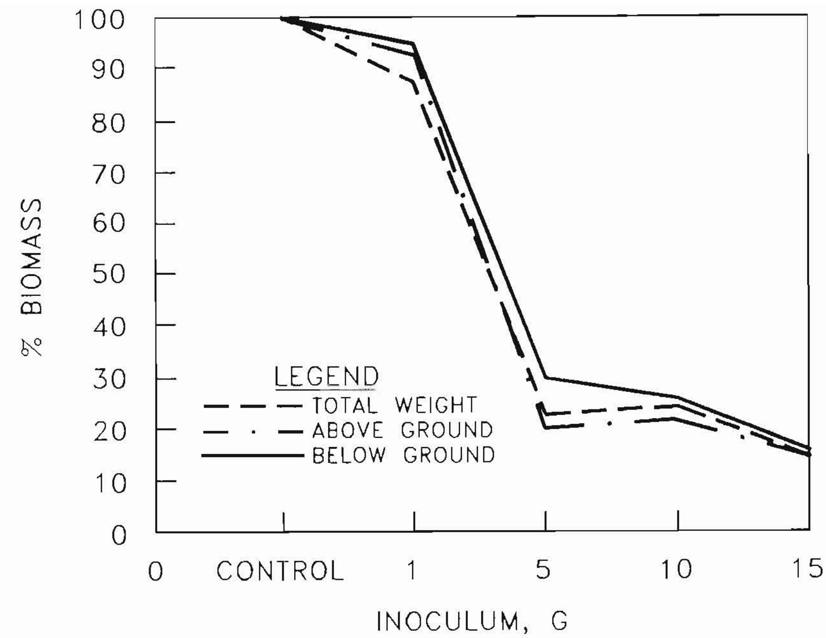

Figure 3. Results of titer test using a wet-pack inoculum

TOXIN FORMATION

We can optimize our utilization of this fungus by discovering more about its mode of action. We designed studies to ascertain whether the degradation of Eurasian watermilfoil by *M. t.* is enhanced by toxin formation. We have completed studies to verify some preliminary results obtained last year.

The plants used in this study were grown and acclimated in a manner similar to those used in the titer studies. Five kinds of fungal inoculum were used. A shake culture of *M. t.* was separated into its supernatant and myceliar components. The mycelium was washed three times with distilled reverse osmosis water, homogenized in a blender, and divided in two portions. The supernatant was divided also. A portion of the supernatant and the mycelium was heated to 160° C in an autoclave and maintained at that temperature for 15 min. The remainder of the supernatant and mycelium was not subjected to any further treatments.

The milfoil plants were inoculated with the 5 ml of the inoculum. Each treatment and the control were replicated 10 times. The study was conducted for 21 days. Biomass tests were done on the plants at the conclusion of the study.

The results of the study can be viewed in Figure 4. Decreases in biomass of 26 and 53 percent were noted with the heated and unheated mycelium, respectively. Decreases were smaller but still evident with the heated and unheated supernatant, 16 and 19 percent, respectively.

We believe that the decreases in biomass of the plants treated with the heated supernatant indicate the presence of a toxin-like effect. The heating process should have

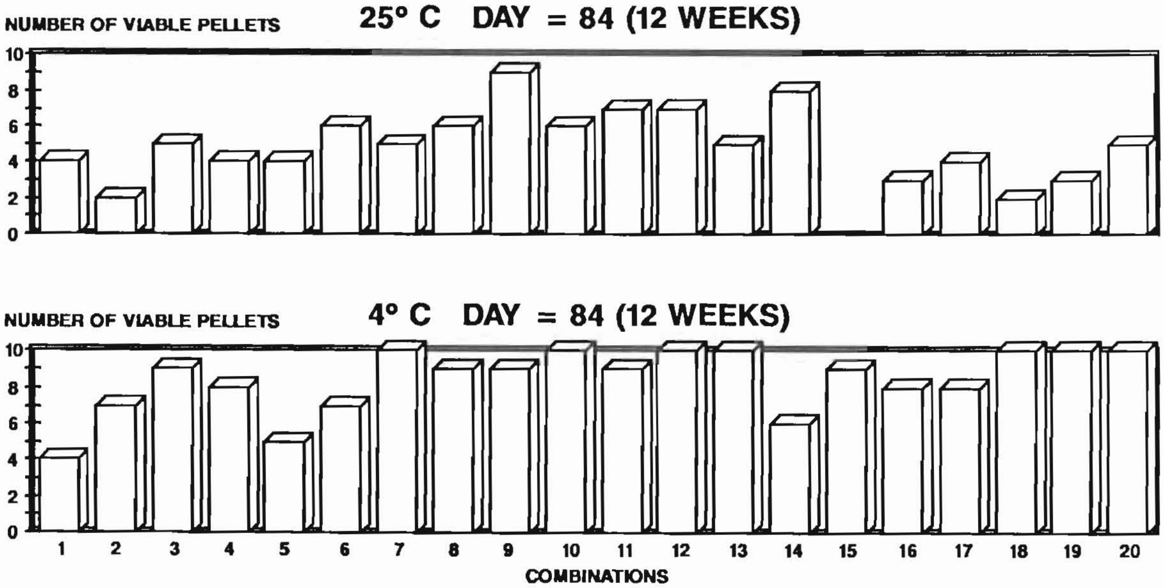

Figure 4. Alginate pellet viability study

inactivated any enzyme present. Therefore, we attribute the degradation of the Eurasian watermilfoil plants to the action of a toxin.

FUTURE WORK

We have been using a test site in Lewisville, near Dallas, Texas. It is the site of a former fish hatchery and will fulfill our current requirements for doing contained studies. Four-sided clear Plexiglas test modules will be used during our preliminary testing. We will then scale up our study to include much larger areas. Some of our trials will be conducted here at Lewisville and some at other sites that are under consideration.

Mycoleptodiscus terrestris is proving efficient at decreasing milfoil populations in greenhouse studies. We have obtained up to 85-percent reduction with whole inoculum and 48-percent reduction with washed mycelium alone. If we can obtain similar results in field trails, we will be well on our way to obtaining biocontrol of Eurasian watermilfoil.

REFERENCES

Lewis, J. A., et al. 1985. "Preparation of Pellets Containing Fungi and Nutrient for Control of Soilborne Plant Pathogens," No. 86055413, National Technical Information Service, Fort Belvoir, VA.

Walker, H. L., and Connick, W. J. 1983. "Sodium Alginate for Production and Formulation of Mycoherbicides," *Weed Science*, Vol 31, pp 333-338.

Winfield, L. E. 1988. "Biological Control of Eurasian Watermilfoil with *Mycoleptodiscus terrestris*," *Proceedings, 22nd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 53-58.

Development of the Fungal Agent *Mycoleptodiscus terrestris* for the Biological Control of Eurasian Watermilfoil (*Myriophyllum spicatum* L.)

by
James P. Stack*

INTRODUCTION

There are several approaches to the development of biological agents for the management of aquatic and terrestrial nuisance plants. As in other biological control systems, the probability of achieving successful biocontrol is a function of the knowledge base of the system in which biocontrol is to be effected (Cook and Baker 1983; Stack, Kenerley, and Pettit 1988). The approach that has evolved at EcoScience Laboratories, Inc. (ESL), over the last few years under the direction of Drs. Haim Gunner and David Miller is analytical rather than empirical. It is a systems approach focusing at the organismal level of complexity. We have initiated investigations at the cellular and molecular levels to elucidate the mechanisms of interaction and at the population level to understand the significance of those interactions. At present, ESL is using the *Myriophyllum spicatum* (Eurasian watermilfoil)-*Mycoleptodiscus terrestris (M. t.)* interaction as a model system for the development of fungal biocontrol agents of nuisance aquatic plants.

We are constructing an epidemiological model that describes the interaction of an aquatic plant host with a fungal plant pathogen. There are two fundamental strategies in plant disease control: to reduce the amount of initial inoculum (X_0) or to reduce the rate of disease increase (r) (Fry 1982). For the biological control of an aquatic weed we are trying to create an epidemic rather than prevent one. Consequently, in the milfoil system we want to increase X_0 or r, or both, with the ultimate objectives to eradicate the target plant population (i.e., reduce existing biomass rapidly), inhibit the development of new biomass, and initiate a decline in plant productivity (sustained over seasons). Specifically, we are trying to increase the rate of disease development on a single plant (lesion expansion and lesion number increase) as well as increase the rate of disease progression in a population of plants.

MODEL CONSTRUCTION

Our approach is similar to that previously described for biological control of plant pathogens in terrestrial systems (Stack, Kenerley, and Pettit 1988). It is a task-oriented approach. The first step is to identify the tasks the agent needs to accomplish; i.e., what does the agent need to do to be successful? Second, the attributes that the agent must have in order to accomplish those tasks must be determined. Assays that allow the evaluation of an agent's performance relative to the

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desired attributes must then be developed. At this point, the components of the model become apparent, and preliminary relationships between the components can be established. A preliminary model is presented in Figure 1.

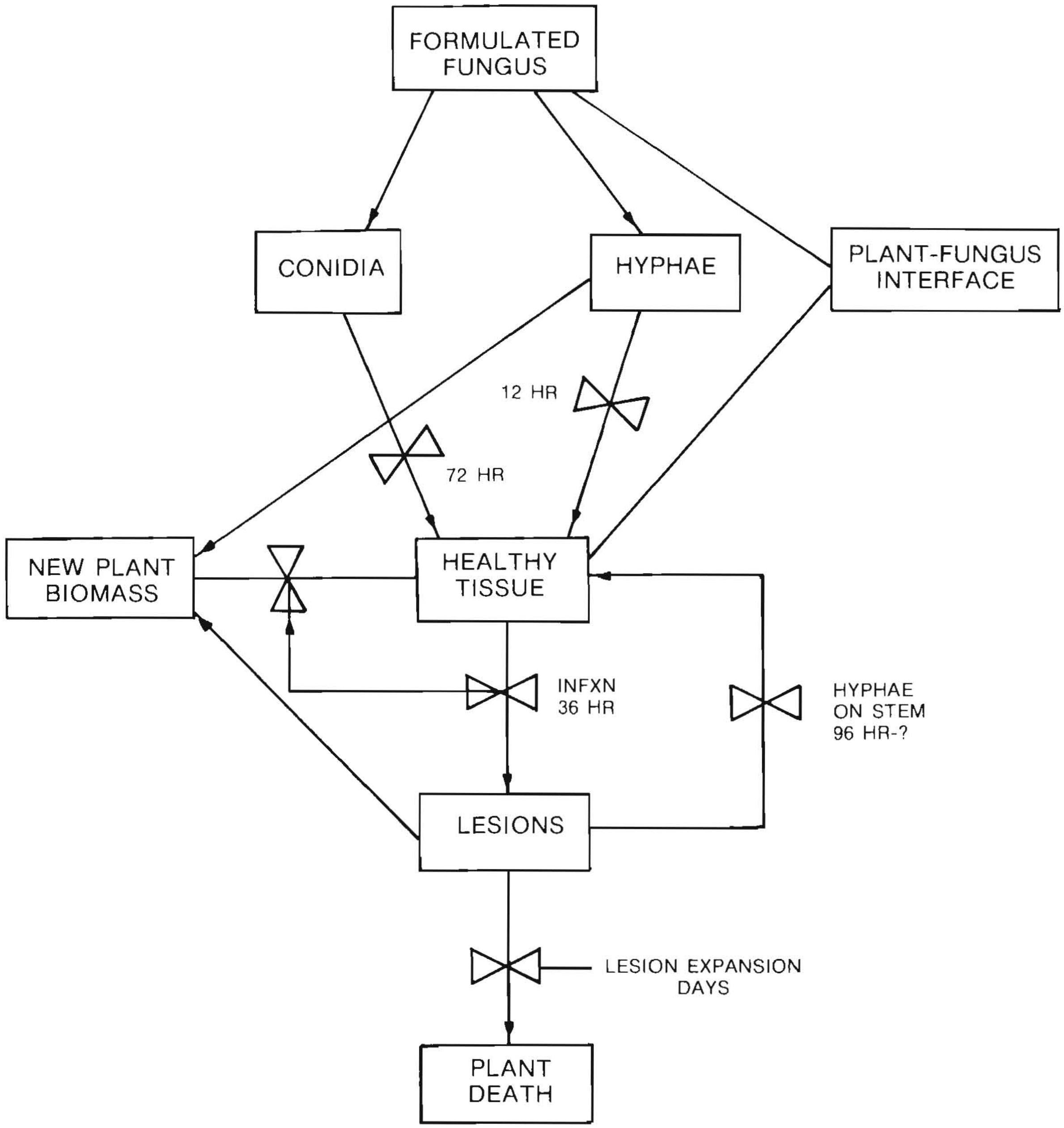

Figure 1. ***Myriophyllum spicatum-Mycoleptodiscus terrestris*** **interaction, preliminary disease progression model**

RESULTS TO DATE

Laboratory experiments

In several assays, *M. t.* hyphae were applied to milfoil plants and resulted in a reduction in plant biomass. In one experiment (Figure 2), naked hyphae (treatment 4)

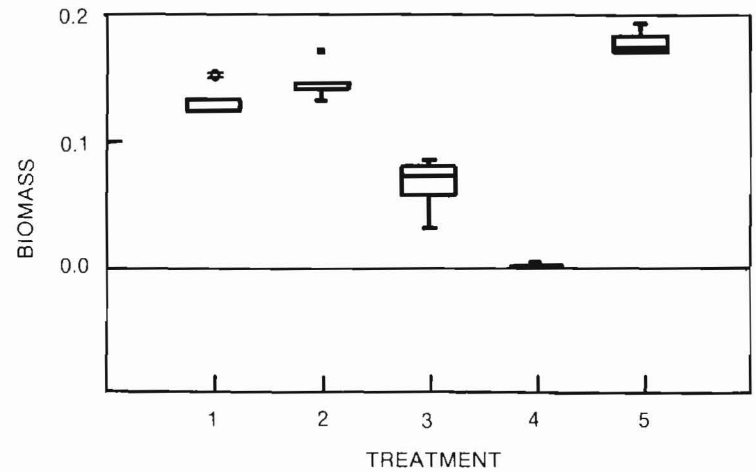

Figure 2. Combined stem, leaf, and root biomass for milfoil plants in a standard laboratory bioassay. Treatments are as follows: 1, no treatment control; 2, formulation control; 3, formulated fungus; 4, unformulated fungal hyphae; and 5, sterile culture filtrate (from same culture as that used for treatments 3 and 4)

resulted in a 98-percent reduction in stem biomass and 81-percent reduction in root biomass (89-percent total biomass reduction) relative to the control (treatment 1). Figure 2 is a box and whisker plot where the median of the sample data is the line within the box while the upper and lower quartiles are the 75th and 25th percentiles of the sample data set. Points outside the box represent extreme values. Although hyphae work well, they have disadvantages that preclude their use at the commercial level. Hence, we have developed a formulated product for application to large plant communities. In that same experiment (Figure 2), a formulated *M. t.* (treatment 3) caused a 56-percent reduction in stem biomass and 40-percent reduction in root biomass over the formulation control (treatment 2). A direct comparison between formulated and unformulated fungus cannot be made in this experiment since there was a 2-log difference in the amount of active ingredient (i.e., colony forming units (CFU)/experimental unit).

A number of formulations were developed, and a range in total biomass reduction (from 66 to 84 percent) after 3 weeks was observed. There was approximately 1 mg of fungus per formulated granule with a viability of approximately 1×10^5 CFU/granule. In subsequent experiments, we observed similar results with lower doses. We are currently determining the minimum amount of fungus and inert ingredients necessary to achieve an acceptable level of biomass reduction.

In one experiment the dose was adjusted by applying specific amounts of formulated fungus on a weight-per-volume basis. The doses ranged from 0 to 2.0 g formulation per liter. The response was linear at the lower doses but quadratic over all doses. The 0.5-g dose resulted in a 71-percent reduction in plant biomass at 3 weeks.

In treatments receiving certain formulations, secondary lesions were observed on distal stems (from the point of attachment of a formulation granule to a stem). Sporodochia containing large populations of conidia were observed on some of the applied formulation granules. Upon close examination (light microscope and scanning electron microscope), conidia were observed at the site of some secondary lesions. The conidia germinated, and penetration structures (appresoria) were observed on the plant surfaces, both stems and leaves. The length of germ tubes prior to the development of an appresorium was variable; some appresoria formed immediately after conidium germination, while other germ tubes reached lengths of greater than 100 μ prior to forming appresoria. The role conidia play in disease progression on a single plant and among a population of plants is being investigated.

Field experiment

The objective of our field test this year was to determine whether we could induce the same sequence of events (application - attachment - infection - lesion formation - conidia production) in the field that we observed in the laboratory assays. Until an Experimental Use Permit is obtained, we are restricted to less than 1 acre surface area application in the United States. Because of that restriction, our field tests this year were of limited scope. One experiment in South Deerfield, Massachusetts, consisted of 40 ponds (ca. 7-sq ft surface area; 300-gal capacity), each containing a population of 36 milfoil plants. The plants were inoculated (eight replicate ponds per treatment) with two hyphal preparations, a formulated fungus, and a formulation control and were monitored for 4 weeks. Eight ponds were left untreated. The plants had been in the pond for about 4 weeks prior to inoculation.

Visual assessments were made at 7-day intervals, and plant material was collected for reisolation of the fungus. The previously stated sequence was in fact confirmed in the field at South Deerfield. In treatments receiving the fungus, the disease incidence and severity ratings were very encouraging. In one hyphal treatment and in the formulated fungus treatment, greater than 90 percent of the plants were infected; greater than 75 percent of their internodes had *M. t.* lesions.

SUMMARY

In laboratory bioassays, formulated *M. t.* reduced milfoil biomass up to 95 percent over the formulated controls. Sporodochia were observed on the formulation granules, and prolific conidia production occurred. These conidia were observed in association with secondary lesions on the stems and leaves of treated plants. In field trials in contained ponds, the sequence of events observed in the laboratory bioassays (application - attachment - infection - lesion formation - conidia production) was also observed.

A model to describe the disease process on milfoil and a submodel to describe the fungus-plant interface are being developed. Although this model was developed using Eurasian watermilfoil and *M. t.*, we hope to validate the approach for other mycoherbicide systems.

The dynamics of infection, lesion development, and secondary inoculum production are being determined. The latent period can be a significant driving variable in a plant disease epidemic (Rufty and Main 1989). A preliminary submodel to describe the interactions at the fungus-plant interface is being formulated (Figure 3). Flow directions and rates will be determined for all important parameters. It is hoped that a

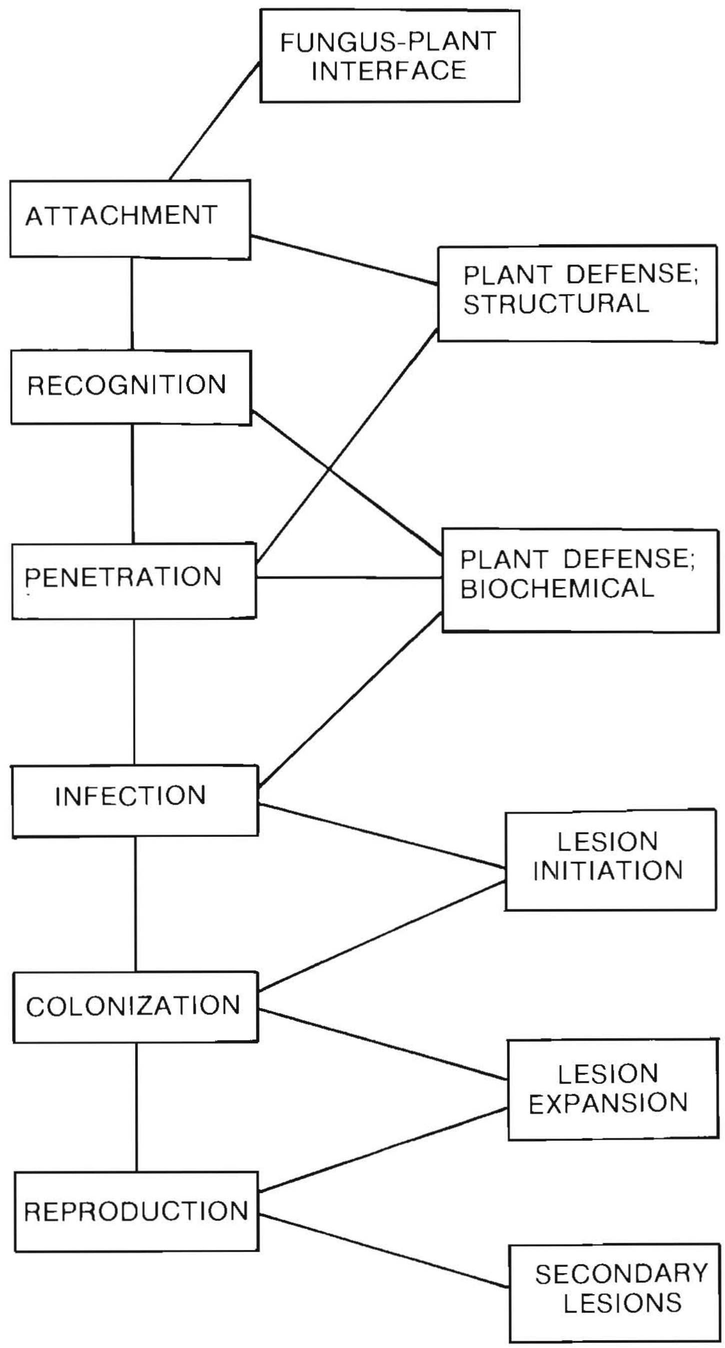

Figure 3. ***Myriophyllum spicatum-Mycoleptodiscus terrestris*** **interaction, preliminary plant-fungus interface submodel**

better understanding of the nature of the interaction at the organismal, molecular, and genetic levels will lead to more effective and efficient control at the population level.

Current short-term studies include efficacy/stability issues and economics of production and application. Long-term studies include mechanisms of action, epidemiology, the role of conidia in disease progression, the rate of disease development in natural populations of milfoil, and fate and persistence of *Mycoleptodiscus terrestris*.

REFERENCES

Cook, R. J., and Baker, K. F. 1983. *Biological Control of Plant Pathogens*, APS Press, St. Paul, MN.

Fry, William. 1982. *Principles of Plant Disease Management*, Academic Press, New York.

Rufty, R. C., and Main, C. E. 1989. "Components of Partial Resistance to Blue Mold in Six Tobacco Genotypes Under Controlled Environmental Conditions," *Phytopathology*, Vol 79, pp 606-609.

Stack, J. P., Kenerley, C. M., and Pettit, R. E. 1988. "Application of Biological Control Agents," *Biocontrol of Plant Diseases*, Vol II, Mukerji and Garg, eds., CRC Press, Boca Raton, FL.

Inhibition of Hydrilla Growth by Aquatic Plant Extracts and Secondary Compounds

by
Craig S. Smith*,** and Harvey L. Jones**

INTRODUCTION

Many plants interfere with the growth of potential competitors by allelopathy, i.e. the production and release of toxic substances into the environment. Many instances of allelopathy between terrestrial plant species have been reported (see Rice 1974 and 1979 for reviews). Allelopathy between aquatic plants has been studied less frequently, although instances of apparent allelopathy by a number of aquatic species have been described (Table 1).

Elakovich and Wooten (1989) examined the feasibility of using allelopathy as a means of managing aquatic plants by evaluating the allelopathic activity of extracts of 16 aquatic plants. They found that, depending on the concentration applied, six or more of the extracts inhibited the growth of lettuce seedlings and five or more of them inhibited duckweed frond production. Lettuce and duckweed differed in their response to particular plant extracts, as shown by the fact that only three of the six most inhibitory plant extracts were the same for the two test species. Two conclusions of particular importance for future studies of allelopathy between aquatic plants emerged from Elakovich and Wooten's work. First, many of the species tested were allelopathic to lettuce and/or duckweed; it is therefore likely that aquatic plant species allelopathic to hydrilla and/or Eurasian watermilfoil exist. Second, since responses to allelopathic materials varied from species to species, plant extracts should be tested for allelopathic activity against the intended target species.

Screening of plant extracts and secondary compounds has just begun, and this report is primarily a description of the approach and techniques that will be used to identify allelopathic species.

MATERIALS AND METHODS

Hydrilla cultures

Cultures of hydrilla were grown from tubers. Tubers were surface sterilized sequentially in 50-percent bleach solution for 10 min, then in 10-percent bleach for 15 min. Sterilized tubers were germinated in sterile growth medium. All stock and experimental cultures were grown in sterile ALW medium, a carbonate-buffered growth medium derived from Gerloff medium (Andrews et al., in preparation). Stock

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**US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Table 1
Instances of Apparent Allelopathy by Aquatic Plants

Allelopathic Species	*Processes Affected*	*Target Species*	*Reference**
American eelgrass	Germination	Lettuce, barnyard grass, wheat	1
Fanwort	Germination	Lettuce, barnyard grass, wheat	1
Cattail	Germination, growth	Cattail	3
Dwarf spikerush	Shoot production	American pondweed, sago pondweed, hydrilla, American elodea, Nuttall's elodea, horned pondweed	4
Hydrilla	Shoot growth	Coontail	2
Giant duckweed	Germination	Lettuce	1
Watermilfoil	Germination	Lettuce, wheat	1
Western elodea	Germination	Lettuce, barnyard grass	1

*Sources: 1, El-Ghazal and Reimer (1986), 2, Kulshreshtha and Gopal (1983), 3, McNaughton (1968), and 4, Yeo and Thurston (1984).

cultures were grown in 6-ℓ polycarbonate jars in the greenhouse. Stock and experimental plant cultures were grown in a 25° C controlled-temperature bath in the greenhouse.

Hydrilla growth bioassay

Prior to examining the effect of any compounds or plant extracts, the basic bioassay technique was tested without any applied treatments to determine the optimum duration of growth experiments and to measure levels of variability. For the bioassay, individual hydrilla shoots were grown in 60 ml of ALW medium in 25- by 200-mm aerated culture tubes (Figure 1). At the start of the assay, terminal hydrilla shoots were cut to 2.0 cm in length. Ten shoots were randomly selected for initial dry weight determination; these were dried at 70° C and then weighed. Forty shoots were placed individually into culture tubes and allowed to grow for 1 to 4 weeks. At the end of each week of growth, 10 randomly selected shoots were removed from the tubes, measured, dried at 70° C, and weighed.

Effect of secondary compounds

The effect of authentic secondary compounds on the growth of hydrilla was investigated in a test tube bioassay. The secondary compounds evaluated are listed in Table 2. These compounds were selected because they are produced by a wide variety

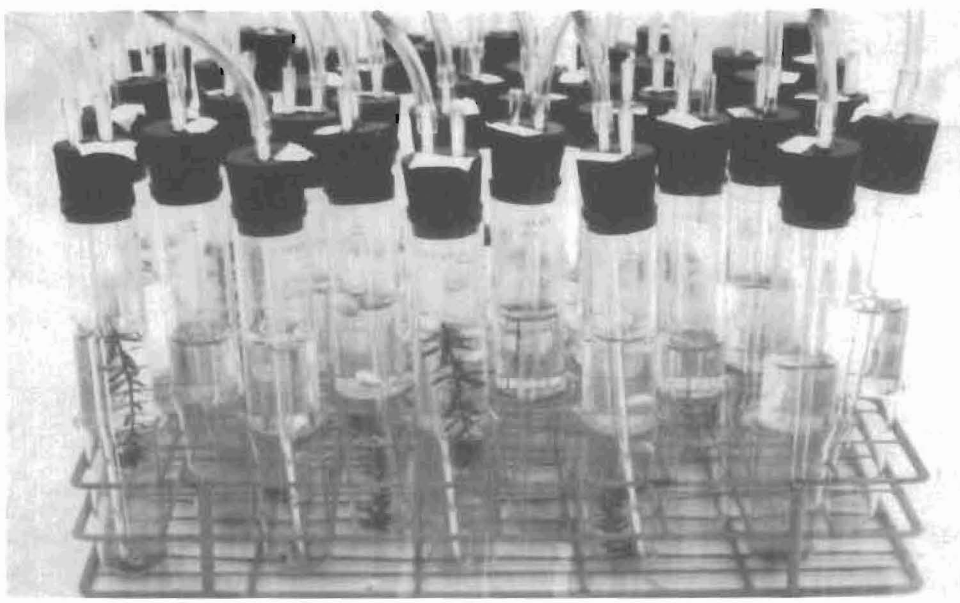

Figure 1. Experimental setup for hydrilla test tube growth bioassay

of plant species and most or all have been implicated as active principals in allelopathic interactions. The bioassay procedure was essentially that described above. One hundred terminal hydrilla shoots were cut to a length of 2.0 cm. Five shoots were randomly selected for initial dry weight determination, dried at 70° C, and weighed. Ninety-five shoots were placed individually into culture tubes with 60 ml ALW medium. Stock solutions of secondary compounds having a concentration of 10^{-2} M were prepared in deionized water. A volume of stock solution sufficient to produce a concentration of 10^{-4} M was added to each tube. The two control tubes received an equal volume of deionized water. Each treatment was applied to five randomly selected shoots. Plants were grown for 2 weeks, removed from the tubes, measured, dried at 70° C, and weighed.

Preparation of plant extracts

Extracts of plant species to be tested for allelopathic activity were prepared using the technique developed by Elakovich and Wooten (1989). Plant species were washed after collection and allowed to air dry until surface moisture had evaporated. Two hundred-gram portions of the fresh plant material were then placed into a blender with 200 ml of deionized water, blended on low speed until all plant material was chopped, and then blended on high for 2 min. The ground plant material was allowed to extract for 1 to 3 days in a refrigerator at ca. 5° C. Plant material was removed from the extract by filtering through cheesecloth, then sequentially through coarse (Whatman No. 4 or 54) and fine (No. 2 or 42) paper filters, and then through a Whatman GF/F glass fiber filter. Filtrates were frozen for later use.

Table 2
Secondary Compounds Tested for Ability to Reduce Hydrilla Growth

Compound	*Abbreviation*
Caffeic acid	CAFA
Catechin	CATN
Catechol	CATL
p-Coumaric acid	COMA
Ellagic acid	ELGA
Ferulic acid	FRLA
Gallic acid	GALA
p-Hydroxybenzaldehyde	HBAL
p-Hydroxybenzoic acid	HBAC
Quercetin	QUER
Protocatechuic acid	PCTA
Pyrogallol	PYRO
Resorcinol	RESC
Salicylic acid	SALA
Syringic acid	SYRA
Tannic acid	TANA
Vanillic acid	VANA
Vanillin	VANN

RESULTS

Bioassay evaluation

Hydrilla shoots grew rapidly under bioassay conditions, doubling their biomass approximately every week (Figure 2). Growth was roughly exponential throughout the 4-week duration of the experiment, even though many stems emerged from the growth medium between the third and fourth weeks. Sensitivity analysis of bioassay results revealed that differences between treatments of approximately 30 percent could be detected at the $P < 0.05$ level with 10 replicates per treatment after 1, 2, 3, or 4 weeks of growth. Based on this analysis, a 2-week growth period was chosen for future bioassays, since 2 weeks was long enough to ensure maximum sensitivity yet short enough to provide a rapid bioassay.

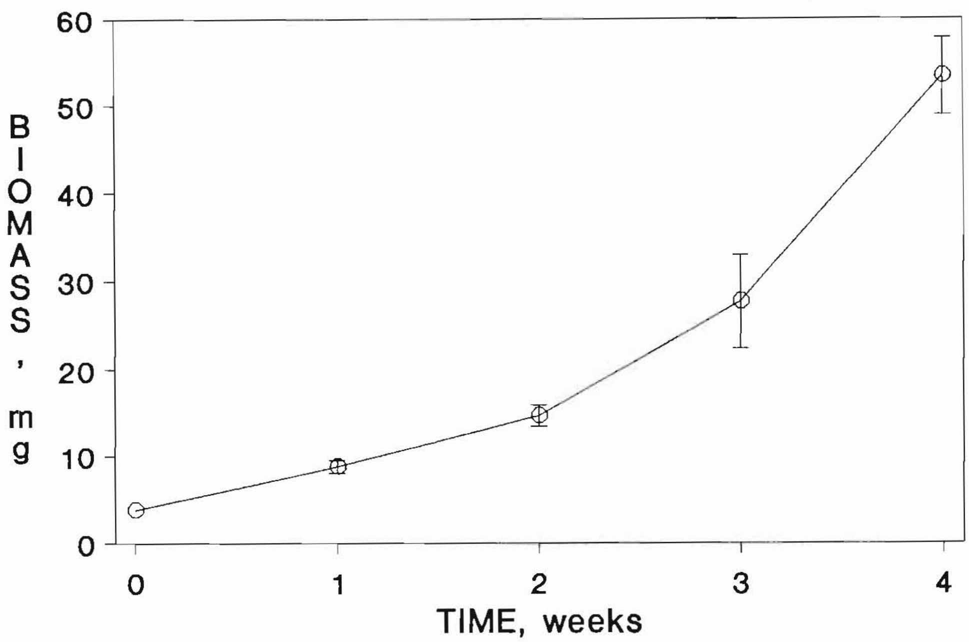

Figure 2. Growth of hydrilla shoots in the test tube bioassay. Each point is the mean of 10 shoots. Brackets indicate ±1 standard error

Effect of secondary compounds

Secondary compounds varied in their effect on hydrilla growth (Figure 3). Only one compound, catechol, significantly reduced hydrilla yield. This was only a small pilot study, and additional replication of the entire experiment is needed. With further replication, smaller differences between treatments will become detectable, and it is likely that other compounds will also be found to reduce hydrilla growth.

FUTURE WORK PLANNED

The potential for using allelopathy as a management tool for nuisance submersed plants will be investigated in three phases (Figure 4). Initially, a two-pronged effort will evaluate the influence of plant extracts and secondary compounds on the growth of hydrilla and Eurasian watermilfoil using rapid-screening bioassays. Information obtained from the evaluation of secondary compounds should help to guide or explain the choice of additional plants. For example, once secondary compounds that are particularly inhibitory to the target plants have been identified, evaluation of plant extracts can emphasize plants from families, genera, or species reported to produce the inhibitory secondary compounds in relatively high concentrations. Similarly, the importance of unidentified or untested secondary compounds can be evaluated by comparing the degree of growth inhibition produced by a plant extract with that expected based on its content of known secondary compounds.

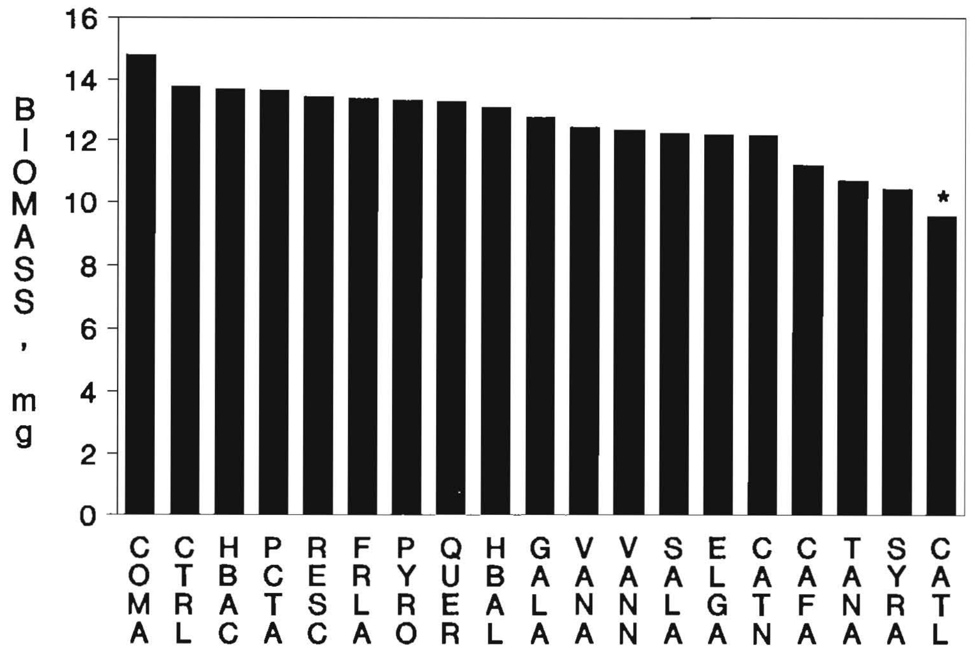

Figure 3. Growth of hydrilla shoots in the presence of 10^{-4} M concentrations of various secondary compounds (See Table 2 for a key to compound name abbreviations). Each bar represents the mean of five shoots. Asterisks identify treatments that differed significantly from the control at $P < 0.05$

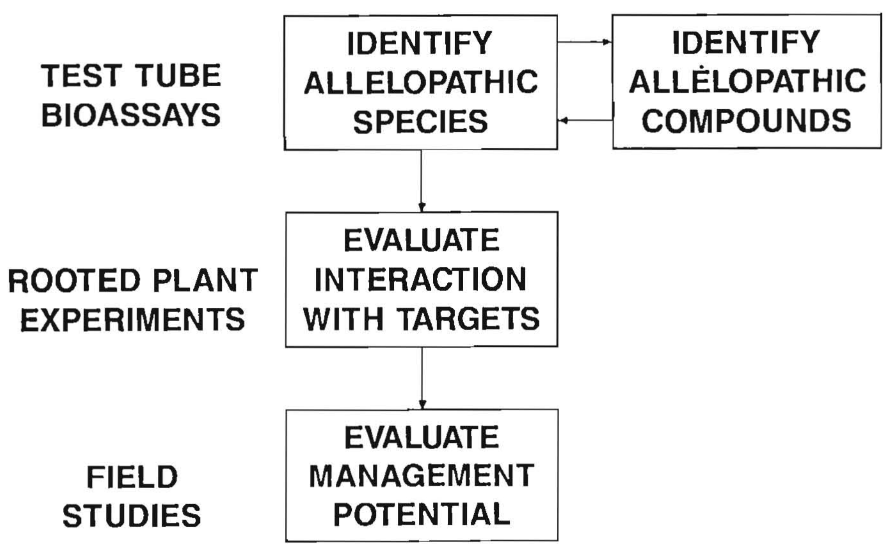

Figure 4. Flowchart of procedures used to evaluate the potential of allelopathy as a management tool for nuisance submersed plants

The second phase will be an evaluation of allelopathic interactions between aquatic plants grown in mixed, rooted cultures. Experiments with rooted plants are essential for several reasons. First, in nature, allelopathic interactions between submersed plants are most likely to involve accumulation of toxic compounds in the sediments, since water circulation will continuously remove compounds released into the water. Conditions in the sediments differ substantially from those in the water. Alteration of plant material during decay in the anoxic sediment environment may influence the toxicity of compounds derived from plant debris in ways not predictable from experiments with aerobically produced plant extracts. Root exudates, released during active plant growth, may also be important in allelopathy.

Once plant species able to suppress hydrilla or Eurasian watermilfoil growth have been identified, techniques for using these species in the field will need to be developed and evaluated. The final phase of this project will investigate ways to manage nuisance submersed plant species (see Table 3) by manipulating more desirable allelopathic species.

Table 3
Aquatic Plants to Be Tested for Allelopathic Activity

Common Name	*Scientific Name*
Fanwort	*Cabomba caroliniana*
Coontail	*Ceratophyllum demersum*
Hydrilla	*Hydrilla verticillata*
Parrotfeather	*Myriophyllum aquaticum*
Eurasian watermilfoil	*Myriophyllum spicatum*
Southern naiad	*Najas guadalupensis*
American lotus	*Nelumbo lutea*
Fragrant waterlily	*Nymphaea odorata*
Pickerelweed	*Pontederia cordata*
Pondweed	*Potamogeton nodosus*
Arrowhead	*Sagittaria lancifolia*
Wildcelery	*Vallisneria americana*

REFERENCES

Andrews, J. H., Harris, R. F., Smith, C. S., and Chand, T. "Host Specificity of Microbial Flora from Eurasian Watermilfoil *(Myriophyllum spicatum)*," Technical Report (in preparation), US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Elakovich, S. D., and Wooten, J. W. 1989. "Allelopathic Potential of Sixteen Aquatic and Wetland Plants," *Journal of Aquatic Plant Management*, Vol 27, pp 78-84.

El-Ghazal, R. A. K., and Reimer, D. N. 1986. "Germination Suppression by Extracts of Aquatic Plants," *Journal of Aquatic Plant Management*, Vol 24, pp 76-79.

Kulshreshtha, M., and Gopal, B. 1983. "Allelopathic Influence of *Hydrilla verticillata* on the Distribution of *Ceratophyllum* Species," *Aquatic Botany*, Vol 16, pp 207-209.

McNaughton, S. J. 1968. "Autotoxic Feedback in Relation to Germination and Seedling Growth in *Typha latifolia*," *Ecology*, Vol 49, pp 367-369.

Rice, E. L. 1974. *Allelopathy*, Academic Press, New York.

Rice, E. L. 1979. "Allelopathy--An update," *Botantical Review*, Vol 45, pp 15-19.

Yeo, R. R., and Thurston, J. R. 1984. "The Effect of Dwarf Spikerush (*Eleocharis coloradoensis*) on Several Submersed Aquatic Weeds," *Journal of Aquatic Plant Management*, Vol 22, pp 52-56.

Attachment of Plant Pathogens to Submersed Aquatic Plants

by
Stewart L. Kees* and Edwin A. Theriot*

INTRODUCTION

In our search for host-specific pathogens for *Hydrilla verticillata* and *Myriophyllum spicatum*, it has become necessary to understand, in a general sense, the mechanisms involved in the infection process of microbes to submersed aquatic plants. We know that there are four distinct phases at which specific association may occur between the host plant and the microbe.

Plant-microbe interactions begin with the colonization of the plant surface. A microorganism must attach and begin to grow if it is to appreciably influence the growth of the plant or to prompt a defensive response (Smith et al. 1989). Attachment, then, represents the first phase of the infection process. After the microbe reaches the host, various other activities proceed at the surface of the plant. Generally, the spores germinate and grow in response to two stimuli: a physical contact stimulus that directs the growth of the main hyphae, and a diffusible substance, the chemical stimulus, which arrests hyphal growth and triggers appressorium formation. The appressorium is the flattened, thickened tip of a hyphal branch by which some fungi attach to their host.

Formation of the appressorium marks the end point of the second phase of the infection process, growth on the plant surface, and the initiation of the third phase of infection, host penetration. Penetration of the host by a fungus can occur in three ways: (a) directly through the intact surface (generally by cellulase or pectinase production), (b) through natural openings such as stomates, and (c) through wounds. The production of disease symptoms in the host is the final phase of infection and is mediated by toxin or lytic enzyme release from an outgrowth of the appressorium called the infection peg (Flentje 1959).

Specificity may occur at any phase of the infection process and can be dependent upon a number of factors, such as the presence or absence of enzyme cofactors, morphological and chemical inhibitors, or even environmental factors. *Puccinia coronata*, for example, will only form appressoria on gelatin in the presence of zinc ions (Sharp and Smith 1952). The moisture on the surface of plant tissue often contains substances released from the underlying tissues that influence spore germination. High malic acid concentrations and toxic phenolic compounds often diffuse to the surface of the plant and prevent spore germination (Brown 1922; Walker, Link, and Angell 1929).

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Environmental factors may positively or negatively influence plant susceptibility to infection. For example, high or low temperature or high or low light intensity may increase or decrease plant susceptibility to several fungal pathogens. High phosphorus, calcium, and potassium are believed to reduce the infection capability of several fungi (Gaumann 1950).

Figure 1 is a 40× micrograph of Eurasian watermilfoil leaves being colonized by the pathogenic fungus *Mycoleptodiscus terrestris*. The igloo-shaped enlargement of the hyphal tip is the appressorium, and it is from a structure such as this that infection begins.

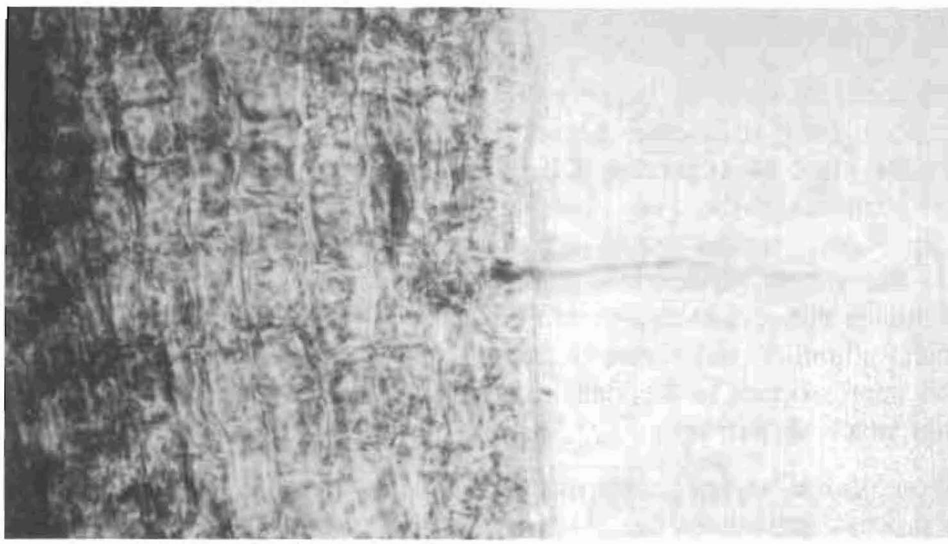

Figure 1. A 40× micrograph of a Eurasian watermilfoil leaf being colonized *Mycoleptodiscus terrestris*

At last year's meeting we presented an assay developed by Dr. Craig Smith and some of his colleagues at the University of Wisconsin at Madison (Theriot and Kees 1989). Figure 2 is a flowchart of that assay. It is reviewed here because it measures pathogenic specificity at each of the four levels just discussed.

Briefly, the plant is placed in a suspension of the test microorganism for 24 hr to allow microbial attachment. Unattached microbes are washed off, and the attached population is measured by macerating the plant tissue and plating portions of the macerate on an appropriate medium. The remaining microorganisms are allowed to grow in association with the plant for 6 days. Three populations of microorganisms are then measured: (a) the epiphytic population (those microbes that have successfully colonized the plant), (b) the endophytic population (those microbes that remain associated with the plant after sterilization with 15-percent hydrogen peroxide), and (c) the population in the plant growth medium (as this population provides a measure of spore production and therefore an index of the microbe's ability to move from host to host).

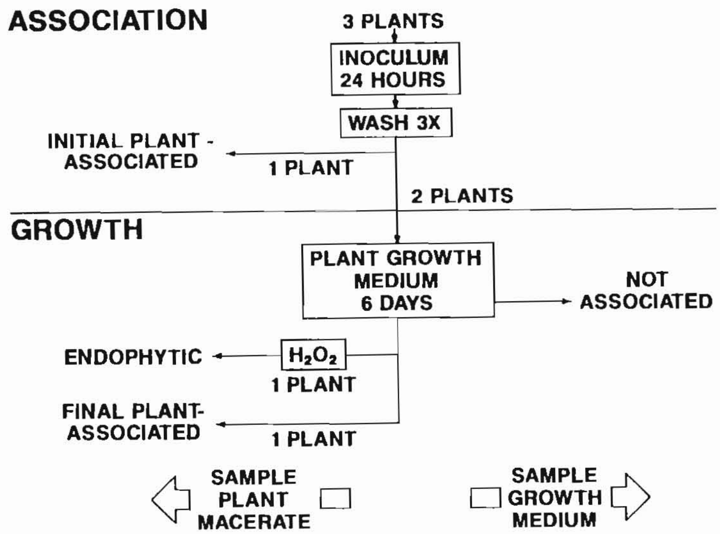

Figure 2. Schematic of secondary screening assay

RESULTS

Of the fungi that have been tested to date with this assay system, only one endophyte, *Colletotrichum gloeosporioides*, and one epiphyte, *Acremonium curvulum*, satisfactorily colonized milfoil. Both these fungi are known to be reasonably host-specific pathogens of milfoil. The next step was to take these two "best" colonizers and test their specificity against three other freshwater macrophytes. Data from these tests are presented in Figure 3 (Smith et al. 1989).

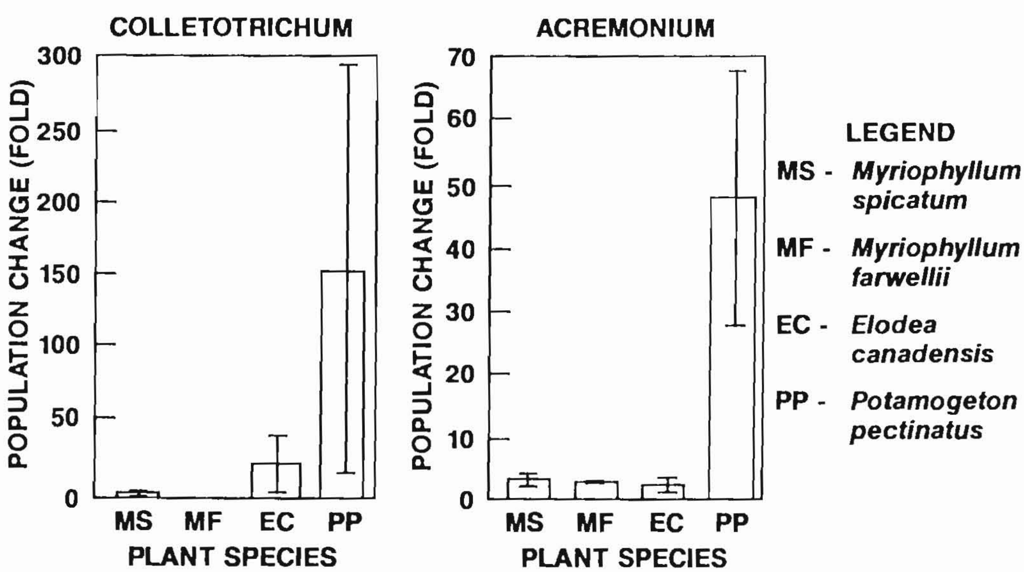

Figure 3. Evaluation of host specificity

As shown in Figure 3, neither fungus showed much population increase on the target species, *Myriophyllum spicatum.* The same is true for *Myriophyllum farwellii* and *Elodea canadensis.* It is strikingly clear, however, that both fungi colonized *Potamogeton pectinatus* significantly better than they did *M. spicatum.* What these data tell us is that these two fungi, which are known to be reasonably host-specific pathogens of milfoil, show no specificity whatsoever for milfoil in terms of epiphytic growth. In fact, *C. gloeosporioides* will colonize acid-washed glass slides. These data lend credence to the assertion that we must be able to evaluate specificity at all four of the levels described earlier.

Last year we also told you that this colonization assay would serve as a secondary screen for microbes and that we were in the process of developing a primary more rapid screening assay designed to enable us to look at large numbers of microorganisms and thereby enhance our chances for finding the most promising microbial pathogen. That assay is now in place, and we have begun screening the 400 or so fungal and bacterial isolates that we have in cryostorage from previous survey years. We continue to isolate new microorganisms from areas where milfoil appears to be declining.

In the rapid-screening assay, we begin with a 5.0-cm apical segment of healthy leafy plant tissue and place it in a petri dish with 50 ml of sterile Smart and Barko medium (Smart and Barko 1989). We then cut six agar plugs from a 7-day-old potato dextrose agar culture of the test microbe with a sterile No. 2 cork borer and place the plugs facedown on the plant. After a 14-day incubation period at 25° C on a 16:8 hr light:dark cycle, the plant tissue is quantitatively evaluated for damage.

This assay has already identified one fungal isolate, designated FMy36, as a potential pathogen of milfoil. For the remainder of this year we will test all fungal and bacterial isolates currently in culture and any new ones collected with both the primary and secondary screening techniques in order to generate a list of specific pathogenic microbes.

It is reasonable to assume that there is a class of microbes that may function at various levels of attachment specificity though they exhibit no gross pathogenesis to the plant tissue. Those microbes might go undetected by the assay techniques previously described. The lectin research we reported last year provides a mechanism to evaluate attachment specificity at the molecular level. Our lectin research has resulted in the isolation of a lectin glycoprotein complex from hydrilla. This lectin has demonstrated an affinity for α-L-fucose. We have developed a micro-agglutination assay that tells us conclusively whether a microbe has the appropriate surface antigen (carbohydrate) to interact with the surface lectins of hydrilla.

In the lectin agglutination assay, we homogenize to a fine slurry a 7-day-old potato dextrose broth culture of the test microbe. We then combine 50 μl of the test microbe with 50 μl of affinity chromatography-purified plant lectin and incubate for 1 hr at room temperature. We examine the droplet at a magnification of 10× and 40× for evidence of agglutination. This assay will contribute to generation of a list of non-pathogenic specific microbes.

SUMMARY AND FUTURE WORK

As this phase of the Genetically Engineered Microorganisms Work Unit comes to a close, the assays now in operation will provide two lists of specific microbes: pathogenic-specific microbes and nonpathogenic-specific microbes.

Our hope for future work is the opportunity to scale up investigations of pathogenic microbes against the target species to aquaria studies, column studies, and eventually small-scale field (pond) studies. Second, we would like to test microbial pathogen specificity against other freshwater submersed aquatic macrophytes from the families *Potamogetonaceae, Ceratophyllacea*, and *Haloragaceae*. Finally, if none of the above strategies produces a sufficiently host-specific pathogen, we can explore the option to enhance the virulence of nonpathogenic-specific microbes through conventional means such as ultraviolet irradiation or chemical mutagenesis.

REFERENCES

Brown, W. 1922. "Studies on the Physiology of Parasitism; VIII, On the Exosmosis of Nutrient Substances from the Host Tissue into the Infection Drop," *Annals of Botany*, Vol 36, p 101.

Flentje, N. T. 1959. "The Physiology of Penetration and Infection," *Plant Physiology, Problems and Progress, 1908-1958.*

Gaumann, E. 1950. *Principles of Plant Infection* (translated by W. B. Breierley), Crosley Lockwood and Son, London.

Sharp, E. L., and Smith, F. G. 1952. "The Influence of pH and Zinc on Vesicle Formation in *Puccinia coronata avenae* Corda," *Phytopathology*, Vol 42, p 581.

Sharp, R. M., and Barko, John W. 1989. "Laboratory Culture of Submersed Freshwater Macrophytes on Natural Sediments," *Aquatic Botany*, Vol 21, p 251.

Smith, C. S., Chand, Tara, Harris, Robin F., and Andrews, John H. 1989. "Colonization of a Submersed Aquatic Plant, Eurasian Watermilfoil, by Fungi Under Controlled Conditions," *Applied and Environmental Microbiology*, Vol 55, p 2326.

Theriot, E. A., and Kees, S. L. 1989. "Genetic Engineering: Host Specificity," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 64-70.

Walker, J. C., Link, K. P., and Angell, H. R. 1929. "Chemical Aspects of Disease Resistance in the Onion," *Proceedings of the National Academy of Sciences*, Vol 15, p 845.

CHEMICAL CONTROL TECHNOLOGY

Chemical Control Technology Development: Overview

by
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The broad objective of the chemical control research area is to improve management of nuisance aquatic plants using herbicides and plant growth regulators in an environmentally compatible manner. The current focus of research within each work unit is on submersed plant control in high water-exchange environments. Accomplishment of this goal requires close coordination with the chemical industry and the US Environmental Protection Agency's (EPA) Pesticide Registration Branch.

The FY 89 direct allotted chemical control research was apportioned among five work units:

- *Herbicide Concentration/Exposure Time Studies.* Research in this area is designed to evaluate registered, as well as experimental use permit (EUP), chemicals for aquatic sites. This work is being conducted at the WES under controlled-environment conditions. Eurasian watermilfoil and hydrilla are treated with various herbicides at selected doses and contact times. Results from these studies will be used to establish herbicide concentration and exposure time relationships for each chemical and target plant. Evaluations have been completed with the herbicides 2,4-D and endothall, while preliminary evaluations have been initiated with fluridone and triclopyr. Future studies will include the evaluation of diquat, bensulfuron methyl, and other appropriate compounds.

- *Herbicide Application Technique Development for Flowing Water.* In this work unit, submersed application techniques are developed and evaluated to minimize the amount of chemical used and the frequency of treatments, while maximizing efficacy for the target plants. Studies are conducted in outdoor flumes or in field situations that exhibit high water-exchange characteristics, such as rivers, canals, large reservoirs, and tidal areas. Recent studies in this area have focused on characterizing water movement in submersed plant stands using flowmeters and fluorescent dye. Water movement can dramatically impact the dispersion of herbicides from treated plots, as well as the vertical and horizontal distribution of herbicides in the water column. Results from this work will be used by operational personnel to optimize the type and timing of various submersed application techniques.

  Water movement studies have been conducted in Eurasian watermilfoil stands in California irrigation canals and in Washington's Pend Oreille River. Similar studies have been conducted in hydrilla stands in the Potomac River, Virginia/Maryland, and in the Crystal and St. Johns Rivers in Florida.

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Submersed application techniques using liquid, polymer, invert, and granular formulations have been evaluated in Lochloosa Lake, Florida. Future water movement and application technique studies will be conducted in the Withlacoochee River and Lake Kissimmee, Florida, as well as in the Pend Oreille and Columbia Rivers, Washington.

- *Herbicide Delivery Systems.* This work unit explores ways to improve herbicide delivery to submersed plants in high water-exchange environments. The research focuses on development of controlled-release carrier systems, e.g., polymers, elastomers, gypsum, fibers, etc. These carriers release herbicides at a slow, predictable rate to the vicinity of the target plant. Reliable information on effective herbicide concentration/exposure times is critical for the development of controlled-release carriers. Those dose/contact time relationships are being provided in the aforementioned Herbicide Concentration/Exposure Time work unit. Future work will include laboratory and field-scale evaluation of dye and herbicide/gypsum controlled-release compounds, the gypsum phase of which is already in operational use as a mosquito larvicide.

- *Field Evaluation of Selected Herbicides for Aquatic Uses.* The most effective application techniques and chemical formulations are evaluated under field conditions in this research area. These studies are cooperative efforts among chemical companies, other Federal and state agencies, universities, and the WES with the aim of obtaining environmental fate and dissipation data on EUP herbicides and/or new formulations of registered herbicides. These data are used to prepare field manuals and reports with recommendations to operational personnel on the activity, use, and application techniques of aquatic herbicides. In addition, chemical companies use this information to fulfill requirements for Federal registration of specific herbicide formulations. Coordination with the EPA is required, since these field evaluations involve changes in registration status, site use, or amendments of residue tolerances.

  During FY 89, the WES, in cooperation with DuPont Chemical Company, the University of Florida, and other Federal/state agencies, conducted EUP dissipation studies on the herbicide bensulfuron methyl (Mariner) in Lake Seminole, Georgia, and Banks Lake, Washington. This study will continue in FY 90. Future research will include field evaluations of triclopyr (Renovate) against Eurasian watermilfoil, and of a new, 30-percent active ingredient endothall granular formulation, as well as bensulfuron methyl, against milfoil and hydrilla. This research will be conducted in cooperation with Dow Elanco, DuPont, Atochem (Pennwalt), and the Tennessee Valley Authority.

- *Plant Growth Regulators for Aquatic Plant Management.* Current efforts to control nuisance aquatic plants reduce the standing crop, often resulting in plant decomposition and disruption of overall plant community structure. In addition, total removal of plant biomass may result in severe fluctuations of nutrient levels, turbidity, and dissolved oxygen, with the loss of habitat dramatically impacting food web relationships. Plant growth regulators (PGRs) offer the potential for slowing the vertical growth rate of submersed plants, thereby reducing the negative impacts that topped-out submersed plants can impose on a water body. Concurrently, the beneficial qualities provided by underwater vegetation (e.g., invertebrate and fish habitat, oxygen production, nutrient sinks, sediment stabilization, etc.) can be retained.

Bioassay testing of PGR formulations is being conducted at Purdue University, under contract to the WES, to identify compounds with the potential for regulating the growth of Eurasian watermilfoil and hydrilla. This work will continue in fiscal years 1990-91. Evaluation of the most promising PGRs will be initiated under controlled-environment conditions at the WES in FY 90 and beyond.

Herbicide Concentration/Exposure Time Relationships: Endothall-Hydrilla and Triclopyr-Eurasian Watermilfoil

by
Michael D. Netherland*

INTRODUCTION

The success or failure of an aquatic herbicide treatment will primarily depend upon two related factors: the concentration of herbicide that comes in contact with the target plant, and the length of time a target plant is exposed to dissipating concentrations of the herbicide in the water column. Herbicide applications to small static systems are generally quite successful since the target plants are exposed to a lethal concentration of herbicide for a sufficient period of time. Flowing-water systems and large reservoirs, in which a high rate of water exchange occurs, present unique problems to the applicator. As the rate of water exchange increases, the concentration of the herbicide and the length of exposure time both decrease. A decrease in either one, or both, of these parameters can lead to a situation in which the desired plant control is not achieved.

Basic relationships between herbicide concentration and the exposure time required to achieve desired plant control must be defined. Information acquired in the herbicide concentration/exposure studies will be used in conjunction with information obtained from dye studies (used to estimate the dissipation of herbicides in the water column) in the field. Determining concentration/exposure relationships for registered herbicides (and herbicides under experimental use permits) will furnish operational personnel with meaningful information when selecting herbicides for use in a flowing-water system.

OBJECTIVES

The board objective of this study is to identify the effective ranges of herbicide concentrations and exposure times that control nuisance submersed plants. The specific objective of the current study was to determine the concentration/exposure time relationships for controlling dioecious hydrilla (*Hydrilla verticillata* (L.f.) Royle) with the contact herbicide endothall and Eurasian watermilfoil (*Myriophyllum spicatum* L.) with the systemic herbicide triclopyr.

MATERIALS AND METHODS

Both experiments were conducted in an environmental growth chamber in which the temperature was maintained at 24° ± 2° C. A photoperiod of 13 light:11 dark was used throughout the experiments; mean photosynthetically active radiation (PAR),

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measured at the water surface, was 490 μE m^{-2} sec^{-1} ± 10%. The experimental design consisted of forty-eight 55-ℓ aquaria (0.75 m × 0.09 m^2) arranged in four rows of 12 tanks each. Treatments (herbicide concentration × exposure time) were randomly assigned to the aquaria (Table 1). The design of the experiment was a completely randomized design with three replications for each treatment. Sediment was obtained from Brown's Lake, Waterways Experiment Station, and was amended with macronutrients (N, P, and K) and micronutrients to decrease the possibility of nutrient limitation during the course of the experiments. Reconstituted hard water (Smart and Barko 1984) was independently supplied to each aquarium throughout the experiments. Peristaltic pumps were calibrated and used to exchange the volume of water in the aquaria every 24 hr.

Table 1
Herbicide Treatment Rates Used for the Endothall-Hydrilla and Triclopyr-Watermilfoil Experiments

Endothall-Hydrilla		*Triclopyr-Watermilfoil*	
Concentration mg/ℓ	*Exposure Time hours*	*Concentration mg/ℓ*	*Exposure Time hours*
0 (Ref)	0 (Ref)	0 (Ref)	0 (Ref)
1.0	6	1.0	12
1.0	12	1.0	18
1.0	24	1.0	24
1.0	36	1.0	36
1.0	48	1.0	48
3.0	6	1.5	6
3.0	12	1.5	12
3.0	24	1.5	18
3.0	36	1.5	24
3.0	48	1.5	36
5.0	6	2.5	6
5.0	12	2.5	12
5.0	24	2.5	18
5.0	36	2.5	24
5.0	48	2.5	36

Note: Each herbicide concentration/exposure time equals a single treatment.

Four apical shoots (12 to 15 cm in length) were planted in 300-ml beakers containing sediment. The exposed sediment was covered with a thin layer of silica sand to prevent excessive turbidity in the water. Eleven beakers containing the planted apical shoots were then placed in each aquarium. Air was constantly bubbled into the system to allow the water to circulate throughout each aquarium.

Prior to herbicide treatment, plants were allowed to grow 2 to 3 weeks, until they had developed a healthy root system and shoots were approximately 10 cm from the water surface. One breaker was randomly removed from each aquarium prior to treatment to provide an estimate of treated biomass.

A stock solution of the test herbicide was made, and the calculated concentration was poured into each tank (the flow-through system was turned off during treatment and for the length of the exposure times). At the end of the exposure times, the aquaria were drained and refilled three times with fresh, reconstituted hard water to remove the remaining herbicide residues. Water samples were taken immediately after treatment (to verify treatment concentration), at the end of the required exposure time (to determine herbicide dissipation) and after the final rinse (to verify that all herbicide residues were removed).

Plants were allowed to grow for 6 weeks after treatment. Weekly visual injury ratings (herbicide-treated plants were rated compared to untreated reference plants) were made on all treatments to record the immediate and long-term effects of the treatment. Quantitative measures of treatment effects included pretreatment biomass, posttreatment shoot chlorophyll content, viable shoot and root frequency, and final shoot and root biomass.

RESULTS AND DISCUSSION

The results of the first experiment using endothall to control hydrilla are shown in Figure 1. Those treatments that have surpassed the initial treated biomass line indicate that the plants have recovered from the treatment and are actively growing and

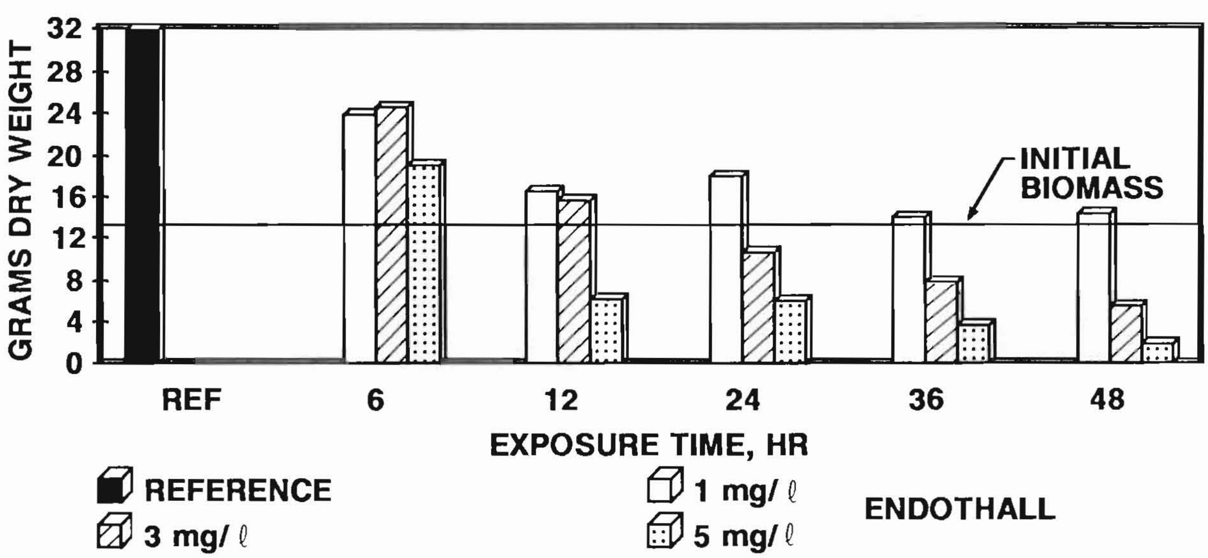

Figure 1. Hydrilla biomass at 6 weeks posttreatment. Each endothall concentration/exposure time represents one treatment. Bars above the initial biomass line indicate plants that are actively recovering from the treatment. Bars below the initial biomass line indicate severely injured plants that are unlikely to recover from the treatment

producing new biomass. Treatments that remain below the initial biomass line indicate that the plants are severely injured and will likely not recover. The prediction of the ability of the plants to recover is based on the presence of healthy shoot tissue in the aquarium and viable roots in the beakers. Treatments in which no healthy shoots or roots are present indicate an inability of the plants to recover. The endothall rate of 1 mg/ℓ never resulted in total plant kill, even at the 48-hr exposure time. The hydrilla treated with 1 mg/ℓ of endothall for 36 and 48 hr had begun to produce healthy green shoots and new roots at the 6-week harvest period. The exposure time of 6 hr did not significantly harm the hydrilla at 3 mg/ℓ or even at the maximum recommended label rate of 5 mg/ℓ.

The data from this first experiment allow us to begin constructing a graph (Figure 2) of concentration versus exposure time for endothall use on hydrilla. The shaded area of the graph represents concentrations and exposure times in which total plant control was achieved. Further experiments will allow us to predict areas of total control as well as areas of good, but not complete, control and areas of little or no control. It is clear from this experiment that as concentration and exposure time are increased, plant control is increased. Previous studies using endothall and 2,4-D on Eurasian watermilfoil (Green 1988, 1989) showed that higher concentrations and/or exposure times resulted in increased plant injury. The information gained from these experiments should be applicable to a variety of flowing-water systems in which plant control operations occur.

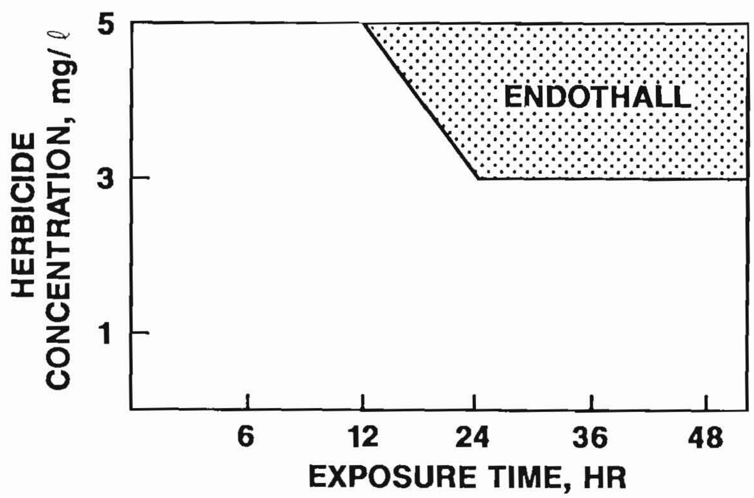

Figure 2. Hydrilla control using endothall. The shaded area represents concentration/exposure times in which severe injury without regrowth occurred. Treatments that are not shaded ranged from very good to no control

Preliminary results of the first triclopyr run suggest that triclopyr was quite effective (at all concentrations tested) at controlling Eurasian watermilfoil, if exposure times were in the range of 18 to 24 hr. Further concentration/exposure evaluations with triclopyr on Eurasian watermilfoil will be conducted.

Results from the laboratory concentration/exposure experiments will provide useful information for the management of nuisance aquatic macrophytes in areas of high water exchange. When used in conjunction with the dye studies, data gathered from both experiments will give applicators more information prior to selecting herbicides and application rates. For example, if the predicted half-life of a herbicide in the field is known, the applicator can use information from the concentration/exposure experiments to choose an effective treatment. Certain treatments could be eliminated due to a need for long exposure times or high concentrations that may be impractical under current field conditions. The choice of the correct herbicide and application rate is important for both economic and ecological reasons.

Data obtained from the concentration/exposure experiments can also be used in development of new formulations and application techniques. Future work will include the completion of the endothall-hydrilla and triclopyr-watermilfoil tests and initiation of tests with bensulfuron methyl or diquat on hydrilla.

ACKNOWLEDGMENTS

The author would like to thank Mr. Reed Green, US Geological Survey-Little Rock, for his technical assistance. The cooperation of the Pennwalt Corporation in providing endothall, and Dow Chemical Company in providing triclopyr, is also greatly appreciated.

REFERENCES

Green, W. R. 1988. "Herbicide Concentration/Exposure Time Studies on Eurasian Watermilfoil," *Proceedings, 22nd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-88-5, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 205-212.

Green, W. R. 1989. "Herbicide Concentration/Exposure Time Studies on Eurasian Watermilfoil," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 106-110.

Smart, R. M., and Barko, J. W. 1984. "Culture Methodology for Experimental Investigation Involving Rooted Submersed Aquatic Plants," Miscellaneous Paper A-84-6, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Plant Growth Regulators for Aquatic Plant Management

by
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INTRODUCTION

Plant growth regulators (PGRs) are synthetic compounds that, when applied to plants, alter or interfere with one or more plant growth processes. PGRs affect a great variety of growth processes and for years have been used in many areas of plant science. For example, in agriculture, growth regulators are used as yield enhancers in the production of sugarcane, and as antilodging agents for many cereal and forage crops to facilitate an easier and more profitable harvest. Applied to fruit crops, growth regulators promote fruit ripening, development, and thinning. In recent years, the use of PGRs has become increasingly popular for turfgrass management. The idea is to slow the growth rate of the grass, thereby reducing mowing frequency. Significant savings can be realized through reduced expenditures in grounds maintenance.

In many ways, aquatic plants are similar to terrestrial plants. For instance, they are both annuals and perennials; they flower and produce seeds; some produce tubers and/or wintering buds; some are more shade tolerant than others; and nearly all of them respond to fertilization. If plant growth regulators can reduce the growth of turfgrasses and other terrestrial plants, then perhaps this same activity could be exploited as a new aquatic plant management tool.

There are several advantages for evaluating PGRs for aquatic plant management. Using a growth regulator means applying lower concentrations of chemical to the water body. PGRs are generally applied at low rates, and in fact, many herbicides when used at lower concentrations exhibit a growth-regulating effect rather than a herbicide effect. By reducing the growth of aquatic vegetation rather than removing it from the water body, as through mechanical and herbicide control methods, a viable plant population remains. Plants are short and therefore not a navigational or recreational nuisance and still function as a part of the aquatic community, providing oxygen, sediment stabilization, and habitat for aquatic organisms. Another important advantage is having an additional management option. The concept of "growth regulating" vegetation rather than "chemical removal" is viewed as being more environmentally compatible. However, currently there are no PGRs registered for use in aquatic environments.

The overall objective of this research effort is to evaluate growth regulator activity on nuisance aquatic plant species and to determine the feasibility of utilizing PGRs as a management strategy.

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EXPERIMENTAL APPROACH

A summary of the methods of approach and the current status of research in this work is as follows:

Phase I: Initial screening for PGR activity

Phase I involves developing a simple bioassay procedure for demonstrating PGR effects on various aquatic plant species. Dr. Carole Lembi, Purdue University, has developed a laboratory bioassay system for screening PGR activity on submersed species, namely Eurasian watermilfoil and hydrilla. To date, tests have been completed for uniconazole, flurprimidol, and paclobutrazol on both hydrilla and watermilfoil. Effective concentrations and exposure periods were identified for each of these growth regulators through the use of this procedure. Preliminary small-scale field experiments were also completed and support bioassay results.*

Phase II: Small-scale evaluation

The most promising compounds identified in the bioassay will be tested further on rooted vegetation. Facilities currently available for conducting these studies include an aquarium system and in outdoor-tank system at the WES. The aquarium system is ideal for testing various PGR concentrations and exposure periods on rooted, submersed aquatic vegetation. This is the same system used for the Herbicide Concentration/Exposure Time work effort. The outdoor-tank system is more conducive to PGR testing on plant species such as waterhyacinth. Preliminary studies evaluating maleic hydrazide and gibberellic acid on the growth of waterhyacinth showed promising results.

Phase III: Field evaluation

Plant growth regulators feasible for field testing, and those in which aquatic registration look promising, will be evaluated in field situations. Field evaluations will be coordinated with industry and will include the necessary protocol for data collection as required by the US Environmental Protection Agency.

SMALL-SCALE EVALUATION OF PGR EFFECTS ON WATERHYACINTH

Waterhyacinth has an extremely fast rate of growth. Since the rapid reproduction of ramets (daughter plants) is the key to the prolific spreading of waterhyacinth, a method that will reduce or suppress ramet production would greatly enhance waterhyacinth control. An additional consideration is the use of PGRs to slow the growth rate of waterhyacinth to facilitate biocontrol effectiveness. The ability of waterhyacinth to reproduce at a faster rate than biocontrol agents is a limiting factor in the success of some biological control methods.

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*C. A. Lembi, Tara Chand, and W. Clark Reed. 1990. See pp 116-119 in this proceedings.

A preliminary study was conducted in 1988 to evaluate the effects of plant growth regulators on the growth and reproduction of waterhyacinth. The study was conducted in the outdoor-tank system at the WES. Waterhyacinth plants of approximately equal age were obtained from stock cultures and transferred to the growth tanks for PGR treatment. Two growth regulators, gibberellic acid and maleic hydrazide, were applied using a hand-held sprayer, at rates of 2.0 mg/ℓ and 2.24 kg active ingredient (ai)/acre, respectively. Gibberellic acid was selected for its ability to induce flowering in waterhyacinth. It has been observed that during flowering, ramet production is greatly reduced. Maleic hydrazide was selected for testing based on its ability to suppress sucker growth of many agricultural crops. Plant number and fresh weight were recorded weekly, for 1 month posttreatment.

Preliminary results indicate that growth of waterhyacinth can be suppressed with applications of these two PGRs. At 3 weeks posttreatment, a 47- to 49-percent reduction in plant number as compared to the untreated controls was observed with applications of gibberellic acid and maleic hydrazide, respectively (Figure 1). Significant reductions in fresh weight (data not shown) were also observed with both treatments. Additional studies evaluating the duration of these effects and the effects of application timing are needed.

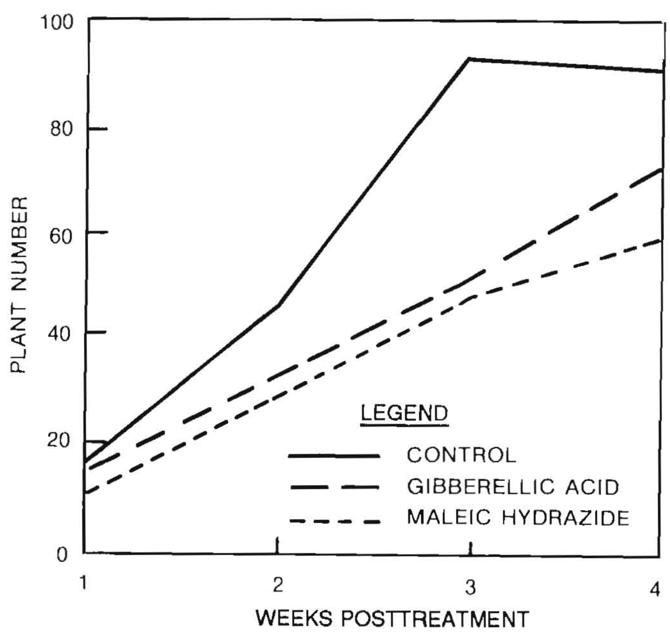

Figure 1. Effects of gibberellic acid (2.24 kg ai/acre) and maleic hydrazide (2.0 mg/ℓ) on number of waterhyacinth plants

FUTURE WORK

In conclusion, our plans for the immediate future in this work unit include the following:

a. Continue bioassay testing of the following compounds: bensulfuron methyl, imazapyr, triclopyr, amidochlor, and maleic hydrazide on hydrilla and Eurasian watermilfoil.

b. Initiate concentration/exposure time studies in the WES aquarium system to test and verify bioassay results using selected PGRs and hydrilla.

c. Conduct additional testing of various PGRs on waterhyacinth using the WES outdoor-tank system.

Plant Growth Regulator Effects on Submersed Aquatic Plants

by
Carole A. Lembi,* Tara Chand,* and W. Clark Reed*

INTRODUCTION

Our research goals over the past few years have been to develop a new strategy for aquatic plant management involving the use of plant growth regulators. The idea is to reduce the height of submersed aquatic weeds without disrupting their ability to function in the aquatic environment, i.e., to provide oxygen, habitat, and sediment stabilization. To this end, we developed a laboratory bioassay system using hydrilla (*Hydrilla verticillata* Royle) and Eurasian watermilfoil (*Myriophyllum spicatum* L.) grown in sterile culture media and under controlled environment conditions. We have emphasized the gibberellin synthesis inhibitors uniconazol, flurprimidol, and paclobutrazol. These compounds inhibit gibberellin synthesis in the plant, thereby inhibiting normal plant elongation. We have found that plant height can be significantly reduced in both hydrilla and watermilfoil without adversely affecting structural integrity or metabolic properties such as photosynthesis and respiration. Preliminary small-scale outdoor tests with hydrilla verified the laboratory bioassay results in terms of dosage effects.

To continue this work, our objectives this past year were to determine (a) the susceptibility of submersed weeds other than hydrilla to gibberellin synthesis inhibitors under small-scale outdoor conditions, (b) the exposure time required to produce a growth-regulating effect under small-scale outdoor conditions, (c) the persistence of flurprimidol in water under small-scale outdoor conditions, and (d) the potential of herbicides currently in development to have useful growth-regulating properties. Tests addressing objectives a-c were conducted in 67-ℓ barrels with soil on the bottom, filled with well water, and set out of doors. Testing for objective d was conducted using the laboratory bioassay method.

RESULTS

Gibberellin synthesis inhibitor effects on submersed plant species

Based on previous bioassay results, flurprimidol and uniconazol concentrations chosen for milfoil testing in the barrels were 0.075, 0.75, and 7.5 ppb active ingredient. Reduction of plant height was not statistically significant (0.05 percent level) at

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any concentration when compared to untreated controls. This appeared to be due to a high degree of variability of milfoil growth in the barrels. However, there was a trend toward reduced plant height at all concentrations. Elodea (*Elodea canadensis*) was also exposed to flurprimidol concentrations of 0.075, 0.75, and 7.5 ppb. Coontail (*Ceratophyllum demersum*) was exposed to the same concentrations plus additional concentrations of 75 and 750 ppb. Statistically significant plant height reductions were obtained only on coontail at 7.5, 75 and 750 ppb. The two lowest concentrations used on elodea were ineffective in reducing growth in relation to the control. However, the 7.5-ppb concentration (although not statistically significant) did show a tendency to reduce growth in this species.

Time of exposure

Barrels were planted with hydrilla and treated with either 75 or 750 ppb flurprimidol. At each time interval of 2 hr, 1, 2, 7, 14, or 28 days, a set of two barrels was emptied of treated water (with a siphon) and refilled with untreated water. The barrels treated with 75 ppb were diluted again on two consecutive days while the 750-ppb barrels were diluted on three consecutive days. Thus, after dilution, flurprimidol concentrations in the barrels should have been less than 0.75 ppb. Plants were then collected 4 weeks after they had undergone dilution, measured for main stem length, and weighed for fresh and dry weights. Control plants were obtained from untreated (but also diluted) barrels. Statistically significant stem length reductions were obtained at all exposure times, including 2 hr, and at both flurprimidol concentrations. Plant dry weight was not significantly affected at any of the exposure times. The data suggest that only short exposure times may be required for hydrilla length reduction but that the amount of biomass produced will not be affected. In other words, approximately the same amount of biomass will be found on short and long plants. The same experiment was conducted on Eurasian watermilfoil. In this case, flurprimidol concentrations were 7.5 and 75 ppb, and the dilution intervals were 2 hr, 1, 3, 7, 14, and 28 days. The only significant reduction in plant length was after a 14-day exposure at both flurprimidol concentrations. No significant impact was found on plant biomass. Again, growth variability of the milfoil probably reduced the overall usefulness of this experiment.

Flurprimidol residues in water

Water samples collected from treated and untreated barrels were analyzed for flurprimidol using gas chromatography. Flurprimidol to generate standard curves was obtained from Elanco, Inc. In the first experiment, water samples were collected on seven dates from 5 June (date of treatment) to 3 July 1989 from duplicate barrels treated with 7.5- and 75-ppb flurprimidol. At both concentrations, the compound showed typical half-life curves. By fitting exponential curves to the data points (r^2 = >0.9 in both cases), the half-life of the compound at both concentrations was 6.8 days. In a second experiment, water samples were collected on seven dates from 1 August (date of treatment) to 9 October 1989 from triplicate barrels treated with 1.0-ppm flurprimidol. After curve fitting ($r^2 = 0.981$), the half-life of the compound was found to be 15.9 days. The shorter half-life early in the season is attributed to higher light incidence in the barrels, since flurprimidol is susceptible to photodegradation.

Herbicides as growth regulators

The laboratory bioassay system was used to study the effects of bensulfuron methyl on Eurasian watermilfoil and of triclopyr on hydrilla and Eurasian watermilfoil. Each concentration was replicated three times, and each experiment was repeated at least once. Concentrations of bensulfuron methyl tested were 0.6, 6, 60, 100, and 300 ppb (all dose ranges were predetermined by a preliminary screening). The minimum effective dose required to produce a statistically significant reduction in plant length was 6 ppb (although a significant reduction was obtained at 0.6 ppb in one of three experiments). The minimum dose causing statistically significant reductions in photosynthesis and root production was 60 ppb. This suggests a 10-fold factor between the concentration required to reduce stem length and that which causes adverse effects (100-fold if 0.6 ppb is taken as the minimum effective dose). These effects contrast with those of bensulfuron on hydrilla in the bioassay, in which only a fourfold difference (0.1 and 0.4 ppb) was found between stem length reduction and adverse effects. Triclopyr concentrations used on hydrilla were 0, 50, 100, 250, 500, and 1,000 ppb. The concentrations used on milfoil were 0, 0.1, 0.5, 1.0, 10, and 100 ppb. The minimum effective dose of triclopyr required to produce a statistically significant reduction in plant length was between 500 and 1,000 ppb on hydrilla and 0.5 ppb on milfoil. The minimum dose causing statistically significant reductions in photosynthesis and root production was 1,000 ppb on hydrilla and 0.5 ppb on milfoil. These results suggest that triclopyr would not provide effective growth regulation on either hydrilla or milfoil but that the compound is primarily herbicidal. Milfoil appears to be more sensitive to triclopyr than hydrilla.

CONCLUSIONS

The results presented above provide additional support for the potential use of PGRs in aquatic systems. Although our testing of gibberellin synthesis inhibitors on milfoil, elodea, and coontail was not completely satisfactory because of difficulties in growing the plants, the results do suggest that these plants are susceptible to these compounds, probably at concentrations of 7.5 ppb and higher. It should be noted that the concentrations used in these barrel studies were taken from the laboratory bioassay, which provides ideal conditions for PGR effects to develop. These concentrations were extremely low (as low as 0.075 ppb); therefore, they may not be totally adaptable for field conditions. However, concentrations in the 7.5- to 750-ppb range appear to be effective and yet are still low enough to provide minimal environmental damage.

The possibility that hydrilla may only require exposure to a gibberellin synthesis inhibitor for a very short period of time (perhaps as little as 2 hr) is phenomenal. However, this result must be taken with caution and verified with additional experiments. Both our small-scale and laboratory tests indicate that hydrilla biomass reduction does not necessarily accompany stem length reduction. In fact, all indications are that the biomass of untreated and treated plants is basically the same. Therefore, the amount of biomass produced by an untreated plant will be compacted in a much shorter zone of plant growth. The effects of this compaction of growth on invertebrate and fish utilization will ultimately have to be determined.

Since flurprimidol is known to be susceptible to photodegradation, the short half-life monitored in shallow (<1 m), relatively clear water is not unexpected. Additional testing under lower light intensities is needed. The partitioning of the compound into plant tissue and soil also must be determined. We are currently developing the extraction techniques we will need to measure flurprimidol residues in plants and soils.

Of the two herbicides tested for PGR effects, bensulfuron methyl on milfoil appears to have the greatest potential to reduce plant growth without altering physiological status. This sort of an effect also has been noted in field trials in California.* Triclopyr, although mimicking 2,4-D (which has PGR effects), seems to be strictly herbicidal. We are currently testing imazapyr, another compound with potential as an aquatic herbicide.

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*Personal Communication, 1989, Lars Anderson, US Department of Agriculture, Agricultural Research Service, University of California, Davis, California.

Coordination of Control Tactics with Phenological Events of Aquatic Plants

by
Kien T. Luu* and Kurt D. Getsinger*

INTRODUCTION

Current aquatic plant management techniques do not consider the importance of physiological weaknesses in the growth cycle of the target plants. Regardless of the control methods used, proper timing of application is often a key for success or failure in aquatic plant management. A better understanding of aquatic macrophyte growth cycles and identification of physiological weak points in those cycles are needed to improve the effectiveness of present control techniques. A weak point is a period during the growth cycle when a plant is least likely to recover following the implementation of a control method. Application of a control tactic during this period should therefore maximize its overall effectiveness.

Once weak points are identified, they must be associated with specific growth cycle events, morphological characteristics, or environmental cues. These latter characteristics can then be used as management guideposts, which would allow field personnel to predict the optimum time for implementing specific control actions. In other words, used in this manner, weak points become control points in the growth cycle of a target plant.

A typical aquatic macrophyte growth cycle, including hypothetical control points, is depicted in Figure 1. The control points are those periods in the growth cycle where control tactics have been applied in conjunction with periods of physiological weakness, e.g., during minimum levels of carbohydrate (CHO) reserves in the spring or preceding propagule formation in late summer.

A series of studies are being conducted in environmental chambers, small outdoor tanks, and the field to identify physiological weak points, and ultimately control points, in the growth cycle of waterhyacinth, hydrilla, Eurasian watermilfoil, and alligatorweed. Results of these studies will be useful to all of the aquatic plant control technology areas, i.e., biological, chemical, mechanical, and ecological, for improving the management of nuisance vegetation.

Results of the small-scale outdoor waterhyacinth studies that have been conducted during the last 3 years are summarized in the following section and in a WES technical report.**

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*US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

**Kien T. Luu and Kurt D. Getsinger. 1990. "Seasonal Biomass and Carbohydrate Distribution in Waterhyacinth: Small-Scale Evaluation," Technical Report A-90-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

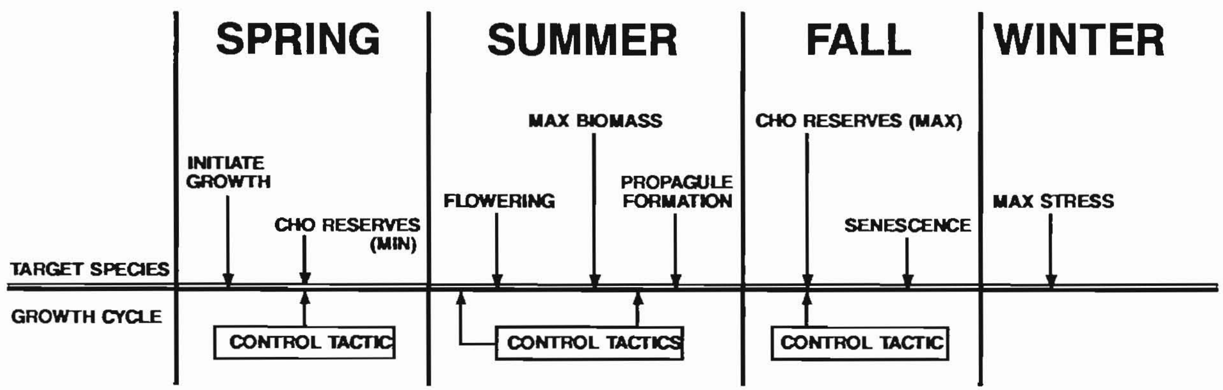

Figure 1. Generalized aquatic macrophyte growth cycle showing potential control points

OUTDOOR STUDIES ON WATERHYACINTH

Experimental approach

Small-scale outdoor studies of waterhyacinth have been completed during the last 3 years at the WES. These studies characterized the seasonal allocation of carbohydrates and dry weights of various plant structures and verified some important growth characteristics of waterhyacinth (such as seasonal growth rates, leaf dimensions and longevity, and winter survival) which have been reported in the literature.

Information on carbohydrate allocation and growth characteristics will help to identify the physiological weaknesses in the plant's growth cycle. In addition, the growth characteristic data will be useful for validation of the existing waterhyacinth growth model.

Results of growth characteristics study

There were two peaks of young ramet production in the growth cycle of waterhyacinth. The spring peak was in the May-June period, while the second peak was in the fall (September-October), following an active period of flowering. Flowering curtails the ability of waterhyacinth to produce young ramets and growth in general.

Maximum plant biomass occurred in early to mid-September, and peak flowering occurred from late August to early September. The highest proportion of plant dry weight was found in mature leaves and petioles when plants were in the vegetative stage. However, when plants were flowering, roots accounted for the highest proportion of dry weight. Root size was apparently related to the onset of flowering. Spring growth tended to create a larger number of plants, while summer growth resulted in larger plant size.

A single plant, formed in late May, can produce over 40 leaves by mid-February, with leaf size dependent on available nutrients and temperature. It takes an average of 16 to 18 days for a leaf to reach maturity (full length), with most leaves surviving longer than 1 month, but not more than 2 months. The bulbous and nonbulbous character of petioles is related to available growing space and/or distribution of light.

Winter survival of the high-density, short-plant population was superior to that of the high-density, tall-plant population. Secondary saprophytes and sunlight limitation probably caused the necrosis of stem-base meristematic tissues in the tall-plant population.

Results of carbohydrate allocation study

Waterhyacinth stored maximum carbohydrates in stem-bases during the September to October period. Stem-bases were the overwintering structures of the plants. These structures play an important role in the seasonal carbohydrate cycle of the plant by providing energy for dormant buds and new growth in the spring.

Starch levels in the stolons increased from late summer to mid-fall, indicating that stolons play a role in the storage of carbohydrate reserves. In addition, stolons contained high levels of free sugars in September-October, suggesting that stolons may function as temporary storage sites, as well as conducting corridors for translocating sugars from mature stem-bases to developing ramets.

Blooming rachises were strong carbohydrate sinks containing the highest level of free sugars (22.6 percent) found in the entire plant.

Conclusions

Based on the growth characteristics and carbohydrate allocation, potential control points in the growth cycle of waterhyacinth are shown in Figure 2. These periods include (a) early spring, when the weather is warm enough for young ramet emergence and carbohydrates in the stem-base are low; (b) shortly before the second peak of ramet production in the fall (coinciding with the second blooming peak); and (c) shortly before mid-September to mid-October, when plants are actively translocating carbohydrates to stem-bases.

FUTURE RESEARCH

Field studies are being conducted at the Lewisville Aquatic Plant Research Facility in Lewisville, Texas, to verify results from the carbohydrate allocation studies at the WES. Field data on growth characteristics will also be obtained for validation of the existing waterhyacinth growth model. Since waterhyacinth occurs in latitudes ranging from central California to southern Florida, the effect of climate on cycling of carbohydrates needs to be evaluated.

Similar studies, determining the control points for hydrilla, Eurasian watermilfoil, and alligatorweed, will be phased into the overall research efforts in the near future.

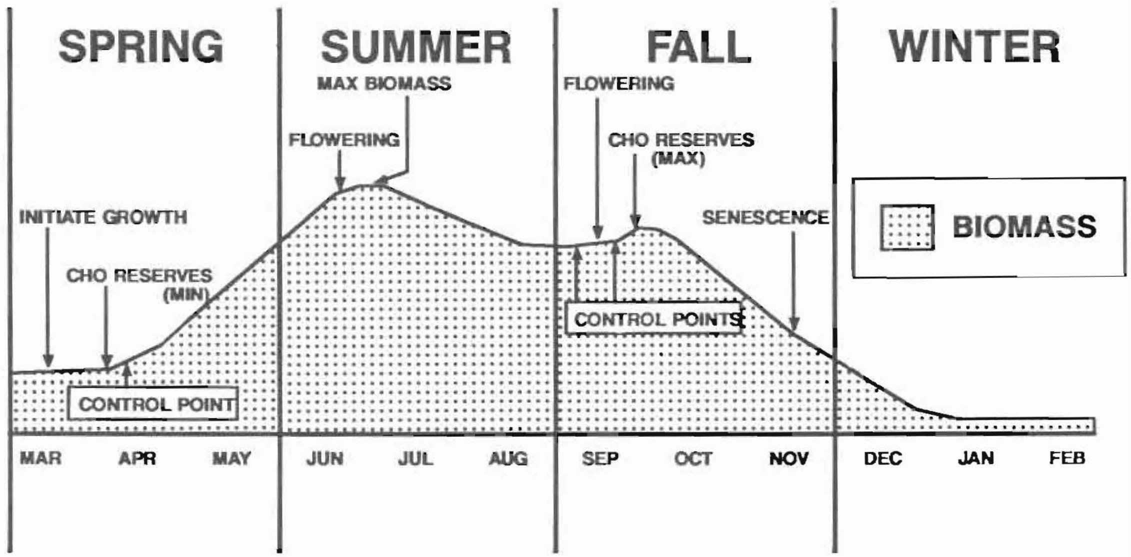

Figure 2. Potential control points in the growth cycle of waterhyacinth

Herbicide Application Techniques for Flowing Water: Evaluation of Submersed Techniques Using Rhodamine WT

by
Kurt D. Getsinger,* William T. Haller,**
and Alison M. Fox**

INTRODUCTION

The movement of water in submersed plant stands can be attributed to flow, wind mixing, thermal stratification, and other hydrodynamic processes and can influence herbicide concentration and contact time. Since chemical control of submersed plants is directly related to herbicide concentration/exposure time relationships, an understanding of water movement within plant stands is essential to improve control in flowing-water systems.

For the past several years, researchers at the WES and the University of Florida Center for Aquatic Plants have been characterizing water exchange patterns in submersed plant stands in reservoirs, rivers, and canals using the fluorescent dye Rhodamine WT (Fox, Haller, and Getsinger 1988; 1989; Getsinger 1989). The overall objectives of this work have been to (a) characterize flow velocities and water exchange in submersed plant stands under field conditions and (b) evaluate application techniques that maximize herbicide contact time in flowing-water environments. Results from the water exchange characterization and application technique studies will provide information needed to select the timing, formulation, and application technique to maximize herbicide efficacy.

The following article presents partial results of a study designed to evaluate submersed application techniques with respect to plant stand conditions, specifically canopy height and water temperature. The initial phase of the study is being conducted in the field under static-water conditions. Once this phase is completed, the most promising application techniques will be evaluated in the field under flowing-water conditions.

MATERIALS AND METHODS

Application technique evaluations were conducted in dense stands of hydrilla in Lochloosa Lake, Florida, during the second weed of June 1989. Seventeen 1-acre plots were established along the west shore of the lake in water approximately 2 m deep (Figure 1). The hydrilla stands were in a surface-matted condition throughout the study site, and stratified water temperatures existed in the stands.

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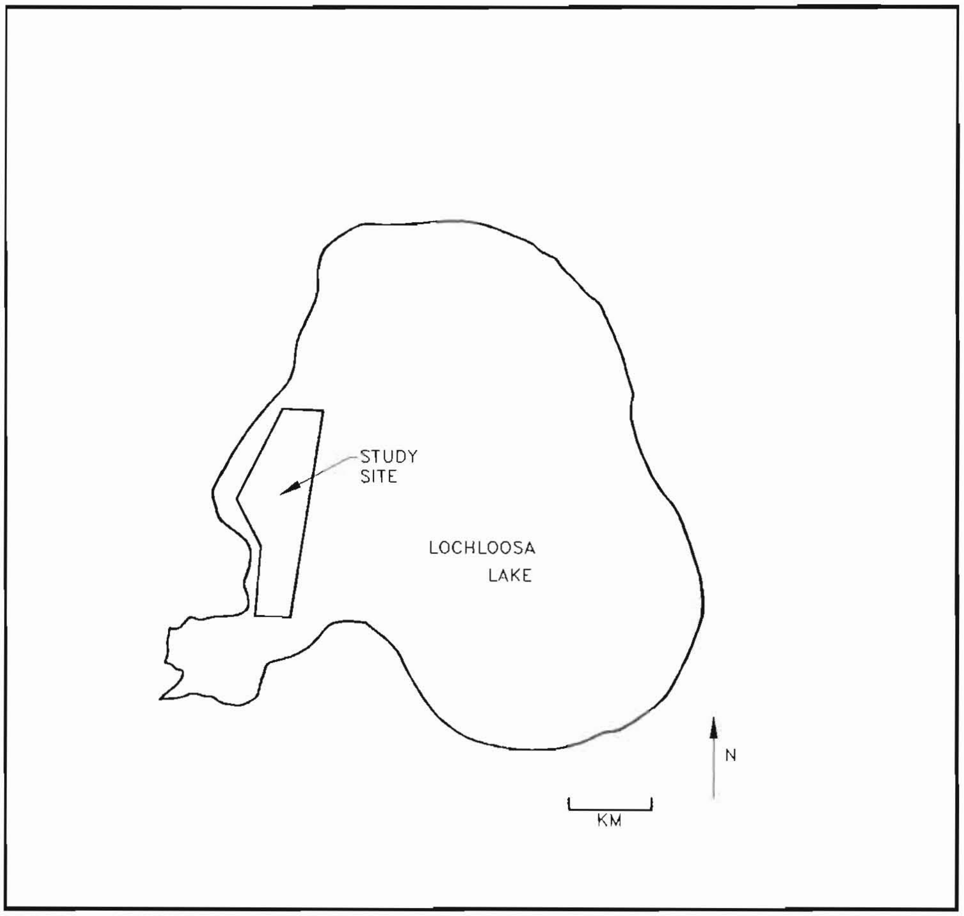

Figure 1. Lochloosa Lake study site

Six submersed application techniques were evaluated during the study (Table 1), with replicates randomly assigned to the plots. Application techniques included the use of long and short hoses, in combination with liquid and polymer dye formulations, as well as a granular dye formulation. The liquid and polymer formulations were created by mixing a 20-percent Rhodamine WT solution with lake water alone, or with lake water and polymer, in a 190-ℓ (50-gal) tank immediately prior to treatment. These dye formulations were applied using a 38-ℓ/min (10-gpm) diaphragm pump and trailing hoses (long = 2.5 m; short = 0.5 m) mounted on an airboat.

The granular dye formulation consisted of clay pellets (identical to those used in the Aquathol Granular herbicide formulation) surface-sprayed with 20-percent Rhodamine WT at the rate of 1 ℓ of dye per 45 kg of granules. This formulation was applied using an electric (12-V) cyclone spreader mounted on the bow of an airboat.

All dye formulations were applied evenly across the plots to achieve a calculated dye concentration of 20 μ/ℓ throughout the water column. Dye was monitored using a Turner Design Model 10-005 field fluorometer that was fitted with a flow-through

Table 1
Submersed Application Techniques Evaluated at Lochloosa Lake, June 1989

Plot Number	*Application Technique*
1, 7, 11, 17	Liquid, short hoses
8	Liquid, long hoses
2, 13, 16, 4	1% polymer, short hoses
3, 14, 15, 5	2% polymer, short hoses
9	2% polymer, long hoses
6, 10, 12	Granular

cuvette system (Fox, Haller, and Getsinger 1988). Water temperature was measured using a YSI 429 thermistor and Cole-Parmer deep-water probe. Dye concentration and water temperature were measured simultaneously at 2, 8, 24, and 48 hr posttreatment, in the center of each plot and in the center of each quadrant in each plot. Measurements were taken at 0.5-m intervals through the water column.

RESULTS AND DISCUSSION

Temperature stratification

A comparison of temperature stratification within the surface-matted hydrilla stands is presented in Table 2. On sunny days, the stands exhibited a high degree of thermal

Table 2
Water Temperature Profiles at 1100 hr in Surface-Matted Hydrilla Stands, Lochloosa Lake, June 1989

	Water Temperature, °C	
Depth, m	*Sunny*	*Overcast*
Subsurface	33.1	27.7
0.5	30.5	27.6
1.0	29.5	27.5
1.5	28.4	27.4
2.0	27.2	27.3
Difference, top to bottom	5.9	0.4

stratification, with the surface waters reaching temperatures nearly 6° C warmer than bottom waters at 1100 hr. Thermal stratification can create a physical barrier that may prevent surface-applied herbicides from mixing below the thermocline. In contrast, overcast atmospheric conditions resulted in a very slight degree of thermal stratification in the stands (0.4° C difference from top to bottom). These near-isothermal conditions will lessen the thermal interference of water column mixing and may enhance the distribution of dissolved substances, such as herbicides, throughout the water column.

Evaluation of application techniques

Results in this section represent comparisons between liquid, long- and short-hose applications; 1 and 2 percent, short-hose, polymer applications; and granular applications. The relative changes in percent distribution of dye in the water column following application with various techniques are shown in Figures 2-4. All of these evaluations were made under stratified water conditions.

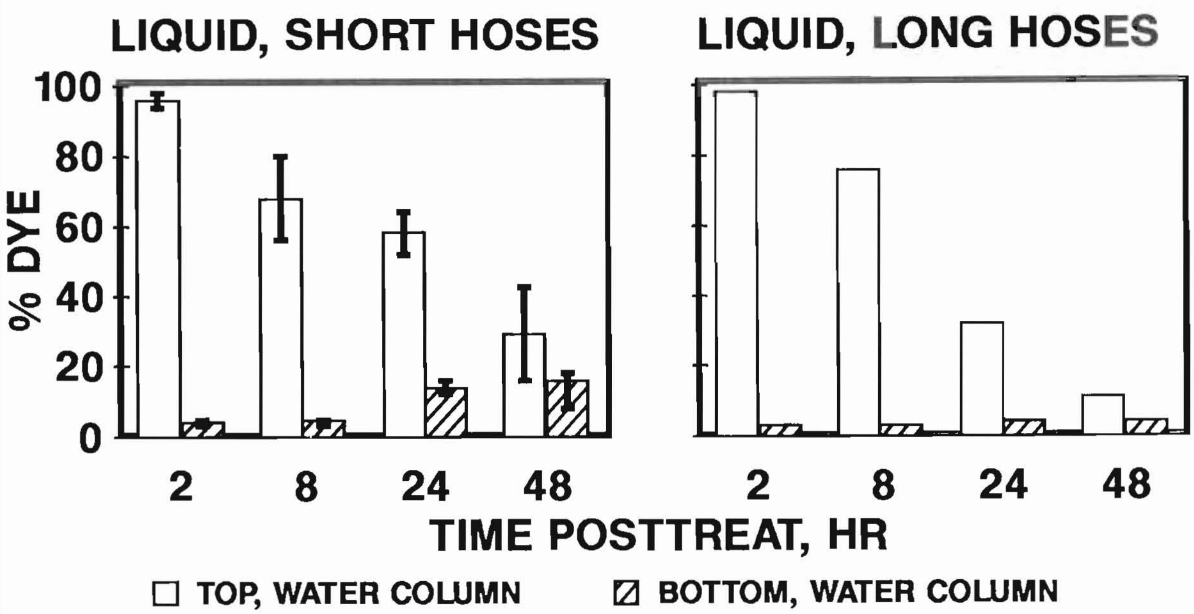

Figure 2. Percent distribution of dye in the top and bottom half of the water column over time, following liquid applications using long and short hoses. Bars represent ±1 standard error

Posttreatment dye distribution in the water column was similar when using short or long hoses and liquid formulations (Figure 2). Dye distribution into the bottom half of the water column was poor using either of these techniques. The decrease in dye concentrations in the top half of the water column was largely the result of lateral dispersion of dye out of the plots, rather than mixing of the dye into the bottom waters.

The polymer/dye formulations (both 1 and 2 percent) showed a dye distribution pattern similar to the liquid technique dye distribution pattern (Figure 3). Very little dye mixed from the surface water into the lower regions of the water column.

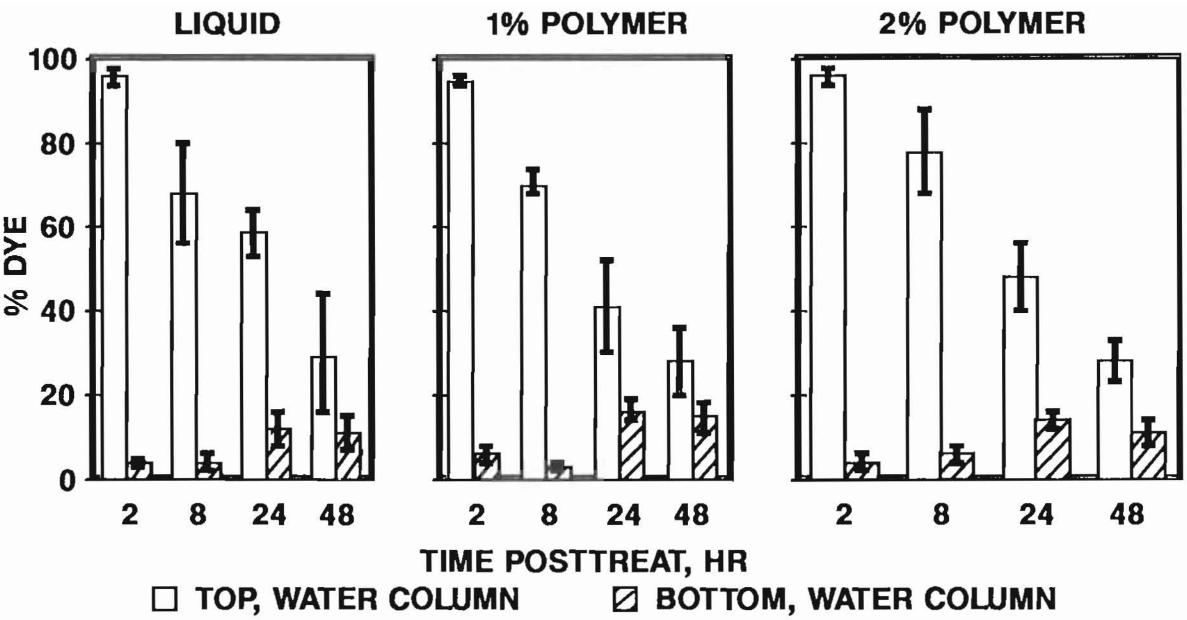

Figure 3. Percent distribution of dye in the top and bottom half of the water column over time, following liquid and polymer applications using short hoses. Bars represent ±1 standard error

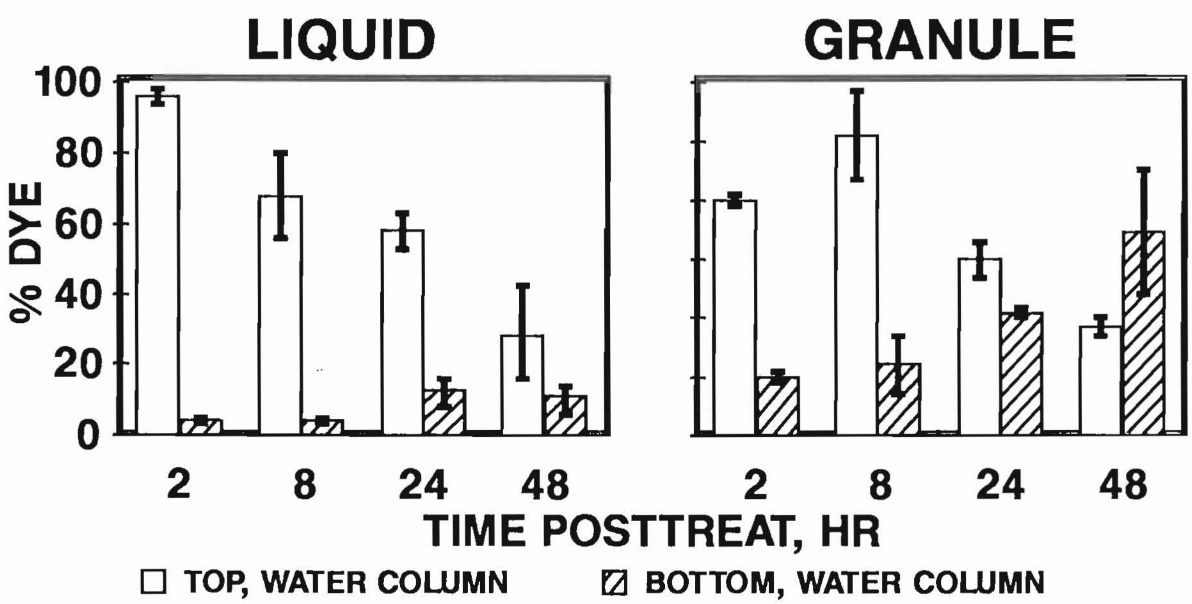

Figure 4. Percent distribution of dye in the top and bottom half of the water column over time, following liquid (short hose) and granular applications. Bars represent ±1 standard error

As opposed to the other formulations tested, the granular treatment provided the best mixing of dye through the water column (Figure 4). Dye concentrations in the bottom half of the water column were almost 6 times greater than those found following the liquid or polymer applications at 48 hr posttreatment.

Results from this initial phase of application technique evaluations suggest the following: (a) granular formulations may dramatically improve the potential mixing of herbicides through the water column when applied to surface-matted stands of hydrilla under thermally stratified conditions and (b) the consideration of plant stand and water temperature conditions, prior to the selection of application techniques and herbicide formulations, may improve efficacy on the target plant.

Studies planned for FY 90 and 91 will continue to determine the potential distribution of herbicides through the water column using dye formulations in stratified, as well as isothermal, conditions. Companion studies will determine the relationships between the dissipation of Rhodamine WT and aquatic herbicides in submersed plant stands.

ACKNOWLEDGMENTS

The authors wish to thank Messrs. Wayne Corbin and Daryl Blackall, St. Johns Water Management District, for invaluable assistance with the dye applications. We are also indebted to Ms. Margaret Glenn and Mr. Charles Hanlon, IFAS Center for Aquatic Plants, and Mr. Reed Green, US Geological Survey-Little Rock, for field assistance. Special thanks are extended to Pennwalt Agchem Division for supplying the granular dye material.

REFERENCES

Fox, A. M., Haller, W. T., and Getsinger, K. D. 1988. "Preliminary Study of the Dilution of Dyes in Tidal Canals of the Crystal River, Florida," *Proceedings, 22nd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-88-5, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 195-201.

Fox, A. M., Haller, W. T., and Getsinger, K. D. 1989. "Factors Affecting the Dispersion of Dyes in Tidal Canals in the Crystal River, Florida," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 103-105.

Getsinger, K. D. 1989. "Herbicide Application Techniques for Flowing Water," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 97-102.

Dye Studies in Submersed Plant Stands in Moving Water

by
Alison M. Fox,* William T. Haller,*
and Kurt D. Getsinger**

INTRODUCTION

Since June 1987 the fluorescent dye Rhodamine WT has been used in Florida in a variety of studies relating to the use of aquatic herbicides in moving water. This paper provides an overview of these uses of Rhodamine WT and a summary of the Florida studies.

USES OF RHODAMINE WT IN RELATION TO AQUATIC HERBICIDES

Estimation of water velocity

Some herbicides are applied to western irrigation channels by repeated or continuous injection. Estimation of frequency and rates of such herbicide applications requires a knowledge of water velocity and discharge. In irrigation systems, these data are usually available from gaging stations or can be measured using conventional flowmeters.

Methods of prolonged herbicide application are being tested in some of Florida's rivers. Gaging stations are rare in these rivers, and flowmeters are of little value in very slow velocities and dense plant stands. In these systems, the maximum and mean water velocities can be estimated by timing the downstream movement of a slug injection of Rhodamine WT.

Estimation of water retention times

Rhodamine WT has been used in several lakes and tidal canals to estimate the maximum retention time of water in plots where herbicide applications have been made or planned. This is of particular value in systems subject to variable rates and directions of water movement. Such estimates of maximum potential herbicide persistence time may aid the manager in selecting an appropriate herbicide and application method.

Determination of factors influencing water retention times

In frequently managed systems that have shown inconsistent efficacy of weed control after herbicide treatments, long-term dye studies can be made to compare water retention times under a variety of pertinent environmental conditions. If the influence on water retention time of the most significant environmental factors can be

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quantified, then the optimum conditions and times for herbicide use (when the period of plant exposure to the chemical is maximized) may be identified. Ideally, a manager would be able to predict these optimum conditions from environmental data that can be easily collected or are already being routinely collected.

Comparison of herbicide application methods

Rhodamine WT has been used in several studies comparing various methods of submersed herbicide application in both moving and static water. Methods investigated have included the use of polymers and different length hoses and pellets, under a variety of water temperature regimes, weed densities, and flow patterns. Using the dye rather than analyzing herbicide residues in such studies not only produces results more quickly and cost effectively, but also allows for repeated applications in the same area without affecting the plants or infringing upon herbicide label regulations.

Simulation of herbicide residues

Since herbicide residues are removed from the water column by processes of adsorption, degradation, and plant uptake, it cannot be assumed that a conservative dye, such as Rhodamine WT, will exactly mimic the long-term movement and changes in concentration of herbicide residues. However, correlations between dye and herbicide concentrations may be significant over short periods of time, the length of which would be related to the half-lives of the herbicides found in closed-pond studies.

Establishing these correlations could allow considerable savings in the time and expense involved in collecting and analyzing herbicide residues, by substituting the quick and inexpensive field measurement of Rhodamine WT concentrations. This substitution would be of greatest value in studies required for herbicide registration that are concerned with the persistence and movement of herbicide residues applied to moving water. Three levels of substitution could be anticipated:

a. Use the dye as a tracer, after concurrent dye and herbicide applications, to show directions of water movement and hence pinpoint where to take herbicide residue samples to obtain significant or maximum concentrations.

b. Following a concurrent treatment, take only enough herbicide residue samples, over a range of dye concentrations, to obtain a reliable correlation and regression line between the concentrations of the two chemicals. Herbicide concentrations could then be extrapolated using the regression line for a large number of dye readings collected in the field.

c. Completely substitute dye measurement for collecting herbicide residue samples after a concurrent treatment, extrapolating herbicide concentrations based upon the estimated initial concentrations of both chemicals.

Establishing correlations between dye and herbicide residue concentrations would also validate the uses of Rhodamine WT to test application methods and to predict the approximate half-lives of herbicides in moving water, from estimates of water retention time as described above.

A summary of the types of Rhodamine WT/herbicide studies (completed, ongoing, and planned) is presented as Table 1.

Table 1
Studies Relating the Use of Rhodamine WT to Herbicidal Control of Hydrilla Conducted or Planned in Florida

Site	*Type of Study**	*Reference***
Three Sisters Canals, Crystal River	2, 3, 4, 5 (endothall and fluridone)	Fox, Haller, and Getsinger 1988, 1989; Fox, Haller, and Shilling, in press[a,b,h]
Other tidal canals	2, 3	Planned[h]
Lake Rousseau	1, 2	Getsinger, Green, and Westerdahl, in press[c]
Lake Orange	2, 4, 5 (diquat)	Report in preparation[d]
Lake Lochloosa	4	Getsinger, Haller, and Fox 1990[e]
Lake Hell 'n Blazes, upper St. Johns River	1, 2, 5 (fluridone)	Fox, Haller, and Shilling, in press[b,e,h]
Lake Washington	2, 5 (endothall)	Fox and Haller, in press[e,f]
Lake Seminole	2	Report in preparation[i]
Wacissa River	1, 2, 4, 5 (endothall)	Planned[f,h]
Withlacoochee River	1, 2	Planned[g,h]

*Study types:
1, Estimation of water velocity
2, Estimation of water retention time
3, Determination of factors influencing water retention times
4, Comparison of herbicide application methods
5, Simulation of herbicide residues

**Project co-operators:
[a]Citrus County Aquatic Plant Management Program
[b]US Department of Agriculture
[c]USAE Lake Rousseau Office
[d]Chevron Chemical Company
[e]St. Johns River Water Management District
[f]Florida Department of Natural Resources
[g]South West Florida Water Management District
[h]USAE District, Jacksonville
[i]DuPont Chemical Company

REFERENCES

Fox, A. M., Haller, W. T., and Getsinger, K. D. 1988. "Preliminary Study of the Dilution of Dyes in Tidal Canals of the Crystal River, Florida," *Proceedings, 22nd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-88-5, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 195-201.

Fox, A. M., Haller, W. T., and Getsinger, K. D. 1989. "Factors Affecting the Dispersion of Dyes in Tidal Canals in the Crystal River, Florida," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 103-105.

Fox, A. M., and Haller, W. T. "Use of Rhodamine WT to Predict Herbicide Dissipation in Moving Water," *Proceedings, EWRS 8th Symposium on Aquatic Weeds, 1990* (in press).

Fox, A. M., Haller, W. T., and Shilling, D. G. "Correlation of Fluridone and Dye Concentrations in Water Following Concurrent Application," *Pesticide Science* (in press).

Getsinger, K. D., Green, W. R., and Westerdahl, H. E. "Characterization of Water Movement in Submersed Plant Stands," Miscellaneous Paper (in press), US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Getsinger, K. D., Haller, W. T., and Fox, A. M. 1990. See pp 125-130 in this proceedings.

SPECIAL SESSION - GUNTERSVILLE RESERVOIR

History of Aquatic Plant Management - Guntersville Reservoir

by
A. Leon Bates*

Guntersville Reservoir, a TVA-operated reservoir, which impounds 67,900 acres of the Tennessee River in Jackson and Marshall Counties, Alabama, and in Marion County, Tennessee, is now 50 years old. Records indicate that submersed aquatic macrophytes were sparse during its early history, although some control of emergent species was conducted to reduce mosquito habitat. The prolification of exotic species such as Eurasian watermilfoil (*Myriophyllum spicatum* L.) began in the early 1960s and persists as a major impediment to consumptive and nonconsumptive water use today.

The morphometry is well suited for colonization by aggressive exotic submersed macrophytes because of a shallow littoral zone created by the flooding of extensive alluvial floodplains. The submersed macrophytes are further submersed by a minimal fluctuation (about 3 ft) as determined by the original design of the impoundment and the fertile soils which are flooded throughout the lower two thirds of the reservoir. The extensive habitat suitable for macrophyte colonization is reflected in the preponderance of exotic submersed macrophytes adapted to "disturbed" aquatic sites.

The perennial macrophyte Eurasian watermilfoil has been the most pervasive exotic species throughout the mainstream reservoirs during the last 25 years. Cloning from an intentional planting by a marine operator in Watts Bar Reservoir about 30 years ago, milfoil's downstream and even upstream dispersion has been rapid and widespread. More than 19,000 acres of Guntersville Reservoir were colonized with dominantly monotypic watermilfoil by 1969; however, plant competition and control measures have reduced the current infestation to about 10,000 to 12,000 acres. If competitive pressure from species such as hydrilla diminished, expansion to the 1969 level would occur.

Watermilfoil has been effectively controlled in most sites using 2,4-D formulations, the exception being midreservoir areas where chemical control is ineffective. Until 1969, the granular butoxyethanol ester formulation of 2,4-D was used. For the last 20 years, the liquid dimethylamine salt of 2,4-D has been effectively used for watermilfoil control.

Efforts to prevent hydrilla introduction began more than 10 years ago in the TVA reservoirs because of its proven "weedy" characteristics in other geographical regions. Hydrilla was discovered in Guntersville Reservoir in 1982 and had expanded to almost 3,000 acres within 6 years. From this original distribution, hydrilla has now expanded and is known to occur in four mainstream reservoirs. Further expansion into vacant "niches" throughout the mainstream reservoirs is expected as the source and number of

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propagules expand. Within Guntersville Reservoir, hydrilla has competitively excluded other submersed macrophytes, even watermilfoil, and because of its lower light requirement could be expected to cover about 29,000 acres, or about 40 percent of the surface area.

Other species, such as spiny-leaf naiad, southern naiad, small pondweed, American pondweed, muskgrass, and coontail, comprise most of the remainder of the submersed macrophyte community. Several emergent species, such as alligatorweed, Uruguayian primrose, and giant cutgrass, cause localized water utilization problems but are minor compared to conflicts caused by submersed species.

Water resource utilization on Guntersville Reservoir runs the gamut of consumptive and nonconsumptive uses. Major industrial users, such as Widows Creek Steam Plant, use large quantities of water and periodically experience clogging problems related to aquatic plants. Hydrilla and other aquatic plants loosened by rainfall-induced high summer flows caused major clogging problems at the Guntersville Dam hydro units in 1989.

Most recreational uses, especially water contact recreation and associated facilities, are severely hampered by dense aquatic vegetation. The tabulation below illustrates the extent and variety of water-oriented recreational activities on Guntersville Reservoir.

Facility	*Number*
State parks	2
City and county parks	11
Camps/clubs	7
Commercial recreational areas	28
Public access facilities	30
Wildlife management areas	4
Natural areas	3

One component of water-oriented recreation, bass fishing, has experienced a boom over several years due in part to publicity arising from several major fishing tournaments. Some aquatic plant management conflicts have emerged with regard to the popularity of this type of sport fishing and the general resistance of participants to weed control efforts. On the other hand, bank fisherman have experienced fishing access problems and desire more weed control. Additional statistics on Guntersville Reservoir fishing are given in the remainder of this section of the proceedings.

Various methods have been used over the last 30 years to control unwanted aquatic vegetation. Eradication of all aquatic vegetation is not desirable or practical and is not the objective of the TVA program. The current control strategy is to reduce excessive aquatic vegetation in areas where greatest conflicts exist. More detail about current and future control technologies employed is presented in other papers in this section of the proceedings.

Guntersville Reservoir, by virtue of its water-level operation scheme, variation in utilization, presence of a diverse native and exotic flora, and demographics, will continue to present a challenge for optimum and acceptable deployment of aquatic plant management technologies. Integration of current aquatic plant management technologies to enhance the use of Guntersville Reservoir will be incorporated into a comprehensive joint agency project, involving TVA, the WES, and the Nashville District, which has been developed to address this complex natural resource management problem.

Herbicidal Control, Guntersville Reservoir

by
Earl R. Burns*

Herbicides have been used for over 20 years on Guntersville Reservoir to supplement water-level manipulations to control nuisance aquatic plants. In the late 1960s, as a result of the introduction and spread of Eurasian watermilfoil in the Tennessee River reservoir system, large-scale herbicidal control efforts were undertaken in an attempt to control this exotic plant. This strategy was soon abandoned because eradication was neither biologically nor economically feasible. Since the early 1970s, TVA has followed an aquatic plant management strategy, rather than a complete control or eradication strategy.

Under the current aquatic plant management program, specific areas of Guntersville, and other TVA reservoirs, are designated as priority areas for herbicide treatment. When aquatic plants become excessive in these areas, herbicide applications are made to alleviate problems caused by the vegetation. Approximately 1,800 of the 69,000 surface acres of Guntersville Reservoir are designated as priority areas. The actual areas of treatment in most priority areas consist of swaths approximately 150 feet wide along the developed shorelines. Priority areas include high-use recreation and public access sites, and areas adjacent to lakeside residences, resorts, camps, commercial marinas, and boat lanes for access. Most priority areas require two or more herbicide applications each year to achieve an acceptable level of control.

Figure 1 shows the herbicide acres (treatments) for Guntersville Reservoir since 1984. Values reported reflect multiple applications to the designated high-priority areas. The increase in herbicide treatment that occurred from 1984 to 1987 was in response to the increase in aquatic vegetation (Figure 2) which occurred as a result of favorable growing conditions caused by an extended drought from 1984 to 1988. In addition, hydrilla, which was discovered in 1982, had begun to spread rapidly, thus requiring herbicide treatment. Herbicide treatments kept vegetation in priority areas at acceptable levels in most cases from 1984 to 1987. In 1988, ideal growing conditions continued, but because of budget limitations, herbicide treatments were halted approximately 1 month early. As a result, many priority areas were heavily infested by late summer and fall. Only 2,758 acre-treatments were made in 1988 compared to over 4,563 in 1987.

In 1989, spring and summer flooding resulted in delayed growth of aquatic vegetation. Figure 2 shows the projected acreage for 1989. Suppression of vegetation by deeper, more turbid water along with an increase in herbicide treatment (Figure 1) resulted in excellent control in all priority areas throughout the growing season.

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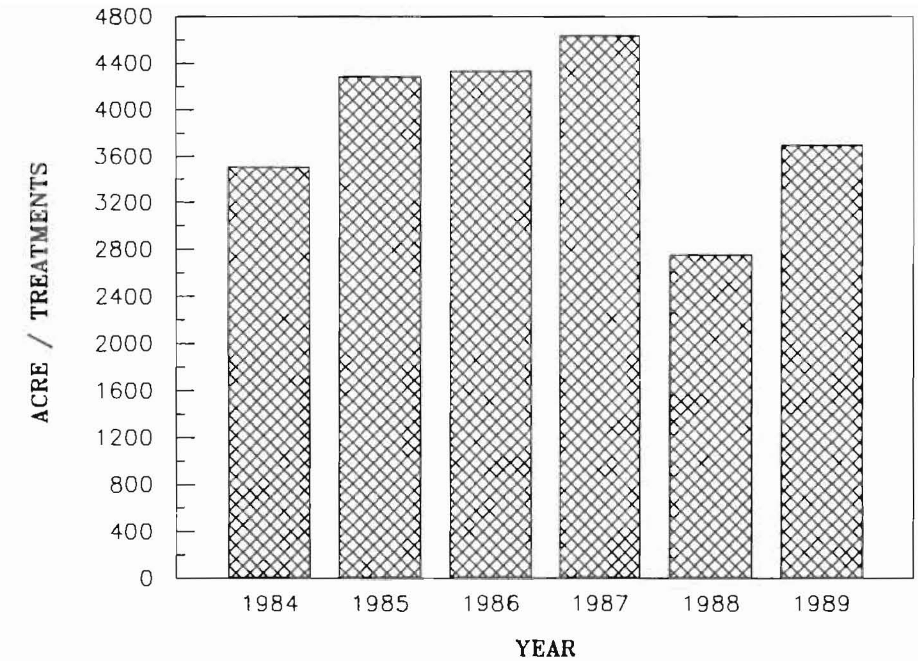

Figure 1. Herbicide treatment from 1984 to 1989 on Guntersville Reservoir

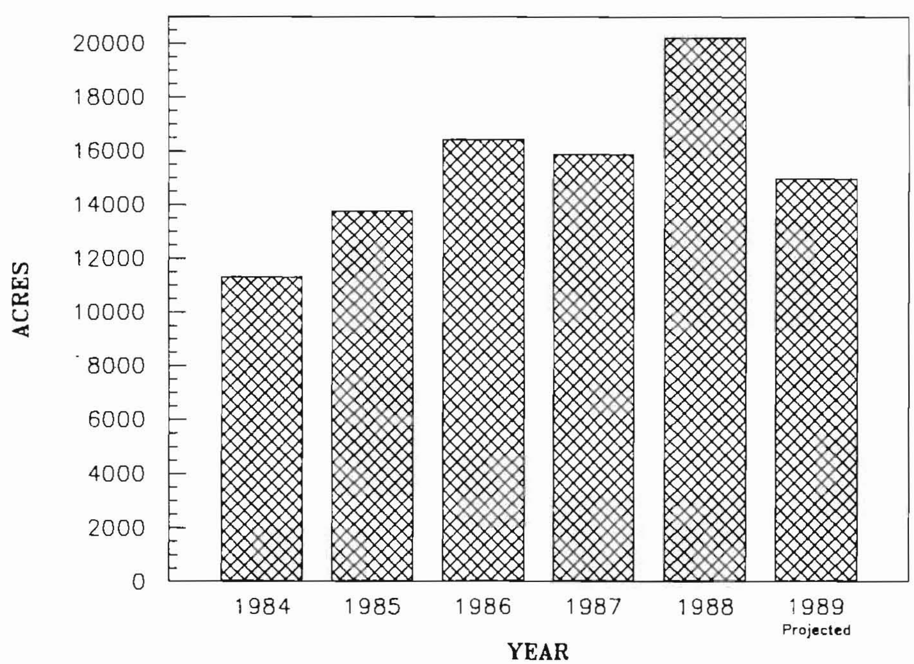

Figure 2. Aquatic vegetation coverage from 1984 to 1989 on Guntersville Reservoir

Table 1 summarizes specific herbicide use for 1989. Herbicide selection was based on weed species in priority areas, specific site characteristics, water use restrictions, and herbicide cost.

Precautions were taken to ensure minimum risk to the public and the environment due to use of aquatic herbicides. Herbicides were applied under the supervision of certified pesticide applicators, and treatment areas were posted with signs denoting water use restrictions and waiting periods. Monitoring of water supplies and fish flesh has shown no accumulation of herbicide residues.

Table 1

Treatment Acreages of Emergent and Submersed Aquatic Weeds by Different Herbicides and Application Methods, Guntersville Reservoir, 1989

Weed Type	*Herbicide*	*Acres (Treatments)*
Emergent	DMA 2,4-D	128
	Rodeo	37
Submersed	DMA 2,4-D (aerial)	105
	DMA 2,4-D (boat)	731
	Aquathol K (aerial)	756
	Aquathol K (boat)	290
	Komeen + Sonar A.S. (aerial)	159
	Komeen (boat)	176
	Komeen + Diquat (boat)	1,282
	Hydrothol 191	16
	Total	3,700

Drawdowns and Grass Carp for Aquatic Weed Control, Guntersville Reservoir

by
David H. Webb*

DRAWDOWNS

Water levels on most reservoirs in the Tennessee River system are drawn down during the late autumn and winter months to provide flood storage capacity for runoff from spring rains. The amplitude of fluctuation between normal summer and winter pool levels along reservoirs of the main stem Tennessee River is 7.5 ft or less. Several of the main stem reservoirs have populations of submersed aquatic macrophytes that conflict with multiple uses of the water resource. Submersed aquatic macrophytes are almost totally absent from tributary reservoirs that operate primarily for flood storage and have drawdowns that commonly exceed 20 ft.

The normal amplitude of fluctuation on Guntersville Reservoir is about 2 ft, although special reservoir operations have been conducted to allow an additional 1-ft fluctuation. The limited drawdown, coupled with extensive shallow overbank habitat, is conducive for the establishment and growth of aquatic macrophytes. About 20,000 acres or approximately one third of the reservoir surface area of Guntersville Reservoir was colonized in 1988 (Burns, Bates, and Webb 1989), which created a number of water resource use conflicts.

Drawdowns during the late autumn and winter months provide effective control of perennial species such as Eurasian watermilfoil. However, this affords a selective advantage to annual species such as naiads (*Najas* spp.), some pondweeds (*Potamogeton* spp.), and macroalgae (*Chara* spp.), which complete their life cycle during the summer months and survive the drawdowns as seed or functionally similar propagules.

To provide partial control of most submersed species and possible long-term control of annuals by disrupting seed production, short-term summer drawdowns were implemented in 1983, 1987, and 1989 specifically for aquatic vegetation control. During these years, Guntersville Reservoir was drawn down in June or July to about 2.75 ft below the normal summer pool elevation of 595 ft and refilled. The entire operation was conducted over a 3- to 4-week period. Normal summer pool levels of 595 ft were extended in 1987 and 1989 for about 3 months. The most effective control was in 1983 and 1987 when drying conditions were maximum during the time of drawdown. These variations in the normal reservoir operation scheme on Guntersville Reservoir have provided effective short-term control of submersed aquatic vegetation in the drawdown zone and will likely be implemented on a periodic basis as a routine control measure.

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GRASS CARP

Grass carp have not been used for operational control of aquatic vegetation on TVA reservoirs. However, two major experimental studies with grass carp were conducted on Guntersville Reservoir during the 1980s.

In September 1984, about 4,500 monosex (female) grass carp were stocked in a 396-acre screened embayment (Town Creek) on Guntersville Reservoir (TVA 1987, 1989). The stocking rate was about 19 fish per vegetated acre. In 1985, the first year after stocking, grass carp caused major reductions in the standing crop of species such as spiny-leaf naiad (*Najas minor*), southern naiad (*Najas guadalupensis*), pondweed (*Potamogeton* spp.), muskgrass (*Chara zeylandica*), and hydrilla (*Hydrilla verticillata*) within the embayment, leaving a monospecific community of the less preferred Eurasian watermilfoil (*Myriophyllum spicatum*). Standing crop of Eurasian watermilfoil declined significantly the first year after stocking and continued to decline through the third year. Total coverage of submersed vegetation declined from about 237 acres in 1984 to about 73 acres in 1987. Coverage of Eurasian watermilfoil almost doubled in 1988, the fourth year after the grass carp were released. Thus, submersed aquatic vegetation in the embayment was significantly reduced without total elimination. Regrowth and expansion of Eurasian watermilfoil indicated that repetitive stockings would be required to maintain desired levels of milfoil control on a long-term basis.

Radiotelemetry studies with grass carp were conducted in 1987 and 1988 on Guntersville Reservoir by Auburn University and TVA (Bain, Steeger, and Tangedal 1988). The primary objectives were to determine movement of grass carp within the reservoir and to determine whether the fish would remain near hydrilla colonies where initially stocked. Grass carp released in July 1987 ranged in weight from 4.0 to 6.0 lb, while those released in June 1988 ranged from 9.0 to 13.0 lb. The juvenile grass carp released in 1987 exhibited limited movement and generally remained near the hydrilla colonies where originally released. However, larger grass carp released in 1988 moved throughout the reservoir and were most frequently found in Eurasian watermilfoil, the most common and widely distributed species in the reservoir. Because of the extensive movements of the fish released in 1988, the grass carp were frequently found in portions of the reservoir where hydrilla had not established. Results of the telemetry study indicated that adult grass carp may move widely within a reservoir at times other than spawning season and likely would not be as effective for hydrilla control in target areas as would juvenile grass carp of stocking size.

REFERENCES

Bain, M. B., Steeger, T. M., and Tangedal, M. D. 1988. "Feasibility of Grass Carp for Hydrilla Control in a Mainstream Tennessee River Reservoir," Alabama Cooperative Fish and Wildlife Research Unit, Auburn University, Auburn, AL.

Burns, E. R., Bates, A. L., and Webb, D. H. 1989. "Aquatic Plant Management Program--Current Status and Seasonal Workplan--1989," TVA Aquatic Biology Department, Water Resources, River Basin Operations, Muscle Shoals, AL.

Tennessee Valley Authority. 1987. "White Amur Project Report," TVA/ONRED/AWR-87/38, Office of Natural Resources and Economic Development, Division of Air and Water Resources, Muscle Shoals, AL.

Tennessee Valley Authority. 1989. "Supplement to White Amur Project Report," TVA/WR/AB-89/1, Resource Development, River Basin Operations, Water Resources, Muscle Shoals, AL.

Aquatic Vegetation--Mosquito Production, Guntersville Reservoir

by
Joseph C. Cooney*

INTRODUCTION

Mosquitoes and aquatic vegetation are closely related with regard to faunal distribution and density, especially involving breeding that occurs in impoundments. This knowledge is very useful in formulating control strategies and has been the basis upon which the Tennessee Valley Authority's (TVA) mosquito control program has operated since its inception. This extensive knowledge has allowed TVA to rely heavily on environmental management measures for mosquito control, thereby reducing dependence on insecticide applications.

The two major groups of impoundment-related mosquitoes requiring attention in TVA's control efforts are the permanent pool types and the floodwater types. The groups have different associations with vegetation regarding breeding habitat.

PERMANENT POOL SPECIES

The major permanent pool species occurring on TVA reservoirs and requiring control are *Anopheles quadrimaculatus*, *Anopheles punctipennis*, and *Culex erraticus*. These species are associated primarily with clear, warm, unpolluted waters containing varying amounts of aquatic vegetation or plant debris. Prior to 1960, larval breeding was primarily associated with herbaceous emergent marginal vegetation such as alligatorweed (*Alternanthera philoxeroides*) and related species, and the woody plant species common buttonbush (*Cephalanthus occidentalis*) and black willow (*Salix nigra*). Since 1960, submersed aquatics have become increasingly important as breeding habitat for permanent pool species, with Eurasian watermilfoil (*Myriophyllum spicatum*) being the primary source.

Eurasian watermilfoil is an exotic plant that was accidentally introduced into the Tennessee Valley watershed about 1960. Since that time it has spread prolifically throughout the reservoir system, colonizing many areas with a water depth less than 15 ft, and resulting in proportionate increases in mosquito population indices. On Chickamauga and Wheeler Reservoirs, population indices for adult females for the years prior to the introduction of Eurasian watermilfoil averaged 2.3 and 10.7, respectively. Indices for these same reservoirs after milfoil became abundant were 7.2 and 18.2, respectively.

Two other groups of submersed species have recently gained prominence--the naiads (*Najas* sp.) and hydrilla (*Hydrilla verticillata*), although they do not provide the ideal

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breeding habitat that Eurasian watermilfoil does. In fact, surveys to date have revealed limited or no breeding associated with monotypic hydrilla. This is of particular significance to the TVA mosquito control program since hydrilla has the potential to colonize extensive areas of the reservoir system (up to 20 ft or more in depth) and to outcompete most other aquatic plants growing in this region. Other submersed species that provide limited mosquito breeding habitat are some of the native pondweeds (*Potamogeton* sp.) although they do not constitute a serious problem due to their limited distribution.

One other group of aquatic plant species that influences mosquito breeding on impoundments is the unattached floating-leaf plants, such as the duckweeds (*Lemna* sp. and *Spirodela* sp.). These species provide limited breeding habitat when in small quantities and in mixtures with other plant species; however, when they occur as dense floating monotypic mats, adult mosquito production for the three identified permanent pool species is almost nonexistent.

FLOODWATER SPECIES

The floodwater species of most concern to the TVA mosquito control program are *Aedes vexans*, *A. atlanticus*, *A. trivittatus*, and *A. sticticus* and *Psorophora varipes*, *P. cyanescens*, *P. ferox*, and *P. ciliata*. Their presence is more related to the extent, duration, and frequency of flood conditions on the reservoir system than it is to aquatic vegetation. However, the presence of certain types of aquatic vegetation can be used as an indication of floodwater mosquito habitat and the presence of mosquito ova in the soil by indicating levels of soil moisture. Several species of herbaceous vegetation can be used as indicators of floodwater mosquito habitat; for example, *Juncus effusus*, *Scirpus cyperinus*, and *Carex lupulina* are usually associated with floodwater mosquito ova in grassland depressions or floodplains. Conversely, floodwater mosquito production in forested floodplains is not very well correlated with tree species, although a very good distinction can be made between the species of floodwater mosquitoes one would expect to encounter in a wooded floodplain versus those occurring in floodplains colonized by herbaceous vegetation.

MOSQUITO CONTROL - VEGETATION MANAGEMENT

An old adage exists among mosquito control personnel that states that if you want to control mosquito production in impoundments, you must either "get the weeds out of the water or the water out of the weeds." This can be accomplished in a number of different ways and at different times during the life of an impoundment. Initially, considerations for mosquito control should be included early in the planning for the construction of a reservoir and commence with the beginning of reservoir basin preparation.

Several specific activities can be considered in the design and construction of the reservoir basin and its margins that will minimize the potential for the presence and growth of vegetation in the impoundment; these include such operations as shoreline modifications and reservoir basin clearing. Shoreline modifications are structural changes designed to create new shorelines with steep slopes, with the ultimate goal of reducing the littoral zone; cut and fill projects are examples. Clearing the reservoir basin of all woody vegetation that would penetrate the water surface removes this potential habitat before the reservoir is filled.

After the reservoir has been impounded, it is still necessary to maintain control of aquatic vegetation that has adapted to the specific reservoir operating mode. Marginal emergent woody vegetation that grows in the seasonal drawdown zones of some reservoirs can be controlled by mechanical mowing on a 2- or 3-year cycle. Submersed aquatic vegetation can be controlled to some extent with seasonal recessions of reservoirs; however, much better results are obtained with planned special water-level operations, e.g., summer drawdown. These special operations, however, are difficult to justify when other program interests are adversely impacted; consequently, effective control of submersed aquatics still relies heavily on the use of selectively applied herbicides.

It is obvious from the foregoing discussion that permanent pool species of mosquitoes are another important detriment associated with excessive aquatic plant growth, and that attaining satisfactory control requires effective aquatic plant management.

Grass Carp Stocking Evaluation in a Large Embayment of a Tennessee River Reservoir

by
William B. Wrenn

The significant increase in aquatic macrophytes in Guntersville Reservoir prompted an investigation to assess the potential of grass carp (*Ctenopharyngodon idella*) to control aquatic plant growth and specifically to determine the impacts of stocking the exotic species on the resident fish population. Fish distribution and abundance were compared over a 6-year period in an 11.1-ha portion of a large, densely vegetated embayment prior to and after stocking grass carp at the rate of 28.5 fish per surface hectare. A screen barrier installed prior to stocking prohibited emigration of grass carp. Fish samples were collected using rotenone.

The results showed:

a. No overall adverse effects on the total fish community.

b. A shift in the forage base from sunfishes to shad.

c. An increase in the growth of largemouth bass.

d. An increase in total fish standing stock.

These results were either directly or indirectly attributed to the significant decline in the amount of submersed aquatic vegetation resulting from grass carp grazing.

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Joint TVA/USACE Project - Guntersville Reservoir

by
A. Leon Bates*

Submersed aquatic vegetation impedes multipurpose uses of Guntersville Reservoir because of its widespread distribution and abundance. Recent expansion of aquatic macrophyte cover to about one third of the reservoir surface area prompted considerable interest in ameliorating the conflicts caused by excessive vegetation and in reversing the upward infestation trend. Local Congressional delegations secured funding and asked the TVA and Corps of Engineers to "pool" their technical expertise and develop a plan that would use the latest aquatic plant management technology for reducing excessive vegetation on Guntersville Reservoir. The TVA was designated as lead agency for the project, with support to be provided by the WES as well as the Nashville District, a District that has an expanding distribution of aquatic vegetation. The Cumberland River drainage connects with the Tennessee River drainage by a barge canal that joins lower Kentucky and Barkley Reservoirs.

While the comprehensive technology demonstration and applied research project is being planned and implemented, the routine TVA operational aquatic weed control program will be continued in order to minimize water use conflicts in designated high-use areas of the reservoir. This is in keeping with TVA's stewardship role for managing the public shoreline lands and impounded waters in the Tennessee Valley.

The joint agency project will extend over a 5-year period beginning in fiscal year (FY) 1990 and will be carried out in phases. The initial phase, primarily conducted by TVA, is scheduled to begin in early 1990 and involves a large-scale test demonstration using sterile triploid grass carp. About 100,000 grass carp will be stocked in the 68,000-acre impoundment during April-June 1990, with goals specifically to reduce the submersed vegetation to an area roughly equivalent to 10 percent of the reservoir surface area and to exert suppression on the primary target species, hydrilla. A detailed monitoring program will be implemented concurrently for study of the changes in the aquatic macrophytes, native fisheries, waterfowl, wading birds, and water quality. Data will also be acquired to be used in the validation and refinement of the grass carp STOCK model developed by WES.

A comprehensive herbicide residue monitoring study will also be implemented to support the operational herbicide control program and to demonstrate environmental safety and compatibility of aquatic herbicides.

Another test demonstration planned on a smaller scale by TVA involves use of a leased mechanical harvester to obtain operational efficiency and cost data, biomass estimates for macrophyte standing crops, boat lane "construction" data quantifying fish biomass removed during harvesting operations, and HARVEST model validation. Harvest operations are projected to continue into FY 1992.

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Applied studies will be conducted and directed by WES technical specialists. These studies include (a) computer simulation modeling, (b) biological control of hydrilla using insects, (c) biological control of Eurasian watermilfoil with plant pathogens, (d) recreation/economic analysis, (e) plant competition studies, and (f) benthic barrier investigations.

The Master Planning process routinely used for planning resource use in Corps reservoir projects will be modified, and the process will be used to develop an aquatic plant management Master Plan. A private contractor will be chosen to conduct public meetings and to develop a Master Plan specifically for Guntersville Reservoir. Aside from this planning and management process, applied studies combined with the test demonstrations and monitoring are expected to yield management strategies for dealing with aquatic weed problems in other TVA multipurpose reservoirs as well as Corps projects throughout the Nation.

ECOLOGY OF SUBMERSED AQUATIC PLANT SPECIES

Synopsis of Recent Studies on the Ecology of Submersed Macrophytes

by
John W. Barko*

INTRODUCTION

Efforts within the ecological technology area have been directed toward determining the response of aquatic macrophytes to complex environmental conditions. Currently we are examining the role of a wide variety of interacting environmental factors affecting the growth of both native and exotic submersed macrophyte species. These studies provide an improved understanding of specific combinations of environmental conditions conducive to the proliferation of invasive species at the expense of native species.

Aquatic systems, even within localized geologic/geographic settings, do not experience macrophyte problems to an identical extent. In many cases "weediness" seems to be a function of macrophyte community composition rather than growth rates per se. Many submersed macrophyte species have beneficial properties with respect to habitat conditions. We are particularly interested in contributing to the development of management techniques that consider beneficial as well as negative attributes of submersed aquatic vegetation.

A significant body of knowledge presently exists linking environmental conditions with the growth potential of submersed macrophytes (e.g., Barko, Adams, and Clesceri 1986); however, only recently have attempts been made to assess the influence of macrophytes on the environment. To improve understanding of macrophyte-environmental relationships, we have recently completed studies examining the influence of submersed macrophytes on water chemistry (Barko et al. 1988a) and on the distribution of both fishes (Killgore, Morgan, and Hurley 1987) and invertebrates (Miller et al. 1989).

As summarized in the following text, investigations in the ecology area have been expanded to consider complex interactions between different macrophyte species in response to environmental conditions, the influence of macrophytes on patterns of sedimentation, and convective circulation between littoral and pelagic regions of reservoirs. This paper provides a brief overview of current research activities and highlights the results of studies reported in greater specific detail elsewhere in this proceedings.

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Interactions between macrophyte species in response to environment

Given the potential of rapidly growing macrophyte species, such as *Hydrilla*, to deplete sediment nutrient pools, it is of interest to assess effects on subsequent macrophyte growth (Barko et al. 1988b). Variations in the capacity of different macrophyte species to contend with reductions in sediment nutrient availability may have an important influence on community composition. Alternatively, variations in response to sediment nutrient replenishment, as in the form of sedimentation for example, may also effect changes in macrophyte community composition. In general, macrophytes with well-developed root systems, particularly those capable of translocating and retaining nutrients upon shoot senescence, appear to have an advantage over other species as nutrient levels in sediments become depleted. Macrophyte succession, which drives changes in community composition, may be linked to variations in the response of different species to sediment fertility.

In studies conducted in the WES Environmental Laboratory greenhouse facility, we have recently investigated the effects of sediment fertility on *Hydrilla* and *Potamogeton* grown under both monotypic and mixed (competitive) conditions. These studies were conducted to evaluate directly the role of sediment type in affecting interactions between macrophyte species. Results of these studies are elaborated in McFarland, Barko, and McCreary (1990) and McCreary, McFarland, and Barko (1990).

In general, *Potamogeton* was much more sensitive to sediment fertility than *Hydrilla*. For example, the former demonstrated an approximate fivefold greater increase in the ratio of root-to-shoot biomass between fertile and infertile sediments than did *Hydrilla*. In mixture, the success of *Potamogeton* over *Hydrilla* was overwhelming. These results, in combination with results reported from other studies (Steward 1988, Smart and Barko 1989), do not support the view held by many that *Hydrilla* is a competitively superior species. Therefore, in order for this species to dominate aquatic systems to the extent found in nature, other mechanisms dictating success must be operational.

Effects of macrophytes on patterns of sedimentation

Sediment deposition is important to macrophyte growth. This process can refurbish nutrients lost due to macrophyte uptake or diffusional processes, and provides new substratum potentially available for macrophyte expansion concomitant with reductions in water depth. Sediment deposition, by altering the benthic habitat, may also influence the distribution and taxa of benthic invertebrates present.

We have investigated the influence of submersed macrophyte communities on patterns of sedimentation both in a north-temperate system, Eau Galle Reservoir, Wisconsin, and in the Potomac River near Washington, DC. Detailed results of these studies are reported in James and Barko (1989) and Eakin and Barko (1990). The influence of macrophytes on sediment deposition in these two systems appears to be quite different.

In Eau Galle Reservoir, submersed macrophytes play an important role in promoting sedimentation and reducing sediment erosion, thus enhancing the stability and growth potential of these plants. In the Potomac River, sedimentation during the growing season is minimal in macrophyte beds compared with the open water. This is largely due to restricted movement of water and sediment into the beds. However, despite reduced rates of sediment deposition during periods of peak macrophyte abundance, deposition occurs uniformly across the bed into the open water during off-seasonal periods of high flow and turbulent mixing. With the recurrence each year of preseasonal sediment and associated nutrient deposition, conditions in the Potomac River appear to be ideal for the continued vigorous growth of submersed macrophytes.

Convective circulation in macrophyte beds

On a daily basis, shallow nearshore regions of aquatic systems typically heat and cool more rapidly than deep open-water regions, due primarily to differences in mixed volume (Stefan, Horsch, and Barko 1989). The presence of submersed macrophytes in shallow regions contributes to the development of thermal gradients in both the vertical and lateral plane (Barko et al. 1988a), since foliage near the water surface converts solar irradiance to heat (Dale and Gillespie 1977). Thermal gradients give rise to density gradients that may promote hydraulic exchange.

Implications of hydraulic exchange driven by convection are potentially far-reaching, since dissolved constituents can be moved with water. Dissolved constituents may include nutrients, contaminants, or herbicides. In the case of nutrients, it is important to determine the extent to which hydraulic transport from the littoral zone of aquatic systems may contribute to pelagic nutrient budgets, thus influencing phytoplankton dynamics (Barko et al., in preparation). In the case of herbicides, information on the periodicity of hydraulic transport would be of value in maximizing both the efficiency and effectiveness of treatment applications.

In Eau Galle Reservoir, we are conducting dye studies in combination with close-interval thermal monitoring in an attempt to evaluate the seasonal dynamics of convective circulation. Owing to the eutrophic nature of this impoundment, our focus has been on phosphorus transport. However, the results would apply to all dissolved constituents, including herbicides. These studies are being conducted as part of our ongoing assessment of the influence of macrophytes on the aquatic habitat.

During studies conducted in July and September 1988, the littoral zone of Eau Galle Reservoir cooled more rapidly at night than the pelagic zone, creating horizontal temperature gradients that resulted in convective water circulation. Water from the littoral zone moved into the pelagic zone as an interflow, while water from the pelagic zone moved into the littoral zone as a surface flow. Because phosphorus concentrations in water of the littoral zone were greater than in water of the pelagic zone, a substantial mass of phosphorus was transported out of the macrophyte bed during convective circulation. This mass accounted for nearly 25 percent of the summer average lakewide internal load of phosphorus to the reservoir. These preliminary results indicate the potential significance of macrophyte beds in affecting chemical budgets in aquatic systems.

CONTINUING STUDIES AND FUTURE INITIATIVES

Major field studies will continue at Eau Galle Reservoir and on the Potomac River. These investigations will again focus on the role of submersed macrophytes in affecting habitat characteristics. Specifically, studies designed to examine effects of submersed macrophytes on convective circulation patterns will be expanded at Eau Galle Reservoir. We intend to eventually extend this line of investigation to other systems in the country. We will continue to evaluate patterns of sediment transport and deposition as influenced by the presence of *Hydrilla* in the Potomac River. In addition, we will evaluate possible relationships between change in sediment physical and chemical properties and the recent (summer 1989) collapse of *Hydrilla* above Marshall Hall in the Potomac River.*

Laboratory studies will continue to further examine interactive effects of environmental factors on the growth of submersed macrophytes. In these studies we will examine in detail the rooting depth of a variety of species in relation to sediment fertility. This information will be of value in assessing the extent to which species with different rooting capacities may respond to sediment scouring or other forms of nutrient loss from surficial sediment. We will continue to examine interactions among invasive and native macrophyte species in relation to sediment characteristics influencing fertility. Results of these laboratory studies will facilitate the design of more complex and environmentally realistic studies of macrophyte competition to be initiated in the Lewisville, Texas, pond facility and elsewhere.

We will evaluate the feasibility of lessening sediment nutrient availability to macrophytes by chemical and biological means, thus retarding the growth potential of nuisance species. As an extension of this effort, we will consider the possibility of perpetuating reductions in nutrient availability to nuisance species by interplanting preferred native macrophyte species. Planting and replanting technologies will be developed as a part of our emerging plant competition effort.

In both laboratory and field studies, we will soon begin to examine the role of submersed macrophytes in the nitrogen economy of aquatic systems. Nitrogen is a key element for the growth of rooted aquatic macrophytes. Thus, advances in our understanding of factors influencing sediment nitrogen availability will be of great value in the development of management approaches based on reductions in sediment nutrient availability.

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*Personal Communications, 1989, N. Rybicki and V. Carter, US Geological Survey, Reston, VA.

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REFERENCES

Barko, J. W., Adams, M. S., and Clesceri, N. L. 1986. "Environmental Factors and Their Consideration in the Management of Submersed Aquatic Vegetation: A Review," *Journal of Aquatic Plant Management,* Vol 24, pp 1-10.

Barko, J. W., Godshalk, G. L., Carter, V., and Rybicki, N. B. 1988a. "Effects of Submersed Aquatic Macrophytes on Physical and Chemical Properties of Surrounding Water," Technical Report A-88-11, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Barko, J. W., Smart, R. M., McFarland, D. G., and Chen, R. L. 1988b. "Interrelationships Between the Growth of *Hydrilla verticillata* and Sediment Nutrient Availability," *Aquatic Botany,* Vol 32, pp 205-216.

Barko, J. W., James, W. F., Taylor, W. T., and McFarland, D. G. "Effects of Alum Treatment on Phosphorus Dynamics and Phytoplankton Response in Eau Galle Reservoir, Wisconsin," Technical Report (in preparation), US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Dale, H. M., and Gillespie, T. J. 1977. "The Influence of Submersed Aquatic Plants on Temperature Gradients in Shallow Water Bodies," *Canadian Journal of Botany,* Vol 55, pp 2216-2225.

Eakin, H. L., and Barko, J. W. 1990. See pp 183-193 in this proceedings.

James, W. F., and Barko, J. W. 1989. "Influence of Submersed Macrophytes on Sedimentation Rates in a North-Temperate Reservoir: An Update," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program,* Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 231-242.

Killgore, K. J., Morgan, R. P., and Hurley, L. M. 1987. "Distribution and Abundance of Fishes in Aquatic Vegetation," *Proceedings, 21st Annual Meeting, Aquatic Plant Control Research Program,* Miscellaneous Paper A-87-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 236-244.

McCreary, N. J., McFarland, D. G., and Barko, J. W. 1990. See pp 171-182 in this proceedings.

McFarland, D. G., Barko, J. W., and McCreary, N. J. 1990. See pp 161-170 in this proceedings.

Miller, A. C., Beckett, D. C., Way, C. M., and Bacon, E. J. 1989. "The Habitat Value of Aquatic Macrophytes for Macroinvertebrates," Technical Report A-89-3, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Smart, R. M., and Barko, J. W. 1989. "Competitive Interactions of Submersed Aquatic Macrophytes in Relation to Water Chemistry and Other Environmental Conditions," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 159-164.

Stefan, H. G., Horsch, G. M., and Barko, J. W. 1989. "A Model for the Estimation of Convective Exchange in the Littoral Region of a Shallow Lake During Cooling," *Hydrobiologia*, Vol 174, pp 225-234.

Steward, K. K. 1988. "Competitive Interaction Between Monoecious *Hydrilla* and *Vallisneria* on Soils of Varying Fertility," Final Report, USDI NPS NCR IA-3040-6-8001 and USDA ARS RA-6629-013-1986.

Monotypic Responses of Submersed Macrophytes to Sediment Fertility at Different Levels of Plant Density

by
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INTRODUCTION

A long-standing challenge to aquatic ecologists has been to assess the role of sediment in determining the species composition of aquatic plant communities (Sculthorpe 1967, Hutchinson 1975, Barko and Smart 1986). Much evidence now indicates that, in most aquatic systems, sediment not only provides an "anchor" for rooted species, but is a major source of nutrients, especially nitrogen (N) and phosphorus (P). Both laboratory (Barko and Smart 1980, 1981a, 1986) and field (Denny 1972) investigations have demonstrated significant variations in the growth of submersed species due to differences in sediment nutrient availability. A key finding of these studies was that variations in responsiveness among species were linked to anatomical and morphological differences in accessing sediment nutrients. Thus, changes in sediment nutrient availability imposed by a variety of processes, e.g., diffusion, advection, mineralization, plant uptake, and sedimentation, may favor the growth of certain plant species over that of others. Collectively, these studies suggest a close relationship between sediment nutrient dynamics and macrophyte succession in littoral communities.

The accessibility of required resources is potentially influenced by the proximity of individuals in a given area. By forcing modifications in plant form and stature, density-related pressures can impact the structural complexity of macrophyte populations. Many density-dependent processes imposed by intraspecific competition have been documented for terrestrial plants, e.g., plasticity, mortality, self-thinning, and decreased growth rates (Harper 1977, Silvertown 1982), but little is known of these responses in aquatic macrophytes. From a management perspective, factors affecting the structure of submersed macrophyte populations are of particular interest due to their possible influences on community interactions.

In this article, we examine independent and interactive effects of sediment fertility and initial plant density on monotypic responses of two freshwater macrophytes, *Potamogeton nodosus* Poiret (= *P. americanus*), a typically innocuous native pondweed, and *Hydrilla verticillata* (L.f.) Royle, an invasive exotic species. Coupled with results of McCreary, McFarland, and Barko (1990), this research is intended to provide insight into processes affecting the competitive interactions of these species as a basis for advancing practices in aquatic plant management.

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*US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

METHODS AND MATERIALS

Hydrilla and *Potamogeton* monocultures were grown during May and June 1989 in 1200-ℓ fiberglass tanks in a greenhouse facility at Waterways Experiment Station, Vicksburg, MS. Tanks were filled 0.8 m deep with the low-alkalinity culture solution described in Smart and Barko (1985). As referenced, the solution (prepared with reagent-grade salts and deionized/distilled water) contained major elements except N and P, to minimize algal growth and allow sediment as the source of these nutrients for plant uptake. Initial pH and conductivity of the solution were approximately 8.0 and 280) μS/cm, respectively. One liquid circulator per tank provided continuous water circulation and temperature control at 25° ± 2° C. The solution was aerated with humidified air to enhance mixing and to increase air-water $C0_2$ exchange. Maximum midday photosynthetically active radiation inside the tanks averaged 500 $\mu E/m^2/sec$ using a neutral-density shade fabric over the roof of the greenhouse that reduced natural irradiance by 75 percent.

A 2 × 2 × 2 factorial design was used in which individual responses of *Hydrilla* and *Potamogeton* were examined at high and low levels of plant density and sediment fertility. The resulting eight treatment combinations were assigned to separate tanks and replicated six times in each. Densities were established at 16 plants/container (high density), and at 8 plants/container (low density). Sediment dredged from Brown's Lake, WES (described in Barko and Smart 1986 and McFarland and Barko 1987), was used to obtain the two fertility levels: one provided as "used" sediment (rendered infertile due to previous support of aquatic plant growth) and the other, as "fresh" N-amended (fertile) sediment, prepared by adding 0.8 g NH_4Cl/ℓ wet sediment. For both sediments, the concentrations of N and other important macronutrients in the interstitial water (i.w.) and extractable nutrient pools are presented in Table 1. Based on our analyses in previous studies (Barko et al. 1988), the N available in unfertilized (used) sediment was growth-limiting.

Hydrilla used in the study was clipped 15 cm long from apices of our dioecious female (Florida) stock. *Potamogeton* rhizomes were obtained commercially from a wildlife nursery in Oshkosh, Wisconsin. Monocultures were established in 30- by 30- by 14-cm polyethylene containers. The propagules were spaced evenly in the containers and submersed in the culture solution immediately after planting.

After approximately 6 weeks of growth, the plants were harvested, measured, and oven-dried to constant mass at 80° C. Morphological responses were measured as variables of maximum shoot length, shoot number, and canopy height (i.e., the position of bulk canopy biomass from the base of main plant stems). Evaluations of growth were based on separate determinations of above- and below-ground biomass of each species. Individual plant biomass was calculated by dividing total biomass by shoot number and incorporating appropriate root-to-shoot ratios. Elemental analyses of sediment and plant tissues were performed according to procedures described in Barko et al. (1988). All data analyses were performed using the Statistical Analysis System (SAS Institute, Cary, North Carolina). Hereafter, statements of statistical significance refer to $P \leq 0.05$.

Table 1
Sediment Nutrient Concentrations*

Nutrient Pool	*Fertilized*	*Unfertilized*
Dissolved, $mg \cdot \ell^{-1}$ i. w.		
Nitrogen (NH_4-N)	92.3 ± 1.8	1.87 ± 0.02
Phosphorus (PO_4-P)	0.9 ± 0.0	0.8 ± 0.06
Potassium	19.9 ± 0.6	12.7 ± 0.91
Extractable, $mg \cdot g^{-1}$ dry sediment		
Nitrogen (NH_4-N)	0.21 ± 0.00	0.01 ± 0.00
Phosphorus (PO_4-P)	0.14 ± 0.00	0.10 ± 0.00
Potassium	0.15 ± 0.00	0.13 ± 0.01

*Values are means ± standard errors based on analyses of six replicate sediment samples.

RESULTS

Biomass production and root-to-shoot ratios

Total biomass production was influenced to a far greater extent by sediment fertility and species than by initial plant density (Figure 1). Across all treatments, the biomass of *Potamogeton* exceeded that of *Hydrilla* by approximately 2:1. The species differential was magnified when sediment N was high and diminished under N-limiting conditions. Of the two species, *Potamogeton* was more responsive to sediment fertility. Although the N-amended sediment promoted a 35-percent increase in biomass produced by *Hydrilla*, the respective increase in *Potamogeton* was about 50 percent.

Density had no effect on the total biomass of *Potamogeton* and only a minor effect on this response in *Hydrilla*. However, determinations of individual plant biomass (Figure 2) revealed that the shoot mass per plant of *Hydrilla* on fertilized sediment was significantly diminished by high plant density. In contrast, the above- and below-ground biomass per plant of *Potamogeton* showed no density effect.

Ratios of root-to-shoot biomass were also strongly affected by sediment fertility and species, but exhibited no effect attributable to plant density (Figure 1). In corresponding treatments, the root-to-shoot ratio for *Potamogeton* was consistently higher than that of *Hydrilla* (averaging 0.46 versus 0.12, respectively). In both species, ratios increased when sediment N was low. Notably, *Potamogeton* responded more so than *Hydrilla* to sediment-nutrient conditions. Between the two sediment treatments, the ratio of root-to-shoot biomass for *Potamogeton* varied over a fivefold greater range (0.14 to 0.80) than for *Hydrilla* (0.05 to 0.18).

Shoot length and shoot number

Variations in maximum shoot length and canopy height primarily reflected independent effects of sediment fertility (Figure 3). Both species were restricted similarly in

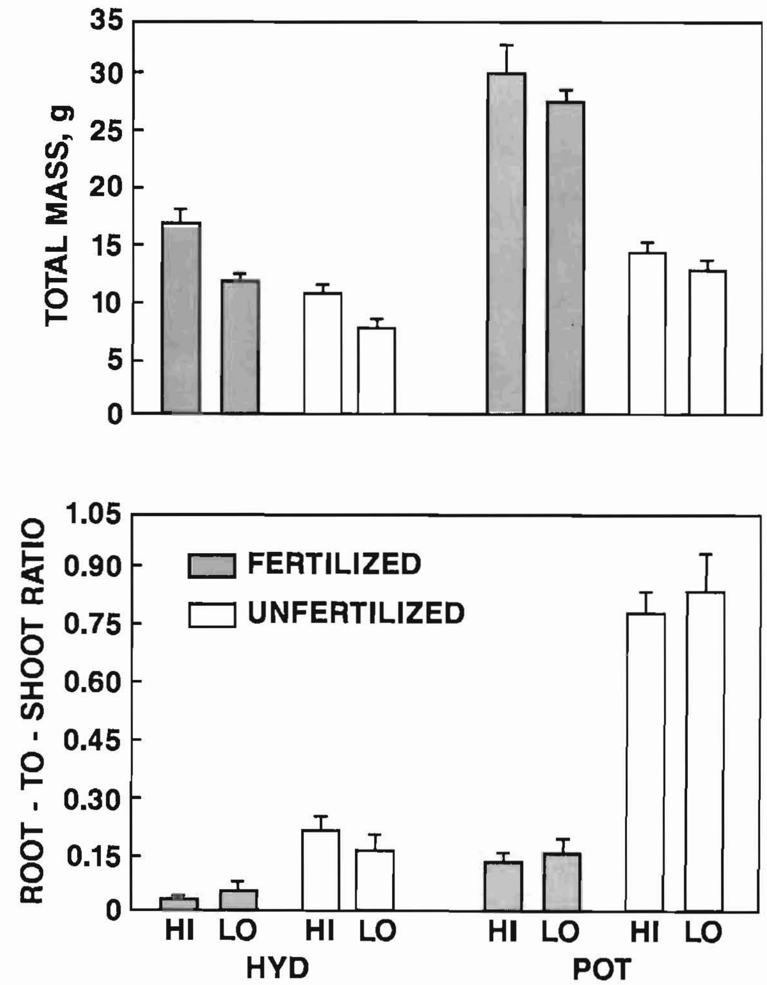

Figure 1. Effects of sediment fertility on growth of *Hydrilla* (HYD) and *Potamogeton* (POT) planted at high (HI) and low (LO) densities. Values are means (n = 6) with associated standard error bars

length when grown on N-poor sediment. Maximum lengths were attained under fertilized conditions, where *Potamogeton* exhibited a somewhat greater capacity than *Hydrilla* for shoot elongation. Canopy development in *Potamogeton* was essentially unaffected by initial plant density, but shoots in *Hydrilla* on fertilized sediment grew 20 percent longer at high than at low density.

Shoot number in *Potamogeton* was relatively unresponsive to initial density, but with increased sediment N, shoot number nearly doubled (Figure 3). Conversely, *Hydrilla* generated nearly the same number of shoots at both fertility levels, with 30 percent more shoots occurring in the high-density treatment. Shoot number was restricted similarly in both species on N-poor sediment, but with N-rich sediment the number of shoots established by *Potamogeton* was about twice that of *Hydrilla*.

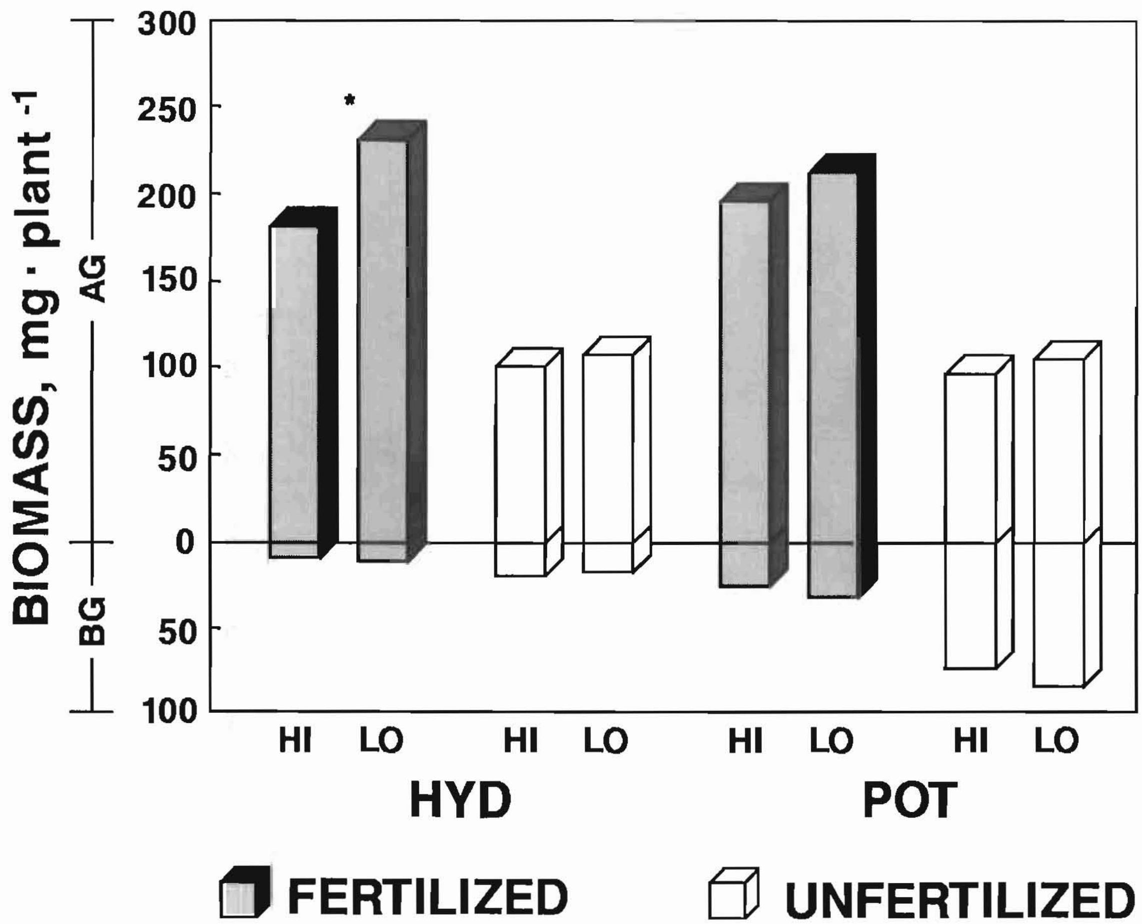

Figure 2. Effects of sediment fertility on above- (AG) and below-ground (BG) biomass of individual *Hydrilla* and *Potamogeton* plants in high and low densities. Asterisks denote significant effects of density on either above- or below-ground structures. (Remaining abbreviations defined for Figure 1)

Nutritional considerations

Differences in tissue N concentrations of *Hydrilla* and *Potamogeton* (Figure 4) were examined to identify nutritional mechanisms alternating to support growth on fertilized versus unfertilized sediment. In both species grown on N-amended sediment, above-ground N concentrations were greater than values obtained in below-ground tissues; also, while shoot concentrations in both species were nearly identical under those conditions, *Potamogeton* required significantly less N per gram of below-ground biomass than did *Hydrilla*. Nitrogen concentrations were substantially diluted in both species when sediment N was low; however, in *Hydrilla*, shoot mass was produced with less N per gram than root mass. Alternatively, *Potamogeton* on unfertilized sediment maintained (as it did on fertilized sediment) a significantly lower N requirement for below-ground than above-ground tissues.

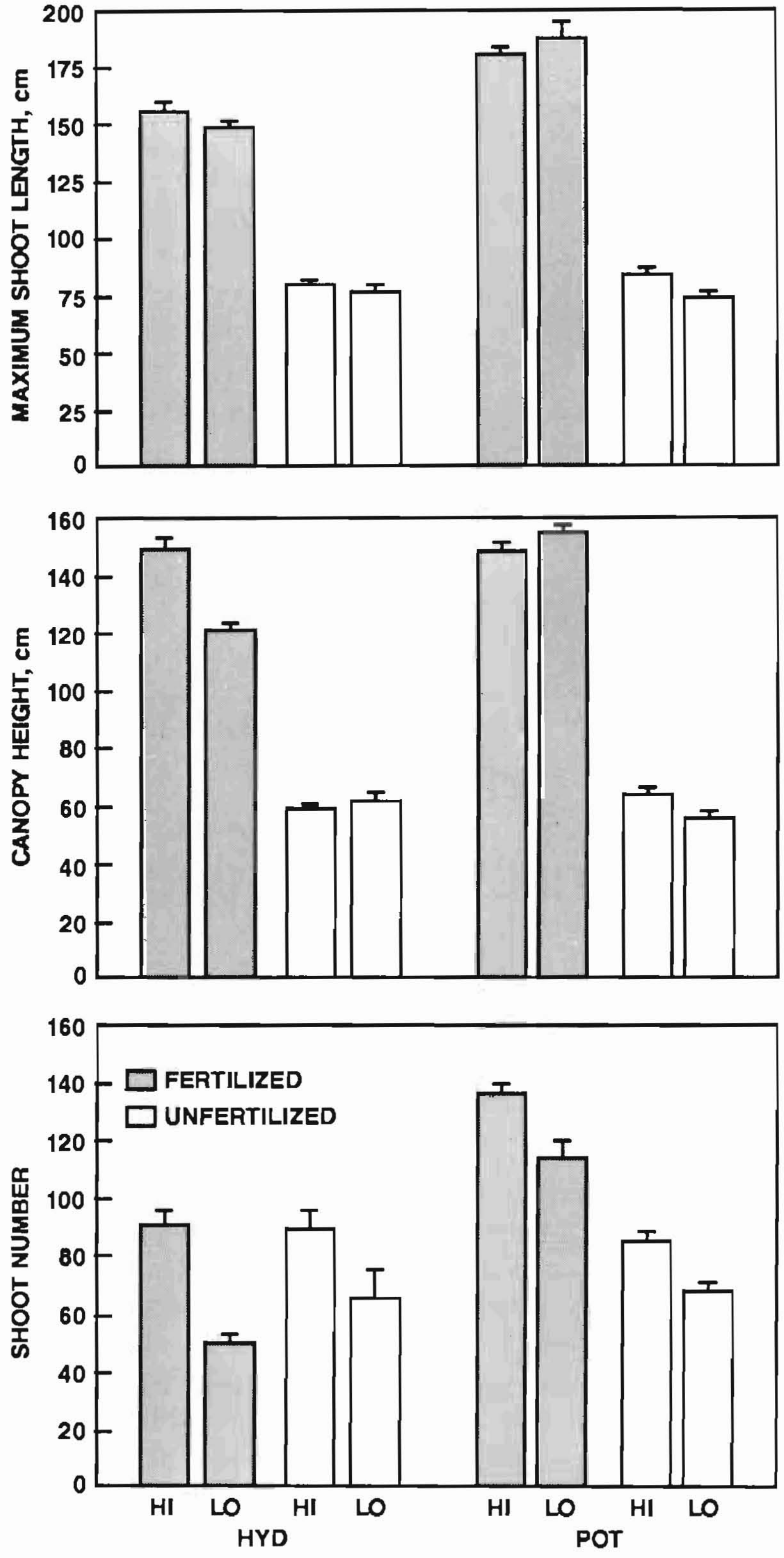

Figure 3. Effects of sediment fertility on shoot morphology of *Hydrilla* and *Potamogeton* planted at high and low densities. Values are means (n = 6) with associated standard error bars. (Abbreviations defined for Figure 1)

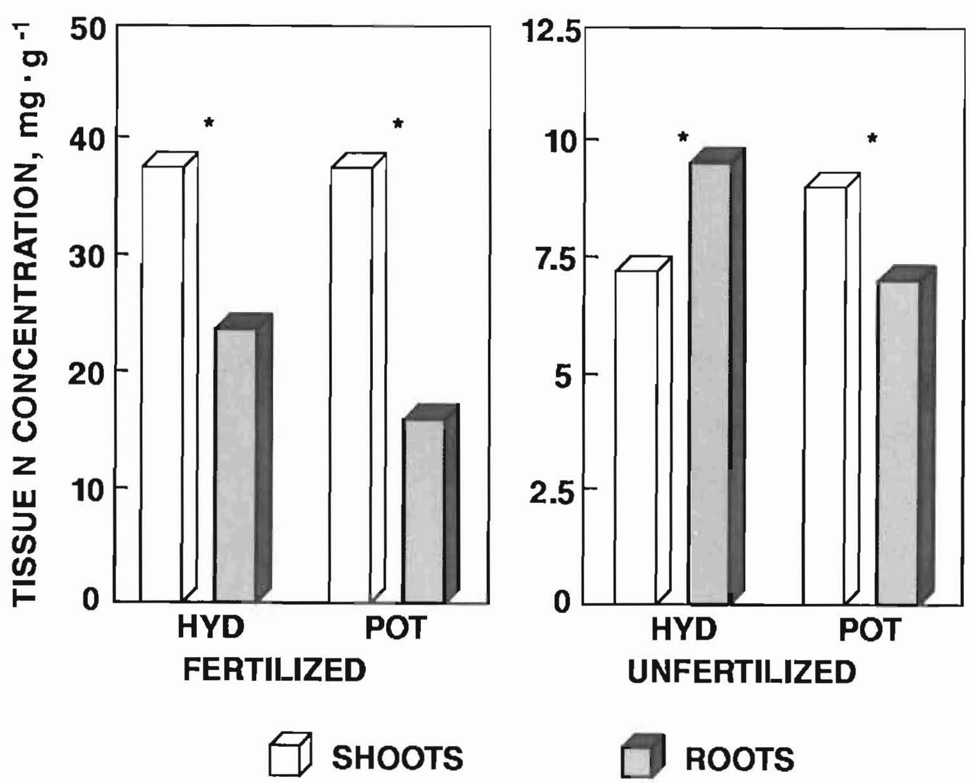

Figure 4. Tissue nitrogen concentrations in above- and below-ground structures of *Hydrilla* and *Potamogeton* planted in fertilized and unfertilized (used) sediments. Asterisks denote a significant difference between concentrations in above- versus below-ground tissues. (Abbreviations defined for Figure 1)

DISCUSSION AND CONCLUSIONS

Growth and morphological responses of both *Hydrilla* and *Potamogeton* in this study strongly reflect main effects of sediment fertility, as documented in many prior studies (Denny 1972, Bruner and Batterson 1984, Steward 1984, Barko and Smart 1986, Barko et al. 1988). Diminished biomass production and high root-to-shoot ratios of these species on sediment previously subjected to aquatic plant growth are responses indicative of nutrient-poor sediment conditions (Denny 1972, Barko and Smart 1986). Density effects, as they occurred particularly in *Hydrilla*, were magnified on fertilized sediment, reflecting a significant density-sediment interaction. However, on the whole, due to the overwhelming response of both species to sediment fertility, the relative influences of density and density-sediment interaction were minimal.

The rapid and successful invasion of *Hydrilla* in many aquatic systems in southern latitudes of this country has suggested competitive advantages over native species. *Hydrilla* possesses a phenomenal ability to elongate to the water surface where it accesses light and free CO_2 (Haller and Sutton 1975, Barko and Smart 1989). In well-established *Hydrilla* beds, species with a lesser propensity for stem elongation are restricted by severe light reduction beneath the canopy. *Vallisneria americana* Michx., a submersed native species that allocates much of its biomass below ground, was unable to compete with *Hydrilla* in conditions allowing extensive canopy formation by the latter (Haller and Sutton 1975). Results of this study and those of others (Barko and Smart 1981b, Barko et al. 1982) show that *Potamogeton* may have a slightly greater capacity than *Hydrilla* for stem elongation. With additional consideration for its heterophyllous (i.e., floating-leaf) life form and its capacity to produce high shoot densities, *Potamogeton* may be superior to *Hydrilla* in its canopy-forming capabilities.

Perhaps the singularly most important advantage that *Potamogeton* has over *Hydrilla* is its ability to modify its root-to-shoot ratio in response to sediment fertility. Owing to its proportionately greater biomass allocation below ground, *Potamogeton* appears to be better adapted than *Hydrilla* to unfavorable sediment conditions. In *Hydrilla*, the production of new shoots is sustained at the expense of shoot elongation, suggesting a strategy to grow away from, or to escape, impoverished sediment. On sediments of low fertility, robust root formation enhances macrophyte nutrition by increasing root surface in direct contact with the sediment (Barko and Smart 1986). This mechanism in *Potamogeton* is facilitated in part by its efficient use of nutrients (N, in particular) in production of root mass (this study). Barko and Smart (1986) speculated that the ability to adjust the ratio of root-to-shoot biomass may increase tolerance of spatial and temporal gradients in sediment nutrient availability; thus, differences among species in this capacity may effect changes in the composition of aquatic plant communities.

Initial emergence and growth rate have been observed to vary according to propagule type. In the presence of *Potamogeton pectinatus* L., *Hydrilla* plants germinated from tubers grew more vigorously than those from turions (Spencer and Rejmanek 1987). Similarly, in a recent investigation of Moen and Cohen (1989), *Myriophyllum exalbescens* Fern. from cuttings grew slower than *P. pectinatus* from tubers. In the present study, *P. nodosus* rhizomes emerged quickly and sustained a higher rate of growth than *Hydrilla* from cuttings. Whether the initial competitive edge for *Potamogeton* would have been lessened had *Hydrilla* tubers been used instead is a subject open to investigation.

Based on our findings, intraspecific competition can result in significant reductions in the biomass of individual plants. But, how does this form of competitive interaction affect propagule mass, and other facets of propagule formation (e.g., number, chemical composition, structure, and viability)? Sutton, Littell, and Langeland (1980) have shown that more tubers are produced by *Hydrilla* planted at high than at low density (although the total biomass of plants in each group was approximately the same). Investigations of this kind, involving a variety of species and propagule types, would provide greater insight into processes affecting the establishment and expansion of aquatic plant populations. Mechanisms of propagule recruitment are undoubtedly linked with nutrition, but as yet are poorly understood. This aspect of the ecology of submersed macrophytes warrants further research because of its potential bearing on successional development in aquatic plant communities.

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REFERENCES

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

Barko, J. W., and Smart, R. M. 1981a. "Sediment-Based Nutrition of Submersed Macrophytes," *Aquatic Botany*, Vol 10, pp 339-352.

Barko, J. W., and Smart, R. M. 1981b. "Comparative Influences 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. 1986. "Effects of Sediment Composition on Growth of Submersed Aquatic Vegetation," Technical Report A-86-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Barko, J. W., and Smart, R. M. 1989. "Interactive Effects of Light, Sediment Fertility, and Inorganic Carbon Supply on Growth of Submersed Aquatic Macrophytes," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 151-158.

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.

Barko, J. W., Smart, R. M., McFarland, D. G., and Chen, R. L. 1988. "Interrelationships Between the Growth of *Hydrilla verticillata* (L.f.) Royle and Sediment Nutrient Availability," *Aquatic Botany*, Vol 32, pp 205-216.

Bruner, M. C., and Batterson, T. R. 1984. "The Effect of Three Sediment Types on Tuber Production in Hydrilla [*Hydrilla verticillata* (L.f.) Royle]," *Journal of Aquatic Plant Management*, Vol 22, pp 95-97.

Denny, P. 1972. "Sites of Nutrient Absorption in Aquatic Macrophytes," *Journal of Ecology*, Vol 60, pp 819-829.

Haller, W. T., and Sutton, D. L. 1975. "Community Structure and Competition Between *Hydrilla* and *Vallisneria*," *Hyacinth Control Journal*, Vol 13, pp 48-50.

Harper, J. L. 1977. *Population Biology of Plants*, Academic Press, New York.

Hutchinson, G. E. 1975. *A Treatise on Limnology; III, Aquatic Macrophytes and Attached Algae*, John Wiley and Sons, New York.

McCreary, N. J., McFarland, D. G., and Barko, J. W. 1990. See pp 171-182 in this proceedings.

McFarland, D. G., and Barko, J. W. 1987. "Effects of Temperature and Sediment Type on Growth and Morphology of Monoecious and Dioecious *Hydrilla*," *Journal of Freshwater Ecology*, Vol 4, pp 245-252.

Moen, R. A., and Cohen, Y. 1989. "Growth and Competition Between *Potamogeton pectinatus* L. and *Myriophyllum exalbescens* Fern. in Experimental Ecosystems," *Aquatic Botany*, Vol 33, pp 270-275.

Sculthorpe, C. D. 1967. *The Biology of Aquatic Vascular Plants*, St. Martin's Press, New York.

Silvertown, J. N. 1982. *Introduction to Plant Population Ecology*, Longman, Inc., New York.

Smart, R. M., and Barko, J. W. 1985. "Laboratory Culture of Submersed Macrophytes on Natural Sediments," *Aquatic Botany*, Vol 21, pp 251-263.

Spencer, D. F., and Rejmanek, M. 1987. "Propagule Type Influences the Competitive Ability of *Hydrilla*," *Bulletin of the Ecological Society of America*, Vol 68, pp 420-421.

Steward, K. K. 1984. "Growth of Hydrilla (*Hydrilla verticillata*) in Hydrosoils of Different Composition," *Weed Science*, Vol 32, pp 371-375.

Sutton, D. L., Littell, R. C., and Langeland, K. A. 1980. "Intraspecific Competition of *Hydrilla verticillata*," *Weed Science*, Vol 28, pp 425-428.

Influences of Plant Density and Sediment Fertility on Interactions Between Submersed Macrophyte Species

by
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INTRODUCTION

The responses of submersed aquatic macrophytes to a variety of environmental factors have been extensively examined. Most notably, the abiotic factors of light (Barko and Smart 1981, 1989), sediment fertility (Smart and Barko 1985, Barko and Smart 1986, Barko et al. 1988), and dissolved inorganic carbon (Titus and Stone 1982, Hough and Fornwall 1988) have been shown to interact in substantially affecting the growth of a number of macrophyte species (Barko and Smart 1989). Yet, assessment of how abiotic factors interact with one another to regulate macrophyte growth is incomplete without consideration of the influence of competitive relationships (Smart and Barko 1989). Along this line of inquiry, the study reported here addresses the interaction between the invasive species *Hydrilla verticillata* and a common native pondweed, *Potamogeton americanus*.

The objectives of this study were to determine the degree of competitive interactions between *Hydrilla* and *Potamogeton* under conditions of both high and low sediment fertility and to quantify the effects of initial planting density. *Hydrilla* exhibits strong intraspecific regulation of growth (Barko and Smart 1989), which may affect its response to potential competitors. However, based upon results obtained under monotypic conditions (McFarland, Barko, and McCreary 1990), we would predict that *Potamogeton* may have a competitive edge over *Hydrilla*. Results of this study are intended to further our knowledge of the factors operating to regulate the growth of submersed macrophytes in nature, which will ultimately affect our choice of management practices.

METHODS

The study was conducted in the Environmental Laboratory greenhouse facility at WES. Twelve large fiberglass tanks (ca. 1,200-ℓ) each housed six replicate containers of *Hydrilla*, *Potamogeton*, or a 50:50 mix of these two species. Six tanks were established using nitrogen-amended (0.8-g NH_4Cl per liter) fresh sediment from Brown's Lake (fertile sediment treatment), while the remaining six tanks held plants grown in nutrient-impoverished previously planted Brown's Lake, WES, sediment (unfertilized sediment treatment). At the beginning of the study, fertilized treatments had mean exchangeable nitrogen levels of 0.21 ± 0.01 mg N/g dry sediment, compared to 0.01 ± 0.00 mg N/g dry sediment for unfertilized treatments. Likewise, interstitial

*US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

nitrogen levels of 92.27 ± 4.43 mg N/ℓ and 1.87 ± 0.05 mg N/ℓ for fertilized and unfertilized treatments, respectively, generated a significant nitrogen differential between sediments.

Within each sediment treatment, plants were established at one of two densities: 8 plants per container (low density) or 16 plants per container (high density). For mixtures, care was taken to distribute plants in an alternate arrangement by species.

Tanks were filled with a culture solution that provided all major elements except N and P (Smart and Barko 1985), with aeration facilitating mixing and CO_2 supply. Light was maintained at moderate levels (ca. 500 $\mu E/m^2/sec$ at midday) with neutral-density shade fabric, while temperature was held at 25° ± 2° C. The experiment was conducted over an approximate 6-week period, at the end of which plants were harvested.

Macrophyte growth was evaluated from changes in above- and below-ground biomass for each species according to the procedures of Barko and Smart (1981). However, below-ground biomass in mixture flats could not be separated by species. For *Potamogeton*, floating leaves formed per container and inflorescence spikes in each tank were counted. The nitrogen content of plant biomass was determined following tissue digestion. Sediment interstitial water nutrients, as well as exchangeable/ extractable fractions of sediment nutrients, were obtained according to procedures described in Barko et al. (1988).

The suppression coefficient (S) for each species was calculated to summarize competitive effects in mixtures relative to growth of plants alone. Developed by Aarssen (1985), this coefficient compares growth of N individuals of species A grown in the presence of N individuals of species B to growth of N individuals of species A alone. It therefore indicates the degree to which the growth of species A is suppressed by the presence of species B. If a species is unaffected by its neighbor, the value of S approaches unity. The yield suppression ratio (YSR) compares S values of more-suppressed species to less-suppressed species. The YSR increases as differences between competitors decline.

Light extinction coefficients were measured in plant canopies according to Wetzel (1983), using readings from a LiCor quantum radiometer at a constant depth (ca. 35 cm) and again just below the water surface.

All calculations were performed using SAS (SAS Institute, Inc. 1988). Unless otherwise indicated, results reported here as significantly different were examined at the 1.0-percent probability level or less, as determined by analysis of variance.

RESULTS

Growth and nutrition

Above-ground biomass showed virtually no differences due to initial planting density, yet varied significantly with sediment fertility, species, and mixture (Figure 1). Above-ground biomass alone indicated that the species were relatively similar to one another when grown on unfertilized sediment. Nonetheless, mixtures were dominated

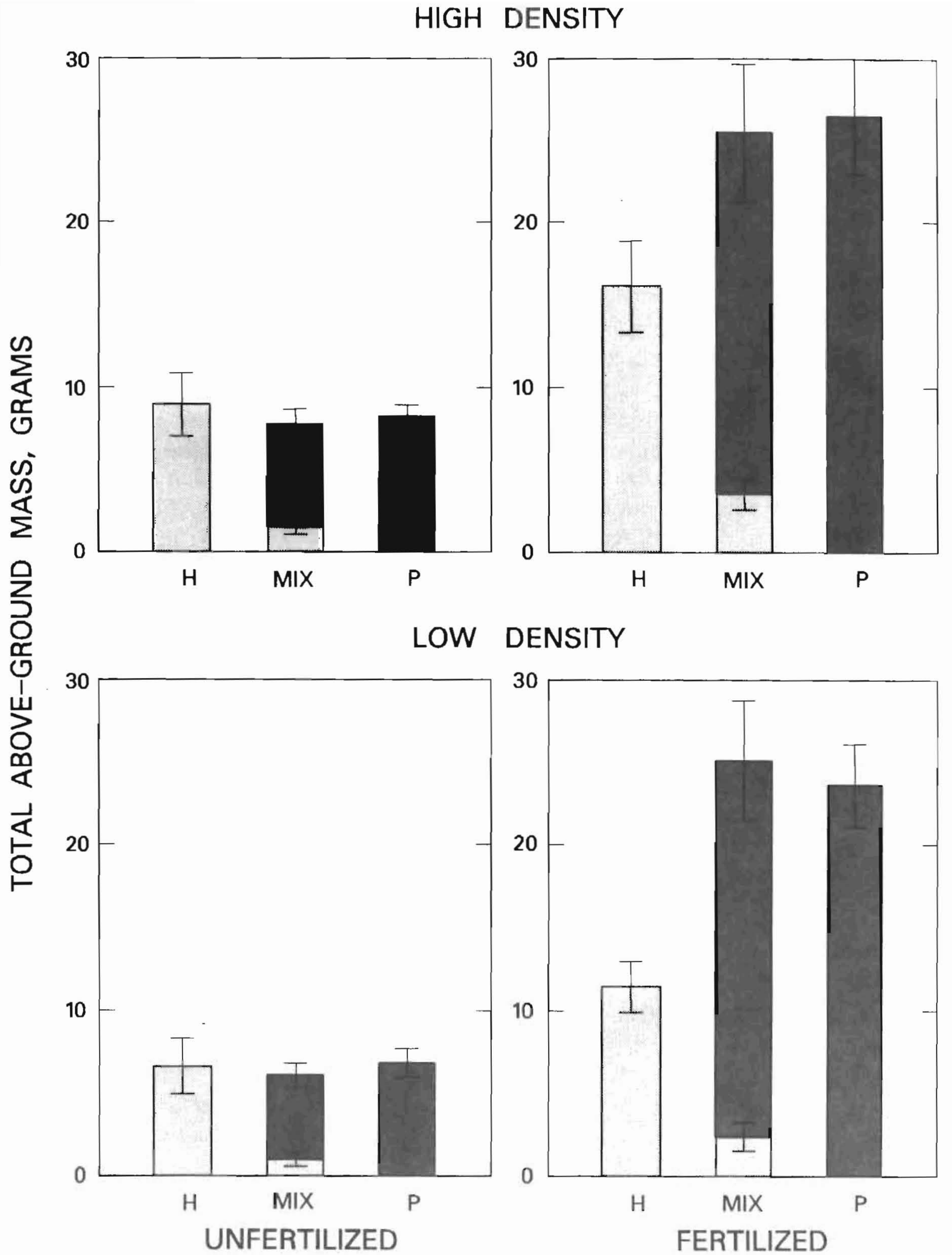

Figure 1. Mean (n = 6) above-ground biomass in grams dry weight for *Hydrilla* (H), *Potamogeton* (P), and 50:50 mixture (MIX). Top panels are responses to high-density treatments; bottom panels are responses to low-density treatments. Left panels indicate growth on unfertilized sediments; right panels indicate growth on fertilized sediments. Standard deviations (±1) are indicated

by *Potamogeton* when grown on this sediment. Differences in growth between the species were exaggerated by increased sediment fertility, with mixtures again dominated by *Potamogeton.*

Both species allocated twice the amount of biomass to below-ground structures when grown on nitrogen-poor sediments, compared to growth on nitrogen-rich sediments (Figure 2). However, *Potamogeton* accumulated substantially more below-ground biomass (ca. 3 times) than *Hydrilla* on both sediments. Overall, the root:shoot ratio for *Potamogeton* exceeded that of *Hydrilla* (0.80 and 0.18 on the average, respectively). Although not separable by species in mixture treatments, below-ground biomass in these treatments was most similar to that of *Potamogeton.*

Differences in accumulation of nitrogen in above-ground tissues (Figure 3) reflect differential nitrogen availability directly attributable to sediment fertilization. Although nitrogen accumulation in below-ground tissues (Figure 4) did not demonstrate such a striking response to sediment fertilization, it did demonstrate a significant difference between species, with more nitrogen incorporated in *Potamogeton* than in *Hydrilla.* With the unfertilized sediment, about 71 percent of the initial exchangeable nitrogen was removed by the end of the study, regardless of species (Table 1). That percentage loss did not differ for *Hydrilla* on fertilized sediment. However, for *Potamogeton* and mixtures grown on nitrogen-amended sediments, loss of nitrogen approached 95 percent (Table 1).

Considering N expense for a gram of above-ground biomass grown on unfertilized sediment, where nitrogen was presumably limiting, *Potamogeton* shoots were significantly more N-costly (9.18 mg N/g) than *Hydrilla* shoots (7.17 mg N/g; $F = 23.95$; $P < 0.0001$). Yet, when N-expense was determined for below-ground tissues, *Potamogeton* was significantly less costly than *Hydrilla* (7.08 versus 9.55 mg N/g, respectively; $F = 20.30$; $P = 0.0002$). For *Potamogeton*, below-ground tissues were less N-costly than shoots, and for *Hydrilla*, the opposite relationship held. However, when differences in root-to-shoot biomass were accounted for, the two species did not differ significantly in N-cost for an average gram dry weight of mass ($F = 0.37$, $P = 0.5481$).

Potamogeton maintained a very high suppression coefficient under both sediment fertility conditions (Figure 5). *Hydrilla* showed considerable suppression of growth, although it was more suppressed under nitrogen-poor conditions than under nitrogen-rich conditions. On a per plant basis, one *Potamogeton* was equivalent to 4.64 *Hydrilla* plants on sediment with nitrogen in short supply. However, that difference was less striking on sediment amended with nitrogen, where *Potamogeton* was equivalent to 2.86 *Hydrilla* plants. The yield suppression ratio in this study increased as sediment nitrogen content increased (Figure 5).

Canopy responses

Extinction coefficients measured just before harvest indicated substantial canopy formation by both species. However, light was more extinguished under *Potamogeton* (9.95 ± 8.49) than under well-developed monotypic *Hydrilla* stands (4.80 ± 1.40), with mixtures demonstrating intermediate extinction coefficients (6.87 ± 2.60).

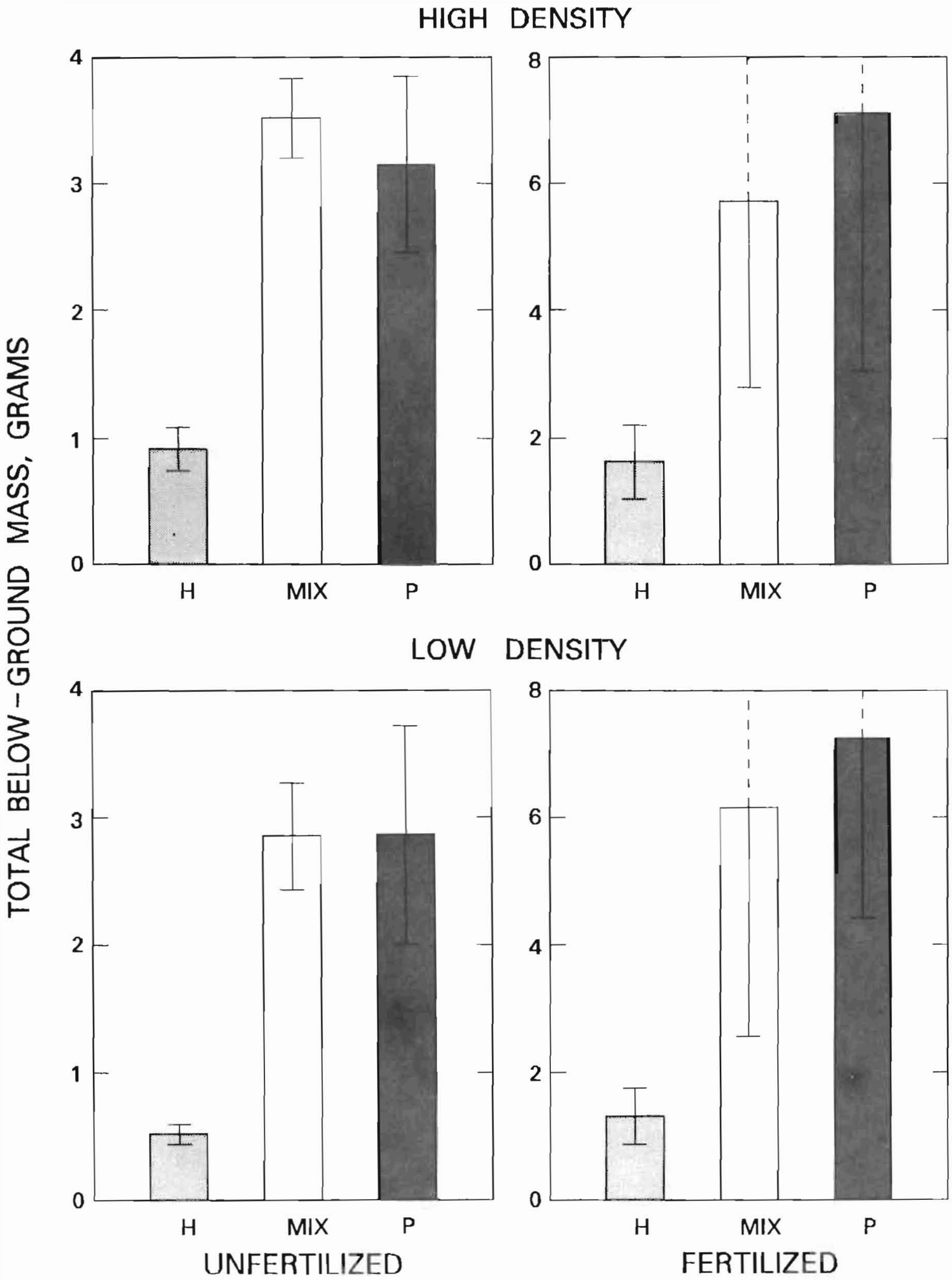

Figure 2. Mean (n = 6) below-ground biomass in grams dry weight for *Hydrilla*, *Potamogeton*, and 50:50 mixture. (Panel orientation and acronyms defined for Figure 1)

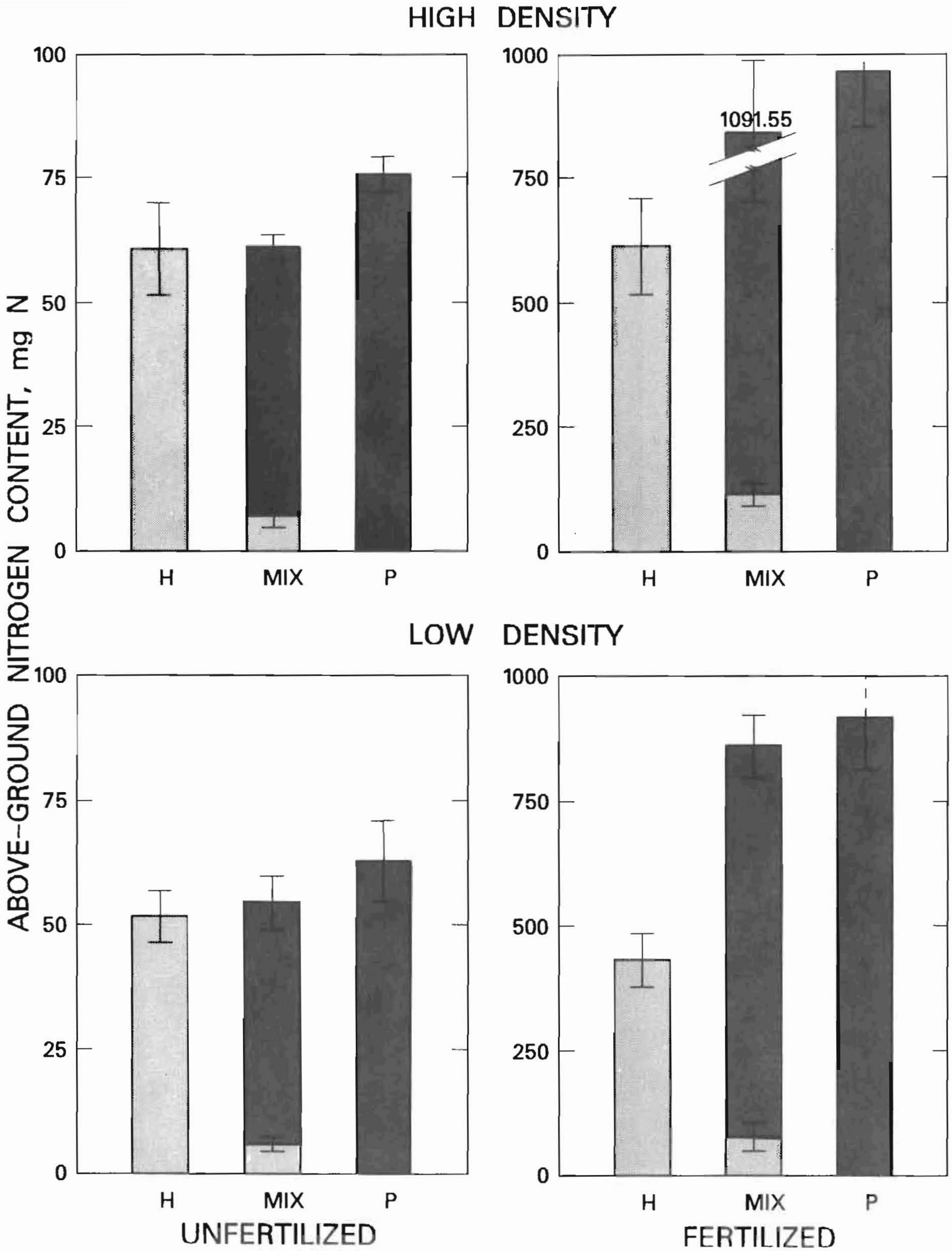

Figure 3. Mean (n = 6) nitrogen accumulation in above-ground tissues for *Hydrilla*, *Potamogeton*, and 50:50 mixture. (Panel orientation and acronyms defined for Figure 1)

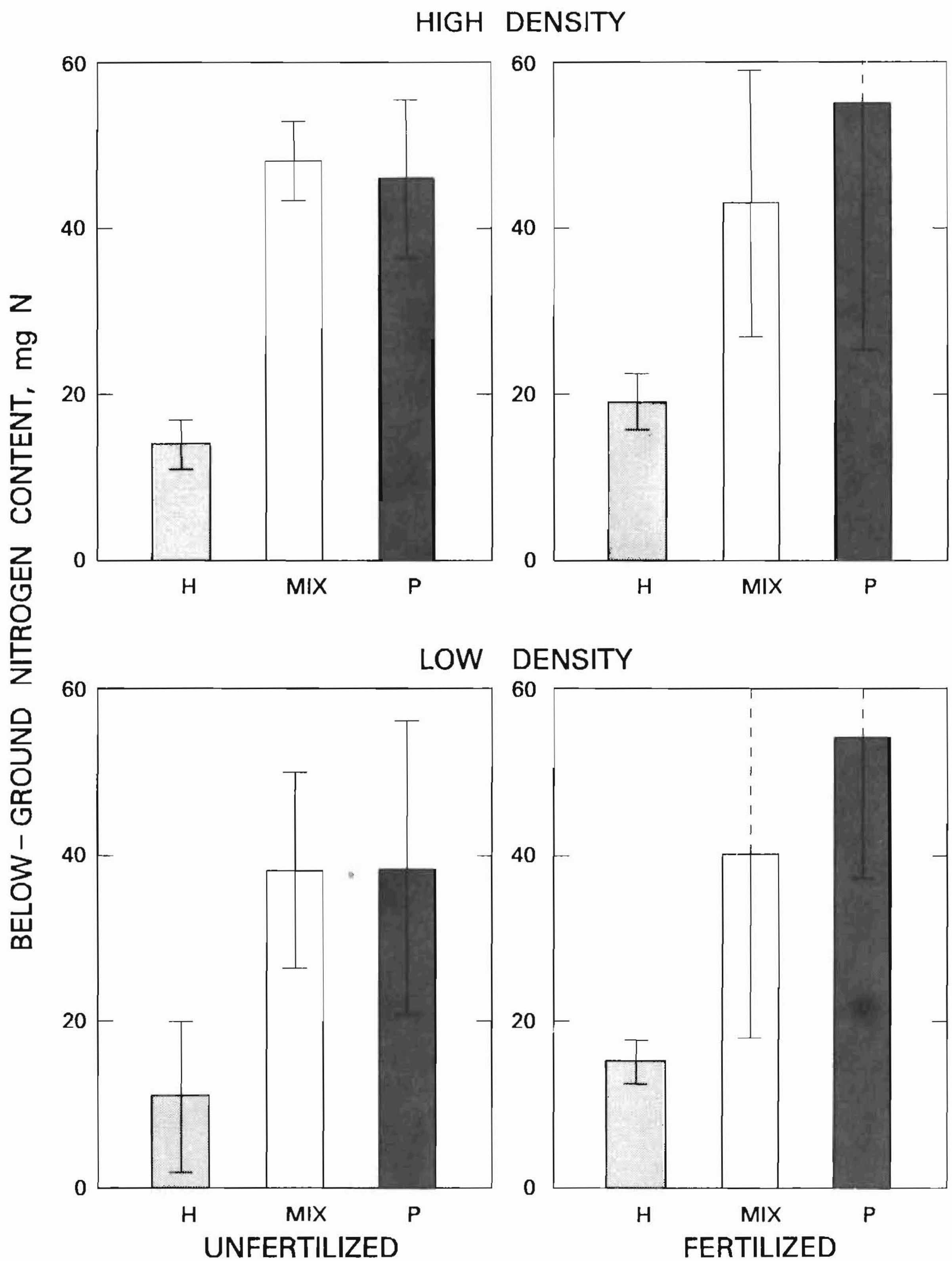

Figure 4. Mean (n = 6) nitrogen accumulation in below-ground tissues for *Hydrilla*, *Potamogeton*, and 50:50 mixture. (Panel orientation and acronyms defined for Figure 1)

Table 1
Sediment Exchangeable Nitrogen, Measured at the End of the Study as NH_4-N (mg N/g dry sediment)

Species	*Low Density*	*High Density*
	Unfertilized Sediments (Initial N = 0.0115 ± 0.0003 mg/g)	
Hydrilla	0.0026 ± 0.0003	0.0033 ± 0.0007
50:50 mixture	0.0031 ± 0.0005	0.0033 ± 0.0005
Potamogeton	0.0035 ± 0.0006	0.0031 ± 0.0004
	Fertilized Sediments (Initial N = 0.2107 ± 0.0049 mg/g)	
Hydrilla	0.0882 ± 0.0331	0.0488 ± 0.0410
50:50 mixture	0.0127 ± 0.0107	0.0137 ± 0.0195
Potamogeton	0.0084 ± 0.0052	0.0067 ± 0.0010

Note: Means of six replicate containers are presented with standard deviations. Mean initial values (n = 6) are indicated parenthetically for comparison.

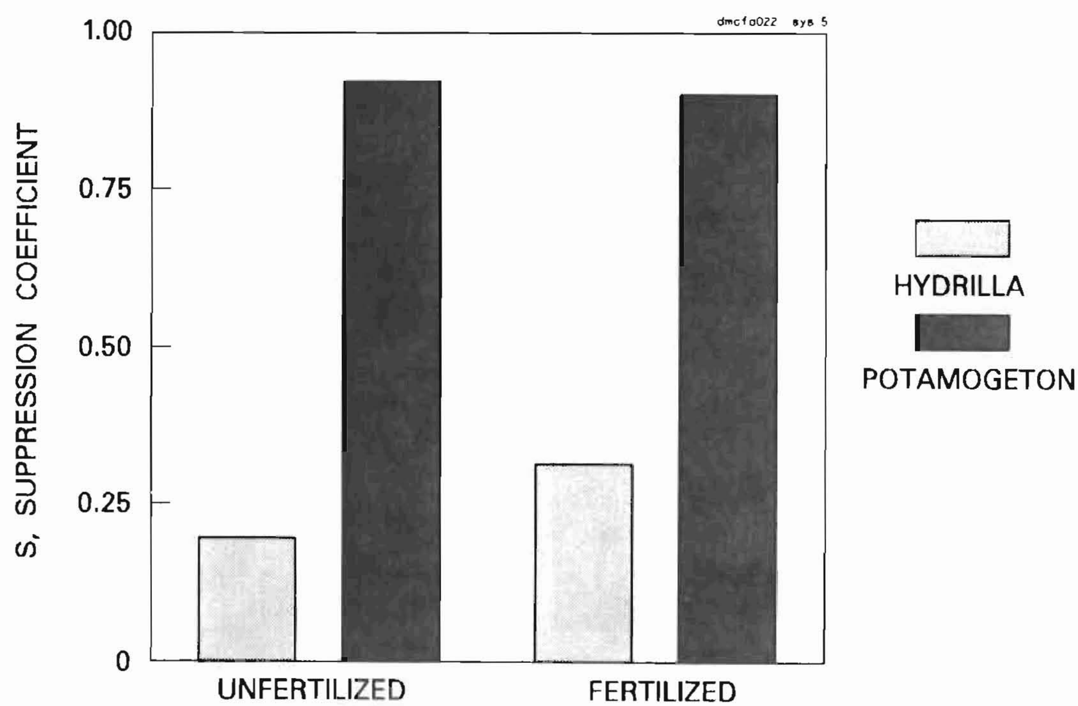

Figure 5. Suppression coefficients (S) for each species by fertility treatment

Floating leaves and inflorescence spikes were formed by *Potamogeton* only when sediment nitrogen was high. On a per initial starting plant basis, *Potamogeton* produced more floating leaves per plant in the presence of *Hydrilla* than when alone (Table 2). Likewise, *Potamogeton* grown alone generated fewer inflorescences than when grown in the presence of *Hydrilla* (Table 2).

Table 2
Inflorescence Count per Tank and Floating Leaves per Initial Plant of *Potamogeton americanus Under High Sediment Fertility**

Plant Parameter	*Potamogeton Monoculture*	*50:50 Mixture*
High density		
Inflorescence count	7	24
Floating leaves per initial plant	17.9 (4.6)	26.4 (6.2)
Low density		
Inflorescence count	19	41
Floating leaves per initial plant	26.5 (2.5)	46.3 (4.5)

*Values represent mean (coefficient of variation, percent); n = 6.

DISCUSSION

This study and others (Steward 1988, Smart and Barko 1989) provide no physiological evidence for *Hydrilla* as a competitively superior species. Indeed, it is at a decided disadvantage in growth situations with a highly competitive species such as *Potamogeton*. In monocultures, *Hydrilla* responded to self-shading by forming new shoots beyond the limits of light occlusion (McFarland, Barko, and McCreary 1990). Therefore, *Hydrilla* appears better adapted for rapid horizontal spread in an effort to locate unoccupied, easily invaded sites. Yet when confronted by *Potamogeton* in the present study, that strategy was inadequate and *Hydrilla* lost the competitive struggle. In essence, *Hydrilla* appears to respond to competitive stress by avoiding it, since it is, in fact, a poor competitor. It might thus be termed a space strategist.

A previous investigation (Smart and Barko 1989) of *Hydrilla* and *Vallisneria americana* interactions suggested that *Vallisneria* held a competitive edge over *Hydrilla* when sediment nutrients (primarily nitrogen) were sufficiently plentiful to enable biomass accumulation in this species. Under these conditions, the slower growing *Vallisneria*, a noncanopy-forming species with a high root:shoot ratio, was able to outcompete *Hydrilla*. *Potamogeton* also typically grows slowly, allocating considerable biomass to below-ground tissue. In addition, *Potamogeton* is heterophyllous and capable of forming a floating-leaf canopy, which, by limiting light availability to a neighboring species, might well reflect another competitive advantage.

Data thus far indicate that, when forced into a competitive situation with either *Potamogeton americanus* or *Vallisneria americanus*, *Hydrilla* is generally inferior. Therefore, in order to invade and dominate aquatic systems to the extent found in nature, *Hydrilla* must be able to offset its competitive inferiority by other mechanisms, for example, rapid vegetative propagation through fragmentation.

In a study comparing *V. americana* and *Hydrilla* as competitors, predictions of competitive advantages for nitrogen were related solely to shoot nitrogen cost in both species (Smart and Barko 1989). Increased sediment fertility apparently strengthened the competitive advantage held by *Potamogeton* in the present study when only above-ground biomass, or above-ground nitrogen content or costs, was considered. However, when below-ground allocation was considered as well, differences between the two species were inconsequential. With a robust root-forming species such as *Potamogeton*, whole-plant nitrogen costs need to be considered in predicting competitive outcomes. Had we assessed only above-ground tissues in this study, we would have missed the influence that below-ground biomass and nitrogen dynamics have on the interaction between *Potamogeton* and *Hydrilla.* By examining whole-plant nitrogen dynamics, the apparent increase in *Potamogeton*'s competitive advantage on fertilized sediments was reevaluated. The margin of superiority for *Potamogeton* actually declined on nitrogen-rich sediments.

Biomass production in *Potamogeton* was only slightly suppressed due to the presence of *Hydrilla*, as measured by suppression coefficients. Given the similarity of *Potamogeton* above-ground biomass in mixtures relative to monocultures, *Potamogeton* appeared to be unaffected by the presence of *Hydrilla.* Yet *Potamogeton* did demonstrate a variety of morphological responses to this competitive situation. Among these, greater production of floating leaves when sediment nutrients are plentiful appears to be a mechanism whereby the growth of neighboring species may become limited through reduction in available light. Although *Hydrilla* is known to be capable of forming extensive canopies (Haller and Sutton 1975; Van, Haller, and Bowes 1978), the degree to which *Potamogeton* extinguished light in the present investigation was far greater than for *Hydrilla.*

Another possible advantage of successful canopy formation is access to atmospheric gas sources. In particular, such access could minimize any periodic carbon limitation during photosynthesis by allowing access to free carbon dioxide. *Hydrilla* has been shown to be very sensitive to carbon limitation (Barko and Smart 1989), while *Potamogeton* floating leaves bear functional stomates that should allow gas exchange (Barko and Filbin, unpublished data).

Finally, by forming more inflorescences in mixtures than in monocultures, *Potamogeton* ensured greater potential for sexual reproduction. Even though *Potamogeton* won the competitive struggle, it was sufficiently influenced by the presence of *Hydrilla* to invest in sexual propagation for future generations. Sexual propagation is energetically and nutritionally costly (Sculthorpe 1967), yet might confer an advantage on future populations by providing genetic variation. Therefore, offspring from sexual union might be better adapted for direct conflicts with a competitor. It may also be that the new plant will germinate in an environment sufficiently altered to displace such a species as *Hydrilla*. With these scenarios, *Potamogeton* represents a time strategist, waiting out the present competitive situation against some future, *Hydrilla*-free, condition.

CONCLUSIONS

In conclusion, we have demonstrated the ability of a native species, *Potamogeton americanus*, to strikingly outcompete a common nuisance species, *Hydrilla verticillata*. We recommend additional studies of such competitive interactions to further understand the mechanisms governing submersed macrophyte growth. If management practices can be specifically tied into the liabilities inherent in the growth strategies of such nuisance species, control might be more easily practiced and natural community changes more accurately predicted.

ACKNOWLEDGMENTS

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REFERENCES

Aarssen, L. W. 1985. "Interpretation of the Evolutionary Consequences of Competition in Plants: An Experimental Approach," *Oikos*, Vol 45, pp 99-109.

Barko, J. W., and Smart, R. M. 1981. "Comparative Influences of Light and Temperature on the Growth and Metabolism of Submersed Freshwater Macrophytes," *Ecological Monographs*, Vol 51, pp 219-235.

Barko, J. W., and Smart, R. M. 1986. "Effects of Sediment Composition on Growth of Submersed Aquatic Vegetation," Technical Report A-86-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Barko, J. W., and Smart, R. M. 1989. "Interactive Effects of Light, Sediment Fertility, and Inorganic Carbon Supply on the Growth of Submersed Aquatic Macrophytes," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 151-158.

Barko, J. W., Smart, R. M., McFarland, D. G., and Chen, R. L. 1988. "Interrelationships Between the Growth of *Hydrilla verticillata* (L.f.) Royle and Sediment Nutrient Availability," *Aquatic Botany*, Vol 32, pp 205-216.

Haller, W. T., and Sutton, D. L. 1975. "Community Structure and Competition Between *Hydrilla* and *Vallisneria*," *Hydrilla Control Journal*, Vol 13, pp 48-50.

Hough, R. A., and Fornwall, M. D. 1988. "Interaction of Inorganic Carbon and Light Availability As Controlling Factors in Aquatic Macrophyte Distribution and Productivity," *Limnology and Oceanography*, Vol 33, pp 1202-1208.

McFarland, D. G., Barko, J. W., and McCreary, N. J. 1990. See pp 161-170 in this proceedings.

Sculthorpe, C. D. 1967. *The Biology of Aquatic Vascular Plants*, Edward Arnold Publishers, Ltd., London, England.

Smart, R. M., and Barko, J. W. 1985. "Laboratory Culture of Submersed Freshwater Macrophytes on Natural Sediments," *Aquatic Botany*, Vol 21, pp 251-263.

Smart, R. M., and Barko. J. W. 1989. "Competitive Interactions of Submersed Aquatic Macrophytes in Relation to Water Chemistry and Other Environmental Conditions," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 159-164.

Statistical Analysis Systems Institute, Inc. 1988. "SAS Version 5.18," Cary, NC.

Steward, K. K. 1988. "Competitive Interaction Between Monoecious *Hydrilla* and *Vallisneria* on Soils of Varying Fertility," Final Report, USDI NPS NCR IA-3040-6-8001 and USDA ARS RA-6629-013-0986.

Titus, J., and Stone, W. H. 1982. "Photosynthetic Response of Two Submersed Macrophytes to Dissolved Inorganic Carbon Concentration and pH," *Limnology and Oceanography*, Vol 27, pp 151-160.

Van, T. K., Haller, W. T., and Bowes, G. 1978. "Some Aspects of the Competitive Biology of *Hydrilla*," *Proceedings, EWRS 5th Symposium on Aquatic Weeds*, pp 117-126.

Wetzel, R. G. 1983. *Limnology*, 2d ed., W. B. Saunders, Philadelphia, PA.

Seasonal and Spatial Variability in Patterns of Sedimentation in Macrophyte Beds in the Potomac River

by
Harry L. Eakin* and John W. Barko*

INTRODUCTION

Since the recolonization of the upper Potomac River by native macrophyte species in the early 1980s after nearly a four-decade absence, the subsequent introduction and expansion of the exotic species *Hydrilla verticillata* (L.f.) Royle (Steward et al. 1984, Rybicki et al. 1986) provides for possible alteration of sedimentation patterns within the river.

An investigation by Madsen and Warncke (1983) indicated 58- to 92-percent reductions in flow velocities around and within a submersed macrophyte bed in a small stream. The most pronounced reduction in velocity was measured nearest the edge of the macrophyte bed.

Reductions in flow velocities by submersed macrophytes suggest that sedimentation occurring around and within macrophyte beds may be increased as a result of lower sediment-carrying capacity. In lotic (i.e., riverine) environments, sedimentation is often dominated by physical processes such as the velocity, direction and depth of flow, water temperature, and the size and composition of particles in the suspended load and bed load (Rust 1982). Changes in patterns of sedimentation in areas of macrophyte beds within rivers could affect nutrient availability necessary for continued growth of rooted macrophytes and, possibly, provide increased colonizable substrate for increased macrophyte distribution. Also, navigation may be adversely impacted with changes in sedimentation patterns.

Objectives of this study were to quantify spatial and seasonal patterns of sedimentation within an extensive *Hydrilla* bed in the Potomac River and to characterize the chemical nature of the sedimenting material that might affect macrophyte growth and distribution.

MATERIALS AND METHODS

The investigation was conducted within the tidal Potomac River near Washington, DC (Figure 1), in an extensive submersed macrophyte bed dominated by *Hydrilla*. Samples were collected in June and September 1988 when macrophytes were present and in March 1989 when plants were absent. Sampling was conducted along a transect perpendicular to the shoreline extending through the macrophyte bed into the open water in an area known as Dyke Marsh. The macrophyte bed extended

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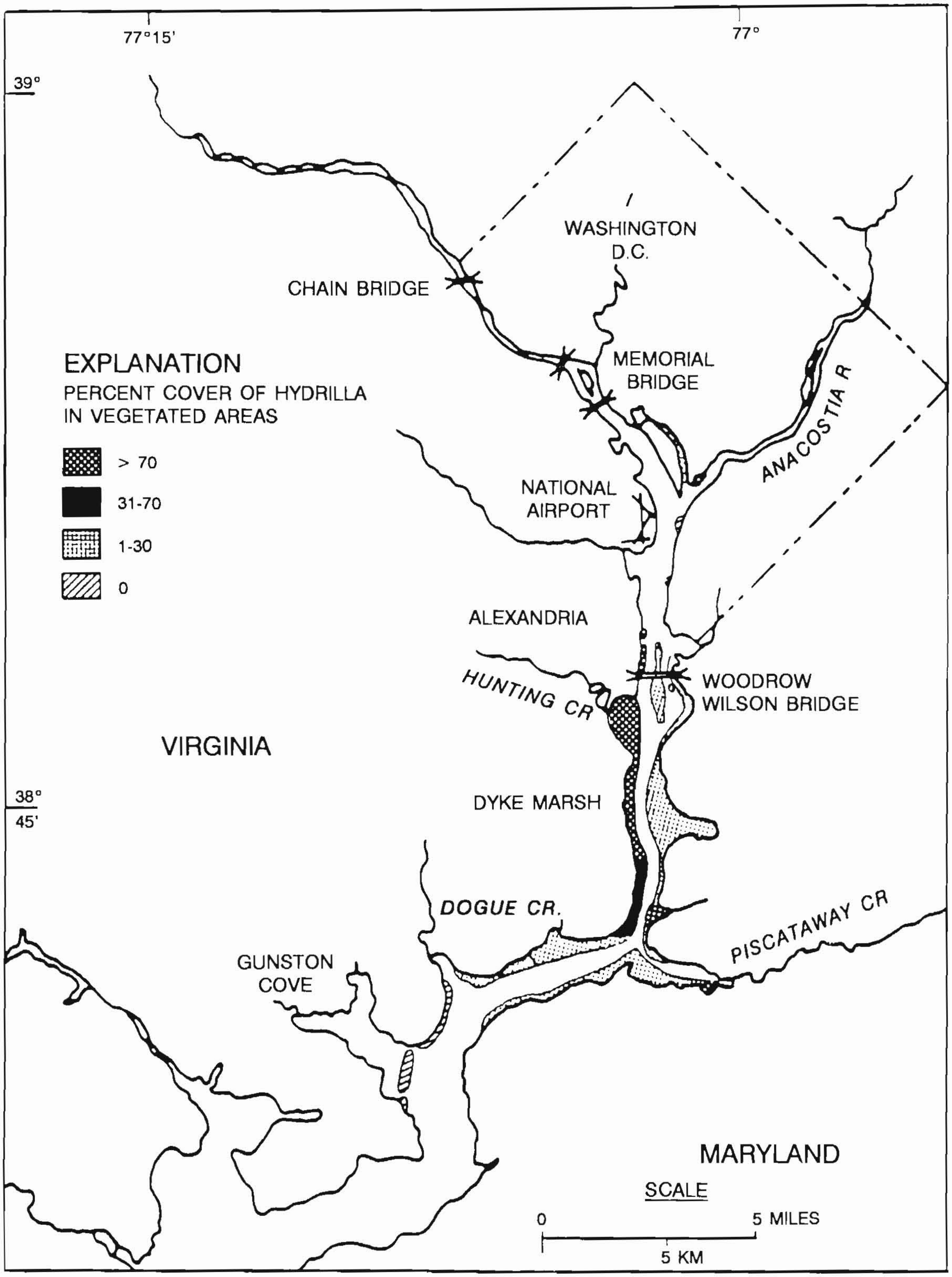

Figure 1. Distribution of *Hydrilla* in the tidal Potomac River, 1985 (from Rybicki et al. 1986)

from the shoreline to 360 m along the transect. Water depth at high tide ranged from about 1.7 m at the nearshore site (50 m) to about 2.9 m at the open-water site (425 m), with tidal fluctuations of approximately 1 m. Sampling sites were located on the transect at 180, 260, 340, and 380 m during the June sampling period. The number of sampling sites during September and March was increased to include 50, 100, and 425 m. However, samples were not collected at the 50- and 340-m sites during the March sampling period due to the loss of equipment.

Apparatus for collecting sedimenting material consisted of plastic (polyvinyl chloride) cylinders (Hargrave and Burns 1979), constructed with an aspect ratio of 6.0 (Lau 1979) to minimize resuspension and possible loss of settled material from the cylinders. Cylinders were deployed in triplicate and allowed to rest vertically (cylinder length = 39 cm) on the sediment surface for 2 weeks during the deployment periods.

Retrieval of collected sediment was accomplished by quantitatively transferring the solid contents of each cylinder into 1-ℓ plastic bottles for transport and storage at 4° C. Sample analyses were undertaken within 36 hr of collection.

Sample aliquots of collected sediment were analyzed for dry weight, total nitrogen, total phosphorus, total iron, and total manganese. Physical analyses were performed according to Standard Methods (APHA 1985). Chemical analyses, using Technicon Autoanalyzer II procedures, followed sulfuric acid/potassium persulfate digestion (Raveh and Avnimelech 1979). The calculation of sedimentation rates was based on the equation provided in Eakin and Barko (1989).

RESULTS AND DISCUSSION

Sedimentation rates

Rates of sedimentation differed both seasonally and with distance along the transect (Figure 2). During the June and September 1988 sampling periods, deposition along the transect exhibited sharp spatial gradients between the open-water sites and sites within the macrophyte bed. The open-water sites, 380-m for June and 380- and 425-m for September, had substantially higher rates of deposition than sites within the macrophyte bed. These gradients were not evident during March 1989, as rates of sedimentation were uniform among all sites along the transect. Rates of deposition that occurred at the open-water sites in June and September were comparable to those that occurred at all sites along the transect in March 1989.

Sedimentation within the macrophyte bed during both June and September was greatest at the 340-m site (located 20 m inward from the open water). In June, deposition within the plant bed decreased gradually from the 340-m site to the 180-m site. Sediment deposition measured in September, however, showed essentially no difference between any of the sites within the macrophyte bed at distances of less than 340 m.

Seasonal variations in rates of sedimentation were probably reflective of both the condition of the macrophyte bed and climatological conditions during each of the

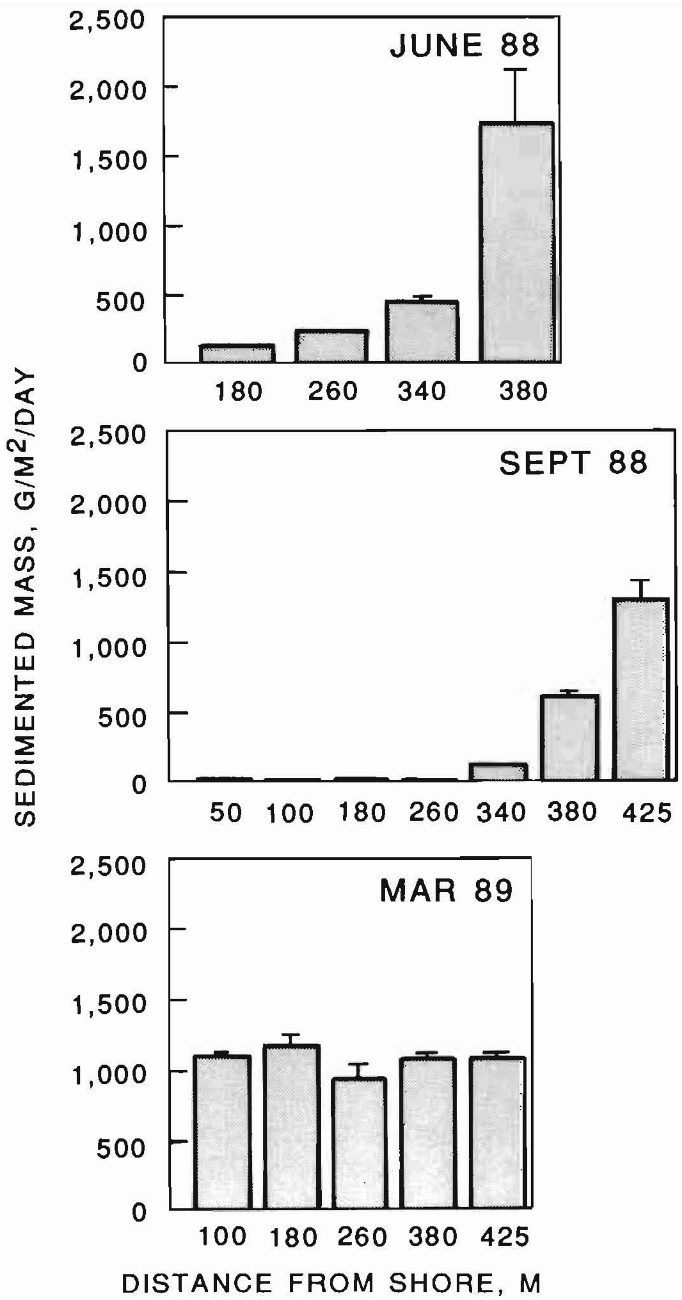

Figure 2. Mass sedimentation rates. Vertical bars represent means (n = 3) with associated standard deviations

deployment periods. During June, the submersed macrophytes had not attained full canopy, and riverine and tidal flows appeared to traverse the entire macrophyte bed with little impedance, especially near the water surface. Also, what appeared to be the effects of late-spring storm-related activity on runoff, i.e., increased turbidity and elevated levels of suspended sediment load, were still evident. Visual observations of riverine and tidal flows revealed the diversion of the majority of flows along the outer edge of the plant bed as a result of physical obstruction of water movement by the plants. Combined, these factors might have been responsible for the considerable deposition at the open-water site and gradients observed within the macrophyte bed.

In September, the plants had attained full canopy, which resulted in a considerable reduction of riverine and tidal flows into the macrophyte bed. The reduction in rate of deposition during September may have been reflective of the drought conditions that were prevalent within the drainage basin during late summer 1988. Lessened rainfall resulted in reduced turbidity and suspended sediment load in riverine flows (based on visual observations).

Deposition along the transect in March was quite uniform and most likely reflected the effects of the unrestricted flows during the absence of plants. The differences observed in patterns of sedimentation between periods when plants were present and absent clearly demonstrate how dense macrophyte beds can modify the processes that influence sedimentation in this environment.

Nitrogen and phosphorus

Examination of total nitrogen collected during June 1988 revealed slight spatial gradients of increasing concentration from the open water to the interior of the plant bed (Figure 3). In September, nitrogen concentrations at sites within the plant bed were substantially greater than those observed at the open-water sites. Concentrations of nitrogen at sites within the macrophyte bed in September were basically uniform, and two to three times greater than the values determined in June. Nitrogen concentrations at all sites along the transect in March 1989 were uniform and substantially lower than at sites within the macrophyte bed during the previous summer and fall.

Total phosphorus concentrations of sedimented material differed in magnitude from nitrogen, but exhibited patterns almost identical to those for nitrogen during all sampling periods (Figure 4).

Comparison of nitrogen and phosphorus concentrations with rates of sedimentation for all sites during the 1988 deployment periods reveals an inverse relationship between the amount of material sedimented and its nitrogen and phosphorus content. Significantly higher nitrogen and phosphorus concentrations were observed for material deposited within the macrophyte bed. Together, these patterns suggest that material sedimented within the plant bed was of a different origin than material sedimented in the open water.

Iron and manganese

Comparisons of iron and manganese concentrations (Figures 5 and 6) during all three deployment periods showed quite similar spatial and seasonal patterns. During June 1988 and March 1989, iron and manganese concentrations differed in magnitude from one another, but did not vary among sites along the transect. However, in September 1988, iron and manganese concentrations at the open-water sites were considerably greater than at sites deep within the macrophyte bed. The respective patterns of almost identical deposition of iron and manganese, differing only in magnitude, at

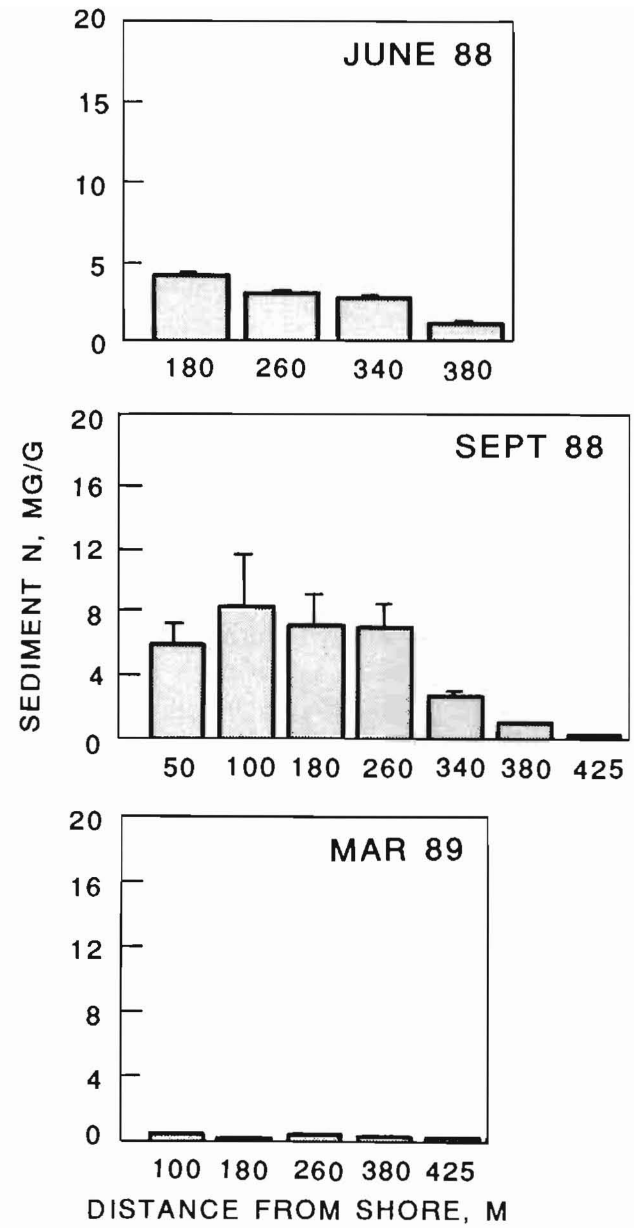

Figure 3. Concentration of total sediment nitrogen. Vertical bars represent means (n = 3) with associated standard deviations

each site along the transect in both June and March is perhaps indicative of the dominance exhibited by physical processes in influencing sedimentation in the river.

Sedimentation results from the complex interaction of physical, chemical, and biological processes. Chemical processes such as the conversion of dissolved materials into particulate forms by precipitation, coprecipitation, flocculation, or sorption are more evident in lentic (i.e., lacustrine) than in lotic environments (Otsuki and Wetzel 1972). Likewise, biological processes, e.g., seston fallout from planktonic activities, decomposition of organic materials, or perturbations of the bottom sediments by benthic

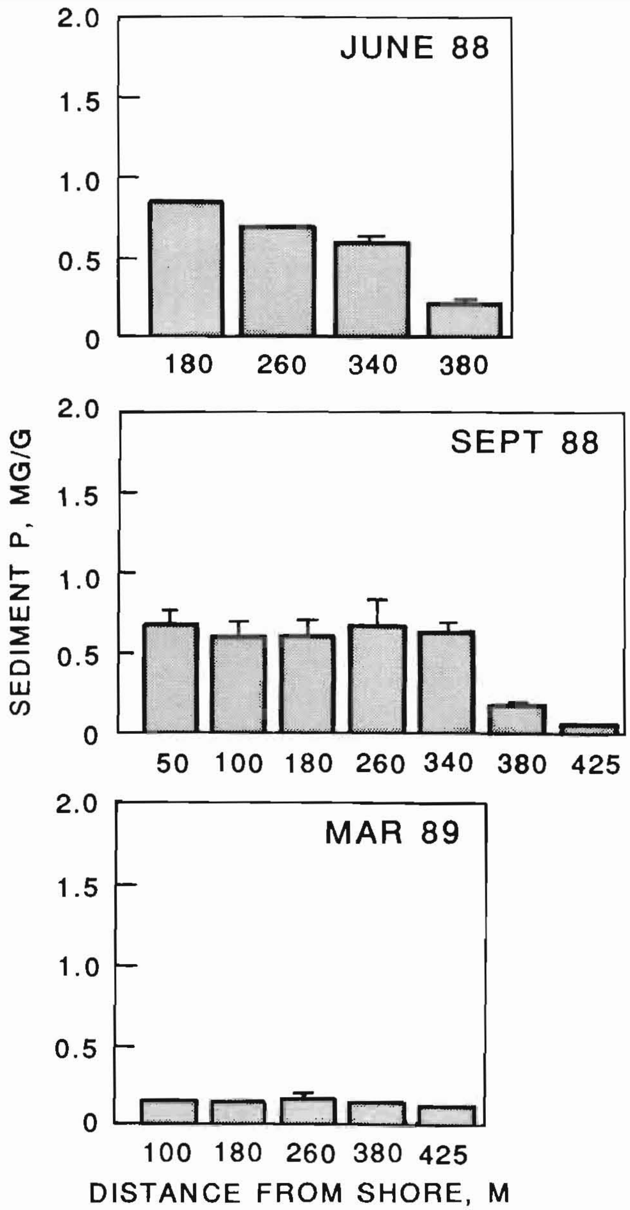

Figure 4. Concentration of total sediment phosphorus. Vertical bars represent means (n = 3) with associated standard deviations

organisms, that influence sedimentation are also more likely to predominate in lentic environments. Deposition within the lotic environment of the Potomac River appears to be dominated by physical processes in areas where plants are absent, but may be dominated more so by chemical and/or biological processes within the dense macrophyte beds.

In March, when plants were absent, there was no obstruction to riverine and tidal flows along the transect; thus, rates of deposition and the respective concentrations of all elements examined here were fairly uniform along the transect. The strength of

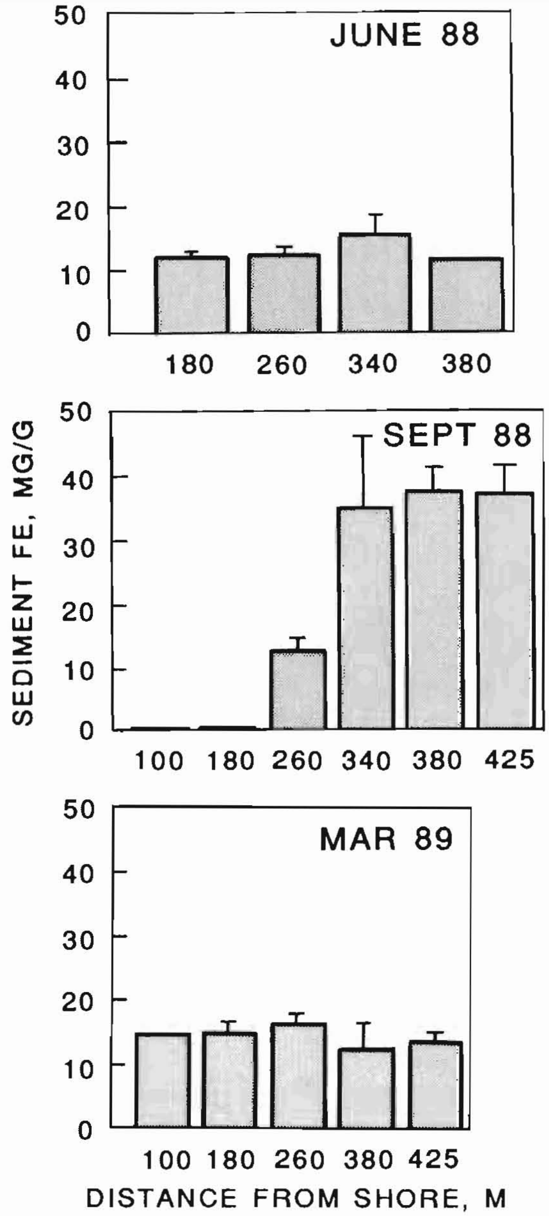

Figure 5. Concentration of total sediment iron. Vertical bars represent means (n = 3) with associated standard deviations

gradients in the chemical composition of sediment accreted between the open-water sites and sites within the plant bed seems to be influenced strongly by the types of processes dominating sedimentation at particular sites in the river.

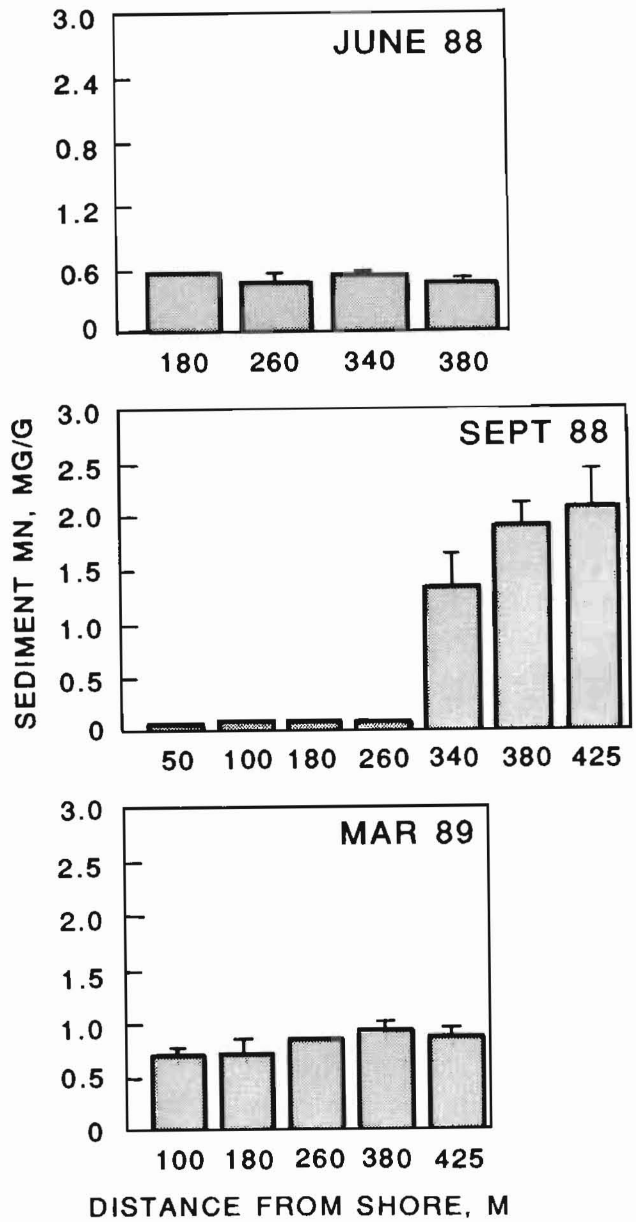

Figure 6. Concentration of total sediment manganese. Vertical bars represent means (n = 3) with associated standard deviations

SUMMARY AND CONCLUSIONS

Spatial and seasonal sedimentation patterns were examined in the tidal Potomac River in association with a large expansive macrophyte bed dominated by *Hydrilla*. Physical impedance of riverine and tidal flows by the plants during June and September 1988 caused deposition to decrease within the plant bed. The magnitude of the reduction in material deposited was most evident during September when flows through the plant bed were greatly diminished. With no plants present during March 1989 to impede flows over the transect, no pronounced variability in spatial patterns of sedimentation was evident. Seasonal variability in rates of sedimentation in the open-water sites was most likely related to variations in loadings affected by climatological conditions. Seasonal variability at sites within the plant bed appeared to be most dependent on the quantity of riverine and tidal flows able to traverse the plant bed, but perhaps also on biological and chemical processes occurring within the macrophyte bed.

Uptake by the plants of nutrients from the sediments during their growth cycle (Barko and Eakin, unpublished) coupled with the coincidental decrease in deposition of nutrients within the plant beds potentially results in a net loss of available nutrients in the sediments. However, due to the substantial input of nutrients from sedimentation during periods when plants are absent, there appears to be minimal chance of nutrient limitation of macrophyte growth.

Findings from this investigation suggest that there was no enhancement of sedimentation within the macrophyte bed in this particular environment. In fact, decreased deposition was evidenced within the macrophyte bed. However, the 340-m sampling site, selected to characterize the "edge," may have been located too far from the actual periphery of the macrophyte bed. Further examination of sedimentation patterns within a few meters (e.g., 0 to 5 m) of the "edge" zone is therefore needed.

Ultimately, changes in sedimentation patterns in areas of the Potomac River containing extensive *Hydrilla* beds must result in increases in deposition elsewhere, if not in the upper Potomac estuary, then possibly in the lower Potomac estuary or even the Chesapeake Bay.

ACKNOWLEDGMENTS

The authors with to thank V. Carter and N. Rybicki of the US Geological Survey and W. Taylor of the US Army Engineer Waterways Experiment Station (WES) for their contributions to study design, sampling, and logistical support. Appreciation is also extended to G. Bird and K. Piggot of the WES for analytical assistance and to G. Bird for assistance with data management. W. Taylor and D. McFarland of the WES provided technical review of this manuscript.

REFERENCES

American Public Health Association (APHA). 1985. *Standard Methods for the Examination of Water and Wastewater*, 16th ed., Washington, DC.

Eakin, H. L., and Barko, J. W. 1989. "Effects of Submersed Macrophytes on Patterns of Sedimentation in the Potomac River," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 219-230.

Hargrave, B. T., and Burns, N. M. 1979. "Assessment of Sediment Trap Efficiency," *Limnology and Oceanography*, Vol 24, pp 1124-1136.

Lau, Y. L. 1979. "Laboratory Study of Cylindrical Sedimentation Traps," *Journal of the Fisheries Research Board of Canada*, Vol 36, pp 1288-1291.

Madsen, T. V., and Warncke, E. 1983. "Velocities of Currents Around and Within Submerged Aquatic Vegetation," *Archiv fur Hydrobiologia*, Vol 97, pp 389-394.

Otsuki, A., and Wetzel, R. G. 1972. "Coprecipitation of Phosphate with Carbonates in a Marl Lake," *Limnology and Oceanography*, Vol 17, pp 763-767.

Raveh, A., and Avnimelech, Y. 1979. "Total Nitrogen Analysis in Water, Soil, and Plant Material with Persulphate Oxidation," *Water Research*, Vol 13, pp 911-912.

Rust, B. R. 1982. "Sedimentation in Fluvial and Lacustrine Environments," *Hydrobiologia*, Vol 91, pp 59-70.

Rybicki, N., Anderson, R., Shapiro, J., Jones, C., and Carter, V. 1986. "Data on the Distribution and Abundance of Submersed Aquatic Vegetation in the Tidal Potomac River, Maryland, Virginia, and the District of Columbia, 1985," Open-File Report 86-126, US Geological Survey, Reston, VA.

Steward, K. K., Van, T. K., Carter, V., and Pieterse, A. H. 1984. *Hydrilla* Invades Washington, DC, and the Potomac," *American Journal of Botany*, Vol 71, No. 1, pp 162-163.

The Habitat Value of Aquatic Macrophytes for Macroinvertebrates--A Comparison of Lotic and Lentic Sites

by
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INTRODUCTION

Submersed macrophytes are prominent features of many lentic (slack-water) and lotic (flowing-water) habitats and can profoundly affect biological, physical, and chemical conditions. Moderate levels of macrophytes, about 30 percent areal coverage, provide sources of food and cover for fishes and invertebrates. However, extensive infestations can be detrimental and cause wide fluctuations in pH and dissolved oxygen, can cause imbalances in fish populations, and can interfere with recreational activities. The relationship between submersed macrophytes and aquatic ecosystems has been summarized in excellent reviews by Seddon (1972), Gregg and Rose (1982, 1985), McDermid and Naiman (1983), Pandit (1984), and Carpenter and Lodge (1986).

Numerous investigators have shown that macrophytes increase species diversity and invertebrate density. Miller, Beckett, and Bacon (1989) reported that invertebrate densities were typically more than seven times higher under vegetated areas in Eau Galle Reservoir, Wisconsin, than in nonvegetated zones. Watkins, Shireman, and Haller (1983) observed that infaunal macroinvertebrates in the sediment of a hydrilla bed were four times higher than in nearby sediments of a no-plant zone. In a comprehensive study of submersed macrophytes in Halverson Lake, a 4.2-ha shallow, eutrophic lake in Wisconsin, Engel (1985, 1988) reported that 75 percent of the macroinvertebrate species were found on or beneath macrophytes during summer.

The physical, chemical, and biological effects of macrophytes in aquatic systems have been investigated as part of the Aquatic Plant Control Research Program since 1986. Studies have been conducted in Lake Marion, South Carolina; Saline River, Arkansas; Eau Galle Reservoir, Wisconsin; and Lake Seminole, Florida. The purpose of this paper is to summarize major findings from this research.

METHODS

Studies were designed to investigate the relationship between presence of various aquatic plant species and the distribution of benthic (bottom-dwelling) and phytophilous (plant-dwelling) macroinvertebrates. The same sampling program was employed in all study areas. Replicate samples (usually five) were obtained from

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replicate sites (two to three) located within dense plant beds and in no-plant zones. Every effort was made to have the plant and no-plant zones as similar as possible with respect to physical conditions such as depth and substrate type.

Sediments were collected with a hand-held 5.08-cm coring device described by Miller and Bingham (1987). This sampler was operated from a boat in water greater than 1 m deep, and by wading in shallow water. The design of the core sampler made it possible to collect sediment while excluding plants in the water column. Benthic samples were screened with a No. 60 (250-µ mesh) US standard sieve and preserved with 10-percent formalin. Typically, five whole plants (or individual stems of plants) were collected with a dip net and placed in a plastic bag. Macroinvertebrates were stained with a rose bengal solution to facilitate sorting. All organisms were removed from sediments by microscopial examination at 15× magnification and stored in 70-percent ethanol. Slides of larval chironomids and oligochaetes were prepared for identification by the method described by Beckett and Lewis (1982). All organisms were identified to the lowest practical taxonomic level.

RESULTS

Lake Marion, South Carolina

Lake Marion, a 45,000-ha reservoir in South Carolina, was formed by impoundment of the Santee River in 1941 to provide hydroelectric power. Although Lake Marion is a large lake, the upper regions are characterized by extensive shallow areas less than 3 m deep. Aquatic macrophytes are abundant, and submersed species dominate in zones less than 2.0 m deep. *Hydrilla verticillata* (hydrilla) is the dominant species. *Ceratophyllum demersum* (coontail) and *Egeria densa* (Brazilian elodea) are found in some macrophyte stands but comprise only a small percentage of the total macrophyte biomass. The study site is located in upper Lake Marion near Pack's Landing, approximately 23 km northwest of Highway I-95.

Representative samples of *Hydrilla* were collected on 19 October 1988, and samples of *Hydrilla, Ceratophyllum*, and *Egeria* were collected on 9 June 1989 for macroinvertebrate analysis. Macrophytes in Lake Marion supported a diverse assemblage of macroinvertebrates dominated by larval chironomids. A total of 49 taxa have been identified from plant stems, leaves, and benthic samples. Chironomids constituted 93.1 percent of the total on 19 October 1988 and 87.8 percent of the total on 10-cm sections of *Hydrilla* on 9 June 1989. Naidid oligochaetes (aquatic worms) accounted for only 3.5 and 3.8 percent of the total numbers on the two sampling dates. Planarians were more abundant than naidids on 9 June 1989 and comprised 5.0 percent of the macroinvertebrate population.

Macroinvertebrate density estimates exhibited considerable variation, and in most cases the F-ratio indicated that variances among plants were significantly different ($p < 0.01$). Individual observations on 19 October 1988 ranged from 12.9 to 23.0 individuals per 10-cm section with a mean of 17.3 individuals per 10-cm section (Table 1). On 9 June 1989 the mean number of macroinvertebrates per 10-cm section of *Hydrilla* was 44.4 individuals per 10-cm section with a range of 17.0 to 74.8

Table 1
Mean Number of Macroinvertebrates on Five 10-cm Sections of *H. verticillata* in Lake Marion, South Carolina, 19 October 1988 and 9 June 1989

	19 October 1988		*9 June 1989*	
Taxon	*Mean*	*SD**	*Mean*	*SD*
Hydrozoa	--	--	0.1	0.3
Turbellaria	0.4	0.2	2.2	2.0
Nematoda	--	--	--	--
Naididae	0.6	0.4	1.7	1.0
Gastropoda	0.1	0.1	0.0	0.5
Hydracarina	--	--	0.1	0.1
Amphipoda	0.1	0.1	0.5	0.4
Ephemeroptera	--	--	0.5	0.3
Odonata	--	--	0.1	0.2
Trichoptera	--	--	0.2	0.1
Diptera	16.1	3.6	39.0	21.9
Total	17.3		44.4	

*Standard deviation.

(Table 1). The number of macroinvertebrates per gram of *Hydrilla* on these two dates was 741.7 and 1,539.2 (Table 2) with ranges of 589.9 to 881.2 and 781.3 to 2,603.6 individuals per gram, respectively. Calculated regression coefficients between numbers of individuals per 10-cm stem section and numbers of individuals per gram of plant were both 1.00, which indicated maximum correlation between numbers per 10-cm section and numbers per gram. A Mann-Whitney U test of significance indicated that the numbers of individuals per 10-cm section of stem and the numbers of individuals per gram of plant biomass on 19 October 1988 were significantly different ($\alpha = 0.01$) from the densities on 9 June 1989.

A total of 23 taxa were identified on *H. verticillata* stems and leaves on 19 October 1988 (Table 3). Chironomids of the subfamily Orthocladiinae were the dominant group of chironomids colonizing *Hydrilla* on 19 October 1988 and accounted for 94.0 percent of the total. *Thienemanniella fusca* was the most abundant chironomid and comprised 66.9 percent of all chironomids. *Cricotopus sylvestris* was the next most abundant chironomid (10.8 percent), and *Psectrocladius vernalis* accounted for 8.8 percent of the chironomids. The Shannon diversity index (H') calculated for macroinvertebrates colonizing *Hydrilla* on 19 October 1988 was 2.53. This value was lower due to the dominance of *T. fusca*, which accounted for 62.0 percent of the total individuals present.

Table 2
Mean Number of Macroinvertebrates per Gram on Five *H. verticillata* in Lake Marion, South Carolina, 19 October 1988 and 9 June 1989

	19 October 1988		*9 June 1989*	
Taxon	*Mean*	*SD**	*Mean*	*SD*
Hydroza	--	--	3.9	6.6
Turbellaria	18.3	5.6	69.2	44.5
Nematoda	--	--	1.0	1.4
Naididae	25.8	13.1	60.8	32.4
Gastropoda	4.2	3.8	0.6	1.4
Hydracarina	--	--	2.2	3.0
Amphipoda	2.6	3.7	17.3	9.9
Ephemeroptera	0.6	1.2	17.1	8.4
Odonata	--	--	3.0	4.2
Hemiptera	--	--	0.5	1.2
Coleoptera	0.6	1.2	--	--
Lepidoptera	--	--	1.0	1.4
Trichoptera	0.7	1.4	6.9	4.2
Diptera	688.9	105.7	1,355.7	809.9
Total	741.7		1,539.2	

Five benthic samples were collected at 1.2-, 1.5-, 1.8-, and 2.1-m depths to document variation in macroinvertebrate communities with depth and to show the importance of submersed macrophytes for the benthic fauna. Sample variances were high as indicated by the F-ratio and were significantly different ($p < 0.05$) between all stations except 1.2 m compared to 1.5 m ($p > 0.05$). Despite wide variations in these values, a community trend was apparent and was related to depth and macrophyte abundance. The mean numbers of individuals per square meter at depths of 1.2 and 1.5 m were three to five times higher than from samples collected at depths of 1.8 and 2.1 m. Averages at 1.2- and 1.5-m depths were 22,852 and 17,862 individuals per square meter, respectively. Lower standing crops were observed at depths of 1.8 and 2.1 m, with mean numbers of 6,928 and 4,638 individuals per square meter, respectively. A Kruskal-Wallis test of significance indicated that the sample means at 1.2 m were not significantly different from sample means at the 1.5-m depth ($p > 0.05$), but means at the 1.8- and 2.1-m depths were significantly different from the 1.2- and 1.5-m depths ($p < 0.05$). The Mann-Whitney U test of significance also indicated that the means were significantly different except at the 1.2- and 1.5-m depths ($\alpha = 0.10$). Shannon

Table 3
Macroinvertebrates Per Gram of *H. verticillata* (N = 5) in Lake Marion, South Carolina, 19 October 1988

Taxon	*Mean*	*SD*
Macrostomum sp.	18.3	5.6
Gyralus sp.	4.2	3.4
Hyallela azteca	2.6	3.4
Pristina leidyi	10.7	9.9
Stylaria lacustris	14.2	11.5
Nais pseudobtusa	0.9	0.9
Caenis sp.	0.6	1.1
Stenelmis humerosa	0.6	1.1
Ablabesmyia parajanta	26.8	19.7
Labrundinia neopilosella	1.6	3.0
Corynoneura scutellata	5.7	4.3
Corynoneura taris	10.0	8.6
Cricotopus sylvestris	74.9	4.5
Cricotopus intersectus	4.5	5.4
Cricotopus bicinctus	3.8	7.0
Cricotopus tremulus	20.2	20.8
Dicrotenipes nervosus	7.3	8.4
Nannocladius rectinervis	1.6	3.0
Orthocladius sp.	6.0	11.0
Psectrociadius vernalis	60.6	8.8
Tanytarsus glabrescens	5.6	6.7
Thienemanniella fusca	462.1	72.8
Orthotrichia sp.	2.3	2.9
Total	745.1	

diversity indices (H') indicated a higher diversity at the 1.8- and 2.1-m depths because stylet-bearing and nonstylet-bearing nematodes usually associated with plants were less abundant at the greater depths. Diversity indices at the four depths were 1.2 m (2.86); 1.5 m (2.03); 1.8 m (3.17), and 2.1 m (3.17).

Saline River, Arkansas

The Saline River is formed by the confluence of four second-order streams in western Saline and Garland Counties, Arkansas. Our sampling area was 120 km from the origin of the river, and 72 km upriver from the confluence of the Saline with the Ouachita River. The river reach in the study area has exposed gravel bars, riffles consisting of medium-sized gravel, and short pools. The dominant macrophyte is *Potamogeton nodosus* with lesser quantities of *Dianthera americana.*

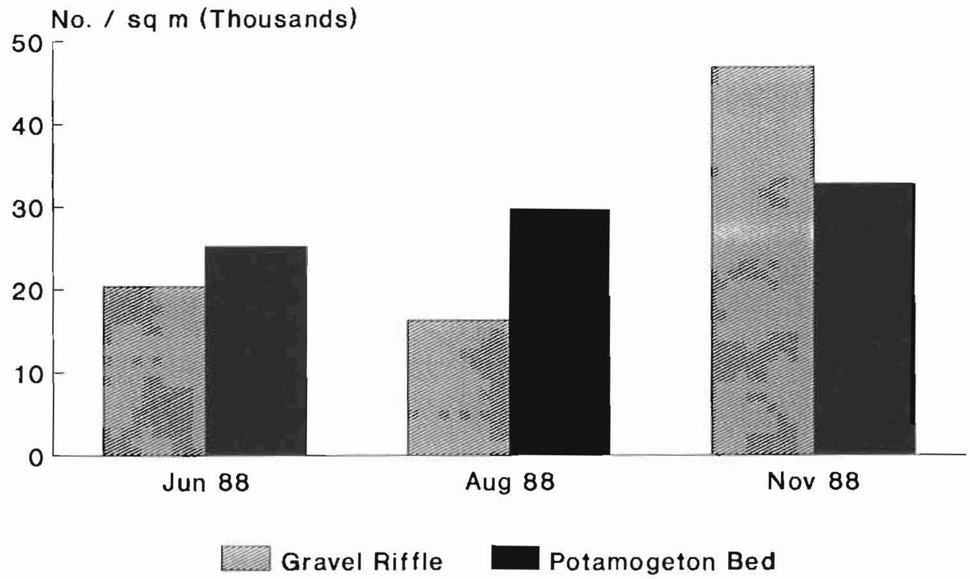
Five replicate samples for macroinvertebrates were collected from three sites located within and three sites located immediately adjacent to *Potamogeton* beds in June, August, and November 1988. A dense and diverse macroinvertebrate fauna has been found in the sediments and on the plant stems. Twenty species of chironomids have been identified. The phytophilous fauna was dominated by *Rheotanytarsus exiguus*, and *Polypedilum scalaenum* was the most abundant chironomid (immature fly) in the sediments. In addition to the chironomids, the sediments were dominated by the oligochaetes *Dero nivea* and *Pristina syclites*, as well as immature tubificids.

Total macroinvertebrates densities were greater in *Potamogeton* beds than in adjacent gravel riffles in June and August, although the reverse was true in November 1988 (Figure la). Pelecypods, which included mainly the Asiatic clam *Corbicula fluminea*, dominated *Potamogeton* the spring and summer, although densities were similar in the no-plant zones in November (Figure lb). It is likely that in the spring and summer the *Potamogeton* beds stabilize the substrate and allow macroinvertebrates to quickly colonize and develop. By the fall the water levels had subsided, and protection from spates was not as critical; differences between habitat types were either nonexistent (pelecypods) or unrelated to presence of plants (total macroinvertebrates).

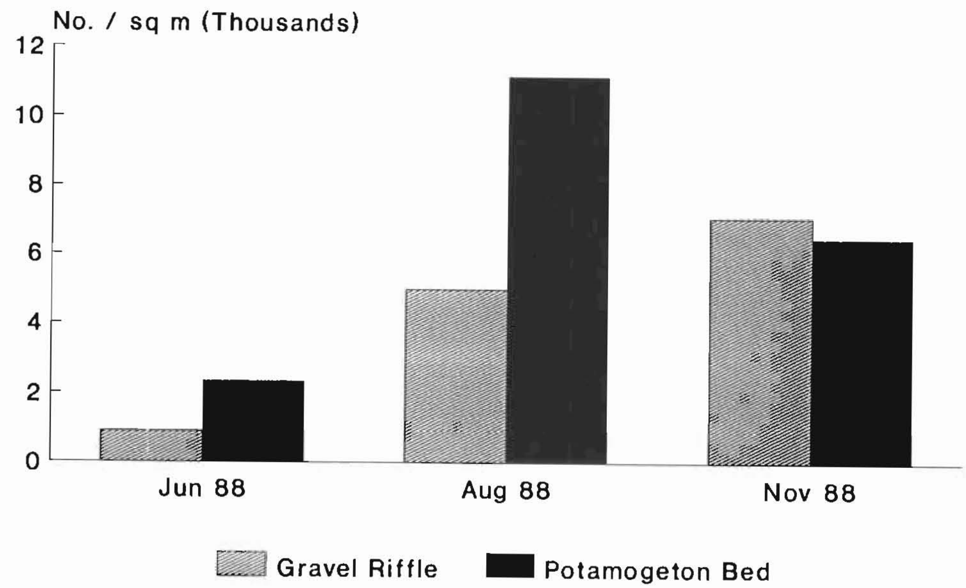
Nematodes were more abundant in sediments in *Potamogeton* beds than in the adjacent riffles during the three sampling periods (Figure lc). Some worms in this group are specialized for biting and chewing plant tissues whereas others are equipped with a rigid, hollow stylet to pierce plant cells and remove plant fluids by the sucking action of the muscular pharynx (Pennak 1989).

Eau Galle Reservoir, Wisconsin

A benthic barrier was placed in the littoral zone of Eau Galle Reservoir in July 1988. This was part of a test of the barrier as a means for controlling nuisance levels of aquatic plants (Gunnison and Barko 1989). There were no significant differences between total macroinvertebrate densities in the two areas when the barrier was put in place (Figure 2a). Within 2 months, densities inside and immediately outside the influence of the barriers differed by approximately 50 percent. An additional set of samples was collected in the summer of 1989; similar differences between areas affected and unaffected by the barrier were noted.

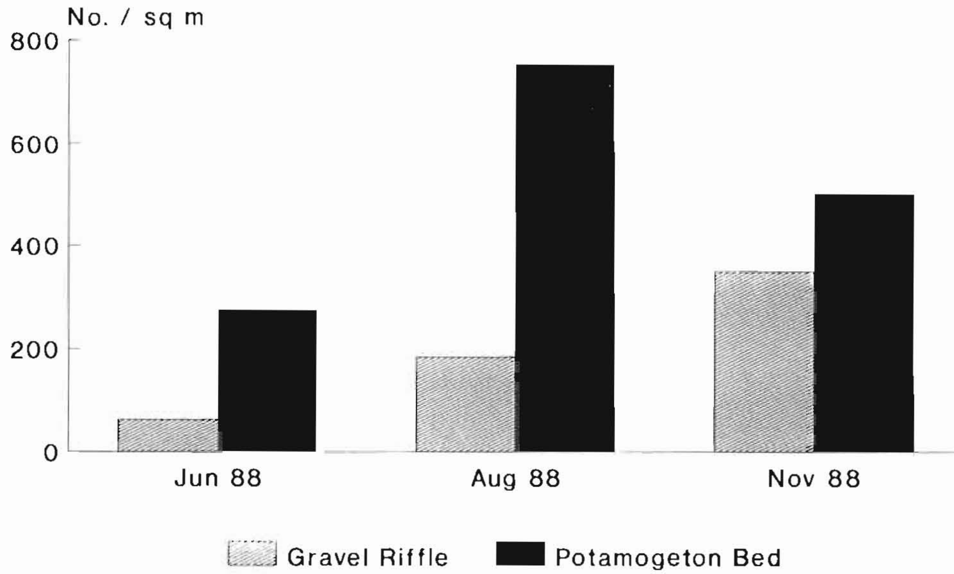


a. Total macroinvertebrates



b. Pelecypods

Figure 1. Macroinvertebrate densities, Saline River, Arkansas, 1988 (Continued)



c. Nematodes

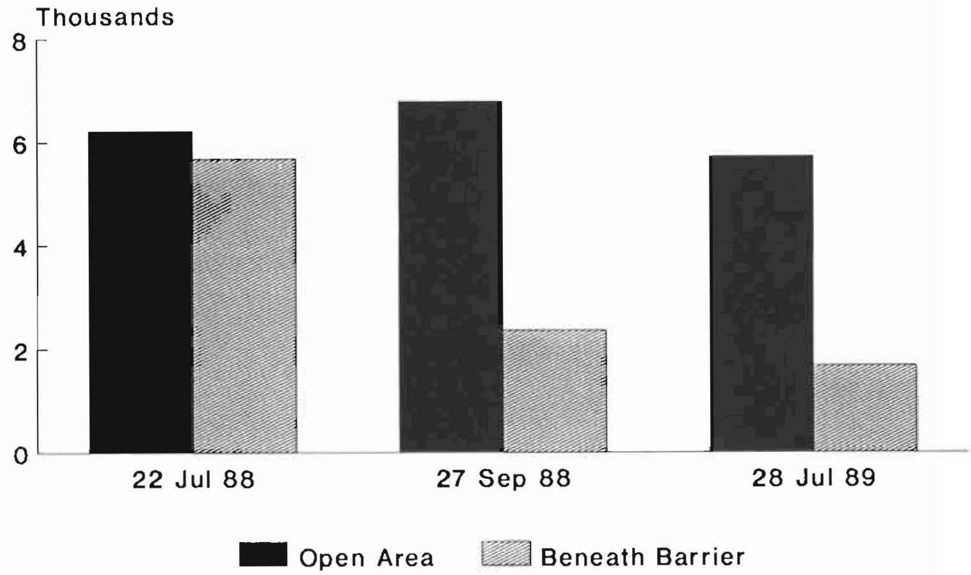
Figure 1. (Concluded)

Macroinvertebrate community composition in areas affected by the barriers differed slightly from conditions in areas unaffected by the barrier. Sediments unaffected by the barrier were dominated by oligochaetes and chironomids. Beneath the barrier the community was dominated by amphipods (a bottom-dwelling macroinvertebrate), although relative abundance of other groups was not substantially different than in natural sediments. Benthic barriers depress (but do not totally eliminate) macroinvertebrates and exert minor effects on community composition. Additional studies will be conducted to evaluate macroinvertebrate recolonization rates after benthic barriers have been removed.

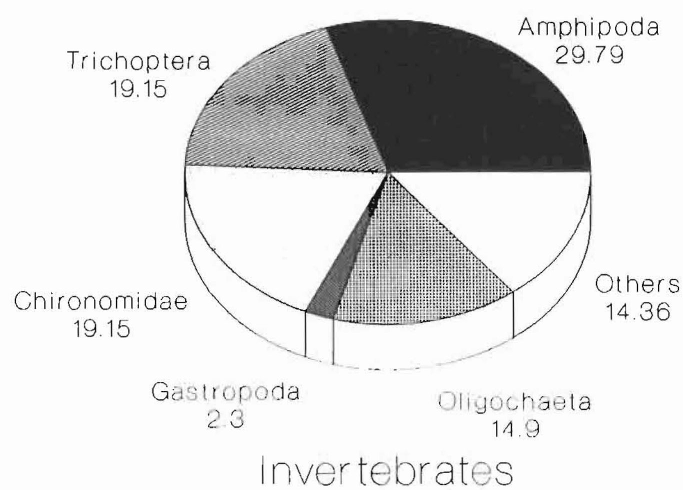
Lake Seminole, Florida

Lake Seminole is located in the southwest corner of Georgia and was formed by the impoundment of the Chattahoochee and Flint Rivers. The reservoir has a surface area of 152 sq km and a shoreline of 402 km. Mean depth of the lake is approximately 3 m.

Although 11 species of oligochaetes were identified on aquatic macrophytes in the lake, five species dominated the assemblage (Figure 3a). Oligochaete community composition was similar on *Hydrilla* and *Potamogeton*, which both supported about equal percentages of *Allonais pectinata* and *Pristina leidyi*. Composition of dominant oligochaetes was markedly different on the large, flat leaves of the waterlily (Nymphaca). The percentage of *A. pectinata* on this plant was about half that on the more finely dissected leaves of *Potamogeton* and *Hydrilla*. *Dero pectinata* was dominant on Nymphaca, whereas it was either subdominant or absent on *Hydrilla* and *Potamogeton*, respectively.

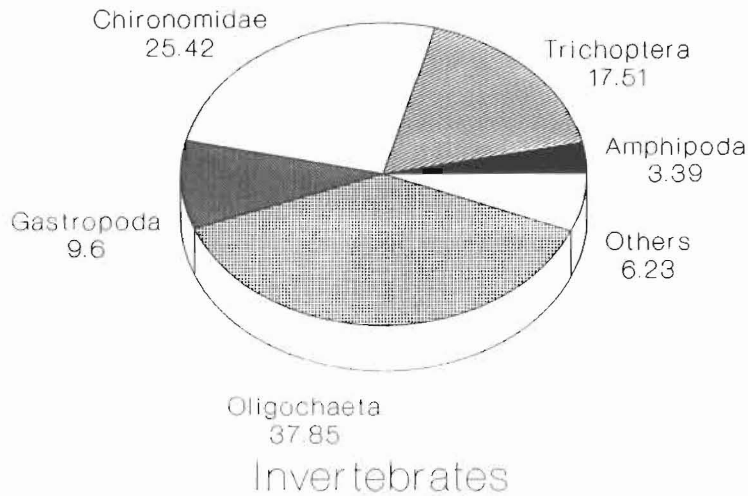


a. Invertebrate density (thousands of individuals/square meter)



b. Invertebrate community percentage composition beneath the barrier

Figure 2. Effects of benthic barriers on macroinvertebrates in Eau Galle Reservoir, 1988-89 (Continued)



c. Invertebrate community percentage composition in natural sediments adjacent to the barrier

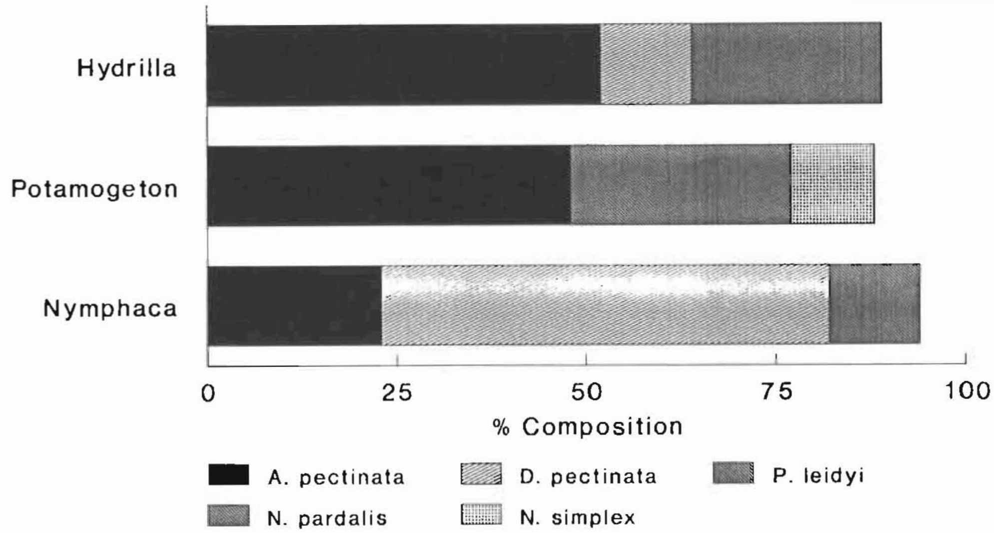
Figure 2. (Concluded)

Three families of oligochaetes were in similar proportions on *Hydrilla*, *Potamogeton*, and *Nymphaca* (Figure 3b). However, relationships among oligochaete families were dissimilar in the sediments below *Hydrilla* and *Potamogeton/Hydrilla*. Tubificid worms tended to be more common in fine-grained sediments, whereas naidid worms were comparatively more common on plant stems.

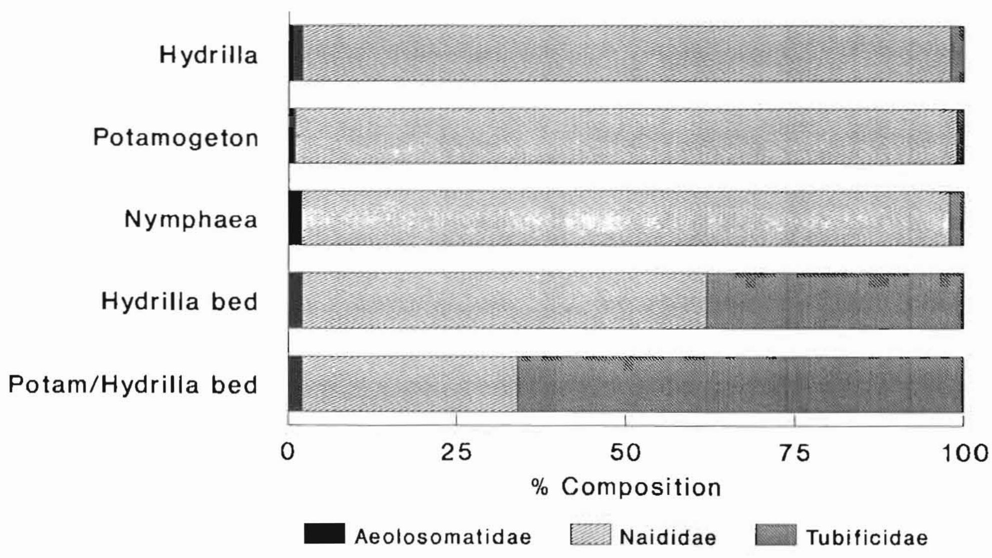
SUMMARY

These studies illustrate that submersed aquatic plants exert a profound effect on macroinvertebrates in lotic and lentic habitats. In flowing-water systems, roots and stems stabilize the substrate and protect macroinvertebrates from erosive action of spates. Stabilizing effects were most notable in the spring and early summer when high discharge was common; however, by fall when water levels were low, the effects of plants on the benthic community were less notable. Payne et al. (1989) reported that demographic patterns of bivalves are affected by substrate stability; riffle areas unaffected by spates support organisms with greater numbers of age classes.

Some benthic macroinvertebrates, notably the nematodes, are directly dependent on aquatic plants. In a study of 32 lakes in Poland, Prejs (1986) reported that the underground parts of vascular plants were abundantly inhabited by stylet-bearing nematodes of five different genera, and that some genera were higher in plant roots and rhizomes than in nearby sediments. A positive relationship between submersed aquatic plants and nematode densities was noted in the Saline River as well as Lake Marion, South Carolina. Plant structure exerts a strong influence on macroinvertebrate community composition. The relative abundance of oligochaete families in the benthos was



a. Dominant oligochaete species on three plant types

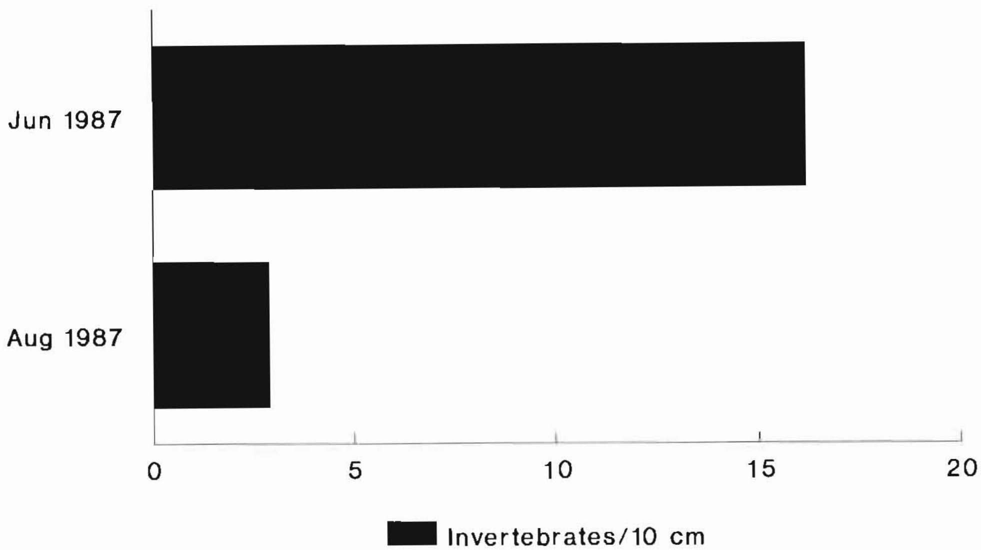


b. Abundance of oligochaete families

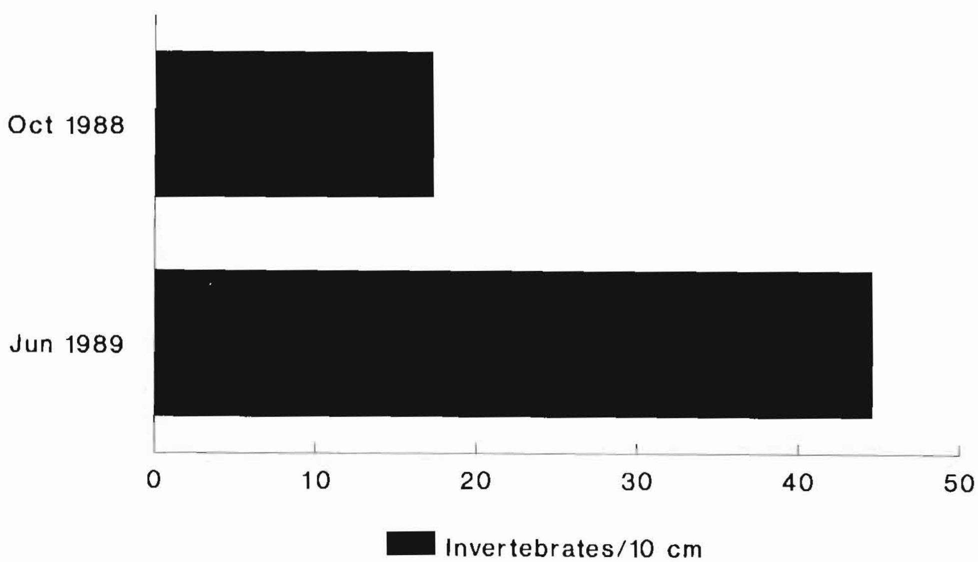
Figure 3. Effects of macrophytes on oligochaetes in Lake Seminole, Florida

dissimilar in sediment beneath *Hydrilla* versus *Hydrilla/Potamogeton* (Figure 3b). However, relative abundance of phytophilous oligochaetes was not markedly affected by plant species.

Sampling on a seasonal basis allows for determination of the effects of plant growth and senescence on macroinvertebrates. Densities of macroinvertebrates on plants tended to be greater in the spring as compared with the fall (Figure 4a,b). It is likely that plants are initially colonized by macroinvertebrates, which later emerge or migrate into the sediments. Macrophytes have a higher habitat value for macroinvertebrates in the spring and summer than they do in the fall.



a. *Ceratophyllum* in Eau Galle Reservoir, Wisconsin



b. *Hydrilla* in Lake Marion, South Carolina

Figure 4. Effects of season on macroinvertebrate density

REFERENCES

Beckett, D. M., and Lewis, P. A. 1982. "An Efficient Procedure for Slide Mounting of Larval Chironomids," *Transactions of the American Microscopical Society*, Vol 101, pp 96-99.

Carpenter, S. R., and Lodge, D. M. 1986. "Effects of Submersed Macrophytes on Ecosystem Processes," *Aquatic Botany*, Vol 126, pp 341-370.

Engel, S. 1985. "Aquatic Community Interactions of Submerged Macrophytes," Technical Bulletin No. 156, Department of Natural Resources, Madison, WI.

Engel, S. 1988. "The Role and Interactions of Submersed Macrophytes in a Shallow Wisconsin Lake," *Journal of Freshwater Ecology*, Vol 4, pp 329-341.

Gregg, W. W., and Rose, F. L. 1982. "The Effects of Aquatic Macrophytes on the Stream Micro-Environment," *Aquatic Botany*, Vol 14, pp 309-324.

Gregg, W. W., and Rose, F. L. 1985. "Influences of Aquatic Macrophytes on Invertebrate Community Structure, Guild Structure, and Microdistribution in Streams," *Hydrobiologia*, Vol 128, pp 45-56.

Gunnison, D., and Barko, J. 1989. "Effects of Benthic Barriers on Substratum Conditions," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 175-177.

McDermid, K. J., and Naiman, R. J. 1983. "MacroPhytes: Freshwater Forests of Lakes and Rivers," *The American Biology Teacher*, Vol 45, pp 144-150.

Miller A. C., and Bingham, C. R. 1987. "A Hand-Held Benthic Core Sampler," *Journal of Freshwater Ecology*, Vol 4, pp 77-81.

Miller, A. C., Beckett, D. C., and Bacon, E. J. 1989. "The Habitat Value of Aquatic Macrophytes for Macroinvertebrates: Benthis Studies in Eau Galle Reservoir, Wisconsin," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 190-201.

Pandit, A. K. 1984. "Role of Macrophytes in Aquatic Ecosystems and Management of Freshwater Resources," *Journal of Environmental Management*, Vol 18, pp 73-88.

Payne, B. S., Miller, A. C., Hartfield, P. D., and McMahon, R. F. 1989. "Variation in Size Demography of Lotic Populations of *Corbicula fluminea* Muller," *The Nautilus*, Vol 103, pp 78-82.

Pennak, R. W. 1989. *Fresh-Water Invertebrates of the United States: Protozoa to Mollusca*, 3rd ed., John Wiley and Sons, New York.

Prejs, K. 1986. "Occurrence of Stylet-Bearing Nematodes Associated with Aquatic Vascular Plants," *Ekologia Polska*, Vol 34, No. 2, pp 185-192.

Seddon, B. 1972. "Aquatic Macrophytes As Limnological Indicators," *Freshwater Biology*, Vol 2, pp 107-130.

Watkins, C. E., Shireman, J. V., and Haller, W. T. 1983. "The Influence of Aquatic Vegetation Upon Zooplankton and Benthic Macroinvertebrates in Orange Lake, Florida," *Journal of Aquatic Plant Management*, Vol 121, pp 78-83.

Evaluation of Triploid Grass Carp Introductions in Lake Marion, South Carolina: Fisheries Investigations

by
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INTRODUCTION

The US Army Engineer District, Charleston, is evaluating the use of triploid grass carp to control problem aquatic plants in Lake Marion, South Carolina. Approximately 20 percent of the littoral zone is colonized by aquatic plants, including hydrilla (*Hydrilla verticillata*). Beginning in the spring of 1989, 100,000 triploid grass carp (250 to 350 mm total length) were stocked, and the current plans are to continue this stocking rate each year over a 2-year period for a total stocking of 300,000 fish.

A 5-year monitoring plan involving three tasks is being conducted to monitor grass carp stocking. Task 1 is to monitor movements of grass carp in the Santee-Cooper reservoir system using radio telemetry; Task 2 is to document changes in the abundance of the aquatic plant community using aerial photography, and Task 3 is to evaluate the effects of grass carp on invertebrates and fishes. In addition to assessing the capability of triploid grass carp to control aquatic plants in large reservoir systems, this research project will improve the data base on the grass carp STOCK model.

The control of aquatic plants using grass carp will in part depend on their residence time in areas with dense stands of aquatic plants. Since grass carp are migratory species, there is a potential that they can move out of the area where they were released, resulting in reduced control levels of target plant species. Therefore, the objective of the radio telemetry study (Task 1) is to monitor the spatial and temporal movement of grass carp using radio-transmitter devices. This work is being conducted by Clemson University and the South Carolina Wildlife and Marine Resources Department and is scheduled for completion in September 1990.

To evaluate the effectiveness of the triploid grass carp in controlling target plants, remote sensing techniques (Task 2) will be employed to develop maps of the aquatic plant community. These maps will establish baseline plant conditions at the time of the initial grass carp stocking and will be compared to plant distributions in succeeding years. Color infrared aerial photographs at 1:10,000-scale will be acquired of Lake Marion on an annual basis, and detailed planimetric maps will be prepared that depict the distribution and aerial coverage of emergent and submersed plants. This work is being conducted by the University of Georgia.

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The remainder of this paper summarizes baseline fishery data collected from October 1988 to October 1989 (Task 3). It is anticipated that the distribution and abundance of resident fishes will be altered if grass carp gradually reduce the abundance of aquatic plants over a long-term period. Therefore, the objective of the fishery studies is to monitor changes in key population parameters (abundance, age, and growth) of native fishes and grass carp as a function of plant abundance.

STUDY SITE

Lake Marion is a 45,000-ha lake formed by the impoundment of the Santee River in 1941 by the US Army Corps of Engineers for the dual purpose of hydroelectric power generation and flood control. The study area is located in upper Lake Marion (Figure 1), from the confluence of the Congaree and Wateree Rivers (forming the Santee River) downstream to Interstate 95 bridge. Although the dominant aquatic macrophytes are hydrilla (*Hydrilla verticillata*) and Brazilian elodea (*Egeria densa*), a number of other aquatic macrophytes are present in Lake Marion (Welch, Remillard, and Slack 1988).

Three types of areas were chosen for intensive study with a variety of gear types: areas with low plant density (or no plants), areas with intermediate plant density, and areas of high plant density. In upper Lake Marion, these sites were typically composed of either hydrilla and Brazilian elodea, or a combination of these two species. Each collection site will be characterized by the following variables: plant density, plant height, plant aerial density, plant species composition, temperature, dissolved oxygen, pH, turbidity, conductivity, water depth, and site position relative to an unvegetated or main channel area in order to consider the influence of "edge effects" and "open-water" habitat on aquatic organisms.

Eight discrete sites in upper Lake Marion were selected for study. Sites 1 and 2 (Figure 1) were located in Sparkleberry Swamp, with site 1 in open water immediately above a dense cypress-tupelo stand and site 2 in the dense cypress and tupelo stand. Only electroshocking was done at sites 1 and 2. Site 3 was located at Pack's Flats, an important area for study since grass carp were released at Pack's Landing in 1989. A variety of submersed aquatic habitat types and densities were available for study in this area. Electroshocking, popnets, and larval light traps were used in this area. Site 4, sampled only by electroshocking, was on the main stem of the Santee River and represented riverine habitat. Site 5 was Elliott/Bee Tree Cut, through a variety of marsh habitats, from the Santee River through to Elliott's Flats, and was sampled by electroshocking. Site 6, sampled by electroshocking, was located in Stump Hole Swamp, an area where herbicide was being employed on a regular basis to control hydrilla. Sites 7 (Persanti Island) and 8 (Jack's Creek) were located downstream of the other six sites. These sites were added in 1989 and were sampled by electroshocking.

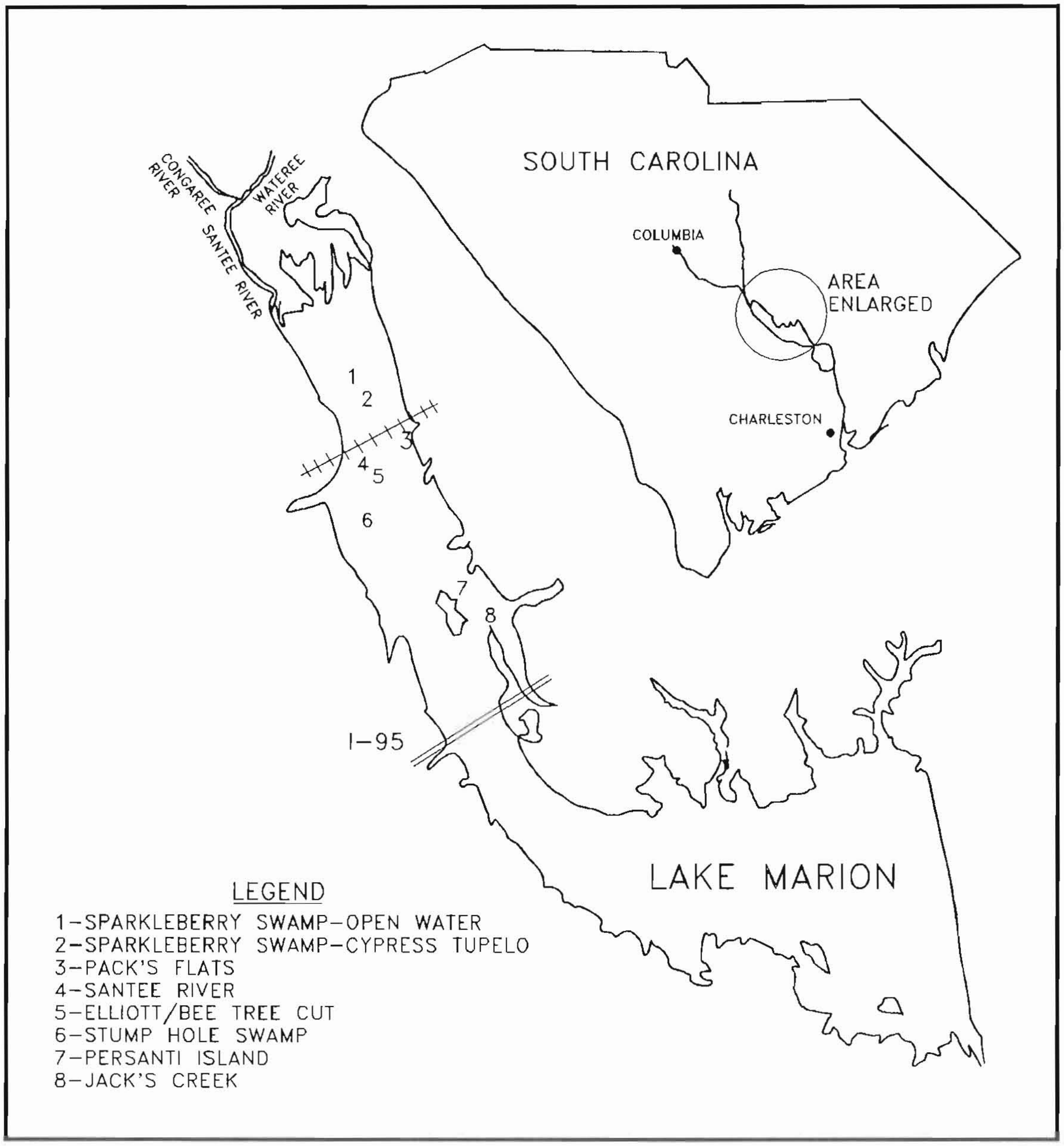

Figure 1. Study sites, Lake Marion

METHODS

A combination of electroshocking, larval light traps (Morgan, Baker, and Killgore, in review), popnets (Morgan, Killgore, and Douglas 1988), and seines was used to determine the occurrence and abundance of all size groups of fishes in submersed aquatic plants. All fish collected were identified, weighed, and measured (total length). Small specimens were preserved in 10-percent formalin and identified in the laboratory.

The boat-mounted electroshocker provided a pulsed, direct current output of approximately 400 volts at 3 to 6 amps. Usually, three 360-sec samples were made per site on each sampling date. An effort was made to collect all stunned fish. The larval light traps consisted of a clear, Plexiglas cylinder with an activated chemical light stick inserted inside to attract fishes through 5- to 10-mm slits. In October 1988, three collections were made: two 4-hr periods during two consecutive nights and a 20-hr period during the day. During each collection period, five traps were placed in dense beds of hydrilla and five were placed in an area without plants. Eight popnets (two replicates over 2 days at depths of 1.1 and 1.8 m) were set in submersed aquatic vegetation (SAV) densities of 1,700 to 2,000 g/m^2 wet weight but were spaced at different depths. In addition, four popnets (two replicates over 2 days) were placed in areas with SAV wet weight of 200 g/m^2 at water depths of approximately 2.8 m. Popnets were set in the afternoon and fished approximately 1 hr after sunset.

Effects of grass carp introductions on largemouth bass will be monitored through analyses of growth rates based on weight-length data and aging of scales and otoliths. The analyses of growth rates will be a long-term project and cannot be completed until after the last year's collection of samples. In this report, species richness, density (number/m^2), and length-frequency distributions will be summarized.

RESULTS

A total of 49 fish species from 17 families were collected with four gear types during 1988 and 1989 (Table 1). Except for the introduced triploid grass carp, the remaining fishes represent a species assemblage typical of southern coastal systems. Forty-five species were collected by electroshocking, 6 species by larval light traps, 19 species by popnets, and 8 species by seines (Table 2).

Popnets

Popnets were set in October 1988, to be followed by successive popnet sampling during the same time period until 1992. Hurricane Hugo passed through the Lake Marion area just prior to the scheduled sampling in October 1989, causing massive changes throughout the drainage basin, including high water levels resulting in high turbidities and scouring of plant beds. The most evident illustration of damage to the lake ecosystem was the massive fish kill, probably caused by a reduction in dissolved oxygen. Dissolved oxygen concentrations on 11 October 1989 were still low (1.5 to 5.8 mg/ℓ) throughout all of the sampling sites. In the popnet sampling area (site 3, Figure 1) where submersed aquatic vegetation was normally dense, dissolved oxygen

Table 1
Scientific and Common Names of Fishes Collected from Lake Marion, South Carolina, During Sampling in 1988 and 1989

Species	*Common Name*
Amiidae	
Amia calva	Bowfin
Anguillidae	
Anguilla rostrata	American eel
Aphredoderidae	
Aphredoderus sayanus	Pirate perch
Atherinidae	
Labidesthes sicculus	Brook silverside
Menidia beryllina	Inland silverside
Catostomidae	
Erimyzon sucetta	Lake chubsucker
Ictiobus bubalus	Smallmouth buffalo
Minytrema melanops	Spotted sucker
Centrarchidae	
Centrarchus macropterus	Flier
Enneacanthus chaetodon	Blackbanded sunfish
Enneacanthus gloriosus	Bluespotted sunfish
Enneacanthus obesus	Banded sunfish
Lepomis gulosus	Warmouth
Lepomis macrochirus	Bluegill
Lepomis marginatus	Dollar sunfish
Lepomis microlophus	Redear sunfish
Lepomis punctatus	Spotted sunfish
Micropterus salmoides	Largemouth bass
Pomoxis nigromaculatus	Black crappie
Clupidae	
Alosa aestivalis	Blueback herring
Alosa sapidissima	American shad
Dorosoma cepedianum	Gizzard shad
Dorosoma petenense	Threadfin shad
Cyprinidae	
Cyprinus carpio	Common carp
Ctenopharyngodon idella	Grass carp
Hybognathus regius	Eastern silvery minnow
Notemigonus crysoleucas	Golden shiner
Notropis petersoni	Coastal shiner
Notropis niveus	Whitefin shiner

(Continued)

Table 1 (Concluded)

Species	*Common Name*
Cyprinodontidae	
Fundulus chrysotus	Golden topminnow
Esocidae	
Esox niger	Chain pickerel
Ictaluridae	
Ictalurus furcatus	Blue catfish
Ictalurus natalis	Yellow bullhead
Ictalurus nebulosus	Brown bullhead
Ictalurus punctatus	Channel catfish
Pylodictis olivaris	Flathead catfish
Noturus gyrinus	Tadpole madtom
Amblyopsidae	
Chologaster cornuta	Swampfish
Lepisosteidae	
Lepisosteus oculatus	Spotted gar
Lepisosteus osseus	Longnose gar
Mugilidae	
Mugil cephalus	Striped mullet
Percichtyidae	
Morone americana	White perch
Morone chrysops	White bass
Morone saxatilis	Striped bass
Percidae	
Etheostoma olmstedi	Tesselated darter
Perca flavescens	Yellow perch
Poeciliidae	
Gambusia affinis	Mosquitofish
Heterandria formosa	Least killifish
Umbridae	
Umbra pygmaea	Eastern mudminnow

Table 2
Species Collection by Gear Type for Fishes Collected from Lake Marion, South Carolina, During Sampling in 1988 and 1989

	Collection Technique			
Species	***Electroshocking***	***Light Trap***	***Popnet***	***Seine***
Alosa aestivalis	X			
Alosa sapidissima	X		X	
Amia calva	X			
Anguilla rostrata	X			
Aphredoderus sayanus			X	
Centrarchus macropterus	X			
Chologaster cornuta	X			
Ctenopharyngodon idella	X			
Cyprinus carpio	X			
Dorosoma cepedianum	X		X	
Dorosoma petenense	X		X	
Enneacanthus chaetodon	X		X	
Enneacanthus gloriosus	X		X	
Enneacanthus obesus	X			X
Enneacanthus sp.			X	
Erimyzon sucetta	X		X	
Esox niger	X			
Etheostoma olmstedi				X
Fundulus chrysotus	X			X
Gambusia affinis	X	X	X	X
Heterandria formosa	X			
Hybognathus regius	X			
Ictalurus furcatus	X			
Ictalurus natalis	X			
Ictalurus nebulosus	X			
Ictalurus punctatus	X			X
Ictiobus bubalus	X			
Labidesthes sicculus			X	

(Continued)

Table 2 (Concluded)

Species	Collection Technique: Electroshocking	Light Trap	Popnet	Seine
Lepisosteus oculatus	X			
Lepisosteus osseus	X			
Lepomis gulosus	X	X	X	
Lepomis macrochirus	X	X	X	
Lepomis marginatus	X			X
Lepomis microlophus	X		X	
Lepomis punctatus	X	X	X	X
Lepomis sp.			X	
Menidia beryllina	X	X	X	
Micropterus salmoides	X			
Minytrema melanops	X			
Morone americana	X			
Morone chrysops	X			
Morone saxatilis	X			
Mugil cephalus	X			
Notemigonus crysoleucas	X		X	
Notropis petersoni	X			X
Notropis niveus	X			
Notropis sp.		X	X	
Noturus gyrinus	X			
Perca flavescens	X			
Pomoxis nigromaculatus			X	
Pylodictis olivaris	X			
Umbra pygmaea	X			
Total number of species collected by gear type	45	6	19	8

levels were 0.5 mg/ℓ on the bottom and 1.5 mg/ℓ on the surface. Because of aberrant dissolved oxygen concentrations at site 3 in 1989, popnet sampling was not done.

Popnet data from 1988 (Figure 2) illustrated the size distribution of fishes associated with SAV. The more inshore SAV set was closer to shore, and all of the fishes caught were smaller than observed in the other habitats. The fish caught in SAV from 1.8 m were larger than the shallower set, but smaller than the deep set. Not only were the fish larger in the deeper open-water set, but the species composition changed to more open-water species (Table 2) such as clupedids. Fish densities (number/m^2 ± 1 standard deviation, SD) in the 1.1-m popnet sets averaged 3.0 ± 2.1. Densities in the 2.1-m SAV set averaged 1.6 ± 1.1 and 0.58 ± 0.7 in the 2.8-m set.

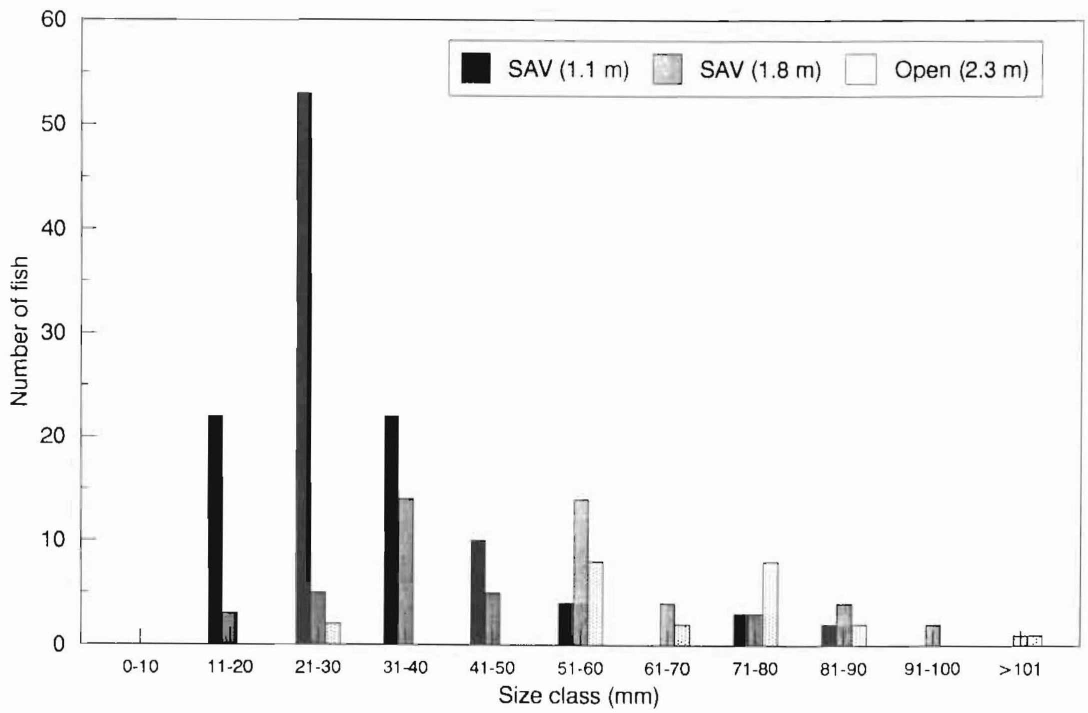

Figure 2. Size frequency distribution (millimeters) for fishes caught in popnets from Lake Marion in 1988

Larval light traps

The majority of fish captured in the larval light traps in October 1988 were between 20 and 50 mm total length. Preliminary data from 1988 indicated only minor differences in fish captures between vegetated and nonvegetated habitat at site 3 (Figure 1). For 4-hr night sets, the difference in catch (number/hour ± 1 SD) was 0.04 ± 0.11 in no vegetation versus 0.15 ± 0.14 fish/hr in the vegetated habitat for one sample period and 0.04 ± 0.11 versus 0.65 ± 1.05 for a second set of samples taken the next day. For the day set, the difference was 0.01 ± 0.23 for nonvegetated habitat and 0.35 ± 0.20 for the vegetated habitat. Fishes captured in the nonvegetated sites were more open-water species, while the species composition in the vegetated habitat was more similar to the fish assemblage captured in the SAV samples taken in the popnets.

Electroshocking

Electroshocking was employed primarily to determine the abundance of larger fish species not normally collected by either larval light traps or popnets and to collect largemouth bass for growth studies. Over the course of four sampling periods, a total of 45 species were collected by electroshocking.

Larger species associated with site 3 (Figure 1) were spotted gar, gizzard shad, carp, largemouth bass, striped mullet, chain pickerel, and spotted sucker, all larger species rarely collected in popnets. Depending on the specific location at site 3, the number of species collected ranged from 5 to 7 and 26 to 56 individuals per set of three removals. Following Hurricane Hugo in October, only a few specimens of gizzard shad were collected at site 3; dissolved oxygen was 1.5 mg/ℓ because of decaying vegetation.

Sparkleberry Swamp sites 1 and 2 were of interest because of the difference in habitat structure to site 3 at Pack's Flats--the popnet area. During the October 1988 sampling, species numbers ranged from 7 to 8 and 17 to 23 individuals at the two sites. At site 2 in April 1989, the number of species was nine with 46 individuals collected. However, in sampling site 2 during June 1989, no fish were collected because of a dissolved oxygen sag. Low dissolved oxygen was apparently prevalent in this area during late spring and resulted in substantial fish kills. Following Hugo, only six species were collected in October, although the oxygen level had risen to 4.3 mg/ℓ.

Stump Hole Swamp (site 6) was of interest because of the use of herbicides to control SAV. Fishes (nine species, 135 individuals) were abundant in April 1989, followed by a decline in June (eight species, 12 individuals). Following Hugo, 25 individuals of eight species were collected.

The Santee River (site 4) collections were dominated by fishes associated with riverine habitat (eight species and 636 individuals in April 1989, ten species and 52 individuals in June, and nine species and 145 individuals in October), especially threadfin shad and white perch. Site 5 was a channel connecting the Santee River to Elliott's Flats, with a diversity of habitats present. Eighteen species and 95 individuals were collected in October 1988, eighteen species and 166 individuals in April 1989, eleven species and 27 individuals in June 1989, and eleven species and 28 individuals in October 1989. Site 5 had the most diversity of species among all the sites. The sites at Persanti Island and Jack's Creek (7 and 8) were only sampled in October 1989 following Hurricane Hugo. Nine species and 57 individuals were collected at site 7, and ten species and 71 individuals at site 8.

Seining

Only limited seining work was done in upper Lake Marion because of the lack of suitable areas. Eight species (Table 2) were collected by seining, but these were collected by other techniques.

DISCUSSION

Any alteration of SAV will influence the distribution and abundance of fishes associated with this habitat. The importance of SAV to fishes is based primarily on the additional structure provided (Crowder and Cooper 1979), resulting in the formation of structurally complex habitat. Fish abundance is normally higher in areas with aquatic plants (Laughlin and Werner 1980; Holland and Huston 1984; Killgore, Morgan, and Rybicki 1987), but high densities of SAV may limit foraging success (Durocher, Provine, and Kraai 1984; Wiley et al. 1984). However, biological or chemical control of SAV is often needed because of reduced access to marinas and boat landings as well as impacts to other water uses.

Recent work by Crane (1986) documented the abundance of a number of fishes in Lake Marion associated with SAV, especially with an emphasis to growth rates. Crane found large fishes to be more abundant in vegetated areas while young-of-the year were abundant in nonvegetated areas. However, all of the sampling work was done using electroshocking which usually underestimates the density of small fishes in dense SAV. In addition, growth rates tended to be faster in vegetated areas than in nonvegetated areas, and relative condition of fishes was better in the vegetated habitat.

The current monitoring work illustrated the importance of aquatic vegetation to fishes as well as the variety of techniques to be employed to evaluate the impact of grass carp introductions. Associated with the distinct habitats in Lake Marion are a large number of species, with many having high abundances. Unfortunately, the path of Hurricane Hugo effectively altered the lake ecosystem, at least on a short-term basis. In addition, low dissolved oxygen during the spring and early summer in the area north of Pack's Flats is of concern to the success of the grass carp project. There are no reliable estimates on mortality of grass carp resulting from the two major fish kills that occurred in the spring of 1989 and following Hugo. However, future monitoring work and stocking strategy of grass carp will have to take these impacts into account.

ACKNOWLEDGMENTS

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REFERENCES

Crane, J. S. 1986. "Fish Community Structure in Weeded and Non-weeded Habitat in Lake Marion, South Carolina," Job Completion Report WC-3, October 15, 1984 - June 30, 1986, Wateree-Congaree Project, South Carolina Wildlife and Marine Resources Department.

Crowder, L. B., and Cooper, W. E. 1979. "Structural Complexity and Fish-Prey Interactions in Ponds: A Point of View," *Response of Fish to Habitat Structure in Standing Water*, D. L. Johnson and R. A. Stein, eds., North Central Division Special Publication 6, American Fisheries Society, Bethesda, MD, pp 2-10.

Durocher, P. P., Provine, W. C., and Kraai, J. E. 1984. "Relationship Between Abundance of Largemouth Bass and Submerged Vegetation in Texas Reservoirs," *North American Journal of Fisheries Management*, Vol 4, pp 84-88.

Holland, L. E., and Huston, M. L. 1984. "Relationship of Young-of-the-Year Northern Pike to Aquatic Vegetation Types in Backwaters of the Upper Mississippi River," *North American Journal of Fisheries Management*, Vol 4, pp 514-522.

Killgore, K. J., Morgan, R. P., and Rybicki, N. B. 1987. "Seasonal and Temporal Distribution and Abundance of Fishes Associated with Submersed Aquatic Plants," *North American Journal of Fisheries Management*, Vol 9, pp 101-111.

Laughlin, D. R., and Werner, E. E. 1980. "Resource Partitioning in Two Coexisting Sunfish: Pumpkinseed (*Lepomis gibbosus*) and Northern Longear Sunfish (*Lepomis megalotis peltastes*)," *Canadian Journal of Fisheries and Aquatic Sciences*, Vol 37, pp 1411-1420.

Morgan, R. P., II, Baker, J. A., and Killgore, K. J. "Description of a Larval Light Trap," *North American Journal of Fisheries Management* (in review).

Morgan, R. P., II, Killgore, K. J., and Douglas, N. H. 1988. "Modified Popnet Design for Collecting Fishes in Varying Depths of Submersed Vegetation," *Journal of Freshwater Ecology*, Vol 4, pp 533-539.

Welch, R., Remillard, M. M., and Slack, R. B. 1988. "Remote Sensing and Geographic Information System Techniques for Aquatic Resource Evaluation," *Photogrammetric Engineering and Remote Sensing*, Vol 54, pp 177-185.

Wiley, M. J., Gorden, R. W., Waite, S. W., and Powless, T. 1984. "The Relationship Between Aquatic Macrophytes and Sport Fish Production in Illinois Ponds: A Simple Model," *North American Journal of Fisheries Management*, Vol 4, pp 111-119.

An Overview of Competition Studies and the Development of the Lewisville Aquatic Plant Research Facility

by
R. Michael Smart*

AQUATIC PLANT COMPETITION

While it is widely held that weedy species such as *Hydrilla* and Eurasian watermilfoil can outcompete (and thus displace) most native species such as *Vallisneria*, this occurrence has not been adequately documented. There are, in fact, indications that native vegetation can persist over long periods, even when surrounded by weedy species. Weedy species thus may not be able to competitively displace native species; however, they are capable of more rapidly exploiting both newly created habitats and open habitats resulting from disturbance of existing plant communities. The primary competitive advantage held by weedy species may thus be their ability to rapidly colonize available habitats through fragmentation and rapid dispersal of propagules. In examining interactions among species we must, therefore, broaden our consideration of environmental conditions to include both availability of habitat and the frequency of disturbance. Rapid reproduction rates, wide dispersal patterns, and regrowth from perennating organs such as tubers are biological characteristics that will convey competitive advantages under conditions of frequent disturbance.

The goal of aquatic plant control efforts in the past was often been the complete eradication of aquatic vegetation. However, frequent removal of existing vegetation may actually promote the proliferation of weedy species that are well adapted for recolonization or invasion following disturbance. Recently, resource managers are beginning to realize that the removal of all vegetation is neither practicable nor desirable. One approach to aquatic plant control might be to control vegetation only in the more critical areas and to promote the development of native plant communities in the surrounding areas. By surrounding trouble spots with more desirable species, we may be able to slow the spread of weedy species, thus reducing the need for continual control measures.

The objective of the research is to examine competitive interactions occurring among submersed aquatic plant species. Particular attention will be given to identifying important factors and mechanisms involved in competition between introduced weedy species and native nonweedy species. To identify the factors involved, we have studied competitive interactions between species grown under different environmental conditions in controlled-environment facilities (Smart and Barko 1989; McCreary, McFarland, and Barko 1990). These studies have indicated that sediment nitrogen availability is likely to affect competition between rooted submersed aquatic plants. Controlled-environment studies will be followed by longer term studies

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conducted in ponds to verify research findings and to further elucidate mechanisms involved in competition between different species. These studies will be conducted at the Lewisville Aquatic Plant Research Facility.

LEWISVILLE AQUATIC PLANT RESEARCH FACILITY

In March 1988 the Waterways Experiment Station (WES) acquired the use of a 125-acre property formerly operated as a fish hatchery by the Texas Department of Parks and Wildlife (Figure 1). The property, consisting of 55 earthen ponds, a laboratory building, and several outbuildings, is located in Lewisville, Texas, adjacent to Lewisville Lake, a Corps of Engineers reservoir. The facility is being developed and used by the Aquatic Plant Control Research Program (APCRP) as a national center for aquatic plant research. Research conducted at the facility will support each of the technology areas included in the APCRP.

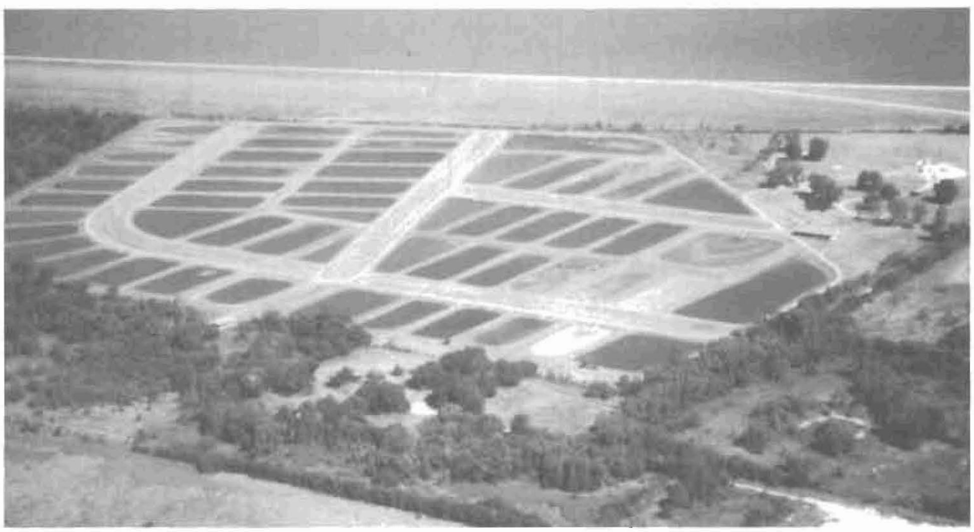

Figure 1. Aerial view of the Pond facility with Lewisville Lake in the background

The ponds range in size from 0.5 to 2 acres, with a maximum depth of 7 to 8 ft (Figure 2). Gravel roadways completely encircle the facility, and wide berms surround each of the ponds, providing easy vehicular access to all sides of the ponds. Each of the ponds is equipped with independent controls for filling and draining, allowing investigators to vary water conditions as needed. Water for filling the ponds is supplied from Lewisville Lake.

A 2,700-sq ft building has been renovated for use as an onsite laboratory. A weather station has also been installed at the site to obtain a continuous record of environmental factors affecting plant growth such as air, water, and sediment temperatures, solar radiation, wind speed and direction, and rainfall.

Figure 2. Plan of the pond facility

Pond preparation and planting methods were developed during 1989, and several species of submersed aquatic plants, including *Hydrilla verticillata, Myriophyllum spicatum, Egeria densa,* and *Vallisneria americana*, were collected and planted in stock culture ponds. Growth of these plants will be monitored to obtain basic information on their life cycles, and these plants will also be used for establishing populations in research ponds. Several research projects have been initiated at the facility, including studies of the life cycle of waterhyacinth and a field test of the efficacy of a commercial formulation of a microbial pathogen for control of Eurasian watermilfoil. Several additional research projects are scheduled to be conducted at the facility during 1990. These projects include studies of plant competition, the effects of aquatic plants on fish and invertebrates, and the efficacy and environmental effects of benthic barriers.

The acquisition of this facility has greatly expanded the research capabilities under the APCRP by filling the gap between small-scale laboratory studies and large-scale field testing. It is often difficult to extrapolate research results obtained in short-term laboratory studies to the prediction of events occurring over longer time scales in large and complex reservoirs and waterways. Research conducted in ponds will thus be of great value in extending research results to the "real world."

REFERENCES

Smart, R. M., and Barko, J. W. 1989. "Competitive Interactions of Submersed Aquatic Macrophytes in Relation to Water Chemistry and Other Environmental Conditions," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 159-164.

McCreary, N. J., McFarland, D. G., and Barko, J. W. 1990. See pp 171-182 in this proceedings.

Environmental Factors Influencing Gas Evolution Beneath a Benthic Barrier

by
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INTRODUCTION

Benthic application of barrier fabrics provides a means to physically limit nuisance growths of aquatic plants.** Benthic barriers afford an attractive alternative to many other types of control, because they can be deployed once and left in place for an entire growing season, thus eliminating the need for repetitive treatment efforts. However, before widespread use of benthic barriers can be advocated for Corps of Engineers water resources projects, it is important that the effectiveness and environmental consequences of barrier placement be thoroughly understood.

Benthic barriers are supposedly gas permeable; that is, some degree of gas diffusion through the barrier fabric is possible. This property is desirable to (a) allow gases to escape from beneath the barrier and (b) permit continuous renewal of dissolved oxygen levels at the sediment surface. The former process is essential to prevent pockets of gas from developing and buoying the overlying barrier fabric up to the water surface, where wind and wave action can then displace the barrier from the original site of placement. The latter process is necessary to support the degradation process and permit benthic fauna to survive at normal composition and densities.

This work unit was initiated in July 1988 to provide quantitative information on the effectiveness and environmental effects of benthic barriers. The specific objective of the work described herein was to evaluate the effects of key environmental factors on the rate of formation and composition of gases released beneath a barrier.

METHODS AND MATERIALS

Plastic trays were filled with either Brown's Lake (WES) sediment (BLS) or a washed masonry sand intermixed with 25 percent (v/v) BLS. Sediments receiving organic amendments were treated with an addition of 13 g of freeze-dried *Ceratophyllum* (roughly equivalent to 200 g plant material/m^2 surface area). Both amended and unamended sediments were covered with 2 cm of washed masonry sand. Gases evolved from sediments were captured under barrier fabric welded to an inverted funnel that was held above the sediment surface on a tripod (Figure 1a). Trays and their fabric-and-trap covers (collectively termed "flats") were placed on the bottom of constant-temperature water tanks maintained at either 15° or 30° C. The

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*US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

**G. D. Cooke. 1986. "Sediment Surface Covers for Macrophyte Control," *Lake and Reservoir Restoration*, G. D. Cooke et al., eds., Butterworth Publishers, Stoneham, MA.

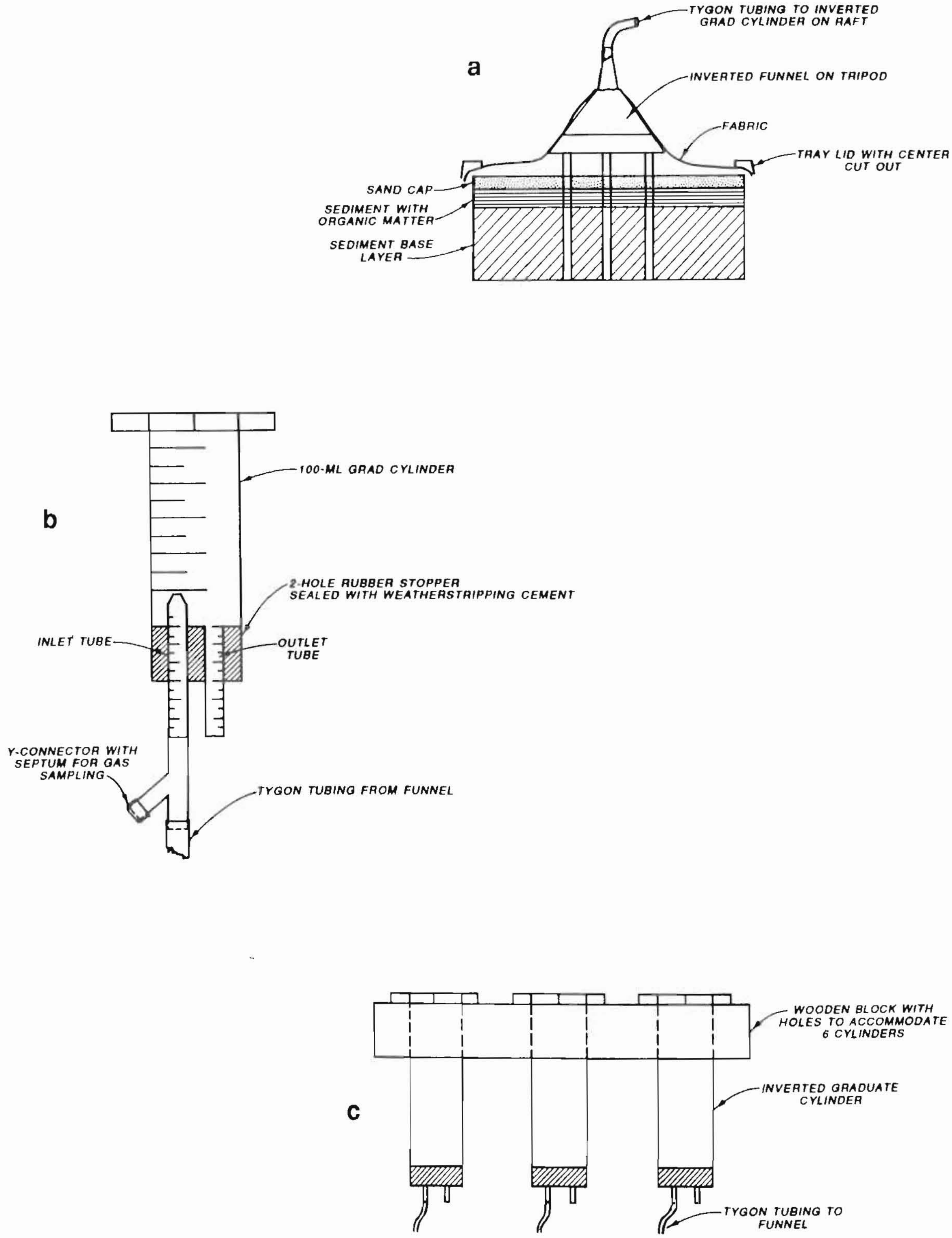

Figure 1. Major components of the sediment tray and trap system: (a) sediment tray showing sediment composition and funnel and barrier fabric trap on tripod, (b) inverted graduate cylinder with inlet and outlet devices, and (c) support raft

funnel from each flat was attached to tubing that ran up to an inverted graduate cylinder designed to collect gases through water displacement (Figure 1b). Sets of six of the graduate cylinder traps were suspended from the water surface on a raft (Figure 1c).

Gas evolution rates for individual treatments were determined by monitoring twice weekly the volume of gas trapped in cylinders attached to replicate flats. Samples were collected and analyzed for gas composition once each week. Gas samples were injected into a Packard Model 419 Gas Chromatograph (Packard Instruments, Inc., Downers Grove, Illinois) equipped with an Alltech CRT-1 dual gas separation column (Alltech, Inc., Deerfield, Illinois) attached to a thermal conductivity detector. Helium was used as the carrier gas under ambient temperature conditions at a flow rate of 60 ml/min.

Statistical determinations of gas evolution data and comparison of treatment effects were conducted using the SAS system for data analysis (SAS Institute, Inc., Cary, North Carolina). Statements of significance were limited to those analyses having a probability of 99 percent ($p < 0.01$) or better.

RESULTS AND DISCUSSION

Rates of gas release from the various treatment combinations are depicted in Figure 2. Unamended sediments maintained at 15° C produced no gas. Unamended sediments consisting of sand mixed with BLS and held at 30° C produced a brief release of gas only at day 43, achieving a rate of 0.202 ml/m^2/hr. By contrast, unamended BLS sediments held at 30° C produced gas, albeit very erratically and at a low rate, reaching a maximum of 2.82 ml/m^2/hr at 48 days, before dropping back to 1.13 ml/m^2/hr at 56 days.

All sediments amended with plant material produced gas, but there were some notable differences in production rates achieved at different temperatures and with different substrates (Figure 2). Sand mixed with BLS and held at 15° C had a very low production rate, first becoming apparent at day 20, reaching a maximum of 12.6 ml/m^2/hr at day 27, and slowly declining toward the origin, reaching 2.72 ml/m^2/hr at day 56. The same material held at 30° C exhibited a moderate production rate starting on the seventh day of incubation, peaking on the twelfth day at a rate of 42.1 ml/m^2/hr, and then gradually declining to baseline levels by day 56. BLS amended with plant material and held at 15° C also showed a low gas production rate, first becoming evident on day 15 and reaching a peak of 17.7 ml/m^2/hr on day 20, before falling off to 1.65 ml/m^2/hr on day 56. BLS with organic matter held at 30° C had the highest gas production rate of all combinations tested, with releases first appearing on day 3 and reaching a peak of 123 ml/m^2/hr on day 7. Here release rates fell markedly at first, then gradually reached a value of less than 1.00 ml/m^2/hr by day 56.

Gas composition patterns demonstrated a marked similarity between different treatments and incubation temperatures. This was particularly true of methane and carbon dioxide contents, as shown in Figure 3. Methane and carbon dioxide first appeared at detectable levels in the amended treatments held at 30° C. These gases appeared next

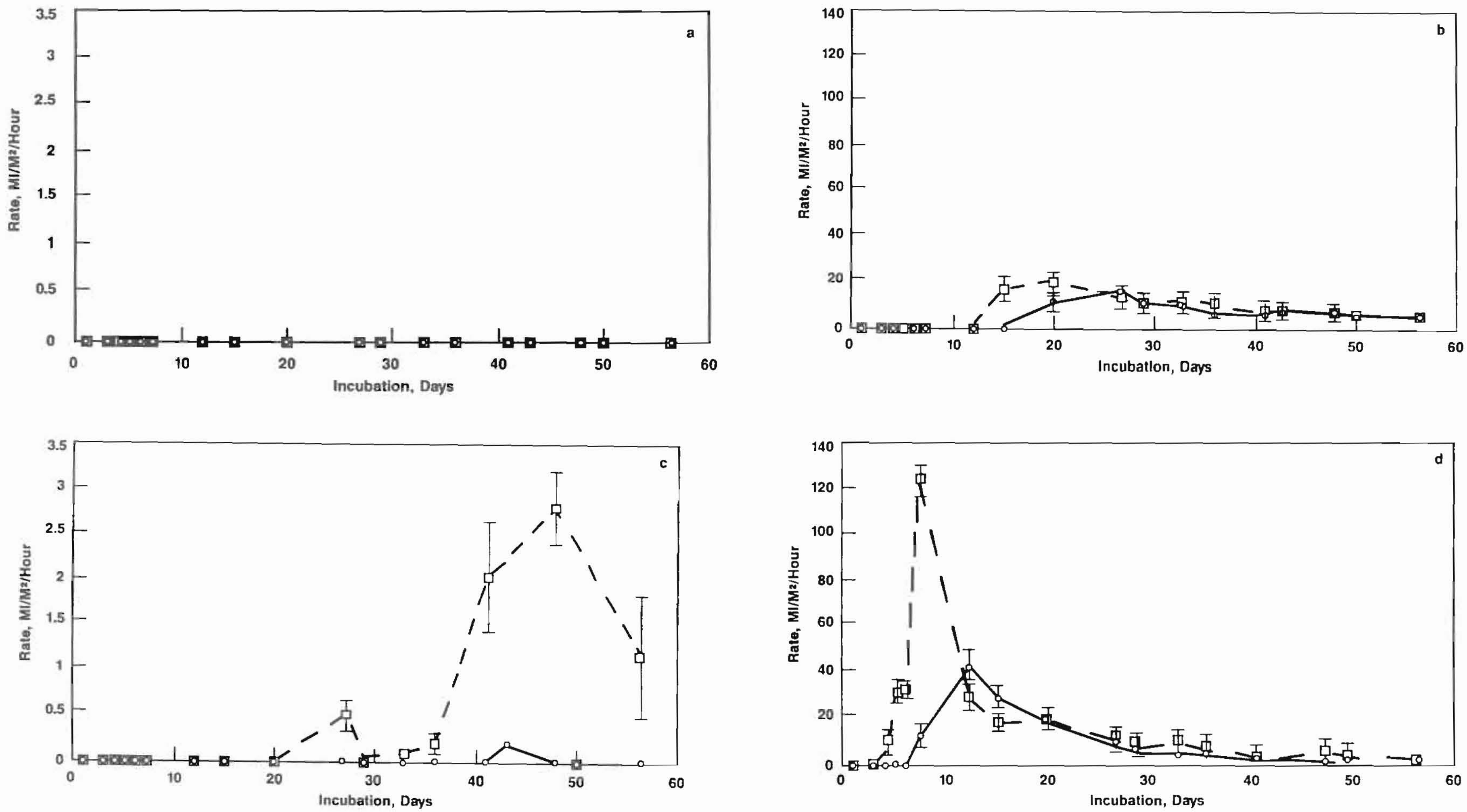

Figure 2. Gas evolution rates for BLS and sand sediments: (a) unamended sediments at 15° C, (b) unamended sediments at 30° C, (c) amended sediments at 15° C, and (d) amended sediments at 30° C. Dotted lines represent Brown's Lake sediments, and solid lines represent sand amended with Brown's Lake sediments

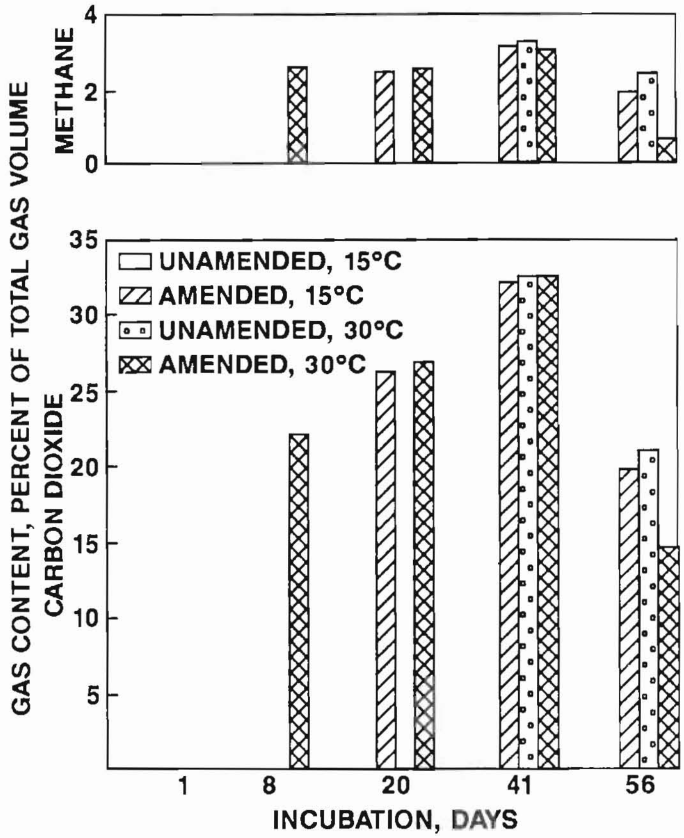

Figure 3. Methane and carbon dioxide contents of gas releases from unamended and amended sediments at 15° and 30° C. Because there was so little difference between the two sediment types, data for Brown's Lake and sand sediments were pooled to produce this figure. Neither of the unamended sediments held at 15° C released any gas

in amended treatments held at 15° C, with the levels in these treatments being nearly the same as those in the 30° C treatments. Methane and carbon dioxide appeared last in the unamended treatments held at 30° C; again, the levels of these gases were similar to those in the other treatments. The ratio of carbon dioxide to methane was maintained at nearly 10:1 over the entire course of the incubation.

The presence of organic matter had the most marked effect on gas evolution rate and gas composition. Temperature followed by substrate had the next most important influence on gas evolution rate. Temperature-substrate interactions followed by substrate had the next most important effects on gas composition.

Interestingly, oxygen remained at detectable levels throughout the incubation period in all units, never dropping below 5 percent of the total gas volume. The formation of an iron oxide coating, both on the sediment surface and the inside face of the barrier fabric in those treatments containing an organic amendment, provided further evidence for the presence of oxygen in the flats. This coating forms when dissolved iron released by sediment oxidizes in the presence of oxygen to form iron oxides. Under anaerobic conditions, iron oxides disappear as microbial reduction produces soluble ferrous iron. The presence of oxygen also helps to explain the low levels of methane and high levels of carbon dioxide encountered in this study. The presence of oxygen and methane supports the growth of methanotrophic (methane-consuming) bacteria, which then utilize these substrates to produce carbon dioxide and water. Apparently, the barrier fabric permitted some dissolved oxygen to diffuse into the flats, which otherwise would have been expected to become anaerobic. Some methane may have been lost from the flats to the surrounding tank water by this same mechanism. Dissolved oxygen may also have been incorporated through entrainment by bubbles rising from the sediment.

The presence of organic matter is an important factor in determining the rate and extent of gas formation under a barrier. The results of this study indicate that for areas having high densities of rooted aquatic plants, the desirable time for barrier deployment is during those times of the year when the standing crop of plants is low. If the plants are present year-round, the next most important factor to consider is the water temperature. Barriers should be emplaced during the colder months of the year when microbial decomposition of plants and other organic matter is at a low point, thus decreasing the release of barrier-buoying gas.

FUTURE WORK

The obvious question that follows from this work is: Is there a critical density of plant material, below thich there is no significant gas formation? This question is presently being addressed using organic matter amendments in a log-order progression--0.01, 0.1. 1, and 10 times the amount used in the study presented here. Future lab studies will examine the effects of different types of organic matter amendments on gas evolution rates.

Future studies will involve comparative field studies to determine the environmental effects of barriers in a wide variety of situations. Investigations will focus primarily on effects of barriers on the interstitial water chemistry and benthic invertebrate populations of the underlying sediment. Present and possible future sites include Lake Guntersville, Eau Galle Reservoir, and the experimental pond facility at Lewisville, Texas.

ACKNOWLEDGMENTS

The authors thank Harry L. Eakin and Dwilette G. McFarland for their assistance in the design of the study. Harry L. Eakin and Gail Bird conducted the laboratory analyses. Dwilette G. McFarland, Monica Humphrey, Cynthia B. Price, and Wanda Dee performed the greenhouse work. Support for this study was provided by a work unit of the Aquatic Plant Control Research Program.

COMPUTER-AIDED SIMULATION PROCEDURES

Simulation Technology Development: An Overview

by
R. Michael Stewart*

INTRODUCTION

Personal computer-based software packages are being developed under the Aquatic Plant Control Research Program (APCRP) to model/simulate the interactions among nuisance aquatic plants and control techniques implemented for their management. The work includes development of plant growth simulation models for four exotic plant species; biological control simulation models for certain insects and fish; and chemical control simulation models for commonly used herbicides labeled for aquatic plant application. Environmental data are being compiled in a digital format compatible with the simulation models to allow simulations to be produced for site-specific conditions.

Simulation Technology Development research tasks have been grouped within four technical areas: (a) plant growth simulation research, (b) biological control simulation research, (c) chemical control simulation research, and (d) aquatic plant database development. A brief summary of work completed under each of these technical areas during FY 89, and work planned for FY 90, is presented in the following sections.

PLANT GROWTH SIMULATION RESEARCH

FY 89 accomplishments

Plant growth simulation research conducted during FY 89 focused on developing improved relationships for the first-generation dioecious hydrilla plant growth model and initiating development of a first-generation Eurasian watermilfoil plant growth model. Wooten** briefly describes the results of these efforts.

FY 90 scheduled work

Field and laboratory experiments will be conducted during FY 90 to collect data needed to perform validation tests of existing plant growth models for waterhyacinth, hydrilla, and Eurasian watermilfoil. Waterhyacinth data collection efforts will be conducted at the Lewisville Aquatic Plant Research Facility, Lewisville, Texas, under a cooperative effort with researchers in other APCRP technology areas. Hydrilla and Eurasian watermilfoil data collection efforts will be conducted as part of the joint Tennessee Valley Authority (TVA)/USACE, WES project for aquatic plant management in Guntersville Reservoir.

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*US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.
**J. W. Wooten. 1990. See pp 236-242 in this proceedings.

BIOLOGICAL CONTROL SIMULATION RESEARCH

FY 89 accomplishments

Biological control simulation research conducted during FY 89 focused on revising the diploid white amur stocking rate model (AMUR/STOCK Version 1.0). The revised model (AMUR/STOCK Version 1.5) is described in Boyd and Stewart;* also reported in this paper are preliminary simulation results for several stocking scenarios of triploid white amur in Guntersville Reservoir.

FY 90 scheduled work

Data collection efforts will be initiated for verifying assumptions and testing relationships included in the AMUR/STOCK (Version 1.5) model. These data collection efforts will be conducted under the joint TVA/WES project for management of aquatic plants in Guntersville Reservoir. Data collected during FY 90 will represent white amur impacts during the first poststocking year. These data should be useful for verifying assumptions made in the AMUR/STOCK (Version 1.5) model regarding feeding preferences by white amur for the different plant species occurring in Guntersville Reservoir (Boyd and Stewart).*

CHEMICAL CONTROL SIMULATION RESEARCH

FY 89 accomplishments

Chemical control simulation research conducted during FY 89 included further development of the HERBICIDE model for waterhyacinth and 2,4-dichlorophenoxyacetic acid (2,4-D DMA). The revised model, HERBICIDE (Version 2.0), is briefly described by Clifford, Rodgers, and Stewart (1990).** These same authors also present comparisons of simulation results produced by the HERBICIDE (Version 2.0) model with actual measurements of 2,4-D residues in waterhyacinth plant tissues and water samples from a small-scale field study conducted near Wallisville, Texas.

FY 90 scheduled work

Further development of the HERBICIDE model will be continued during FY 90 to include algorithms for other aquatic herbicides and target aquatic plants. Fate and effects algorithms will be developed for diquat application to waterhyacinth and for 2,4-D (BEE), diquat, endothall, and fluridone application to hydrilla and Eurasian watermilfoil. Plant growth modules for hydrilla and Eurasian watermilfoil will be coupled to the fate and effects modules so simulations can be generated for regrowth of these plants following a herbicide application.

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*W. A. Boyd and R. M. Stewart. 1990. See pp 243-256 in this proceedings.

**P. A. Clifford, J. H. Rodgers, Jr., and R. M. Stewart. 1990. See pp 257-266 in this proceedings.

AQUATIC PLANT DATABASE DEVELOPMENT

FY 89 accomplishment

Development of a digital database for Guntersville Reservoir environmental data was initiated in FY 89. Kress, Causey, and Ballard* briefly describe the structure and components of this database and provide example applications of the database as an aquatic plant management tool.

FY 90 scheduled work

During FY 90, software interfaces will be developed to link plant growth simulation models for hydrilla and Eurasian watermilfoil to the Guntersville Reservoir digital database. Applications of the linked software package for aquatic plant management decision making will be demonstrated.

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*M. R. Kress, E. M. Causey, and J. R. Ballard, Jr. 1990. See pp 267-278 in this proceedings.

Plant Growth Simulation Models for Hydrilla and Eurasian Watermilfoil

by
Jean W. Wooten*

INTRODUCTION

The purposes of this paper are to describe changes made to the first-generation computer simulation model for dioecious hydrilla growth and to provide a brief overview of the new model for simulation of Eurasian watermilfoil growth.

HYDRILLA MODEL

The conceptual design of the first-generation dioecious hydrilla plant growth simulation model is presented in Wooten and Akbay (1988). Wooten (1989) describes development of the hydrilla model and includes comparisons of simulation results of hydrilla biomass from the model with biomass estimates from field samples collected monthly from Lake Conway, Florida, during 1977. These comparisons, shown here as Figure 1, indicate that hydrilla spring regrowth and fall senescence processes at Lake Conway occurred earlier in the growing season than depicted in the biomass simulation results. Consequently, development work during fiscal year (FY) 1989 centered on improving spring regrowth and fall senescence relationships for simulations that include winter "dieback" of plant biomass. Because tubers are such an important factor in initial plant growth (Haller 1976), revisions to the model to initiate earlier regrowth were accomplished by modifying relationships governing the onset of tuber production and tuber germination. The modifications include (a) lowering the air temperature threshold for initiation of tuber production to 10° C and (b) allowing input data on the initial number of tubers. Modifications were also made which improve the vertical growth of hydrilla from the bottom layers of the water column into upper layers where sufficient light is available for positive net photosynthesis.

If one assumes that plants die back in winter, initial biomass (input by the user) is allocated only to the bottom layer of the water column. On days of the simulation period that have proper conditions for tuber production, including an average air temperature of 10° C, calculation of an updated plant biomass in the bottom layer of the water column includes relationships that depict redistribution of a portion of the bottom layer plant biomass into a tuber "storage" pool. On days following initial creation of the tuber "storage" pool, if conditions are proper for tuber germination, plant biomass is redistributed from the tuber "storage" pool into the first water column layer above the bottom layer that contains no plant biomass. This procedure is followed on

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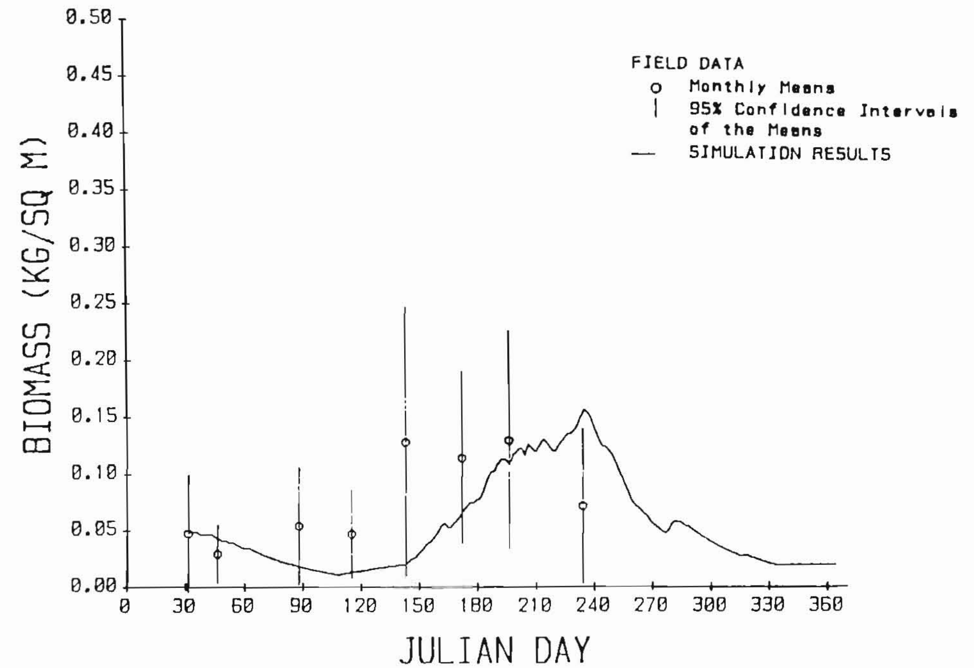

Figure 1. Comparison of hydrilla growth model simulation results with 1977 Lake Conway, Pool 4, summarized field data. Simulation results are from Wooten (1989) and were produced with a version of the hydrilla plant growth model that did not include the revisions described in this manuscript

all simulation days with corresponding average air temperatures greater than 10° C until all water column layers contain biomass. Thereafter, on simulation days for which the average air temperature is greater than 10° C, net biomass changes resulting from tuber production and tuber germination are distributed in layers within the top 1.5 m of the water column.

In layers below 1.5-m depth, changes in biomass result from relationships that depict leaf sloughing from hydrilla stems beneath a "topped out" hydrilla canopy. Changes to plant biomass within each layer also include the net results of daily photosynthesis processes. For layers in which these results are positive, the derived increase in biomass is assumed to occur within the respective layers. If negative results are calculated for any layers, the associated loss in plant biomass is distributed among all layers above the 1.5-m depth which contain plant biomass.

Fall senescence process relationships were also improved during FY 89. During the simulation period, the onset of the senescence process is marked by the first day following Julian Day (JD) 140 with an average air temperature less than 10° C. On this simulation day and each subsequent day meeting the same average air temperature requirement, the biomass in the uppermost layer containing plant biomass is assumed to be redistributed within the water column layer immediately below. Because senescence processes are in effect only on days meeting certain air temperature conditions, the plant biomass simulation results may end with plant biomass distributed at varying levels within the water column, depending on air temperature conditions used in the simulation.

SIMULATIONS COMPARED WITH LAKE CONWAY DATA

Plant biomass simulation results were generated using the revised plant growth model and are presented for comparison with results of the original model and with the Lake Conway field data. The first simulation was for the same simulation conditions as reported by Wooten (1989). The model input data were as follows: water depth = 3.0 m; plant dieback during winter; number of tubers input = 0; beginning JD of simulation = 31 with 0.0472 kg/m^2 of biomass; pH = 7.1 to 8.0; tuber production = minimum level; Secchi depth = 2.5 m (extinction coefficient, calculated within the model = 0.56); and weather data (Figures 2-4), from Gainesville, Florida, for 1977. The simulation period was 334 days.

Simulation results showed production of 47 tubers, 32 of which germinated during the 334-day simulation period. All layers contained biomass on JD 95. Senescence processes in the simulation effected the elimination or dieback of biomass from the top 1.9 m of the water column by the end of the simulation period. The model simulation results (Figure 5) for total plant biomass in the water column compare well with the Lake Conway field data. There is excellent agreement with the Lake Conway data except for the period JD 150 to JD 180 where simulation results were slightly higher than, but within the confidence intervals of, the sample means. However, since the Lake Conway data represent field conditions at monthly intervals, it is possible that the daily simulation results quite closely reflect the daily biomass levels in Lake Conway during 1977.

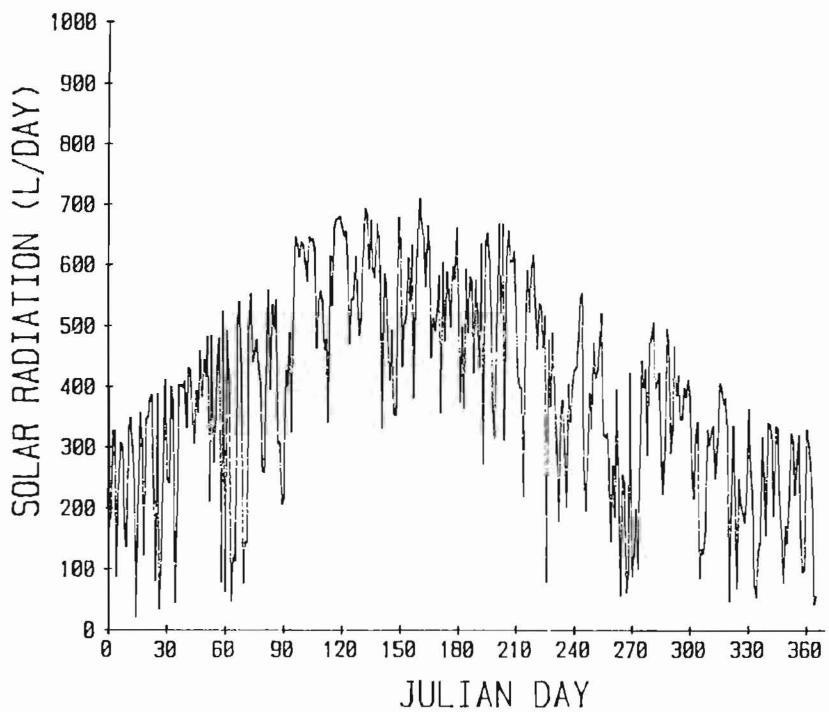

Figure 2. Solar radiation (Langleys/day) from Gainesville, Florida, 1977

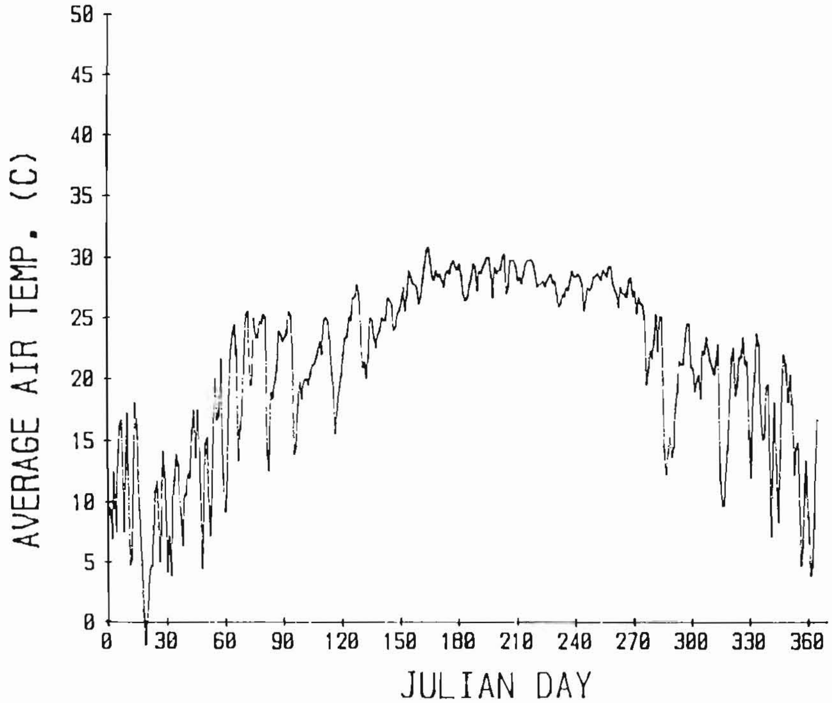

Figure 3. Average air temperatures (Celsius) from Gainesville, Florida, 1977. Values calculated from daily records of maximum and minimum temperatures

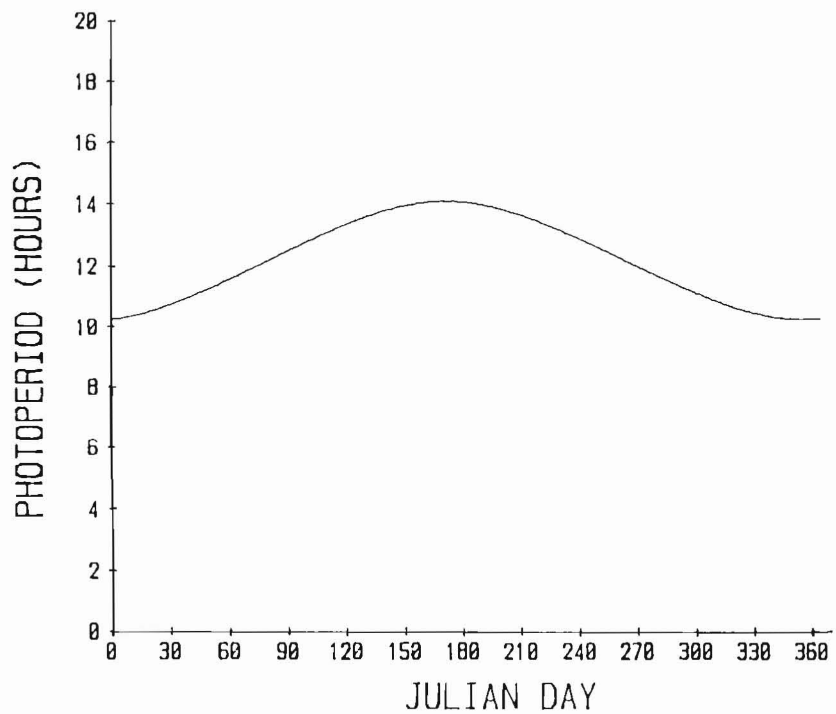

Figure 4. Photoperiod (hours:minutes) for Lake Conway, Florida, 1977. Values calculated by interpolation for latitude 28.3 deg N from the ephemeris

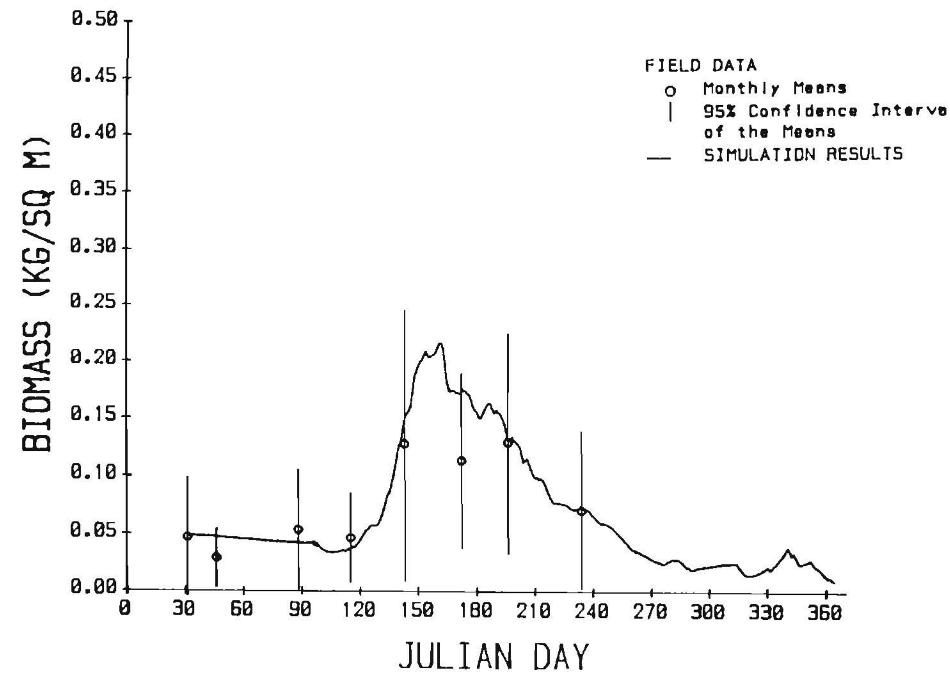

Figure 5. Comparison of simulation results for hydrilla biomass from the revised hydrila growth model with 1977 Lake Conway, Pool 4, field data. Simulation conditions were identical to conditions used to generate simulation results shown in Figure 1

To further demonstrate enhancements made to the model, a second simulation was run using the same input conditions except for the number of tubers. For this run, 14 tubers/m^2 were assumed to be present the first day (JD 31) of the 334-day simulation period. These simulation results (Figure 6) showed a maximum plant biomass of 0.287 kg/m^2, a value greater than depicted in the field data. Since all environmental conditions were identical between the two simulations described above, the shapes of the biomass curves shown in Figures 5 and 6 were expected to be similar. The differences in the maximum biomass levels that occurred demonstrate how the hydrilla plant growth model can be used to evaluate effects of initial plant conditions on resulting plant growth at a particular site.

EURASIAN WATERMILFOIL MODEL

The conceptual model for Eurasian watermilfoil growth contains many elements similar to the hydrilla model (Wooten and Akbay 1988, Wooten 1989). It provides for a maximum simulation time of 1 year and computes the biomass growth in a water column in a 1- by 1-m water surface area. Each three-dimensional column is subdivided into 1- by 1- by 0.10-m (depth) layers. The input data are similar to those used in the hydrilla model. These data are:

- The weather data (code for selected locations and years as stored in the model).
- Overwintering condition of plants (code: intact = 1, dieback = 2).

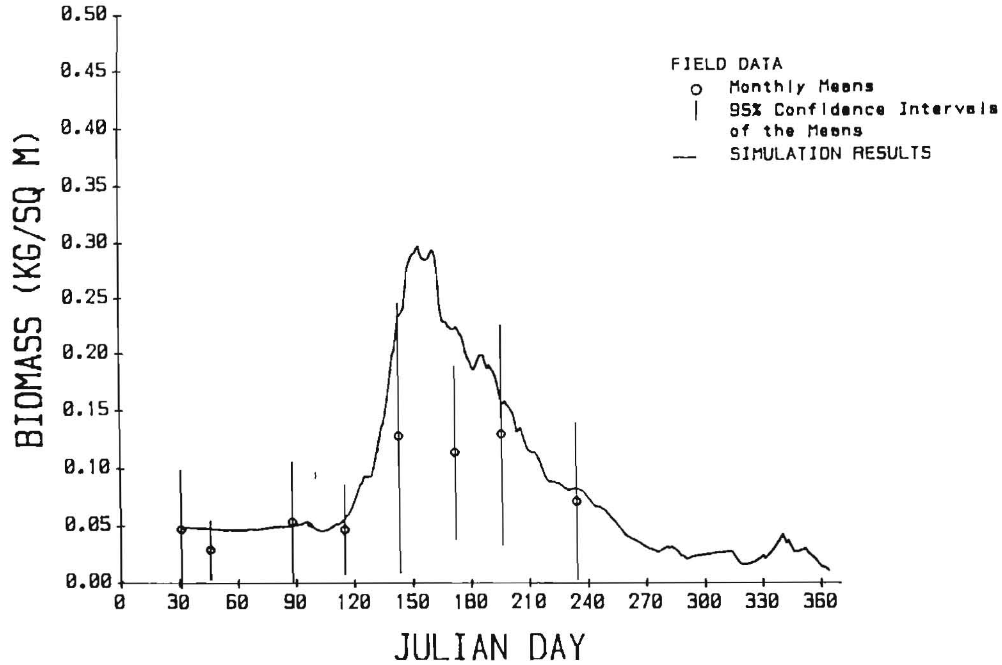

Figure 6. Comparison of simulation results for hydrilla biomass from the revised hydrilla growth model with 1977 Lake Conway, Pool 4, field data. Simulation conditions were identical to conditions used to generate simulation results shown in Figures 1 and 5, except for the addition of 14 tubers on JD 31, the first day of the simulation period

- First day of simulation (Julian Day).
- Last day of simulation (Julian Day).
- Average depth of vegetated portion or photic zone of lake (meters).
- Initial dry weight of the plant biomass (kilograms per square meter).
- Secchi depth (meters).

The daily change in biomass is computed for each layer, and total plant biomass in all layers is distributed among vertical layers of the 1-sq m water column using algorithms similar to those used in the hydrilla model (Wooten 1989). Since Eurasian watermilfoil does not form tubers, stored biomass in the roots is assumed to provide materials for upward plant growth through water column layers that do not receive sufficient light (i.e., "light limited") for positive net photosynthesis to occur. Root biomass is assumed to change little through the growing season. If root biomass does not change seasonally, overwintering root biomass, based on a shoot:root ratio of 1.39, would be about 40 percent of the standing crop (Titus and Adams 1979). Model algorithms assume that 20 percent of the root biomass is available to be used for shoot growth. The total root biomass available to each layer for light-limited vertical growth is calculated by dividing root biomass by the number of water column layers. Net photosynthetic production of plant biomass is determined by the combined effects of gross photosynthesis, dark and photorespiration, plant mortality, and leaf sloughing.

FUTURE WORK EFFORTS FOR THE MODELS

Research efforts in progress will result in the following enhancements to the plant growth models:

a. Algorithms for flowering of Eurasian watermilfoil.

b. Improved graphics routines that will allow the user to compare simulation results with available field data.

c. Development of an integated model to simulate hydrilla and Eurasian watermilfoil, or a mixed stand.

d. Inclusion of additional water temperature data sets for other water bodies/geographical areas.

REFERENCES

Haller, W. T. 1976. "Hydrilla, A New and Rapidly Spreading Aquatic Weed Problem," Circular 3-245, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL.

Titus, J. E., and Adams, M. S. 1979. "Comparative Carbohydrate Storage and Utilization Patterns in the Submersed Macrophytes *Myriophyllum spicatum* and *Vallisneria americana*," *American Midland Naturalist*, Vol 102, pp 263-272.

Wooten, J. W. 1989. "Description and Update: An Improved Hydrilla Growth Model," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 283-289.

Wooten, J. W., and Akbay, K. S. 1988. "HYDAMUR: Hydrilla and Triploid White Amur Growth Model," *Proceedings, 22nd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-88-5, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 169-175.

Preliminary Simulation Results of Triploid White Amur Stocking Rates for Guntersville Reservoir Using AMUR/STOCK (Version 1.5)

by
William A. Boyd* and R. Michael Stewart*

INTRODUCTION

The level of infestation and growth of aquatic plants in Guntersville Reservoir, Alabama, interferes with the intended uses of the reservoir. Aerial surveys conducted by the Tennessee Valley Authority (TVA) during fall 1988 concluded that over 20,000 acres of the 68,000-acre reservoir were infested by aquatic plants. Aquatic plant acreage estimates** from TVA surveys include approximately 14,000 acres of Eurasian watermilfoil, 3,000 acres of hydrilla, and 3,000 acres of mixed plant species that include a shallow-water community of "annuals" located within the reservoir's normal drawdown zone.

As part of an operational effort to reduce the aquatic plant infestation level in Guntersville Reservoir, TVA intends to stock triploid white amur fish. In 1989, the TVA asked the Waterways Experiment Station (WES) to assist them in determining a stocking rate of triploid fish that would support TVA's long-range aquatic plant management objectives for Guntersville Reservoir. These aquatic plant management objectives include priority control of hydrilla and maintenance of infestations of all other aquatic plant species at levels equivalent to normal maximum seasonal growth within 5 to 10 percent of the surface area of the reservoir.

At the time of TVA's request, relationships in the WES White Amur Stocking Rate Model (AMUR/STOCK) were limited to growth and control of hydrilla with diploid white amur (Miller and Decell 1984). Because Guntersville Reservoir is infested with multiple plant species and TVA plans to stock triploid fish, the AMUR/STOCK model had to be revised before WES could use it to produce simulations for triploid fish stockings in Guntersville Reservoir. This paper gives an overview of the revised plant and fish growth relationships in the updated version of AMUR/STOCK and presents some of the preliminary simulation results for Guntersville Reservoir. Recommendations for efforts at Guntersville Reservoir during FY 90 are presented.

REVISIONS TO AMUR/STOCK MODEL

The original AMUR/STOCK model used several basic relationships to simulate the growth of hydrilla and the consumption of hydrilla by white amur, both as a function

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*US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.
**Personal Communication, 1989, Tennessee Valley Authority, Muscle Shoals, Alabama.

of time (Miller and Decell 1984). Net change in the standing crop of hydrilla over the simulation update period (i.e., 1 month) was calculated using the net amount of growth that occurred and the amount of plant material consumed by white amur fish.

Hydrilla growth for the period was calculated as a function of the previous month's standing crop and a growth rate factor for the current month. The growth rate factor was determined by considering the combined relationships for season, water temperature, photoperiod, water body carrying capacity for hydrilla, and hydrilla cropping by white amur. By selecting proper input values, the user is able to generate the hydrilla growth simulations for the particular environmental conditions for the body of water in question.

In the new version of the AMUR/STOCK model, two additional sets of relationships for season, water temperature, photoperiod, water body carrying capacity, and plant cropping have been developed for calculating growth rates of Eurasian watermilfoil and the annual species complex found in Guntersville Reservoir. These relationships were established for Guntersville Reservoir conditions using seasonal plant biomass data for these species reported in TVA documents (see TVA 1983, 1987, 1989).

Major revisions were made to the fish feeding and growth modules in the AMUR/STOCK model to produce simulations for white amur genetic variants other than diploids and plant species other than hydrilla. In general, these revisions consider white amur feeding, growth, and mortality relationships included in the Illinois Herbivorous Fish Simulation System as reported in Wiley et al. (1985) and Wiley and Wike (1986). Modifications to these relationships were made during comparison of initial simulation results with data reported by TVA (1987, 1989) on results of the white amur demonstration project in Guntersville Reservoir.

APPLICATION OF THE AMUR/STOCK MODEL

The AMUR/STOCK model was developed to provide users with a systematic evaluation tool for answering "What if" questions regarding the results of various white amur stocking scenarios. The various stocking scenarios under question may differ by the size of white amur stocked, the number of fish stocked, the number of times fish are stocked, the species of aquatic plant(s) present, the acreage infested by the aquatic plant(s), the maximum seasonal density (tons per acre) of the plant(s), the annual temperature regime in the water body, the time period for the simulation, or a number of other factors. If the scenario includes more than one aquatic plant species, a separate simulation is produced for each plant species. In these situations, the user must determine what proportion of the total number of fish to include in the separate model runs. For simulations reported here, proportions were based on two factors: (a) the feeding preferences of white amur for the plant species included in the scenario and (b) the availability of each plant species.

The user can produce simulation results for a specific scenario by inputting the proper values during initialization of the model. By limiting the choice of scenarios for which simulations are to be generated to those that are probable for a given water body, the AMUR/STOCK model can quickly provide information that will help the user determine a proper stocking rate for his aquatic plant management objective.

PRELIMINARY SIMULATION RESULTS

Simulations were made for many different scenarios to demonstrate how white amur stocking rates affect the aquatic plants under a range of possible Guntersville Reservoir environmental conditions. The model was initialized with a water temperature data file (Figure 1) that represents the average median monthly water temperature measurements from Nickajack Dam tailrace during 1984 through 1987 (TVA, unpublished data). The following summary for three selected scenarios includes the input conditions and simulation output results. The summary of model input conditions will include the following information: (a) infested acreage by plant species, (b) estimates of maximum seasonal standing crop by plant species, (c) number and size of white amur stocked, and (d) month of stocking. Differences in scenario conditions represent the range in conditions requested by TVA.

Simulation results are presented for the following: (a) monthly standing crop estimates for each plant species from a 1-year simulation period without white amur, (b) the highest monthly standing crop estimate for each plant species and for all species combined from a 1-year simulation period without white amur, and (c) the highest monthly standing crop estimates for each year of a 10-year simulation period with multiple white amur stockings.

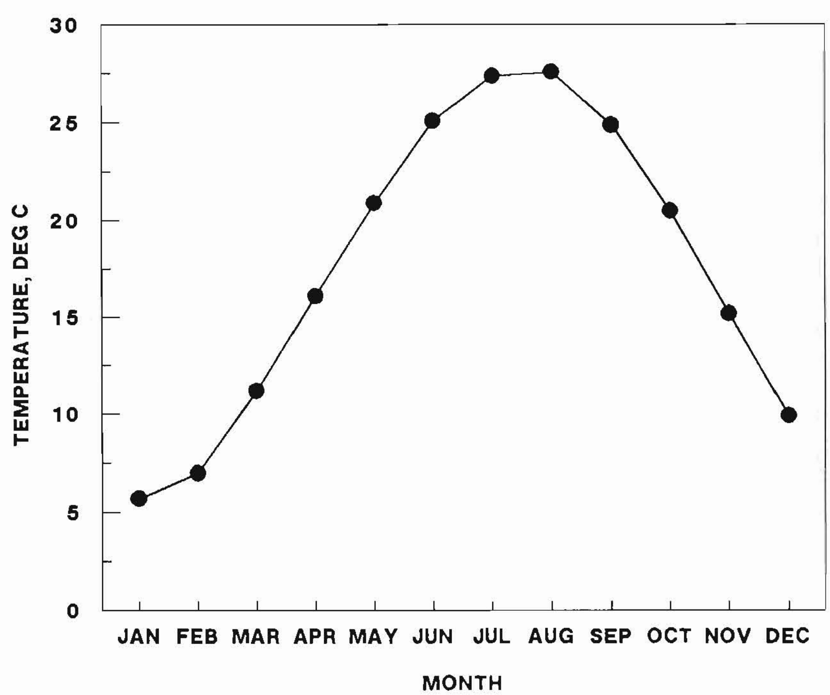

Figure 1. Average median monthly water temperatures from measurements made by TVA, 1984-1987, Nickajack Dam tailrace

Scenario 1 results

Monthly plant standing crop estimates for a 1-year period under Scenario 1 simulation conditions (Table 1) are shown in Figure 2. These plant growth simulations did not include any white amur stockings. A summary of the maximum standing crop weight estimates for the plant species from these 1-year simulations is given in Figure 3. The maximum estimate for all plant species combined was predicted to be 135,797 tons of standing crop during the peak growth month of July (Figure 3).

Table 1
Plant Conditions for Scenario 1

Plant Species	*Infested Area acres*	*Maximum Seasonal Biomass tons/acre*
Eurasian watermilfoil	14,394	7.1
Hydrilla	3,000	5.6
Annual species	3,000	5.6

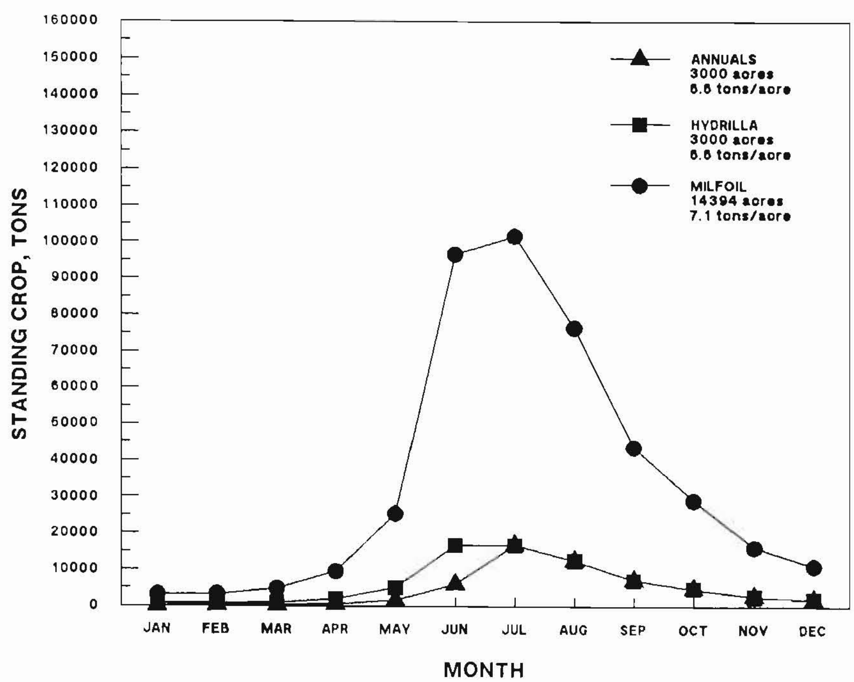

Figure 2. Monthly standing crop estimates for each plant species under Scenario 1 simulation conditions without white amur stockings

The simulations presented in Figure 4 were for a 10-year period. Input conditions used are given in Table 1 and also include multiple white amur stockings of 200,000 fish in April of Year 1 and 100,000 fish in April of Year 7. All fish were assumed to weigh 0.25 lb at the time of stocking. Table 2 shows the proportion of fish used in

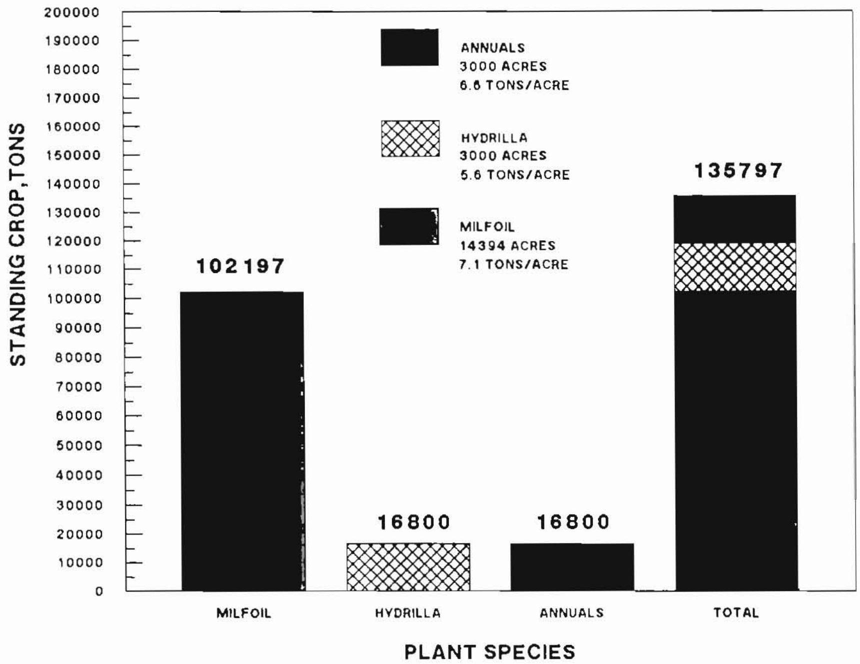

Figure 3. Summary of maximum monthly standing crop weight estimates for each plant species and for all species combined under Scenario 1 simulation conditions without white amur stockings

separate simulations for each plant species. Based on preference and availability assumptions, the stocked fish were equally distributed between the annuals and hydrilla during Year 1. In Year 2, fewer fish were required for complete control of the annuals so approximately one third of the fish fed on Eurasian watermilfoil. We assumed that the annuals would not produce significant regrowth following 2 years of heavy feeding pressure and, therefore, would not be available for the fish to feed on after Year 2.

In Years 3 through 8, only one fourth of the fish remaining were needed to effectively control hydrilla, and the remaining three fourths fed on Eurasian watermilfoil. By Years 9 and 10 the proportion of fish needed to control hydrilla increased to more than one third of the total fish remaining. The increase in the proportion of fish needed to control hydrilla in Years 9 and 10 was a result of fish mortality. As fewer fish were present, a greater proportion was needed to control hydrilla. Consequently, the level of control exerted by the fish on Eurasian watermilfoil was reduced during the last 2 years of the simulated stocking period.

Based on the set of input conditions and assumptions of Scenario 1, simulation results showed control of the annuals and hydrilla by the end of Year 1 (Figure 4). The fish then began to produce a gradual decline in the Eurasian watermilfoil standing crop. By Year 4 of the 10-year period, the combined standing crop of all species was brought within the range (equivalent to 5 to 10 percent of reservoir's surface area) desired for effective control. With the second stocking of fish in Year 7, the plant

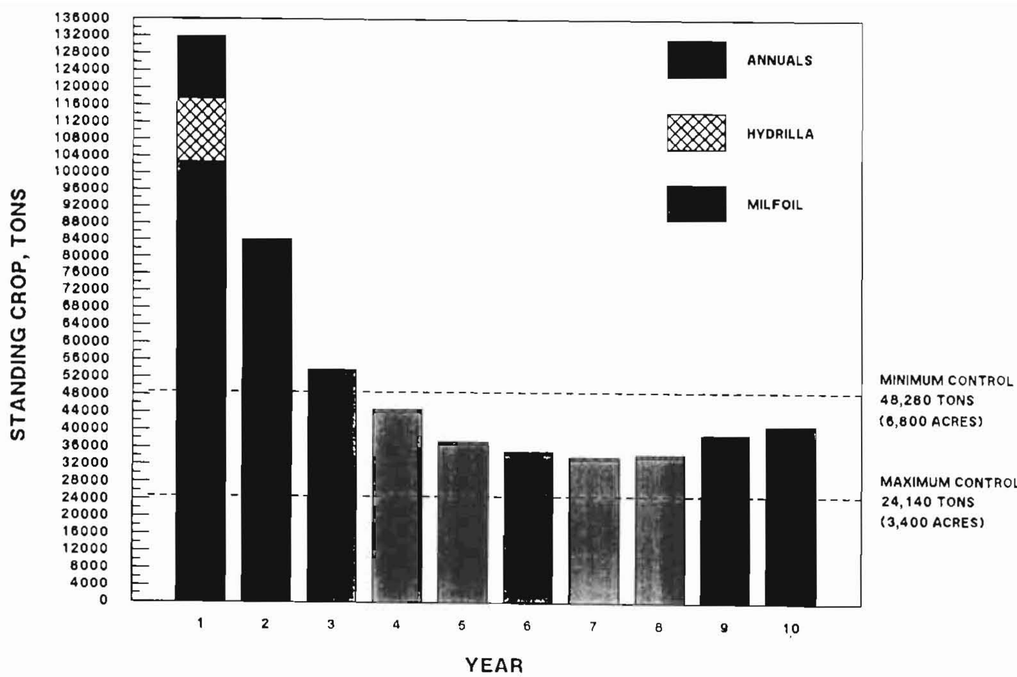

Figure 4. Summary of maximum annual standing crop estimates from a set of 10-year simulations conducted under Scenario 1 conditions with white amur stockings of 200,000 fish in Year 1 and 100,000 fish in Year 7. Refer to the text for a discussion of assumptions made regarding fish feeding. Note that dashed lines mark the upper and lower limits of the maintenance infestation level desired by TVA. These limits represent the product of 5 and 10 percent of the reservoir being infested at maximum standing crop levels for milfoil

Table 2
Assumed Fish Population Feeding Proportions on Each Plant Type During Each Year of Simulations for Scenario 1

Plant	*Year*									
Type	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Annuals	0.50	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrilla	0.50	0.50	0.25	0.25	0.25	0.25	0.25	0.25	0.37	0.37
Milfoil	0.00	0.37	0.75	0.75	0.75	0.75	0.75	0.75	0.63	0.63

standing crop remained within the desired control level for the remainder of the 10-year period.

Scenario 2 results

Monthly plant standing crop estimates for a 1-year period under Scenario 2 simulation conditions (Table 3) are shown in Figure 5. These plant growth simulations did not include any white amur stockings. A summary of the maximum standing crop weight estimates for the plant species from these 1-year simulations is given in Figure 6. The maximum estimate for all plant species combined was predicted to be 131,500 tons of standing crop during the peak growth month of July (Figure 6).

Table 3
Plant Conditions for Scenario 2

Plant Species	*Infested Area acres*	*Maximum Seasonal Biomass tons/acre*
Eurasian watermilfoil	13,000	7.1
Hydrilla	4,500	5.6
Annual species	2,500	5.6

The simulations presented in Figure 7 were for a 10-year period. Input conditions used are given in Table 3 and also include multiple white amur stockings of 100,000 fish in April of Year 1 and 100,000 fish in April of Year 2. All fish were assumed to weigh 0.25 lb at the time of stocking. The proportion of fish used in the separate simulations for each plant species is shown in Table 4. Based on plant preference and availability assumptions, the stocked fish were equally distributed for feeding on the annuals and hydrilla during Year 1. As fewer fish were required for complete control of the annuals during Year 2, a larger proportion of the fish population fed on hydrilla. We assumed that the annuals would not produce significant regrowth following 2 years of heavy feeding pressure and, therefore, would not be available for the fish to feed on after Year 2. In Year 3, only one third of the fish remaining were needed to effectively control hydrilla, and the remaining two thirds fed on Eurasian watermilfoil.

The proportion of fish feeding on hydrilla gradually declined each year until Year 7. By Year 10, over half of the fish were again needed to control hydrilla. The increase in the proportion of fish needed to control hydrilla in Years 7-10 was a result of fish mortality. As fewer fish were present, a greater proportion was needed to control hydrilla. Consequently, the level of control exerted by the fish on Eurasian watermilfoil was reduced during the last 3 years of the simulation period.

Based on the set of input conditions and assumptions for Scenario 2, simulation results showed control of the annuals at the end of Year 1 and of hydrilla at the end of Year 2. The fish then began to produce a gradual decline in the Eurasian watermilfoil standing crop. By Year 5 of the 10-year period the combined standing crop of all

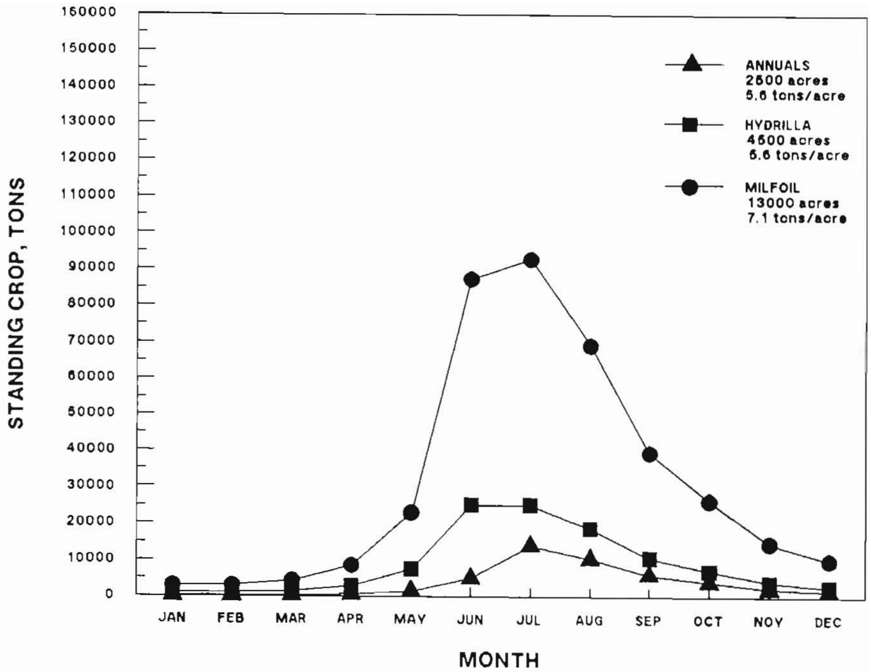

Figure 5. Monthly standing crop estimates for each plant species under Scenario 2 simulation conditions without white amur stockings

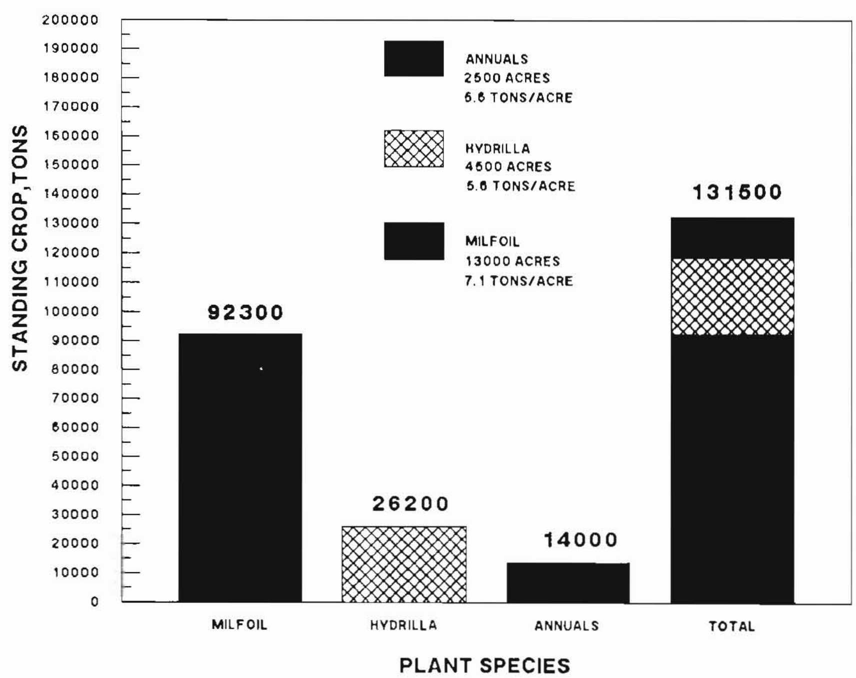

Figure 6. Summary of maximum monthly standing crop weight estimates for each plant species and for all species combined under Scenario 2 simulation conditions without white amur stockings

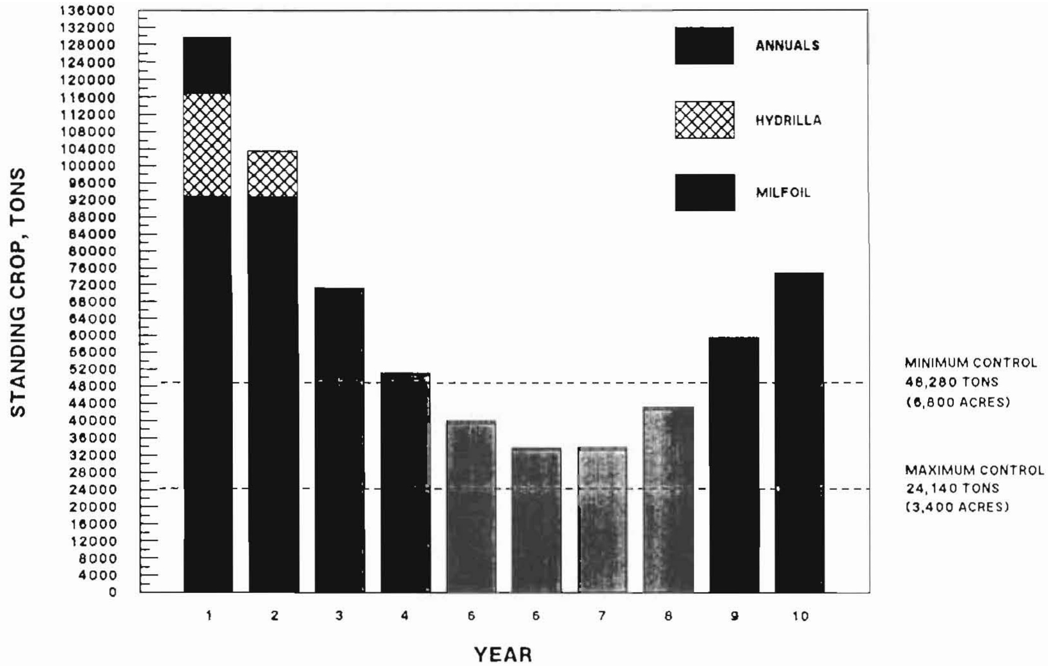

Figure 7. Summary of maximum annual standing crop estimates from a set of 10-year simulations conducted under Scenario 2 conditions with white amur stockings of 100,000 fish in Year 1 and 100,000 fish in Year 2. Refer to the text for a discussion of assumptions made regarding fish feeding. Note that dashed lines mark the upper and lower limits of the maintenance infestation level desired by TVA. These limits represent the product of 5 and 10 percent of the reservoir being infested at maximum standing crop levels for milfoil

Table 4
Assumed Fish Population Feeding Proportions on Each Plant Type During Each Year of Simulations for Scenario 2

Plant Type	*Year* 1	2	3	4	5	6	7	8	9	10
Annuals	0.50	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrilla	0.50	0.84	0.33	0.27	0.23	0.23	0.24	0.33	0.45	0.59
Milfoil	0.00	0.00	0.67	0.73	0.77	0.77	0.76	0.67	0.55	0.41

species was brought within the desired control range. Because of fish mortality, however, during Years 9 and 10 the combined standing crop once again exceeded the desired control range.

Scenario 3 results

Monthly plant standing crop estimates for a 1-year period under Scenario 3 simulation conditions (Table 5) are shown in Figure 8. These plant growth simulations did not include any white amur stockings. A summary of the maximum standing crop weight estimates for the plant species from these 1-year simulations is given in Figure 9. The maximum weight estimate for all plant species combined was predicted to be 213,500 tons of standing crop during the peak growth month of July (Figure 9).

Table 5
Plant Conditions for Scenario 3

Plant Species	*Infested Area* *acres*	*Maximum Seasonal Biomass* *tons/acre*
Eurasian watermilfoil	13,004	11.4
Hydrilla	4,500	11.4
Annual species	2,500	5.6

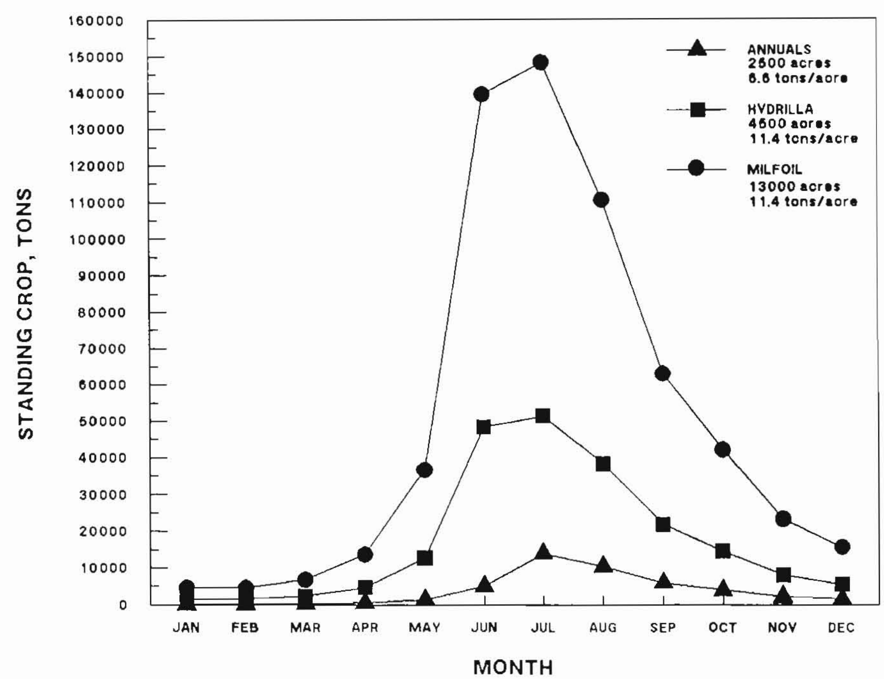

Figure 8. Monthly standing crop estimates for each plant species under Scenario 3 simulation conditions without white amur stockings

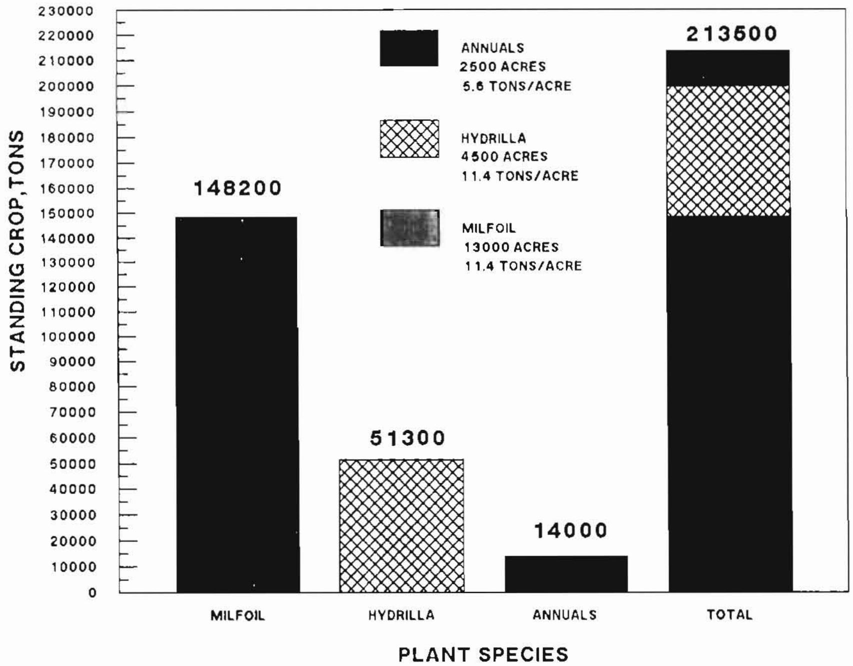

Figure 9. Summary of maximum monthly standing crop weight estimates for each plant species and for all species combined under Scenario 3 simulation conditions without white amur stockings

The simulations presented in Figure 10 were for a 10-year period. Input conditions used are given in Table 5 and also include multiple white amur stockings of 100,000 fish in April of Years 1, 2, 3, and 5. All fish were again assumed to weigh 0.25 lb at the time of stocking. The proportion of fish used in the separate simulations for each plant species is shown in Table 6. Based on plant preference and availability assumptions, the stocked fish were equally distributed between the annuals and hydrilla during Year 1. Fewer fish were required for complete control of the annuals during Year 2; thus, more than four fifths of the fish population fed on hydrilla. We assumed that the annuals would not produce significant regrowth following 2 years of heavy feeding pressure and, therefore, would not be available for the fish to feed on after Year 2.

In Year 3, over half of the fish remaining were needed to effectively control hydrilla, and the remaining fish fed on Eurasian watermilfoil. The proportion of fish feeding on hydrilla gradually declined each year until Year 6. By year 10, nearly one half of the fish were again needed to control hydrilla. The increase in the proportion of fish population needed to control hydrilla in Years 8-10 was due to fish mortality as discussed for Scenarios 1 and 2.

Based on the set of input conditions and assumptions for Scenario 3, simulation results showed control of the annuals at the end of Year 1 and of hydrilla at the end of Year 2. The fish then began to produce a gradual decline in the Eurasian watermilfoil standing crop. By Year 6 of the 10-year period, the combined standing crop of all species was brought within the range desired for effective control. Because of fish

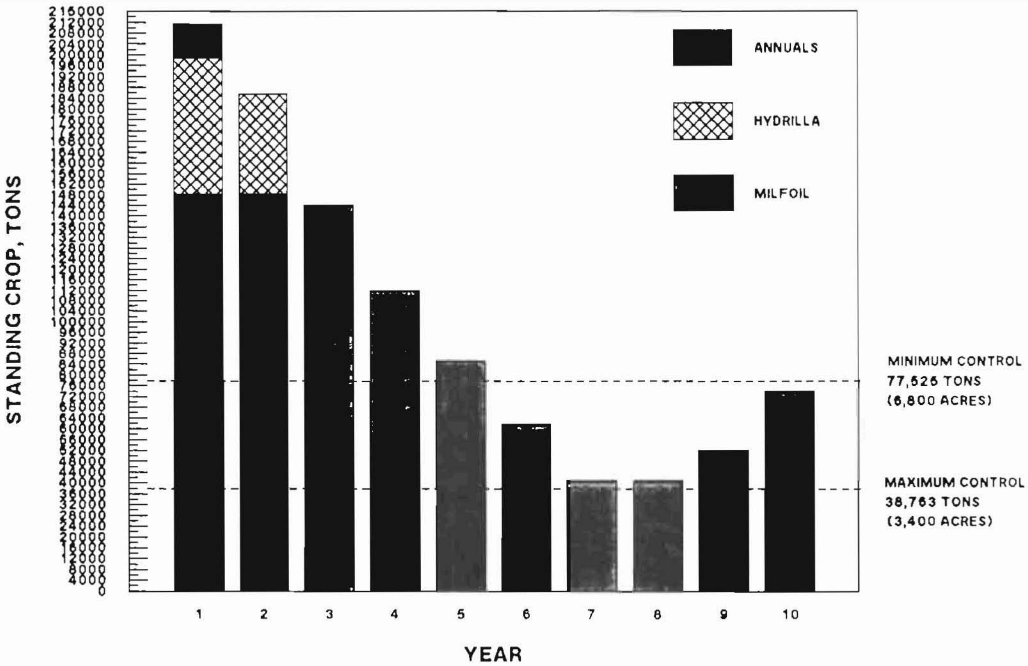

Figure 10. Summary of maximum annual standing crop estimates from a set of 10-year simulations conducted under Scenario 3 conditions with white amur stockings of 100,000 fish in Years 1, 2, 3, and 5. Refer to the text for a discussion of assumptions made regarding fish feeding. Note that dashed lines mark the upper and lower limits of the maintenance infestation level desired by TVA. These limits represent the product of 5 and 10 percent of the reservoir being infested at maximum standing crop levels for milfoil

Table 6
Assumed Fish Population Feeding Proportions on Each Plant Type During Each Year of Simulations for Scenario 3

Plant Type	*Year* 1	2	3	4	5	6	7	8	9	10
Annuals	0.50	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrilla	0.50	0.83	0.57	0.36	0.23	0.22	0.22	0.27	0.34	0.45
Milfoil	0.00	0.00	0.43	0.64	0.77	0.78	0.78	0.73	0.66	0.55

mortality, the combined standing crop began to increase in Years 9 and 10, but it remained within the desired control range.

RECOMMENDATIONS FOR FISCAL YEAR 1990 EFFORTS

As mentioned, assumptions were made as to how the fish would feed based upon fish feeding preference and the availability of the plant types. Fish feeding should be monitored following the scheduled release of white amur in Guntersville Reservoir during 1990 to validate plant preference assumptions used in the AMUR/STOCK model.

The plant biomass estimates used herein are based solely on biomass estimates taken from the study sites at Mud Creek and Town Creek in Guntersville Reservoir. Additional biomass samples should be taken to establish more accurate biomass estimates for other portions of Guntersville Reservoir. These data should be used to update plant growth relationships, and additional plant growth simulations should be generated.

Additional stocking simulations should also be generated for triploid white amur under different temperature conditions. Preliminary results presented here were for simulations using average median monthly water temperatures reported from Nickajack Dam tailrace. New stocking results should be generated using measured water temperature conditions for Guntersville Reservoir.

REFERENCES

Miller, A. C., and Decell, J. L. 1984. "Use of the White Amur for Aquatic Plant Management," Instruction Report A-84-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Tennessee Valley Authority. 1983. "First Preoperational Assessment of Water Quality and Biological Resources of Guntersville Reservoir in the Vicinity of the Proposed Murphy Hill Coal Gasification Project," TVA/ORN/WRF-83/2, Office of Natural Resources, Knoxville, TN.

Tennessee Valley Authority. 1987. "White Amur Project Report," TVA/ONRED/AWR-87/38, Office of Natural Resources and Economic Development, Muscle Shoals, AL.

Tennessee Valley Authority. 1989. "Supplement to White Amur Project," TVA/WR/AB-89/1, Water Resources, Muscle Shoals, AL.

Wiley, M. J., and Wike, L. D. 1986. "Energy Balances of Diploid, Triploid, and Hybrid Grass Carp," *Transactions of the American Fisheries Society,* Vol 115, pp 853-863.

Wiley, M. J., Tazik, P. P., Sobaski, S. T., and Gorden, R. W. 1985. "Biological Control of Aquatic Macrophytes by Herbivorous Carp; Part III, Stocking Recommendations for Herbivorous Carp and Description of the Illinois Herbivorous Fish Simulation System," Aquatic Biology Technical Report 1984(12), Illinois Natural History Survey, Champaign, IL.

Comparison of HERBICIDE Simulation Results with Field Measurements

by
Philip A. Clifford,* John H. Rodgers, Jr.,**
and R. Michael Stewart†

INTRODUCTION

Methodologies are needed that will allow operational aquatic plant management personnel to optimally utilize available control techniques. A variety of site-specific and interacting environmental factors may strongly influence successful application of an aquatic plant control technique. Computer simulation models have proven useful in similar complex situations as decision support systems. Chemical control techniques, including herbicides such as the dimethylamine formulation of 2,4-dichlorophenoxy acetic acid (2,4-D DMA), are used in a variety of aquatic environments. Physical, chemical, and biological components of these systems control the herbicide's fate and effectiveness. The initial concentration of a herbicide introduced to an aquatic system is limited or regulated by its Federal Insecticide, Fungicide, and Rodenticide Act registration label. Thus, the concentration of herbicide to which a target aquatic plant population is exposed may be initially the same in different aquatic systems but may decrease at greatly different rates. Information from both field and laboratory studies is being used to model herbicide fate and persistence, exposure (concentration × time) of the target plant population to the herbicide, and the subsequent effects (plant mortality).

This research effort was directed toward improving Version 2.0 of the HERBICIDE model. Using this simulation model, herbicide application rates can be estimated for optimal target plant population control with the minimum amount of chemical, and as an additional benefit, effects on nontarget species may be minimized. Additions to the HERBICIDE model have allowed simulation of multiple treatments during a growing season and, as such, are being used to estimate optimum treatment timing and number of required treatments during a season. Version 2.0 of the HERBICIDE model allows for simulations of waterhyacinth (*Eichhornia crassipes* (Mart.) Solms) and 2,4-D (DMA). Two other aquatic plants (hydrilla and Eurasian watermilfoil) and several other herbicides (diquat, endothall, fluridone, and the butoxyethylester (BEE) formulation of 2,4-D) will be included in the model during fiscal year 1990.

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MATERIALS AND METHODS

HERBICIDE model simulation results were generated and compared with experimental observations obtained from a field operation conducted at Wallisville, Texas. The field operation consisted of treating a 0.37-ha plot of waterhyacinth with the maximum label application rate of Weedar 64 (a Union Carbide 2,4-D DMA formulation). This application rate is the equivalent to 4.26 kg active ingredient per hectare (9.35 ℓ/ha of formulation).

Plant and water samples were collected periodically during the study from randomly selected locations within the treatment area. Nine 1-ℓ water samples were collected on each sampling date, preserved with sulfuric acid, and stored for later analysis. Each plant sample was obtained by removing all of the plant matter from a 0.25-m^2 area. The plants were rinsed to remove water-soluble 2,4-D from the surface. The total volume of the rinsate was measured, and 1 ℓ was preserved in the same manner as the water samples. The total fresh weight of plants in each sample was determined, and the plants were subdivided into leaves, stems (rhizomes and stolons), and roots. The weight of each subsample was recorded, and the samples were frozen for later analyses. The purpose of this plant sample subdivision was to monitor translocation of 2,4-D throughout the plants through time.

These experiments were performed by Waterways Experiment Station (WES) personnel; the plant and water samples were analyzed by personnel of the University of North Texas (UNT). Procedures used for 2,4-D residue analysis follow those of Knapp (1979), Moses (1985), and Rocchio (1988),

RESULTS AND DISCUSSION

Field measurements

Plant biomass data collected during the 28-day Wallisville field study are summarized in Figure 1. Mean biomass values for the day prior to 2,4-D application (Day -1) were 20.15 kg/m^2 (leaves), 2.93 kg/m^2 (stems), and 5.06 kg/m^2 (roots). Mean biomass values changed little during the 28-day study period since plant tissues affected (killed) by herbicide application were not removed from the samples. Mortality estimates for waterhyacinth at the site were made visually and exceeded 90 percent by Day 28.

Measurements of 2,4-D concentrations in waterhyacinth leaf tissues from the Wallisville field study are summarized in Figure 2. The highest mean 2,4-D concentration over the 28-day study period was 7.17 mg/kg for Day 1 samples. Leaf tissue concentrations of 2,4-D generally declined through the remainder of the study. Translocation of 2,4-D into stems (rhizomes and stolons) of waterhyacinth was observed in the Wallisville field study. The mean measured 2,4-D concentration in waterhyacinth stems (Figure 3) on Day 1 was 0.30 mg/kg. This value increased to a maximum mean value of 0.64 mg/kg on Day 7 and declined during the remainder of the 28-day study period. These observations agree with results reported in Penfound and Minyard (1947) and Hitchcock et al. (1949). Their results show that 2,4-D is efficiently

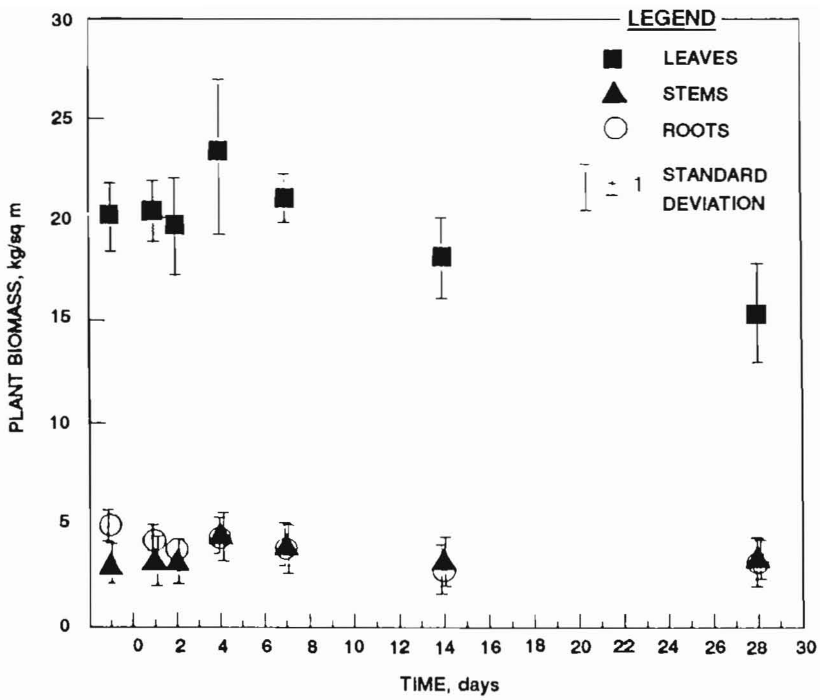

Figure 1. Summary of plant biomass measurements from samples collected during Wallisville field study

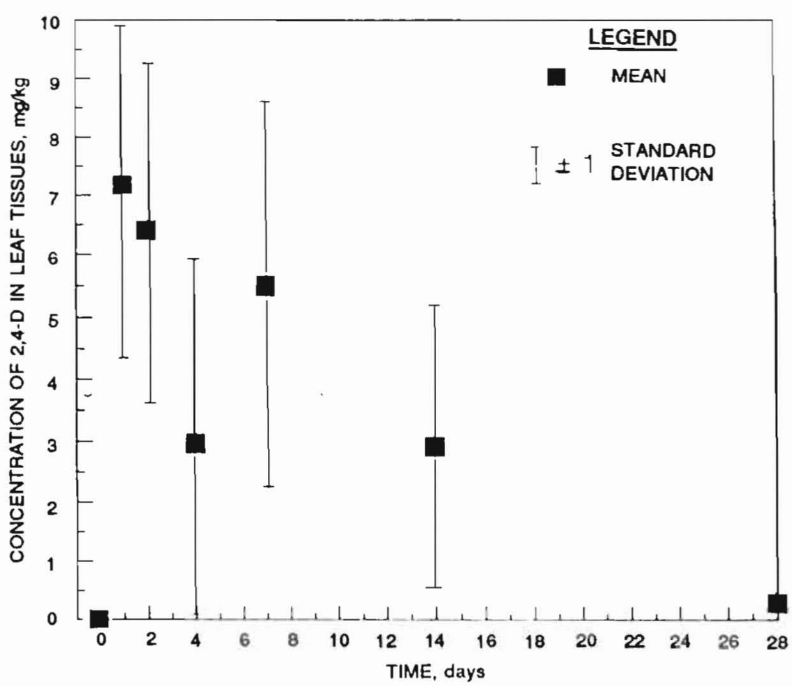

Figure 2. Summary of 2,4-D concentrations measured in waterhyacinth leaf tissue samples from Wallisville field study

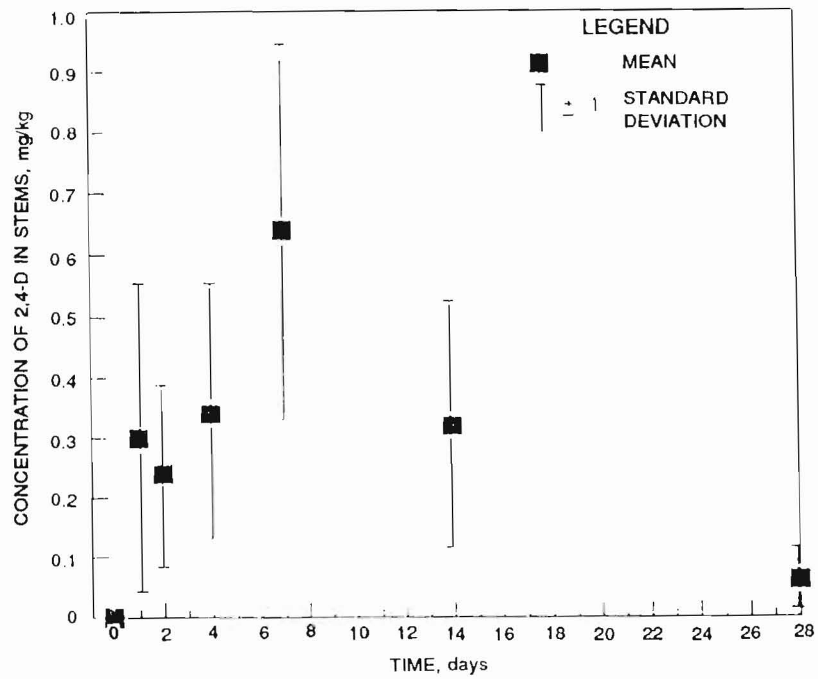

Figure 3. Summary of 2,4-D concentrations measured in waterhyacinth stem tissue samples from Wallisville field study

translocated from the leaves to other areas within a single individual plant of waterhyacinth.

Concentrations of 2,4-D in waterhyacinth root tissues (Figure 4) were relatively constant through Day 14 samples, but Day 28 concentrations indicated a decrease through the remainder of the 28-day study period. Measurements of 2,4-D concentrations in water samples are summarized in Figure 5. Mean 2,4-D concentrations ranged from 0.05 mg/ℓ (Day 1) to 0.016 mg/ℓ (Day 14). It is noted that concentrations in this range are near the lower detection limits of the analytical procedures used in this study. Therefore, the apparent decrease in 2,4-D concentrations in Day 2 and Day 4 water samples, followed by the higher concentration measurements in Day 7 samples, is not necessarily indicative of actual changes that occurred at the site during this time period.

Figure 6 illustrates the amount of 2,4-D that was removed from plants by rinsing with water. The maximum amount of 2,4-D removed relative to the weight of plant tissue rinsed was for Day 1 samples. Since the mean value (0.17 mg/kg plant tissue) for Day 1 was only a fraction of mean plant tissue concentrations (Figure 2) for Day 1, it appears that the majority of the 2,4-D that contacted the leaf surfaces had penetrated plant tissues or been converted to the relatively water-insoluble, acid form.

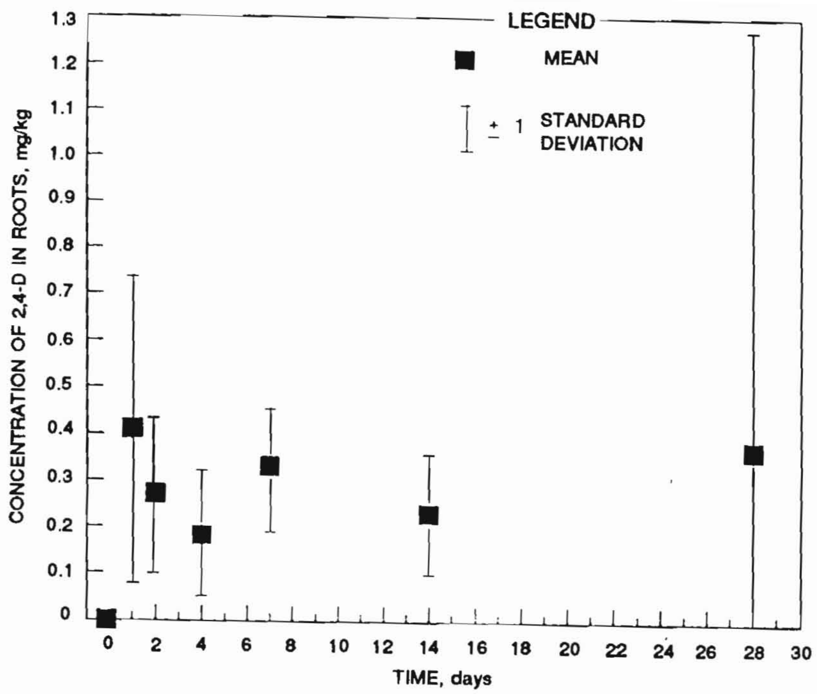

Figure 4. Summary of 2,4-D concentrations measured in waterhyacinth root tissue samples from Wallisville field study

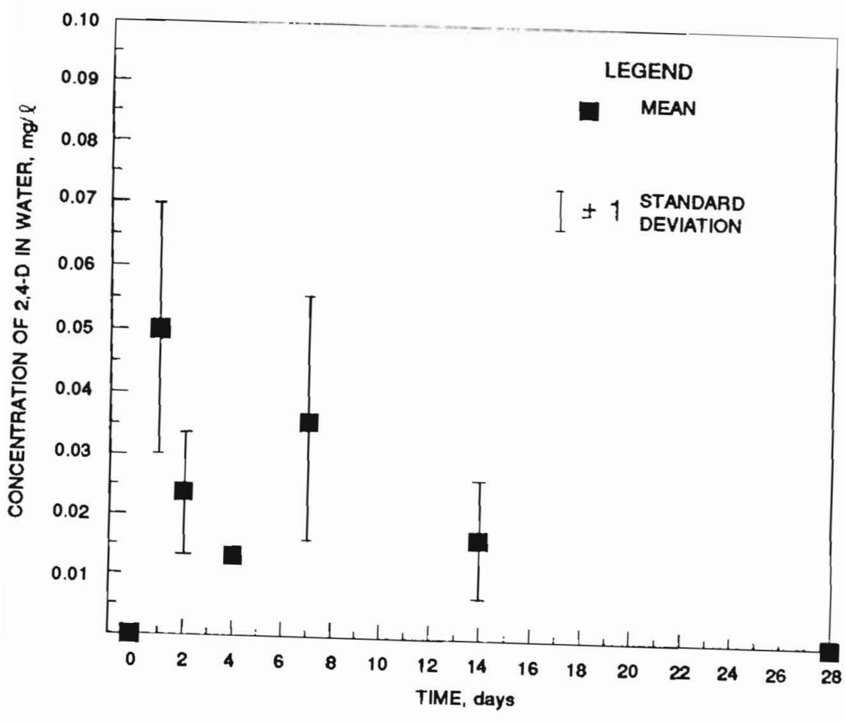

Figure 5. Summary of 2,4-D concentrations measured in water samples from Wallisville field study

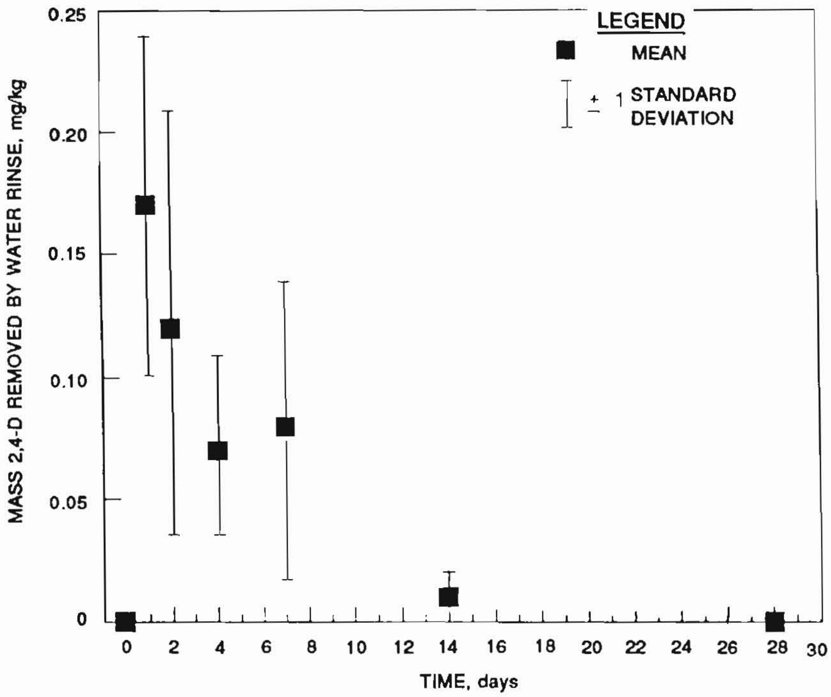

Figure 6. Mass of 2,4-D rinsed from waterhyacinth tissues relative to the weight of waterhyacinth tissues rinsed from Wallisville field study

HERBICIDE simulation results

Table 1 lists the data used for initializing the HERBICIDE model for the Wallisville field site conditions and for chemical properties (Reinert and Rodgers 1987) of the 2,4-D formulation used in the study. Additionally, HERBICIDE Version 2.0 incorporates an algorithm to simulate interception of the spray formulation of 2,4-D by plant tissues. This algorithm was developed using data from the 1988 UNT microcosm studies (Clifford, Rodgers, and Stewart 1989). Plant tissue concentrations of 2,4-D were used in developing this relationship rather than water concentrations because incomplete mixing of the water column would bias the relationship. The relationship between percentage of 2,4-D spray interception and plant biomass is essentially linear ($r^2 = 0.998$) and follows the equation

$$\text{Percent interception} = (0.191 * \text{MASS}) + 0.417$$

where MASS is weight of plants in metric tons per hectare. Based on the mean pretreatment (Day -1) plant biomass value measured at the Wallisville site, a percent interception factor for the 2,4-D spray formulation by plant tissues was estimated to be 54.16 percent (Table 1).

In general, simulation results compared well with field observations. Model-generated results for 2,4-D concentrations in waterhyacinth leaf tissues are plotted against field data in Figure 7. The model estimates are very close to measured values for Day 1 and Day 2 samples and generally follow the observed trend throughout the

Table 1
Data Used for Initializing Module I of the HERBICIDE Model for Comparison of Simulation Results with Measured Values from the Wallisville, Texas, Field Study

Average depth of area to be treated (meters)	1
Water flow rate from treated area (meters/min)	0
Total suspended solids in water (mg/ℓ)	10
Depth of active sediment layer (cm)	0
Sediment water content (percent)	-
Sediment diffusion exchange rate (cm/day)	-
Sedimentation rate (cm/year)	-
Sediment resuspension rate (cm/year)	-
Active ingredient fraction of herbicide (kg/ℓ)	0.455
Application rate (formulation) (ℓ/ha)	9.353
Loss of herbicide due to drift (percent)	0
Herbicide partition coefficient to suspended solids	0.25
Herbicide hydrolysis half-life in water (days)	-
Herbicide hydrolysis half-life in sediment (days)	-
Herbicide oxidation half-life in water (days)	-
Herbicide oxidation half-life in sediment (days)	-
Herbicide biotransformation half-life in water (days)	6
Herbicide biotransformation half-life in sediment (days)	6
Herbicide photolysis half-life in water (days)	-
Herbicide volatilization half-life in water (days)	-
Percent interception	54.16
Plant biomass to be treated (metric tons/ha)	280
Percent dry weight of plant tissue (percent)	7.84

28-day simulation period. Simulation results for 2,4-D concentrations in water (Figure 8) compared very well with measured values for Day 1 samples but were somewhat higher than the measured values for sampling days 2 and 4. However, as noted above, measurements of 2,4-D concentrations in Day 2 and Day 4 water samples are possibly erroneous since 2,4-D concentrations in the water samples were near the lower limits of the detection capability of the analytical procedures. Also, simulation

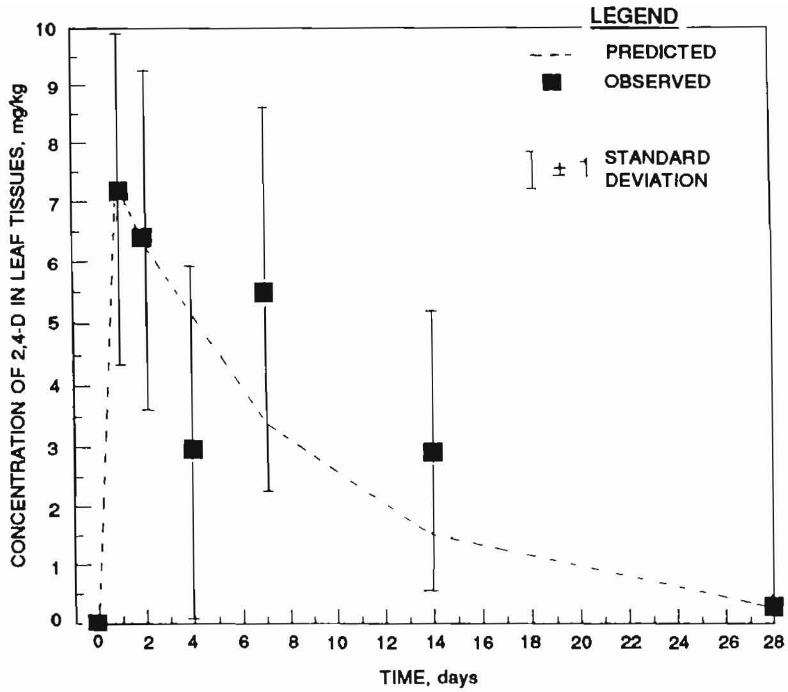

Figure 7. Herbicide model simulation results for 2,4-D concentrations in waterhyacinth leaf tissues compared with measurements from Wallisville field study. Simulation results (predicted) are depicted by dashed line

results for the remainder of the 28-day simulation period followed the trend observed in the field data.

The herbicide exposure-plant mortality relationship for 2,4-D (DMA) and waterhyacinth used by the HERBICIDE model is illustrated in Figure 9. From the simulation results for 2,4-D leaf tissue concentrations (Figure 7), the model calculated an overall herbicide exposure of 65.81 mg/kg-days. This exposure value represents the summation of simulation estimates of 2,4-D concentrations in leaf tissues (Figure 2) calculated in time steps of 0.1 day over the 28-day simulation period. Based on the relationship shown in Figure 9, the model estimated mortality resulting from this exposure to be approximately 98 percent. These model results agree well with the greater than 90 percent mortality value from "visual" field observations.

SUMMARY

HERBICIDE model simulation results were generated and compared with experimental observations obtained from a field operation conducted over a 28-day period at Wallisville, Texas. The field operation consisted of treating a 0.37-ha plot of waterhyacinth with an application rate of 2,4-D (DMA) equivalent to 4.26 kg active ingredient per hectare. Plant and water samples were collected periodically during the study and analyzed for 2,4-D content. Measured values from the field study agreed

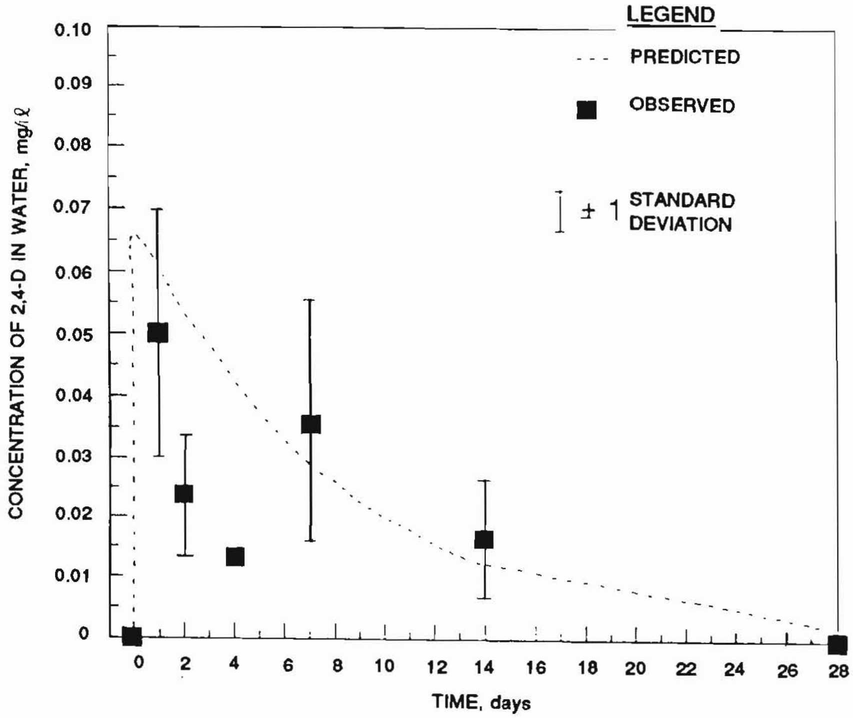

Figure 8. Herbicide model simulation results for 2,4-D concentrations in water compared with measurements from Wallisville field study. Simulation results (predicted) are depicted by dashed line

quite well with simulation results from the HERBICIDE model. The model result for waterhyacinth mortality resulting from the 2,4-D treatment was 98 percent. This predicted mortality value was comparable with "visual" field observations of greater than 90 percent plant mortality.

REFERENCES

Clifford, P. A., Rodgers, J. H., Jr., and Stewart, R. Michael. 1989. "Further Development of Coupled Herbicide Fate and Target Plant Species Effects Model," *Proceedings, 23rd Annual Meeting, Aquatic Plant Control Research Program*, Miscellaneous Paper A-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp 274-282.

Hitchcock, A.E., Zimmerman, P. W., Kirkpatrick, H., Jr., and Earle, T. T. 1949. "Water Hyacinth: Its Growth, Reproduction and Practical Control by 2,4-D," *Contributions from Boyce Thompson Institute*, Vol 15, pp 363-401.

Knapp, D.R. 1979. *Handbook of Analytical Derivatization Reactions*, John Wiley and Sons, New York.

Moses, C. K. 1985. "*Effects of Water Source, Suspended Solids, and Acclimation on Biotransformation of 2,4-Dichlorophenoxy Acetic Acid in Aquatic Systems*," Master's thesis, North Texas State University, Denton, TX.

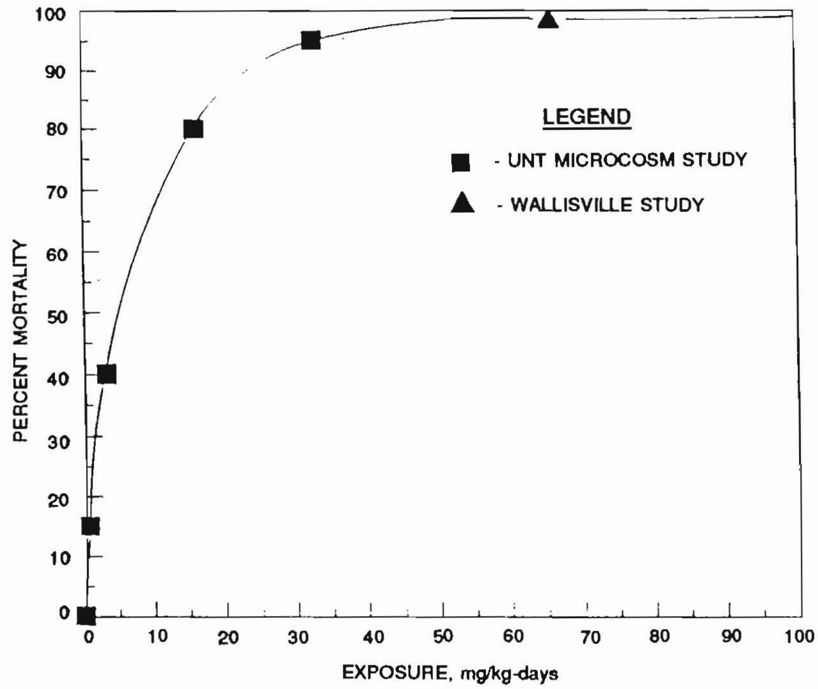

Figure 9. Herbicide exposure and plant mortality relationship used by the HERBICIDE model for simulations of 2,4-D (DMA) application to waterhyacinth. Square points on the curve represent data from the 1988 UNT microcosm study used in developing the exposure/mortality relationship. Triangular point identifies the mortality estimate from the model for Wallisville field study

Penfound, W. T., and Minyard, V. 1947. "Relation of Light Intensity to Effect of 2,4-Dichlorophenoxyacetic Acid on Water Hyacinth and Kidney Bean Plants," *Botanical Gazette*, Vol 109, pp 231-234.

Reinert, K. H. and Rodgers, J. H., Jr. 1987. "Fate and Persistence of Aquatic Herbicides," *Review of Environmental Contamination and Toxicology*, Vol 98, pp 61-89.

Rocchio, P. M. 1988. "Physiological Responses of *Myriophyllum spicatum* to Time Varying Exposures of Diquat, 2,4-D and Copper," Doctoral dissertation, North Texas State University, Denton, TX.

Digital Database to Support Aquatic Plant Control Modeling

by
M. Rose Kress,* Etta May Causey,*
and Jerrell R. Ballard, Jr.*

INTRODUCTION

Computerized digital databases are being developed to support aquatic plant control simulation modeling efforts. These databases consist of two primary parts. The first part may be conceived of as a series of geographically registered data arrays describing the distribution in the water body of such things as plant types and distribution patterns, water body use, water quality, substrate type, and water depth (Figure 1). Second, the database contains the records of detailed field measurements collected at specific times and locations in the water body. These site- and time-specific data are most efficiently maintained in tabular format with the tables tied to the appropriate geographic location in the database.

Geographic Information System (GIS) technology provides the tools necessary to maintain, analyze, and graphically portray the variety of data necessary to support aquatic plant simulation models. The goal of providing a database and interfacing it with the PC-based simulation models under development is to provide an evaluation of aquatic plant control techniques for site-specific conditions.

Currently, specific databases are under development for two locations--Lake Marion, South Carolina, and Guntersville Reservoir, Alabama. The database for Lake Marion is being developed under contract by the University of Georgia and will include aquatic plant distribution data.

DATABASE DEVELOPMENT

The Waterways Experiment Station (WES) has been involved in GIS since 1970 and has supported research and development efforts related to digital database design, development, management, and analysis. In support of the Aquatic Plant Control Research Progam, WES has designed and begun compilation of the digital database for Guntersville Reservoir. This will be a multiyear information base maintained in an easily accessible format. Data formats and structures for the database are being tested and refined on a segment of the proposed reservoir area using existing source materials.

Navigation charts of the reservoir prepared by the Tennessee Valley Authority (TVA) are being used as the geographic reference for the database. Data are being compiled on reservoir locations between Tennessee River miles 349 and 360. The

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*US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

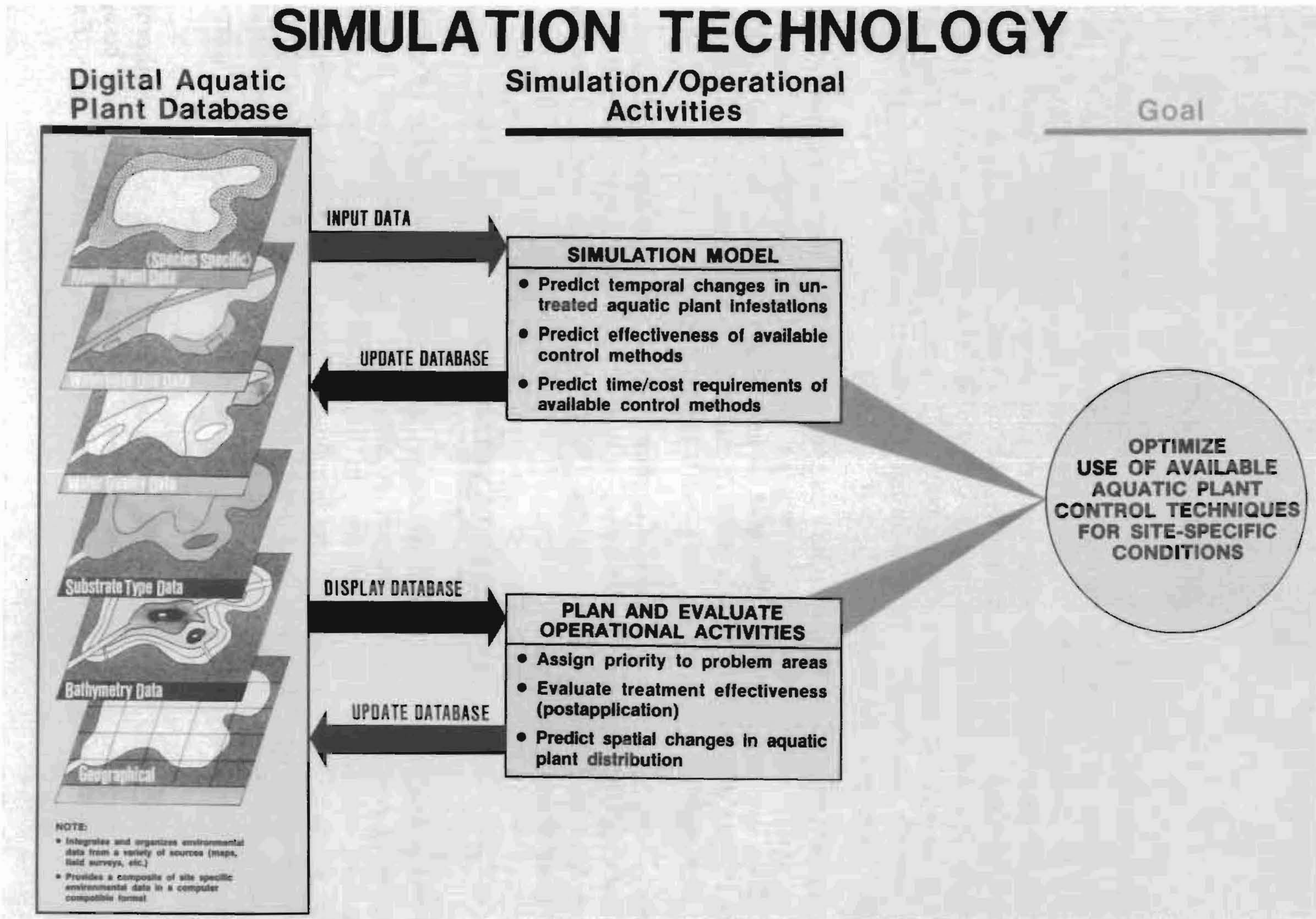

Figure 1. Aquatic plant digital database concept and database interaction with simulation models

navigation charts are not ideal maps for use as base materials since they do not meet national map accuracy standards as established by the US Geological Survey. However, the navigation charts are very convenient for the Guntersville study because they contain lake bottom elevation information.

The lake bottom elevation data on the Guntersville series of navigation charts are 20 years old, but no other data are currently available. In addition, the contour interval for lake bottom elevations on the navigation charts is only 5 ft. This is considered insufficient for modeling requirements as 1-ft changes in water depth can significantly affect aquatic plant growth. To supplement the available lake bottom elevations, field data will be collected during fiscal year 1990 at selected sites.

AQUATIC PLANT DISTRIBUTIONS

The TVA identifies plant species distributions from aerial photography on an annual basis in Guntersville Reservoir and transfers this information onto the navigation charts. These manually prepared plant distribution maps for 1984 and 1988 were digitized into the database at WES. Changes in plant type and distribution pattern over the 4-year period were then determined using the GIS.

The total acreage of plant-infested area (miles 349-360) increased by about 2,000 acres (Table 1). In 1984, 17 percent of the lake area was infested. Infested acreage nearly doubled by 1988, to 30 percent of the open-water area. Plant distribution data for the intervening years (1985, 1986, 1987) are being compiled to depict trends, determine changes from year to year, and correlate these changes with other information in the database on weather, water quality, and known plant control practices.

Table 1
Aquatic Plant-Infested Area, Guntersville Reservoir, Miles 349 to 360

Infested Areas	*1984*	*1988*	*Difference 1988-1984*
Acres	3,078	5,252	+2,174
Percent open water	17.3	29.6	+12.3

Approximately 30 plant associations were identified and mapped by TVA in this area of the lake. In Table 2, these plants have been condensed into seven plant associations, and the increase in infested area of each is listed. Between 1984 and 1988, milfoil-dominated areas increased, small areas dominated by hydrilla became established, and the acreages of other plants decreased. No hydrilla had been mapped in 1984.

Table 2
Plant Association Data, Guntersville Reservoir,
Miles 349 to 360

Association	*Infested Area, acres* 1988	1984	1988-1984
Milfoil; monoculture	4,010	2,136	+1,878
Milfoil; dominant	391	177	+214
Milfoil; dominant with hydrilla	464	0	+464
Hydrilla; dominant	96	0	+96
Najas minor/Potamogeton	137	588	-451
Filamentous algae; dominant	121	130	-9
Ceratophyllum; dominant	26	44	-18

In Figure 2 the distribution of aquatic plants in 1984 is shown near the Highway 69 bridge. Milfoil dominated the distribution with various other plants present along the shorelines. The 1988 plant distribution for the same area is shown in Figure 3. The milfoil population increased in an area south of the bridge. The milfoil population had also increased in an area north of the bridge, and hydrilla had become established. Small hydrilla-dominated areas were also detected.

Figure 4 shows the difference between the 1984 and 1988 plant population distributions. Depicted is the increase in infested area between 1984 and 1988 for all species. The new infested area is broken down into milfoil without hydrilla, milfoil with hydrilla, and hydrilla-dominated areas, as shown in Figure 5. The bridge appears to restrict the spread of hydrilla southward, but a small patch of hydrilla had become established along the eastern shoreline south of the bridge.

Figures 6-9 show the 1984 and 1988 plant conditions for the dock area at the town of Guntersville. The 1984 plant distribution data show no hydrilla or other plant infestations along the dock area (Figure 6). The 1988 plant distribution data (Figure 7) indicate a plant infestation, dominated by hydrilla, along the dock facility. The increase in infested areas between 1984 and 1988 for all plant species is shown in Figure 8. These are areas where plants were present in 1988 but not present in 1984. These new infested areas are broken down into milfoil areas without hydrilla, milfoil areas with hydrilla, and areas dominated by hydrilla, as shown in Figure 9.

In addition to maintaining and analyzing plant distribution trends, the database will serve as the source of input data to the simulation models. The models simulate plant growth under specific sets of water body conditions. Utilizing the database and the capabilities of the GIS, model output can be extrapolated all lake locations with characteristics similar to those used for the model calculations.

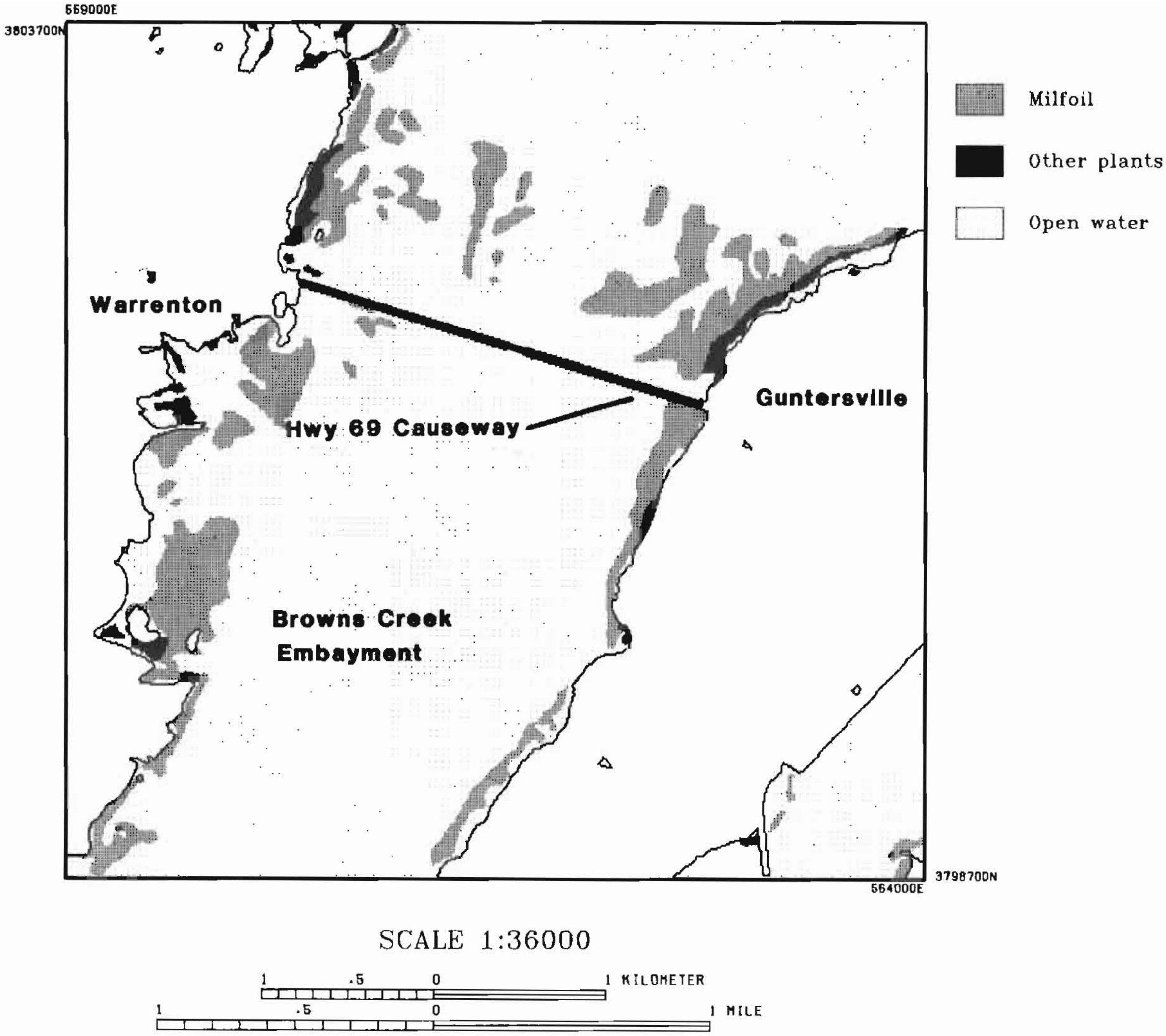

Figure 2. Distribution of aquatic plant infestations in Browns Creek embayment, Guntersville Reservoir, as identified from 1984 aerial photograpy

SUMMARY

Aquatic plant distribution information and other data for a portion of the Guntersville Reservoir were compiled into a digital format and used to support simulation modeling. The database provides input to the models and accepts model output for storage and further analysis. Plant distribution maps covering Tennessee River miles 349 to 360 for 1984 and 1988 were generated. Changes in the acreages of infestations for seven plant associations over the 4-year period were presented.

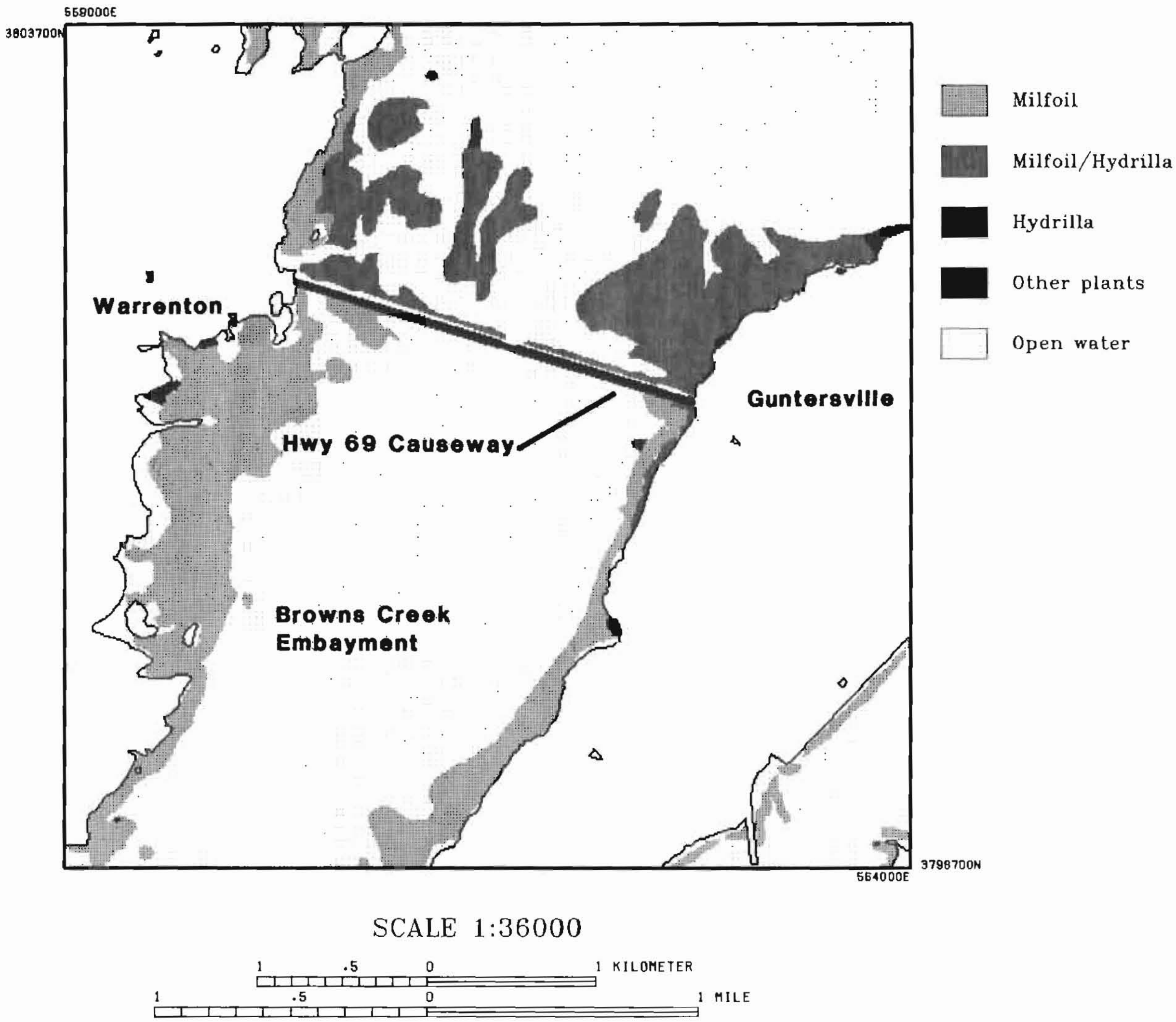

Figure 3. Distribution of aquatic plant infestations in Browns Creek embayment, Guntersville Reservoir, as identified from 1988 aerial photography

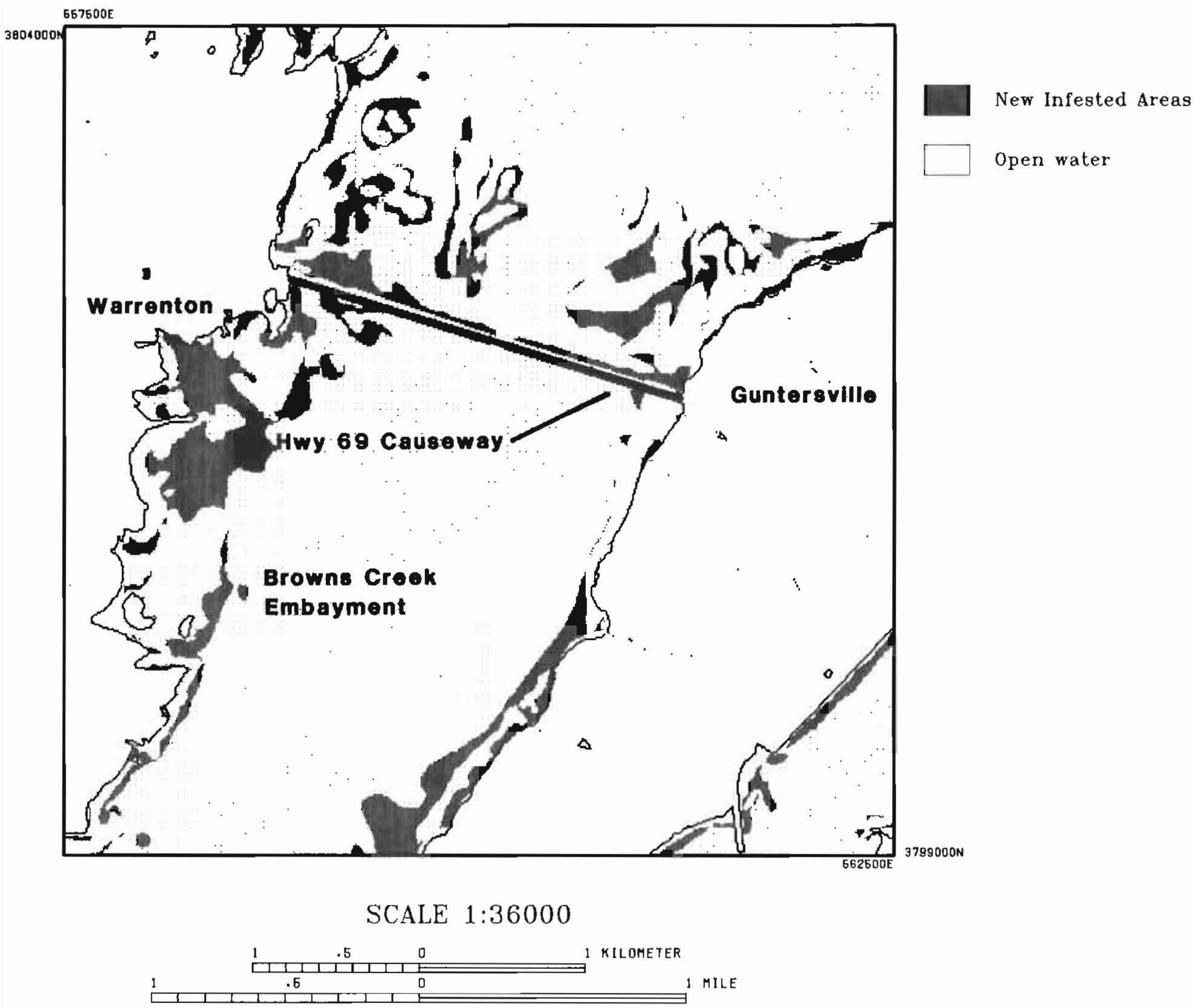

Figure 4. Aquatic plant infestation increase between 1984 and 1988 in Browns Creek embayment, Guntersville Reservoir, as determined from the aquatic plant digital database

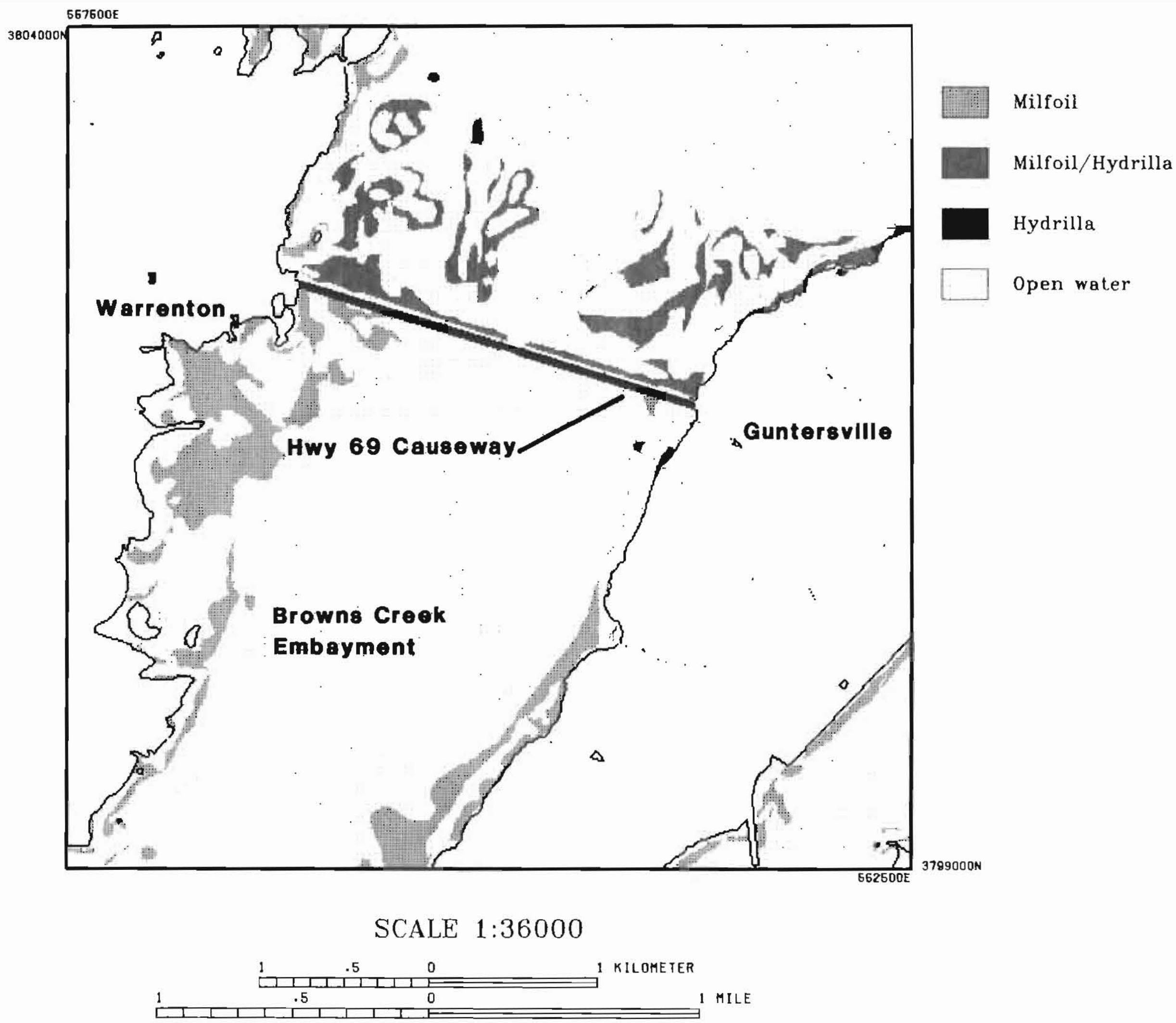

Figure 5. Species identification of aquatic plant infestation increase between 1984 and 1988 in Browns Creek embayment, Guntersville Reservoir, as determined from the aquatic plant digital database

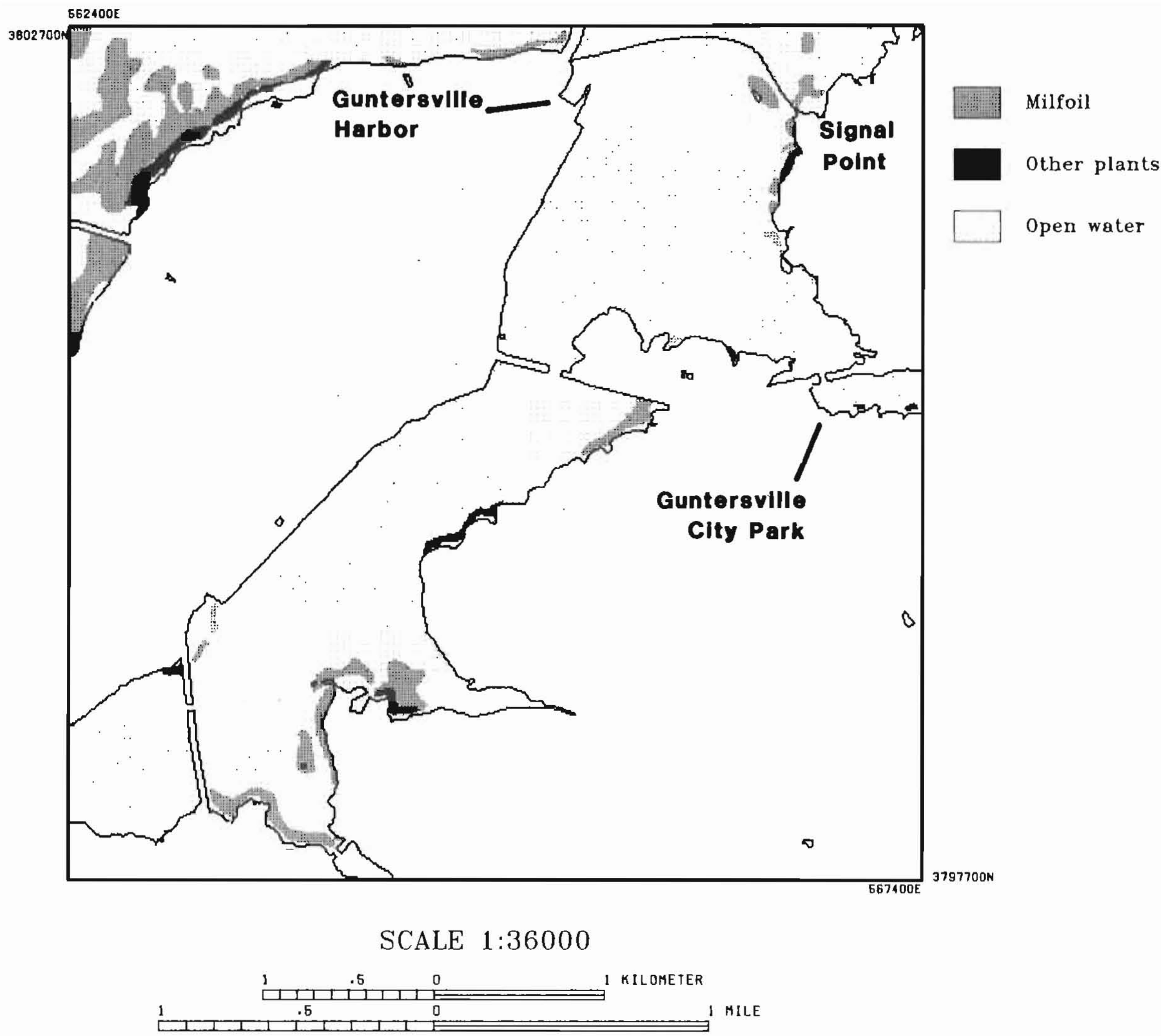

Figure 6. Distribution of aquatic plant infestations near Guntersville Harbor, Guntersville Reservoir, as identified from 1984 aerial photography

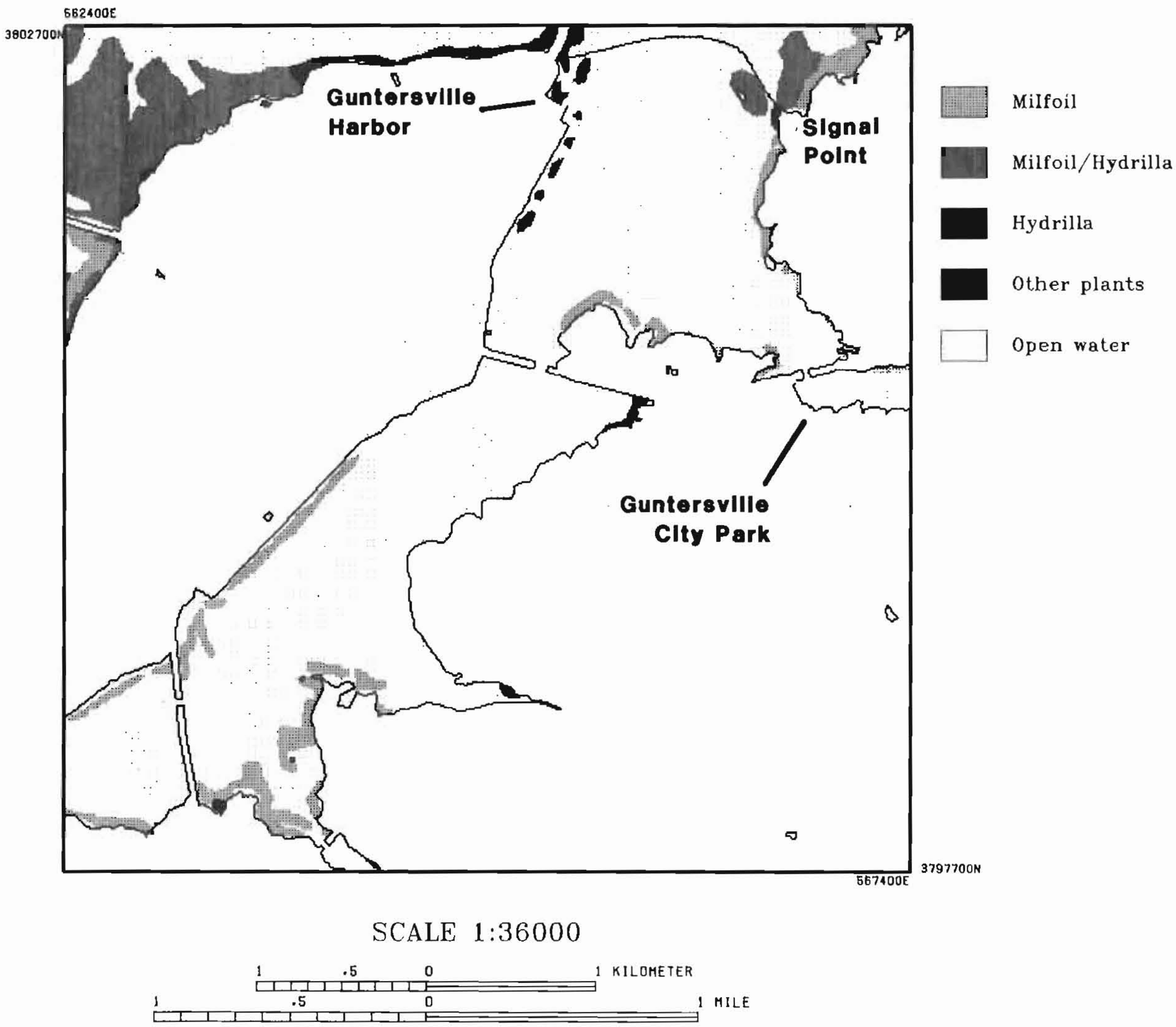

Figure 7. Distribution of aquatic plant infestations near Guntersville Harbor, Guntersville Reservoir, as identified from 1988 aerial photography

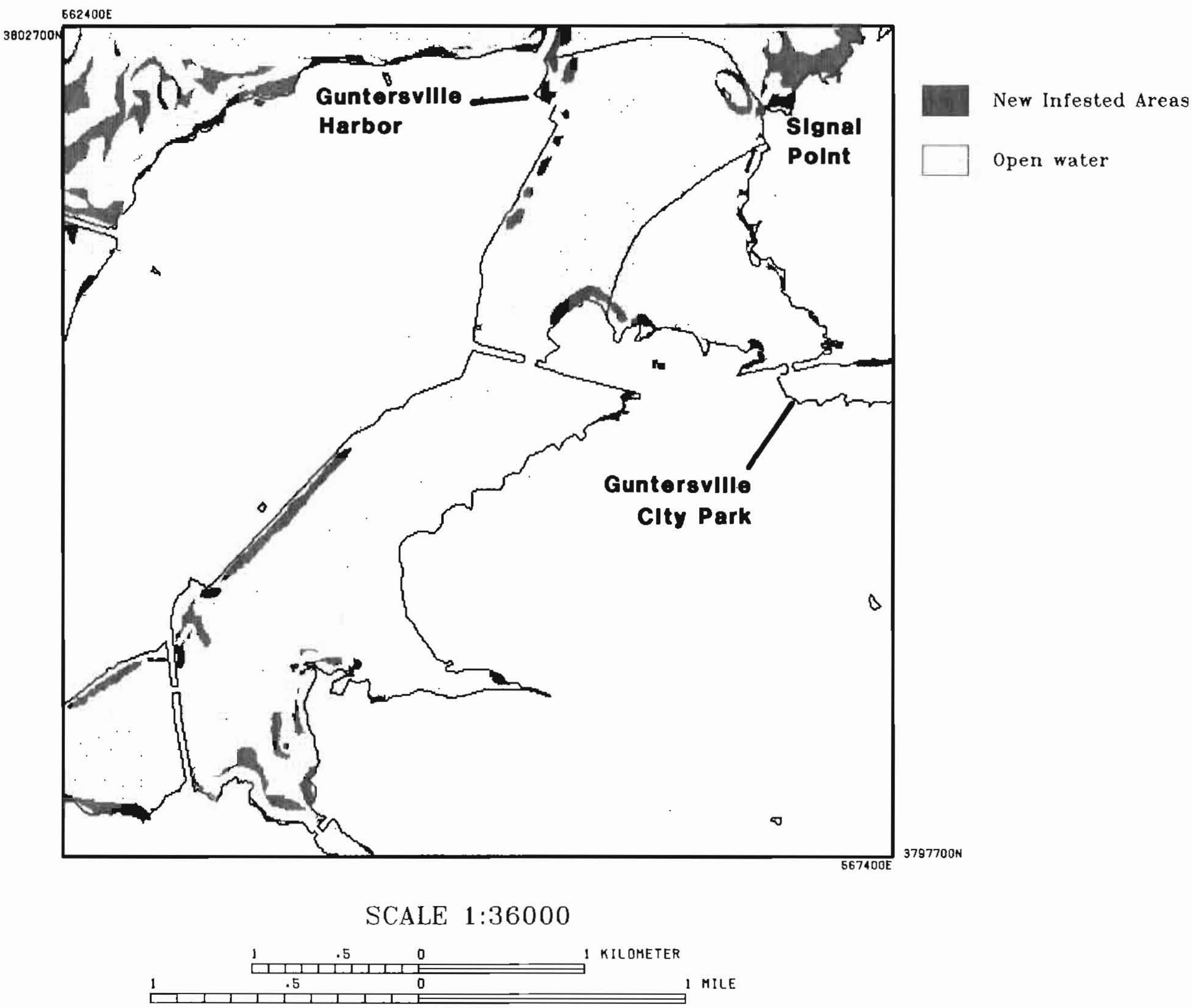

Figure 8. Aquatic plant infestation increase between 1984 and 1988 near Guntersville Harbor, Guntersville Reservoir, as determined from the aquatic plant digital database

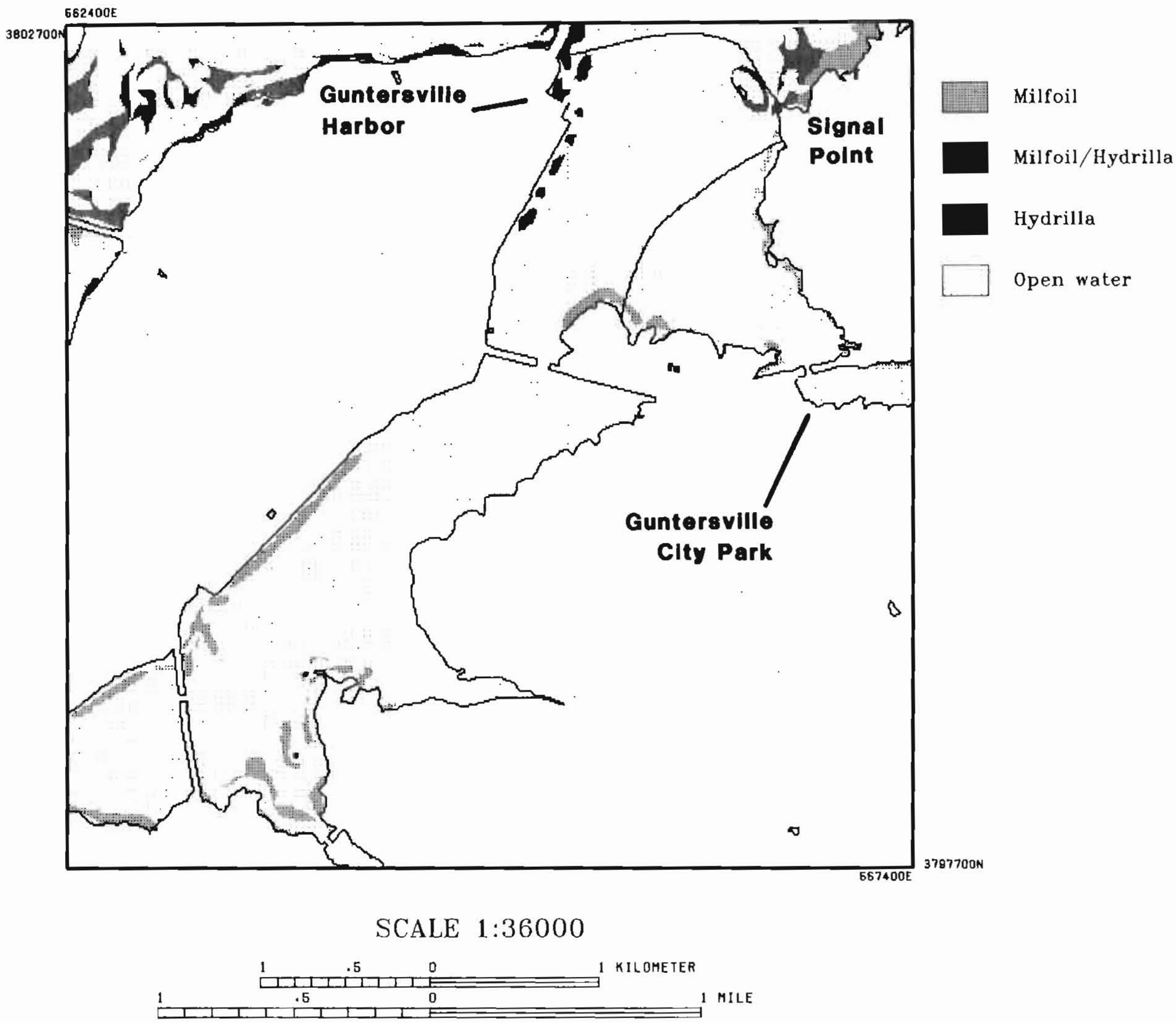

Figure 9. Species identification of aquatic plant infestation increase between 1984 and 1988 near Guntersville Harbor, Guntersville Reservoir, as determined from the aquatic plant digital database

Annual Report - Aquatic Plant Control Operations Support Center

by
William C. Zattau* and Anne N. Galloway*

In October 1980, the Jacksonville District was designated by the Office, Chief of Engineers, as the Aquatic Plant Control Operations Support Center (APCOSC), in recognition of the District's knowledge and expertise gained through the administration of the largest and most diverse aquatic plant management program in the Corps. The APCOSC personnel assist other Corps elements and other Federal and State agencies in the planning and operational phases of aquatic plant control. The specific duties, relationships with other Corps aquatic plant control programs, and guidelines for utilization of the APCOSC are outlined in ER 1130-2-412.

The Center responded to 123 requests for assistance during FY 89. A breakdown of these activities appears in Table 1. Figure 1 indicates the types of information requested; Figure 2 provides a breakdown as to source of information requests.

Table 1
APCOSC Contacts, FY 89

Type Assistance	*Corps OCE*	*Corps WES*	*Corps Div.*	*Corps Dist.*	*Other Fed.*	*Other Country*	*State-Local*	*Industry*	*Private*	*Total*
Planning	3	3	0	5	2	1	2	2	0	18
Operations	3	2	2	32	2	1	11	2	2	57
Research	0	17	1	1	1	1	5	9	2	37
Training	1	3	0	5	1	0	1	0	0	11
Total	7	25	3	43	6	3	19	13	4	123

The demand for, and type of, services performed by the Center vary from year to year, based on the type of problems encountered by Corps Districts or other agencies. Four basic types of information are requested: planning, operations, training, and research. Planning assistance includes determinations of water body eligibility and allowable costs, computation for benefit-cost ratios, methods of data acquisition, and other factors that enter into the process of planning an Aquatic Plant Control Program. Operations assistance involves most aspects of chemical, mechanical, biological, and integrated technology. The Center provides data, information, and recommendations relating to operational activities. Training assistance includes providing materials for use in educational or training programs, and Center staff conducting the Pesticide

*US Army Engineer District, Jacksonville; Jacksonville, Florida.

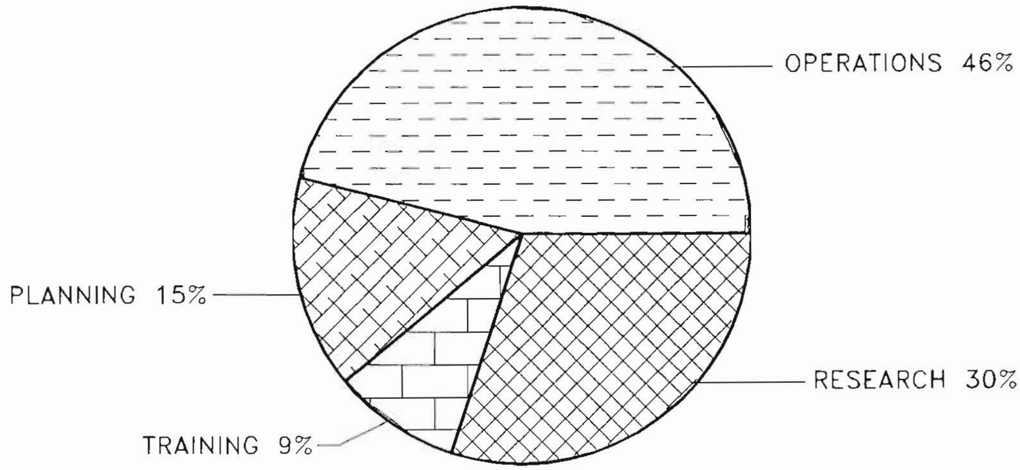

Figure 1. Types of information requested, FY 90

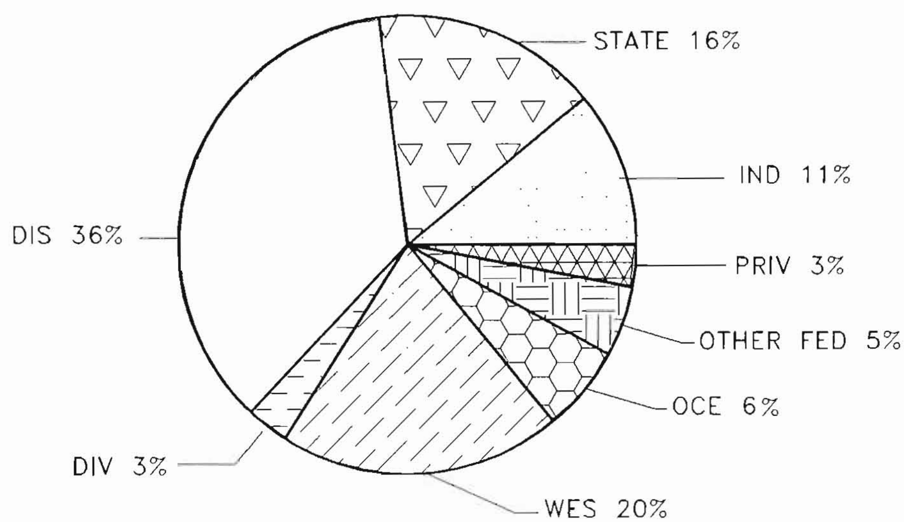

Figure 2. Breakdown of requests for information, FY 90

Applicators Training Course. Information on research activities is provided to requestors if available, or the requests are referred to the WES.

Table 2 shows the various types of assistance performed by the Center during fiscal years 1981-1989. As expected, over 50 percent of the contacts during the past 9 years were for operational assistance. Approximately 31 percent were for planning assistance, followed by research and training requests. These figures do not reflect

Table 2
APCOSC Contacts, FY 81-89

	Planning	*Operations*	*Research*	*Training*	*Total*
FY 81	21	50	6	4	81
FY 82	56	83	15	7	161
FY 83	41	75	9	0	125
FY 84	63	56	5	9	133
FY 85*	--	--	--	--	--
FY 86	32	39	3	6	80
FY 87	23	35	15	6	79
FY 88	26	63	31	8	128
FY 89	18	57	37	11	123
Total	280	458	121	51	910
Percent	31	51	13	5	100

*Information not available.

man-hours expended on each request, and therefore may be misleading. For example, an operations contact may take 1 hr, while one training request (to conduct the Pesticide Course) may require 120 man-hours or more including preparation, travel, and course time.

Table 3 indicates that most requests for assistance came from Corps District offices, followed by State and local agencies and the WES. Fifty-nine percent of the requests

Table 3
APCOSC Requests by Source, FY 81-89

	Corps OCE	*Corps WES*	*Corps Div.*	*Corps Dist.*	*Other Fed.*	*Other Country*	*State Local*	*Industry*	*Private*	*Total*
FY 81	0	6	0	32	12	3	18	8	2	81
FY 82	12	28	5	49	16	2	18	25	6	161
FY 83	7	15	4	32	16	0	26	21	4	125
FY 84	13	7	7	51	18	0	25	9	3	133
FY 85*	--	--	--	--	--	--	--	--	--	--
FY 86	1	5	15	31	9	0	14	2	3	80
FY 87	9	7	3	27	8	0	10	3	12	79
FY 88	13	30	10	39	7	0	19	2	8	128
FY 89	7	25	3	43	6	3	18	13	4	123
Total	62	123	47	304	92	8	148	83	42	909
Percent	7	14	5	33	10	>1	16	9	5	100

*Information not available.

came from the Corps, of which 57 came from Corps Districts. The number, variety, and source of the contacts indicate a cosmopolitan awareness, and use, of Center services.

The Center published four quarterly issues of the APCOSC Information Exchange Bulletin. Included were articles provided by several Corps personnel. The Annual Aquatic Plant Control Program District Survey is being compiled and should be ready for distribution in early 1990.

Synopsis of the District/Division Aquatic Plant Management Operations Working Session

by
William C. Zattau

Forty-five individuals attended the fourth annual Operations Session during the 1989 Aquatic Plant Control Research Program Review. Included were representatives from Headquarters (HQUSACE), WES, four Divisions, 14 Districts, six state cooperators, universities, utilities, and industry. Seven presentations were given. Topics included the aerial imaging system, hydrilla in North Carolina, possible insect decimation of Eurasian watermilfoil in Vermont, Eastman Lake (Sacramento District) and the proposed California cost-shared aquatic plant control (APC) program, the Potomac River, and the Nashville and Galveston District programs.

These presentations took approximately 2 hours and were informative and well received. Following the session, it was decided that selected operations presentations will be given during the formal sessions next year; this shift will allow more time for operations discussions.

Participants discussed past Operations Sessions and the fate of past recommendations such as the creation of an APC Program Efficiency Task Force, quarterly research updates, an electronic bulletin board for the APCOSC, and the issuance of more field-oriented user manuals by the WES. It was noted that no formal recommendations had ever been forwarded up the chain for review, comment, and action. In the future, a memorandum will be prepared to forward such recommendations to the APCRP Program Manager and CECW-ON for review and action.

The Model Local Cooperative Agreement (LCA) was discussed, along with related revisions to ER 1130-2-412. After the next meeting with the LCA Committee, Jim Wolcott (CECW-ON) will inform program personnel of the status of the LCA and the regulation. Most agreed that it is time to finalize the Agreement and try to make it work.

Issues related to in-house administrative costs were discussed. One District felt that in-house expenses, including training and conference travel, should be excluded from the 50:50 cost-sharing requirements. It was further suggested that benefit/cost reviews of certain recurring treatment areas within the program be periodically conducted.

Participants discussed the APC Program Evaluation Guidance (PEG) Task Force. The first meeting was held in October 1989. In attendance were Bill Zattau, CESAJ-CO-OR-A, Team Leader; Lewis Decell, CEWES-EP-L; Joe Kight, CESAM-FO-LS; Bob Rawson, CENPS-OP-PO; Maurice Simpson, CEORN-OR-R; and Vicki Dixon, CESWD-CO-RR. The purpose of this meeting was to discuss the concept of the APC self-appraisal program and to review the requirements and application of the final product(s).

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*US Army Engineer District Jacksonville; Jacksonville, Florida.

Initial discussion revolved around the annual APCOSC APC Program District Survey on operational activities. The content of these surveys has stimulated interest in the effectiveness and efficiency of the APC Program, and this interest was a major reason that this Task Force was convened. Since data in this survey may be used to evaluate or compare District APC programs, or may be used to judge performance, the Task Force recommended revision of the annual survey.

As described in the PEG Charter, the major goal of the Task Force is to develop management self-appraisal checklists. At this time, the Task Force intends to develop checklists for use at the project, District/Division, and HQUSACE levels. These checklists will be designed to simultaneously support several purposes, including, but not limited to, self-monitoring to ensure that all aspects of the program are being adequately addressed, determining program strengths and weakness, determining progressiveness of a particular project or program, and determining compatibility with the basic program philosophy, as a guide for program implementation, and as a document to serve as a guide during program transitions.

Lower Mississippi Valley Division, New Orleans District

by
Glen N. Montz* and Frank J. Cali*

Waterhyacinth remains the number one problem nuisance aquatic plant in Louisiana. Control operations are also targeted at hydrilla, salvinia, water paspalum, water pennywort, alligatorweed, egeria, Eurasian watermilfoil, frog's-bit, watershield, coontail, and American lotus.

In-house Corps of Engineers and Louisiana Department of Wildlife and Fisheries spray crews treated many acres of unwanted aquatics during FY 89. Aerial spraying operations were used by both agencies to supplement spray boat activities.

Our efforts to permit floating aquatics to shade hydrilla revealed that at least two growing seasons are needed for this to be effective. This year, movement of floating aquatics throughout Lake Boeuf and Lake Theriot resulted in additional spraying efforts on waterhyacinths. Kills on hydrilla and waterhyacinths in 5-acre plots and strong winds constantly moving the floating aquatics permitted penetration of sunlight and regrowth of submersed aquatics. Mats of hydrilla tend to hold floating aquatics in place, and when removed, the vegetation is able to move freely in the water body. We will continue to inspect these plots in both lakes to determine if this approach is feasible.

Unwanted aquatics declined considerably in two watersheds this year. Inspections in the Upper Barataria Waterway south of New Orleans and the Belle River area south of Baton Rouge revealed sporadic growths of waterhyacinths and hydrilla. In the past, waterways in both these areas were in constant need of treatment of these aquatics. It is surmised that saltwater intrusion was the factor affecting growth of aquatics in the Upper Barataria Waterway area. Water samples taken by the State of Louisiana revealed high concentrations of tannins in the Belle River area, which may be adversely affecting both floating and submersed aquatics in that watershed.

While aquatics were scarce in these two areas in south Louisiana, waterhyacinths, hydrilla, and salvinia exploded in many other water bodies. Waterhyacinths jammed many bayous, canals, and lakes in St. Charles, Jefferson, Lafourche, and Terrebonne Parishes in coastal Louisiana. Hydrilla, which was found only in fringes and patches in Lake Penchant near Houma and Grassy Lake near Morgan City, has completely covered the water surface in both lakes. Salvinia is increasingly becoming a pest throughout coastal waterways and has stacked up to several inches when pushed against banks by strong winds.

Several environmental groups in Louisiana have attacked biological control of aquatics. Newspaper articles have argued that the alligatorweed beetle has destroyed many acres of coastal marsh, resulting in further deterioration of the state's wetlands.

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*US Army Engineer District, New Orleans; New Orleans, Louisiana.

Other newspaper articles, mainly by US Department of Agriculture researchers, have discussed positive aspects of biological control on waterhyacinth and alligatorweed in Louisiana.

The New Orleans District participated in field studies with Dow Chemical U.S.A. in connection with the Garlon 3A Experimental Use Permit program. Dow is seeking expanded use registration for Garlon 3A (triclopyr) for aquatic sites. Using a standard treatment protocol and supplemental label rates, treatments were made at 24 sites in Lake Boeuf, Louisiana. The sites were evaluated for effects on waterhyacinth, frog's-bit, water pennywort, and waterlettuce. Efficacy data are now being analyzed by Dow.

New England Division, Baltimore District

by
Robert Blama*

The Baltimore District transferred management of the Aquatic Plant Control Program to the Washington Council of Governments (COG) in 1989. The responsibilities of the COG were to negotiate contracts for harvesting and inspection, issue work orders, perform monthly ranking surveys, gain easements for unloading points and disposal areas, and maintain public awareness of the program.

The aquatic plant control program for the Baltimore District continued as mechanical harvesting in the Potomac River. The drainage basin for the Potomac experienced above-average rainfall and above-average flows in the river (Tables 1 and 2). The higher flows caused increased turbidity levels and appear to have limited the growth of hydrilla and other aquatic plants in the Potomac.

Table 1
Flow Data

	*Flow, bgd**		
Time Period	***June***	***July***	***Average***
1989	8.5	7.7	4.6
1988	4.0	1.5	0.9
Average	5.0	2.6	2.3

*bgd = billions gallons per day.

Table 2
Rainfall Data

	Rainfall, in.		
Time Period	***June***	***July***	***Average***
1989	6.02	5.66	1.15
1988	0.95	3.74	2.39
Average	3.35	3.88	4.40

*US Army Engineer District, Baltimore; Baltimore, Maryland.

In 1988, 106 acres were mechanically harvested from 17 sites in Maryland and Virginia. In 1989, only 37.4 acres were harvested from 12 sites in Maryland and Virginia. Of the 37.4 acres, 21.8 acres were new areas that needed harvesting. These areas were farther south in the Potomac and may not have experienced the effect of turbidity like the northern portion of the river.

During the harvesting season of 1989, the cost per acre was based on the density of the bed. The inspector at the site would determine if the area harvested contained a low, medium, or high density of aquatic plants according to a preset formula. Although the cost of a medium density area was $1,500/acre, the average cost per acre in 1989 was $1,590.

Vermont Aquatic Plant Control Program

by
Michele Farmer*

The New York District Corps of Engineers and the State of Vermont completed the eighth year of a cooperative program for the control of nuisance species of aquatic plants on Lake Champlain. The major species of concern to date have been Eurasian watermilfoil (*Myriophyllum spicatum*) and waterchestnut (*Trapa natans*).

For the first year since the program began in 1982, Eurasian watermilfoil was not harvested, because no proposals for harvesting were submitted to the State. The 1989 program was therefore confined to the harvesting of waterchestnut from southern Lake Champlain. The purpose of this harvesting was to prevent the further northward spread of this plant in the lake.

Approximately 130 acres of waterchestnut were mechanically harvested, using a combination of deepwater harvesters, shallow-water harvesters, a high-speed transport barge, and a two-person hand-pulling crew operating from a boat. No new areas of infestation were harvested due to a reduction in State funding; however, in certain areas, smaller harvesters than those used in previous years were employed, due to a decrease in the amount of waterchestnut. Harvesting took place between 25 July and 30 August 1989.

Mechanical harvesting is considered to be very affective in controlling the northward spread of waterchestnut in Lake Champlain. However, the harvesting must be done each year to prevent reinfestation.

Future proposals for this program involve adding Lake Bomoseen as a treatment area and consideration of certain biocontrol measures for Eurasian watermilfoil.

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Ohio River Division, Nashville District

by
Maurice Simpson*

Infestations of Eurasian watermilfoil in the Cumberland River system increased significantly in 1989. Milfoil in Lake Barkley increased from approximately 55 acres in 1988 to over 400 acres in 1989. Old Hickory Lake reported its first known milfoil infestation, with a total of approximately 75 acres observed in widely scattered areas of the lake. Distributions and early growth stages lead to suspicion of deliberate planting by unknown persons. Scattered milfoil within a 20-acre area was also discovered this year in Dale Hollow Lake, a project that experiences a +20-ft annual drawdown.

The largest concentrations of milfoil in Lake Barkley were treated by aerial application of granular 2,4-D under contract with TVA. Mop-up of small areas was conducted by boat. Initial kill appeared good. However, quick regrowth was noted in nearly all treatment areas. This resulted from basinwide high flows from extended periods of rain throughout the spring and early summer. Contact time of the herbicide was thus reduced below that required for complete kill. Due to lack of funds Corps-wide, we were unable to procure sufficient herbicides to retreat the plants, and only minor follow-up treatments with on-hand supplies of granular aquathol were conducted.

All known populations of milfoil in Old Hickory Lake were treated with granular 2,4-D or aquathol. Kill of established colonies appeared good. However, floating fragments were observed to be widespread in the lake throughout late summer, and the likelihood of significant new infestations next year is good.

Milfoil in Dale Hollow was restricted to one relatively shallow cove that should be totally exposed during the winter drawdown period. Several plant clumps were marked and will be monitored for regrowth following inundation next spring. Unless milfoil unexpectedly exhibits an ability to withstand long-term exposure and freezing, we do not believe it will become a nuisance due to control by the annual drawdown at that project.

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A New Hydrilla Strain in North Carolina

by
Charles R. Wilson*

Hydrilla (*Hydrilla verticillata*) was discovered in Burnt Mill Creek during the winter of 1988-1989. Burnt Mill Creek is a channelized stream located within the city of Wilmington, New Hanover County, North Carolina, and is a tributary to Smith Creek, which flows into the northeast Cape Fear River (Cape Fear River drainage).

It is not known how long Burnt Mill Creek has been infested with hydrilla. The site is also infested with egeria (*Egeria densa*). Egeria was first reported from Burnt Mill Creek in 1984 (North Carolina DNRCD 1985), and due to the similarity of appearance between hydrilla and egeria, hydrilla could have been there several years and gone undetected.

This is the only known population of hydrilla in the coastal area of North Carolina. All previous collections in the state have been from inland sites located in or near the North Carolina piedmont.

Burnt Mill Creek hydrilla is of particular interest to aquatic plant experts and researchers in the state. The morphology and phenology of the hydrilla collected from this site are different from hydrilla known from other sites in North Carolina.

The hydrilla collected in Burnt Mill Creek has several visually discernible morphological characteristics that differ from the monoecious hydrilla found at other sites in the state. It appears to be robust, possesses large tubers, and has pronounced ventral leaf spines, all characteristics generally associated with the dioecious strain of hydrilla from Florida. The floral characteristics of the Burnt Mill Creek hydrilla are unknown. The hydrilla from this site had not yet flowered when last sampled in late October 1989.

It also appears that hydrilla overwinters in Burnt Mill Creek. Healthy plants were collected from the site in late January and March 1989. Previous studies by Harlan, Davis, and Pesacreta (1984) have indicated that vegetative portions of hydrilla did not overwinter in North Carolina. They reported that hydrilla beds began to break up in October and were essentially absent by late December.

Based on morphological and phenological characteristics and preliminary comparison of isoenzymes stained after electrophoresis of tuber extracts (USDA Aquatic Weed Research Lab, University of California, Davis), it appears that the Burnt Mill Creek hydrilla is dioecious. If so, this infestation is the first occurrence of a dioecious hydrilla strain in the state. Prior to this discovery, it had been indicated that all hydrilla populations in North Carolina were monoecious (Langeland and Schiller 1983, Langeland and Pesacreta 1986).

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Whether the morphological and phenological differences between the Burnt Mill Creek hydrilla and that collected at other sites in the state are caused by genetic differences or ecophenotypic expression is unclear. Further research to clarify this situation is needed.

Additional electrophoresis, to confirm the preliminary findings, and detailed surveys of hydrilla tuber densities at Burnt Mill Creek are planned. However, the site has been recently dredged, and our schedule is uncertain. Although it appears that hydrilla continues to infest Burnt Mill Creek, it has been disturbed to the point that it is not likely to be suitable as a research site this year. Future analysis may be possible prior to the next scheduled channel maintained in 1991.

REFERENCES

Harlan, S. M., Davis, G. S., and Pesacreta, G. J. 1984. "Phenological Studies," *Hydrilla Management in North Carolina*, R. G. Hodson et al., eds., Report 217, Water Resources Research Institute, University of North Carolina.

Langeland, K. A., and Schiller, D. H. 1983. "Hydrilla in North Carolina," *Aquatics*, Vol 5, pp 8-14.

Langeland, K. A., and Pesacreta, G. J. 1986. "Management Program for Hydrilla (A Monoecious Strain) in North Carolina," Report 225, Water Resources Research Institute, University of North Carolina.

North Carolina Department of Natural Resource and Community Development, Division of Environmental Management. 1985. "Aquatic Macrophyte Summary, 1984," Raleigh, NC.

Southwestern Division, Galveston District

by
Jim Barrows*

The Aquatic Plant Control (APC) Program carried out within the boundaries of the State of Texas is done so under the authority of the Galveston District in cooperation with the Texas Parks and Wildlife Department. The Fort Worth and Tulsa Districts are responsible for the operation and maintenance of some individual Corps projects within Texas, including aquatic plant control at these projects. However, such control work is not a part of the cost-shared APC program.

The Galveston District has had an active control program for noxious aquatic plants since 1968. A General Design Memorandum and Environmental Statement for the control of alligatorweed and waterhyacinth were published in the early 1970s. As a result, the control of alligatorweed and waterhyacinth is authorized in all 18 river basins and work areas of Texas.

During the mid-1970s hydrilla began showing its nuisance characteristics, particularly in the eastern portion of Texas where the clear, relatively warm lakes offered prime habitat. In 1985, a Supplement No. 1 to the General Design Memorandum and an Environmental Assessment (EA) were completed to recognize that hydrilla and Eurasian watermilfoil were fast becoming problem plants and should be included in the Texas APC Program. This Supplement and EA provided for the incorporation of 11 lakes into the APC Program for control of hydrilla and milfoil. In the past year, environmental assessments were completed for the inclusion of an additional 14 lakes into the program.

The surveys for problem areas and the methods used to control aquatic plants are carried out by the Texas Parks and Wildlife Department. The herbicide 2,4-D is used to control waterhyacinth. Endothall and fluridone are used for hydrilla control. In Texas at the present time, alligatorweed is controlled predominantly by the flea beetle *Agasicles hygrophila*. When herbicide is required to augment biological control of alligatorweed, the chemical glyphosate is often used.

From April through October, the heaviest months of the herbicide spray program, the state has four to six crews stationed in three areas to treat waterhyacinth. The treatment of hydrilla is done on an as needed basis by the field crews. During FY 89, about 6,000 acres of waterhyacinth and 375 acres of hydrilla were chemically treated.

Because of an increasing concern with safety in the use of pesticides, the Galveston District and the Texas Parks and Wildlife Department contracted with the Aquatic Plant Control Operations Support Center in Jacksonville, Florida, for a training course with heavy emphasis on the proper handling of pesticides, from an environmental as well as a human health standpoint. This coursework was presented 2 weeks ago in

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Austin, Texas, and was attended by members of the State field crews as well as Federal and State administrators of the APC program in Texas.

The use of biological means to control aquatic plants is spearheaded by personnel at the Corps of Engineers Waterways Experiment Station, most notably Al Cofrancesco and Mike Grodowitz. Through their efforts, the Texas Parks and Wildlife Department has accepted the principle of biological control as a viable part of the program. The use of the flea beetle against alligatorweed, as mentioned earlier, is a good example of this acceptance. Another agent for the control of alligatorweed is the thrip *Amynothrips andersonii.* In addition, weevils such as *Neochetina bruchi* and *Neochetina eichhorniae* have been introduced for waterhyacinth control.

For the 7 years prior to 1989, populations of the flea beetle in Texas were supplemented with insects shipped in from Florida or Louisiana through the Aquatic Plant Control Support Center. Unfortunately, 1989 was a bad year for flea beetles in Florida. Texas did not receive supplemental shipments for release into new areas with alligatorweed problems. Therefore, the populations of flea beetles that survived from last year's infestations were the main controllers of alligatorweed this year.

For the future, field tests with the fly *Hydrellia pakistanae* are being planned with the intention of developing a biological control program for hydrilla. Such a program will be mandatory if fiscal and manpower constraints continue, if public perceptions of pesticides as inherently evil grow, and if the per-acre treatment cost of herbicides for treating hydrilla is not greatly reduced.

In recognition of the severity of the hydrilla problem, a Regional Task Force was formed in 1986 by several State agencies. An outgrowth of this task force is the Texas Aquatic Plant Management Society (TAPMS), an affiliated chapter of the national Aquatic Plant Management Society. The first annual meeting of TAPMS was held in Austin (7 November 1989).

The APC Program in Texas is currently operating under a contract that is in its last year of renewal. During 1988, the Galveston District completed the negotiation of a 50 percent cost-shared, cooperative agreement with the State. However, the Washington office revised the guidelines sent down to the District office and has issued new ones. We are currently preparing to renegotiate with the State on another 50 percent cost-shared, cooperative agreement. The renegotiation will have to be accomplished before the end of the year for Federal participation in the APC program to continue in Texas.

Pacific Ocean Division

by
Kisuk Cheung*

A reconnaissance study for the Hawaiian Islands was completed by contract in 1986. The contractor's report was circulated to various public agencies for review. Although various review comments were subsequently received, no aquatic plant infestation has yet been identified for which there is a clear and definite Federal interest, and for which the other principal criteria governing the Aquatic Plant Control Program can be met. The study remains at the reconnaissance stage pending further information or analysis.

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Aquatic Plant Control Program in California

by
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Since 1966, the Sacramento District has periodically received requests from both public agencies and private individuals to evaluate problems associated with the growth of waterhyacinth in the Merced, Tuolumne, and lower San Joaquin Rivers, and in waterways of the Sacramento-San Joaquin delta. The initial requests were concerned with waterhyacinth in Merced River and its impacts on flood control. Preliminary analysis in 1973 indicated that removal of the waterhyacinth would not be economically justifiable.

Subsequent requests have been more concerned with waterhyacinth impacts on irrigation and recreation in the Sacramento-San Joaquin delta. By letter of 28 September 1981, the California Department of Boating and Waterways (DBW) requested assistance from the Corps of Engineers to find a solution to the waterhyacinth problems in the delta. A State Design Memorandum was completed in May 1984 that recommended Federal involvement in the operational plan with the State. However, DBW notified the Corps that the State Control Program had reduced the problem to one of maintenance, that State funding is adequate to operate the current waterhyacinth maintenance program, and that Federal assistance is not needed at this time. The State Control Program included chemicals to eliminate the immediate problem and biological control agents to provide long-term control. WES conducted a research program to identify pathogens which might help control waterhyacinth in the delta. The research document was provided to the State for their use.

Since 1976, the Department of Food and Agriculture (CDFA), the lead agency for aquatic plant control in the State, and their cooperators have spent more than $15 million in pursuing a program of eradication of hydrilla. Since the initial discovery, hydrilla has been found in various locations from Redding to El Centro. Most of the infestations have been eradicated. Two major infestations have been discovered within the last 4 years. In 1985 and 1986, hydrilla was found infesting 11 ponds adjacent to the Sacramento River near Redding. In 1988, hydrilla was detected in seven ponds within the Bear Creek drainage system near Wallace. Bear Creek flows southwest from Calaveras County through San Joaquin County and enters the California delta. The presence of hydrilla in these two locations poses a significant risk in that it could become established in the Sacramento River, California, delta and associated water systems. Hydrilla infestations in El Centro, Wallace, and Redding have been significantly reduced, and eradication is projected within 5 to 7 years. Recent identification of hydrilla in the Chowchilla River and Eastman Lake in Madera and Mariposa Counties requires the expansion of CDFA eradication efforts. While the Corps is

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responsible for the aquatic plant problems in Eastman Lake, the State is responsible for the River and all other nonproject areas.

Due to the seriousness of the hydrilla situation in the Sacramento River and delta area, a Science Advisory Panel (SAP), consisting of aquatic weed scientists from the CDFA, Corps of Engineers, and Tennessee Valley Authority, was convened to evaluate the problem and develop recommendations. Based on a description of past flood events and drainage characteristics of the infested sites, the SAP members were of the opinion that hydrilla had already been introduced into the Sacramento River and the California delta. To mitigate the impact of hydrilla, the SAP recommended that: (a) survey and detection efforts in the Sacramento River and delta be intensified and (b) the CDFA and Corps initiate discussions aimed at developing a cooperative effort between the agencies. Having been requested by the CDFA to provide assistance, the Corps is currently conducting a reconnaissance study, the first phase being to develop a cost-shared local cooperation agreement with the State.

A Sudden Decline of a Eurasian Watermilfoil Population in Brownington Pond, Vermont

by
S. P. Sheldon*

INTRODUCTION

Brownington Pond, in northeast Vermont, is a small mesotrophic lake, with a surface area of approximately 65 ha, a maximum depth of 10.7 m, and an average depth of 5.5 m. Submersed macrophytes grow throughout the littoral portion of the lake.

DISCUSSION

In 1986 when Vermont state biologists examined the lake, the littoral zone was densely colonized by Eurasian watermilfoil (*Myriophyllum spicatum*). The milfoil plants surfaced and flowered. However, when the lake was revisited in the end of August 1989, very few watermilfoil plants were found.

On further examination, the *M. spicatum* had been reduced to one bed, approximately 75 by 10 m. Plants on the periphery of the bed appeared in very poor condition. The plants were heavily colonized by herbivorous macroinvertebrates, particularly two aquatic caterpillars (*Acentria nivea = Acentropus niveus* and *Parapoynx* sp.) and at least one species of aquatic weevil, *Eurhynchiopsis lecontei*. Stems were damaged and necrotic. The *M. spicatum* plants in the interior portion of the bed appeared more vigorous; however, few plants surfaced, no flowers were seen, and few plants retained their apical meristem.

In contrast, in other areas of the littoral zone, many native plants were found. Plants appeared healthy; for example, *Heteranthera dubia* was >2 m tall and bushy. Plants now found commonly in the lake include *Heteranthera dubia*, *Najas flexilis*, *Potamogeton amplifolius* and *P. gramineus*, *Sagittaria*, *Isoetes*, *Chara*, and *Bidens beekii*. Of these, only *P. amplifolius* had damaged leaves. Single *M. spicatum* fragments, approximately 10 to 15 cm long, were found in the mixed native beds. Each milfoil fragment examined housed at least one caterpillar, while the contiguous native plants did not have caterpillars on them.

In September 1989 the pond was examined, and quantitative plant and invertebrate samples were taken on the periphery and in the center of the *M. spicatum* bed and in the native plant beds. In the milfoil bed, there were high densities of macroinvertebrates, including chironomids, caterpillars (both *Acentria nivea* and *Parapoynx* sp.), weevils, three species of tricopteran larvae (including *Polycentropus*), a mining caddisfly, two species of odonates, and two species of ephemeroptera. On the edge of the

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bed, many milfoil plants were entirely encrusted with the bryozoan *Plumatella*. In contrast, native beds had no weevils, no *Acentria*, few *Parapoynx*, and fewer tricopterans than the milfoil bed. Chironomids were also in high densities.

While declines of milfoil have been noted before in the United States, for example in Wisconsin,* the causes of the declines have been unclear. In Canada, Painter and McCabe** followed rapid milfoil declines in the Kawartha lakes system and found that the caterpillar *Acentria* was responsible for the milfoil decline there.

In Brownington Pond we have a milfoil population with many potential sources of control already living in the lake, including *Acentria*, *Parapoynx* and *Eurhynchiopsis*. The goals of the next few years of study are to follow *M. spicatum* and its herbivores in Brownington Pond, to carry out experiments to determine the cause of the watermilfoil decline, and to evaluate the potential of one or more of the aquatic herbivores to control Eurasian watermilfoil in other lakes.

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*S. R. Carpenter. 1980. "The Decline of *Myriophyllum spicatum* in a Eutrophic Wisconsin Lake," *Canadian Journal of Botany*, Vol 58, pp 527-535.

**D. S. Painter and K. J. McCabe. 1988. "Investigation into the Disappearance of Eurasian Watermilfoil from the Kawartha Lakes," *Journal of Aquatic Plant Management*, Vol 26, pp 3-12.