current

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AQUATIC INVASIVE SPECIES

"...to make known the world of water, both fresh and salt."

THE NATIONAL MARINE EDUCATORS ASSOCIATION brings together those interested in the study and enjoyment of the world of water. Affiliated with the National Science Teachers Association, NMEA includes professionals with backgrounds in education, science, business, government, museums, aquariums, and marine research, among others. Members receive *Current: The Journal of Marine Education*, *NMEA News*, and discounts at annual conferences. Membership information is available from: NMEA, P.O. Box 1470, Ocean Springs, MS 39566-1470, (228) 374-7557, email: johnette.bosarge@usm.edu, or visit our website online at **www.marine-ed.org/**.

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LISA M. TOOKER, MANAGING EDITOR
DR. JOHN DINDO AND
JEFFREY SCHARDT, ISSUE EDITORS
CHRISTINA RIVERS, DESIGN

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Editorial and advertising offices: **NMEA**, c/o Johnette Bosarge, P.O. Box 1470, Ocean Springs, MS 39566-1470

Front cover: Jeffrey Schardt (background image, middle left); John Madsen (top left); Dr. Andrea Copping, Washington Sea Grant Program (bottom left); Jeff Marx, Louisiana Department of Wildlife and Fisheries (bottom right)

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c/o Johnette Bosarge
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INSIDE **CURRENT**

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CURRENT LOG *This issue of* Current *is dedicated to invasive species. What is an invasive species? Invasive species are non-native or introduced species that have entered a habitat that is outside their natural global range. Invasive species can cause damage to the environment, economy, or human health. Introductions can be passive, such as a hitchhiker on a large ocean going ship or oil platform to intentional releases by mankind, as is the case with water hyacinth to enjoy its showy lavender flower. Since the early 1800s, over 50,000 species have been introduced into the United States, with 6,500 species establishing permanent populations. Today, an estimated $138 billion dollars a year is being spent to attempt to slow down or eradicate invasive species in the United States. Although this issue features invasive species found within the United States, invasive species from North America present the same problems in other parts of the world. The key to management of invasive species is education. The National Marine Educators Association (NMEA) is a leader in aquatic and marine education, and through this issue of* Current, *readers will glean a better understanding of invasive species and how we can take an active role in helping to control and manage invasive species.*

DR. JOHN DINDO is a senior marine scientist and chairman of the Discovery Hall Programs, the educational division of the Dauphin Island Sea Lab. Dr. Dindo has been working at the Dauphin Island Sea Lab as a scientist and educator for 27 years. Today, over 12,000 K-12 students and 300 teachers annually take classes in marine science through the Discovery Hall Programs. Dr. Dindo's research centers on nesting and migration in coastal birds.

JEFF SCHARDT is the administrator of Florida's aquatic plant management program conducted in more than a half million hectares of public lakes and rivers; a position he has held with the Florida Department of Environmental Protection for the past 17 years. He is President Elect of the Aquatic Plant Management Society and serves on the national Invasive Species Advisory Committee.

CONTENTS

This issue of *Current* is sponsored by the Aquatic Plant Management Society, the National Oceanic and Atmospheric Administration's National Sea Grant and the Mississippi Alabama Sea Grant Consortium, and the Dauphin Island Sea Lab.

Volume 21 • Number 2 • 2005

Introduction to Aquatic Invasive Species

IN SEPTEMBER OF 2000, *the Gulf of Mexico Program (GMP) released a report entitled,* An Initial Characterization of Non-Indigenous Aquatic Species in the Gulf of Mexico Region. *GMP had compiled technical information and became a regional information center on aquatic non-indigenous species. Although this information was readily available to scientists and managers, principal investigators at the Dauphin Island Sea Lab in Alabama and the J.L. Scott Marine Education Center in Mississippi wrote the first of three proposals to Mississippi Alabama Sea Grant Consortium and the National Sea Grant office to fund teacher programs on non-indigenous aquatic species. In an effort to have a broader dissemination about invasive species and to enhance scientific knowledge in classrooms, four key species (Cogon grass, nutria, Mozambique tilapia, and Australian jellyfish) found within Mississippi and Alabama were used to develop classroom curricula, lesson plans, and activities on invasive plants and animals.*

The following list of terminology and critical concepts were used in workshops hosted in both Mississippi and Alabama:

1. biodiversity
2. community
3. environment
4. exotic species
5. food web
6. genetic variation
7. habitat
8. habitat preservation
9. introduced species
10. invasive species
11. native species
12. niche roles
13. non-indigenous
14. nuisance species
15. physical adaptations
16. population
17. predator
18. prey
19. management policies
20. sustainability

Education mini-camps were held in each state and most participants obtained graduate credit through their respective state universities.

This grant was followed by a subsequent proposal that focused on the same issue, both terrestrial and aquatic invasive species, with an emphasis on outreach throughout the regions in both states. Workshops were conducted on both coasts and through outreach programs around the state. The developed projects are correlated with the National Science Education Standards, the Professional Development Standards, and the AAAS Benchmarks.

Broader impacts of the invasive species grants were reached through an on-line course that was recently completed in the spring of 2004. Three keynote scientists were featured, one each week with on-line interaction between the scientist and the participant during that week. Three hundred and twenty six people from across the United States participated in this workshop and were provided classroom curricula.

In an effort to continue to reach formal and informal educators on this critical subject area of invasive species a collaborative effort with the National Marine Educators Association (NMEA) will take place. The NMEA is a not-for profit educational organization that has a membership of 1,200 throughout 17 chapters across the United States. NMEA publishes a high quality journal *Current* that is received by all members as well as many libraries and informal education sites such as aquariums and museums.

This issue of *Current* features invasive species. Mr. Jeff Schardt and Dr. John Dindo are field editors for this issue. Mr. Schardt is the administrator of the Florida Department of Environmental Protection's invasive aquatic plant management program. He co-authored the workbook, *Understanding Invasive Aquatic Weeds*, 350,000 copies have been distributed to all chapters of the NMEA. Funds for this publication were received through the efforts of the Aquatic Plant Management Society. Dr. Dindo is a senior marine scientist and chairman of the Discovery Hall Programs, the educational division of the Dauphin Island Sea Lab. Mr. Schardt and Dr. Dindo are engaging researchers that work with invasive species, and together, they have gathered articles on the topic for this issue. Mr. Schardt worked with three authors who focused on aquatic plants from various areas across the United States. Dr. Dindo worked with Dr. Monty Graham who wrote an article on invasive jellyfish, along with other authors who wrote articles on topics that include: nutria, green crabs, and other animal species. This issue has links to developed Sea Grant educational materials, Environmental Protection Agency materials, and materials developed by the Gulf of Mexico Program. In addition, you'll find curricula materials for the classroom and web-based links through the NMEA web site at www.marine-ed.org/.

This issue will be distributed to all members, libraries, and informal education groups that are part of the NMEA. In addition, Drs. Dindo and Walker will distribute to teachers involved in the latest outreach grant funded by Sea Grant, which includes Florida and Delaware. Appropriate copies will be made available to funding agencies.

Successful Management of Invasive Water Hyacinth in Florida's Public Waterways

By Jeffrey D. Schardt

Invasive species issues have been addressed on local and regional levels for many years, but have only recently received national attention. The signing of Executive Order 13112 in February 1999 established the National Invasive Species Council consisting of 10 federal departments and agencies to develop a nationwide comprehensive invasive species management plan (http://www.invasivespecies.gov). During the decade leading up to the Executive Order, numerous reports documented millions of acres of natural and agricultural areas overrun with invasive plants and animals, as well as billions of dollars in economic losses and management costs associated with these invasions. Such reports are essential in raising awareness to reduce potential for future invasions and to initiate management strategies. But collectively, they can also generate an overwhelming sense of futility among policy makers because of the magnitude of effort and costs to bring established invasive species under control. This article addresses the environmental and economic devastation associated with invasive water hyacinth in Florida's public waterways. More importantly, it provides a model for how integrating control options and strategies into a comprehensive and coordinated management plan can successfully reduce even established, widespread, and seemingly insurmountable problems by reducing economic losses and restoring human uses, plant and animal diversity, and natural processes.

BACKGROUND

Florida lies entirely within a temperate zone, but because it is surrounded on three sides by water, much of the climate is subtropical with wet humid summers and dry cool winters—ideal conditions for a wide variety of plants to thrive. Nearly 4,000 plant species grow in the state; more than 30 percent of which were introduced after the arrival of Europeans and the naming of *La Florida* by Juan Ponce de Leon in 1513 (Wunderlin, 2003).

Many of the approximately 1,300 non-native plants were intentionally brought to Florida to supply food for people and livestock, or were imported for their horticultural appeal. Important agricultural plants have been imported to the U.S. from other continents, including wheat from Asia, oats from Europe, millet from Africa, and potatoes from South America. Most plant introductions are relatively benign and do not survive outside cultivated areas. However, a small percentage of these non-native or exotic plants are considered to be invasive in that they are capable of quickly overgrowing crops or taking over and altering entire natural ecosystems.

Figure 1. Water hyacinth plants and flowers. Note weevil feeding scars on leaves.

The Florida Department of Environmental Protection, Bureau of Invasive Plant Management recognizes 126 invasive aquatic, wetland, and upland plants among the nearly 1,300 plant species that have been brought into Florida since the Spanish colonial period. Eleven of the 22 exotic plants found in Florida's public lakes and rivers are considered to be invasive. Perhaps the most invasive of these is the floating water hyacinth *Eichhornia crassipes* (see Figure 1). Water hyacinth is recognized as one of the world's worst weeds (Holms, 1977), and it has caused significant problems in North America, Asia, Africa, and even recently in its area of origin in tropical South America.

WATER HYACINTH INVASION IN FLORIDA

Most aquatic plants are not invasive in their home ranges; evolving among biological and environmental conditions that keep them in check. Other plants may compete with them for space, and disease or herbivory may provide enough stress to keep their populations low. Likewise, temperatures, droughts, or periodic flooding may prevent an aquatic plant from becoming invasive in its natural setting. Introducing a plant species with several or many invasive qualities into an environment without its natural stressors and controls can result in ecosystem-level changes and large-scale economic problems. Such is the tale of water hyacinth in Florida.

Water hyacinth is reported to have been introduced into Florida as a horticultural curiosity during the late 1880s (Tabita and Woods, 1962). The showy lavender flowers made an appealing display at the 1884 Cotton States Exposition in New

INVASIVE PLANTS SHARE SEVERAL CHARACTERISTICS INCLUDING:

- rapid growth;
- early reproductive maturity;
- multiple reproductive methods;
- wide dispersal and survival capability;
- broad environmental tolerance; and
- resistance to management.

Orleans. It is said that some of these plants were brought back to Florida by a visitor at the fair and placed in a pond near Palatka along the St. Johns River in the northeastern part of the state. Excess plants, that quickly outgrew the confines of the pond, were discarded into the river. By 1896, water hyacinth had spread throughout most of the river basin, and by 1900, rafts of water hyacinth interfered with logging and steamer traffic along the more than 500 kilometers of St. Johns River and its many tributaries (see Figure 2). Water hyacinth was transported to other watersheds by farmers who mistakenly thought it would make good cattle fodder. Although it is not freeze-tolerant, water hyacinth thrives even in northern Florida. The self-insulating plant mats and warm microclimates at the water surface allow water hyacinth to weather north Florida's three to four month span with frequent subzero Celsius overnight temperatures. While cold weather is a regulating factor in northern Florida, water hyacinth grows year-round in the central and southern part of the peninsula.

Water hyacinth floats erect in the water. Bulbous, spongy petioles support waxy, aerial leaves that can reach one meter tall with submersed roots and rhizomes suspended a half-meter or more below in the water column. Water hyacinth reproduces sexually, with each flower generating many minute seeds, and asexually by stolons that branch horizontally from the parent plant. Seeds are viable for many years in Florida and are prone to mass germination during re-flooding after sediments are exposed during droughts. This invasive exotic is extremely productive, creating dense floating mats that provide a substrate for other plants to colonize and grow. Growth rates for water hyacinth, measured in terms of dry biomass, exceed that of any terrestrial, salt, or fresh water vascular macrophyte (Wolverton and McDonald, 1979). Biomass doubling times in Florida range between seven to 14 days.

Environmental, economic, and human safety and welfare problems are associated with the dense mats that, if left unmanaged, can grow from a few plants to hundreds of hectares in just one year (see Figure 3). Large floating water hyacinth mats can degrade water quality, leading to dramatic changes in plant and animal communities. Acidity and carbon dioxide elevate and oxygen declines under water hyacinth mats compared to open water (Penfound and Earle, 1984). Evapotranspiration rates are up to six times higher than for open water in Florida. Center and Spencer (1981) report that leaves represent 60 to 70 percent of water hyacinth biomass and leaf turnover rates range between 60 to 70 percent per month. One hectare of water hyacinth can contain more than 1.6 million plants from which Joyce (1985) estimated to contribute as much as 11.7 metric tons/ha (dry weight) organic detritus to the sediments per year.

While the edges of water hyacinth mats support large numbers of invertebrates in the root system and harbor fish seeking shelter and food sources, oxygen levels under the interior of the mat are too low to support fish spawning. Low oxygen levels also retard decomposition of water hyacinth detritus leading to accelerated organic deposit accumulation. Water hyacinth root masses slow water velocities in flowing systems, causing increased siltation as suspended particles drop out of the water column. Agitation from shifting water hyacinth mats uproots native plant beds, and low light underneath persistent mats reduces or eliminates native plant growth. Consequently, dense water hyacinth mats can impact critical fish and wildlife

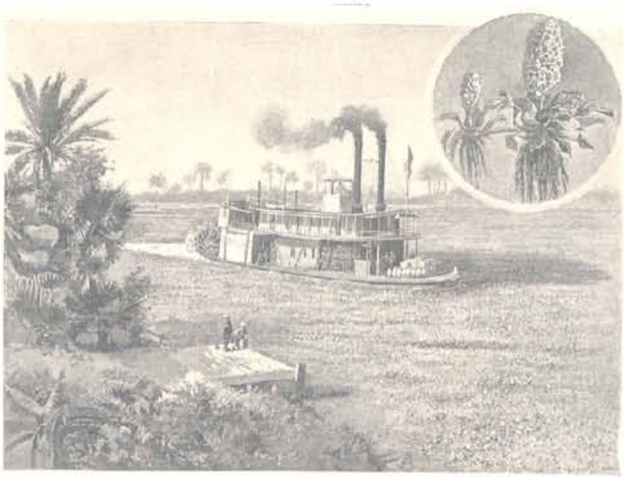

Figure 2. An illustration from *Harper's Weekly* magazine in 1898 about water hyacinth infesting Florida's St. Johns River.

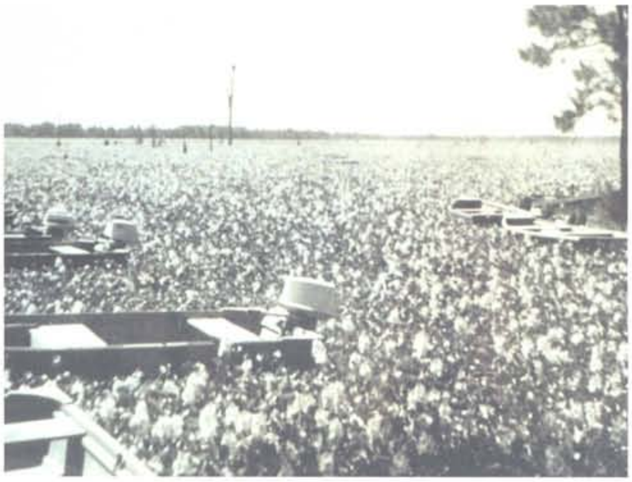

Figure 3. Water hyacinth blocking boat access on Lake Rousseau in the mid 1960s.

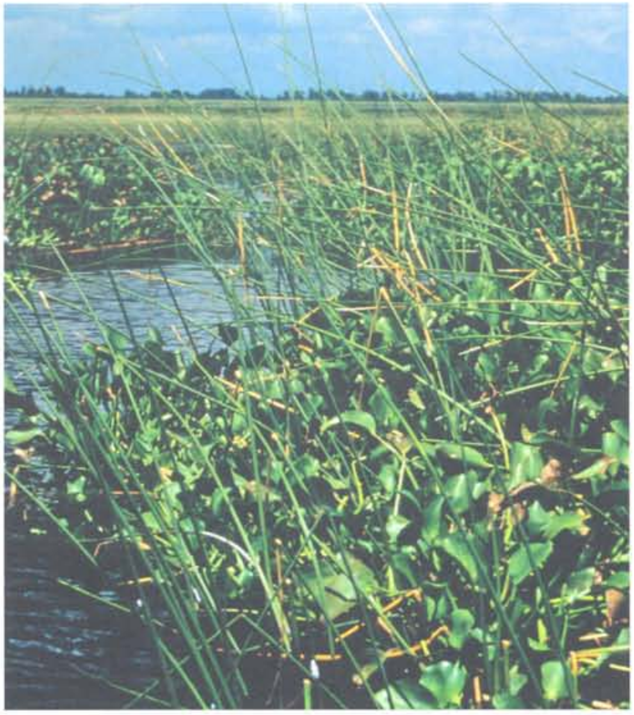

Figure 4. A raft of water hyacinth pushing over bulrush (*Scirpus* spp.) in Lake Okeechobee.

Figure 5. This shows water hyacinth covering Fisheating Creek west of Lake Okeechobee.

habitats (see Figure 4). For example, declines in nesting success of the endangered Everglades kite (*Rosthramus socibilis*) have been attributed in part to dense water hyacinth mats uprooting kite habitat (*Typha* spp.). It is also difficult for kites to locate their primary prey, apple snails (*Pomacea* spp.) when water hyacinth mats cover the water surface.

In addition to ecological invasions, dense water hyacinth mats generate significant human health, safety, and welfare problems. Water hyacinth harbors mosquitoes, especially *Mansonia* spp. that have voracious bites and are potential disease vectors. Water hyacinth masses pose problems to navigation and flood control as well as transportation. Most of Florida's public lakes and rivers are interconnected via natural sloughs or streams, or by means of flood control structures and canal networks. Water hyacinth mats that blocked steamer and logging traffic in the late 1800s and early 1900s can also stop today's recreational and commercial boat traffic. Even seemingly small water hyacinth populations growing along shorelines or in adjacent marshes can be condensed and deposited by wind, water currents, or wave action and jammed against bridges and flood control structures or in narrow restrictions in rivers and between lakes (see Figure 5).

STEMMING THE WATER HYACINTH TIDE

Management History

Water hyacinth-related problems began in Florida as early as 1894; just 10 years after its introduction into the state. Paddle wheel steamers were frequently hindered and sometimes blocked from dock access or pushed off course by rafts of water hyacinth. In 1899, the 55th Congress authorized the U.S. Army Corps of Engineers (USACE) through the Rivers and Harbors Act to crush, divert, or remove water hyacinth from the St. Johns River. In May of the same year, the Florida Legislature took preventive action by enacting Chapter 4753 to prohibit the placing of water hyacinth in streams and waters of the state and to prescribe penalties for violations.

At the beginning of the 20th Century, only the USACE attempted water hyacinth control in Florida. The Rivers and Harbors Act was amended in 1902, directing an integrated management approach to water hyacinth "extermination" using mechanical, chemical, or any other means. Passive log booms and fences were placed across creeks and to protect navigation channels on the St. Johns River. Physical labor was applied to break up small mats that collected on pilings and docks, allowing them to drift toward the Atlantic Ocean. Mechanical conveyors, derricks, and grapples were used along shorelines and around bridges.

Inorganic chemicals like sodium arsenite, sulfuric and carbolic acids, and kerosene were tested, but rejected because of toxicity to cattle and applicators. The 1931 Florida Legislature passed Chapter 1465 to allow the use of "...any poisonous substance, chemical or spray in killing water hyacinth... provided no such poisonous substance, chemical, or spray shall be used which might injure fish life or human or other animal life..." This resulted in the almost exclusive use of mechanical means to control water hyacinth until the late 1940s.

Although innovative devises were developed during this period, including more efficient harvesters and elevators that removed water hyacinth, crusher boats that squashed water hyacinth, and saw boats that shred the plants, mechanical controls had little effect in reducing the water hyacinth

Figure 6. Harvesting water hyacinth from the Caloosahatchee River in the late 1930s.

onslaught. Machines could not operate in shallow water, leaving a continuous source for reinfestion. The sheer mass and volume of water hyacinth was an impediment to success, and water hyacinth growth rate was too great for turn of the century machines despite round-the-clock operations in some cases (see Figure 6). Modern machinery can remove only a few ha of water hyacinth per day and has other substantial drawbacks. Machines are not selective, meaning they also remove non-target plant and animal life in their paths. After just a few cuts, machines can actually select for invasive water hyacinth because it regrows in the harvested area before slower growing native plants can recover. Building bigger and faster machines results in increased control of animal life.

In the early 1940s, the herbicidal properties of the organic, phenoxy chemical 2,4-D were discovered and evaluated. Following aquatic and terrestrial field trials, the USACE began using 2,4-D operationally in Florida waters in 1948. The USACE remained focused on controlling water hyacinth for commerce and navigation. Therefore, the Florida Game and Freshwater Commission (now Florida Fish and Wildlife Conservation Commission) began managing water hyacinth in 1952 to conserve fish and wildlife habitat in areas not managed by the USACE. During the early 1960s other federal, state, and local governments began controlling water hyacinth for various reasons, especially mosquito and flood control.

Despite extensive management efforts, and essentially the same tools available to managers today, the program remained fragmented with no clear goals and no entity to fund, direct, or coordinate activities. Several agencies worked on some water bodies while other waters had no management authority. Water hyacinth in unmanaged waters cross-contaminated controlled waters in Florida's system of interconnected lakes, rivers, and canals. Even in waters with one or more management entities, water hyacinth was allowed to build up to problem proportions, then managed as time, funding, and staffing allowed. Rather than maintain the low levels of management achieved after control operations, most waters were then neglected as crews shifted to cope with crises on other waters, and the populations quickly re-established. As a result the USACE estimated a water hyacinth population exceeding 51,000 ha infesting Florida public waters during 1960 and projected an additional 20,000 ha by the mid 1960s unless improved management strategies were implemented (U.S. Congress, 1965). The USACE concluded that water hyacinth was so widespread, and grew and reproduced so prolifically, that eradication was not feasible; however, management was possible if done on a consistent basis.

MAINTENANCE CONTROL AND PROGRAM COORDINATION

In 1971, the Florida Department of Natural Resources (now FDEP) was tasked by the Florida Legislature as the lead agency to "...direct the control, eradication, and regulation of noxious aquatic weeds and direct the research and planning related to these activities..." The FDEP responded by creating the now titled Bureau of Invasive Plant Management (BIPM). One of the first duties of the BIPM was to coordinate the development of a statewide water hyacinth management strategy and administer its implementation. The strategy, termed "maintenance control" was approved and incorporated as law in 1974. Section 369.22 (3), Florida Statutes reads in part "...It is the intent of the Legislature that the control of non-indigenous aquatic plants be carried out primarily by means of maintenance programs, rather than eradication or complaint spray programs, for the purpose of achieving more effective control at a lower long-range cost." Section 369.22 (1) (d), Florida Statutes describes a maintenance program as "...a method for the control of non-indigenous aquatic plants in which control techniques are utilized in a coordinated manner on a continuous basis in order to maintain the plant population at the lowest feasible level..."

Maintenance control is the cornerstone of Florida's invasive aquatic plant management program. The concept of maintenance control has its roots in USACE policy developed upon completion of Operation Clean Sweep on the St. Johns River in 1973 (Buker, 1982). Prior to this time, water hyacinth was allowed to reach problem levels before implementing control measures. This strategy resulted in killing large amounts of floating plant biomass that in turn resulted in severe detrital loading from controlled plants and from leaf, shoot, and root material constantly senescing and shedding from live plants (see Figure 7 on page 7). Aggressively managing individual plants and small clumps to prevent water hyacinth from reaching large populations avoids severe environmental disturbances and economic losses associated with such crisis management. Joyce reported in 1985 that maintaining water hyacinth at a five percent cover (or less) reduced annual herbicide use by a factor of more than 2.5, reduced organic sedimentation by a factor of up to 4.0, and reduced dissolved oxygen depressions. Consequently, environmental and economic impacts can be kept to a minimum if the policy of maintenance control is employed (see Figure 8).

KEY COMPONENTS TO KEEP WATER HYACINTH AT THE LOWEST FEASIBLE LEVEL IN FLORIDA PUBLIC WATERS:

- Lead, coordinating agency
- Prevention
- Early detection and rapid response
- Labor force to implement management plan
- Sufficient, recurring funding
- Research
- Education and outreach

MAINTAINING WATER HYACINTH AT THE LOWEST FEASIBLE LEVELS REDUCES:

- sedimentation/lake aging;
- native plant damage;
- navigation problems;
- transportation problems;
- flood control problems;
- loss of habitat;
- loss of recreation;
- loss of property values; and
- use of herbicides.

EXAMPLES OF MAINTENANCE CONTROL

Figure 9 on page 8, graphically presents some of the benefits of maintenance control for a 30-year period on the Suwannee River. Water hyacinth covered more than 900 ha along the shores of the Suwannee in the early 1970s. Thousands of metric tons of sediments were produced as live plants shed leaf, root, and shoot material and from plants controlled with herbicides. Hundreds of hectares required control using thousands of kilograms of herbicide active ingredient. Crisis management was replaced by maintenance control efforts in the late 1970s. Since achieving maintenance control in the mid 1980s, relatively little management has been necessary, reducing environmental and economic impacts. Native plants have returned to the shores and adjacent marshes of the Suwannee River, restoring fish and wildlife habitat.

Figure 10 on page 8, demonstrates the affects of applying the maintenance control strategy on the statewide water hyacinth population. This invasive plant that surpassed 50,000 ha in Florida's nearly 515,000 ha of public waters as recently as the 1960s has been held below 2,000 ha at any given time in public waters since 1989. Sustaining this low level requires from 7,500 to 10,000 ha of control at a cost of between $2 and $3 million annually.

EPILOGUE

Once established, eradicating invasive species is not likely, but they may be reduced to minor components within ecosystems that they infest through persistent and routine management efforts. Although water hyacinth is still present in nearly 60 percent of Florida's public lakes and rivers, it rarely reaches population levels that interfere with human uses or natural processes. Florida's water hyacinth management program is successful because a lead agency has the Legislative support, authority, and responsibility for coordinating and implementing a statewide comprehensive management strategy. This strategy is comprised of seven key components that keep water hyacinth and other invasive aquatic plants at the lowest feasible levels in Florida public waters.

Today, several measures are taken to prevent the introduction of invasive aquatic plants into Florida. The U.S. Department of Agriculture inspects commercial shipments of plants into Florida from abroad. The Florida Department of Agricultural and Consumer Services (FDACS) inspects nursery operations, including aquarium plant growers, within the state to monitor for invasive aquatic plants. The BIPM conducts random inspections of retail aquarium stores and water garden outlets for invasive aquatic plants.

While it may be intuitive that preventing the introduction of invasive aquatic plants would prevent future problems, in

Figure 7. Crisis management of water hyacinth.

Figure 8. Maintenance control (spot control) of water hyacinth to conserve native plant habitat.

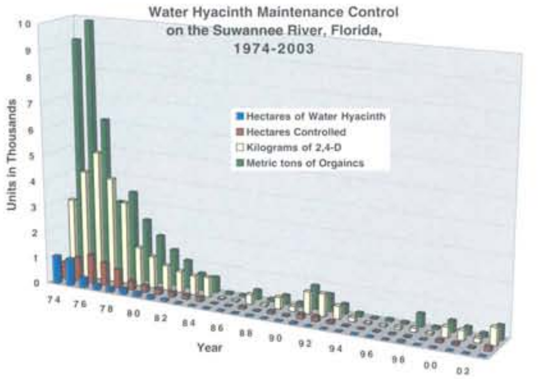

Figure 9. Water hyacinth maintenance control on the Suwannee River in Florida from 1974 to 2003.

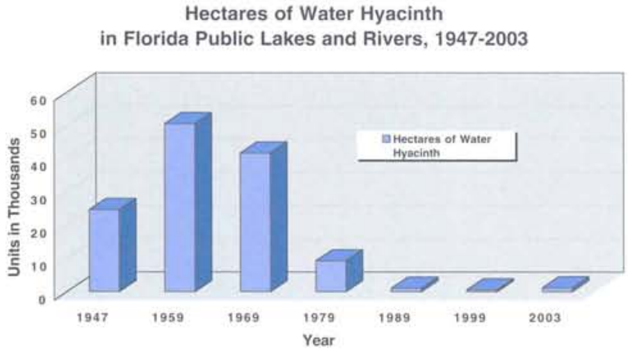

Figure 10. Hectares of water hyacinth in Florida public lakes and rivers, 1947-2003.

reality, there are insufficient inspectors (about 2 percent of the 500 million plants entering Miami International Airport are inspected each year) and interstate plant shipments, especially those generated via the Internet, are difficult to inspect. Therefore, the BIPM coordinates an early detection and rapid response effort in Florida's waterways. Weed alerts listing known and suspected invasive aquatic plants are circulated among agencies with field personnel and water-related responsibilities. BIPM staff inventories aquatic plants at least once each year in Florida's nearly 515,000 hectares of public lakes and rivers. Contracts are in place with federal, state, and local governments as well as commercial management companies, and legislation authorizes these contractors, under BIPM lead agency coordination, to enter upon public and private property to eradicate new infestations of invasive aquatic plants. Government and private sector contractors conduct Florida's routine aquatic maintenance control programs under BIPM coordination as well.

About 15 physical, mechanical, biological, and chemical control methods are available from which managers develop cost-effective water hyacinth control programs that are compatible with the environment and human uses associated with each water body. Physical controls include hand-picking if only a few plants are present. Winter drawdown to desiccate and expose water hyacinth to freezing temperatures is occasionally employed as is periodic flooding to strand floating plants on upland sites. Mechanical controls; harvesters, shredders, and draglines, are still used on a small scale where immediate removal is warranted; for example, against bridges or flood control structures. Three introduced insect species and a native fungus stress water hyacinth reducing plant vigor and flowering, but by themselves, do not control water hyacinth in Florida. Most active water hyacinth management is carried out using herbicides registered by the U.S. Environmental Protection Agency and FDACS for use in Florida waters. Five compounds are available to provide cost-effective and selective water hyacinth control and the most appropriate strategy is chosen for each site.

Sufficient funding is provided via a variety of sources to carry out the legislative mandate of maintenance control of water hyacinth along with 10 other invasive aquatic plants. Funding sources are both recurring and have a logical connection to the aquatic plant management program. A portion of motorboat registrations and gasoline revenues (a percentage of motor boat fuel) are dedicated to aquatic plant control. Also a percentage of the fee on real estate transactions is set aside to acquire cultural and environmentally significant lands. A 2.28 percent share of these revenues is transferred to the BIPM to control invasive plants on sovereignty and newly acquired lands to conserve their ecological integrity.

Research contracted with universities and other institutions continues to test new tools and develop new strategies, especially overseas exploration for additional insects and pathogens, to further stress invasive plants including water hyacinth. Florida has the most extensive aquatic plant management labor force in the country. Technology is transferred from researchers to managers via education and outreach materials, workshops, and conferences. The communication network among government and private sector employees is only part of the education equation. Public outreach is one of the most important but often the most neglected invasive species management tools. In Florida, outreach is integral to invasive species management because of political term limits and a statewide population increase of nearly 10 million during the past 30 years. Government representatives and the public that they serve must understand the economic and environmental threats presented by invasive species like water hyacinth and must have confidence that managers can protect and conserve human uses and natural functions of ecosystems that harbor invasive species.

JEFFREY SCHARDT has spent his 29-year career with the Florida Department of Environmental Protection, Bureau of Invasive Plant Management. After graduating from Penn State in 1976, Mr. Schardt researched biological controls for hydrilla during the 1970s. He helped develop

Figure 11. Plant Management in Florida Waters (http://plants.ifas.ufl.edu).

Florida's aquatic plant permitting, monitoring, and compliance programs in the 1980s, initiating the state's annual inventories to detect and control nuisance aquatic plants in public waterways in 1982. In addition to administering Florida's aquatic plant management program for the past 17 years, Mr. Schardt has been active in education and outreach efforts; collaborating with the University of Florida to produce a comprehensive website on aquatic plants (see Figure 11), as well as developing classroom activities and distributing instructional materials on invasive aquatic plants in cooperation with the University of Florida, Aquatic Plant Management Society, Sea Grant, and NMEA.

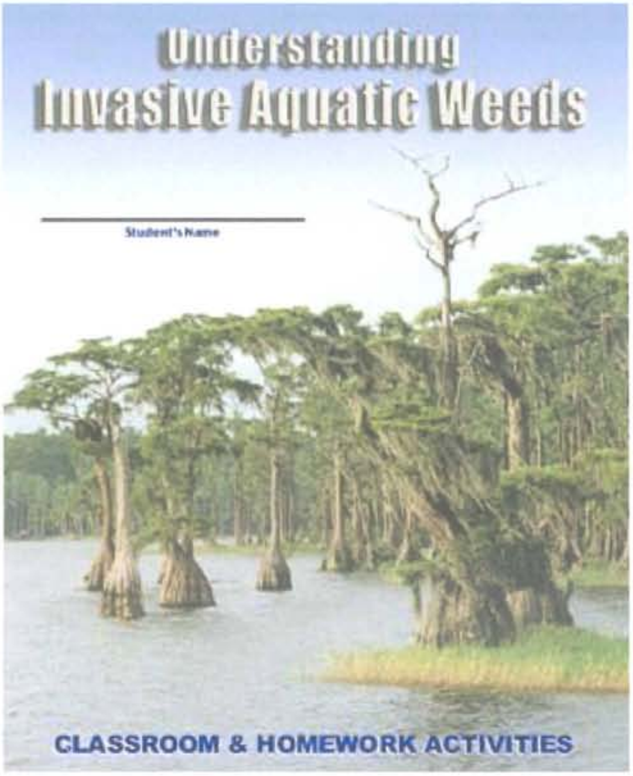

Figure 12. *Understanding Invasive Aquatic Weeds* 16-page activity booklet suitable for grades 3-7 (www.apms.org/book/activity.htm).

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PHOTO CREDITS:

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For details about all facets of Florida's aquatic plant management program, please visit http://plants.ifas.ufl.edu/guide. Teachers with invasive aquatic plant interests may visit the following websites for free posters, curricula ideas, activity booklets, and other useful information for grades K-16: **http://plants.ifas.ufl.edu** and **www.apms.org/book/activity.htm**. The *Understanding Invasive Aquatic Weeds* booklet shown in Figure 12 and on the APMS website is also available at each of the National Marine Education Association chapters.

Volume 21 • Number 2 • 2005

Understanding Complexities of Marine Bioinvasions by Jellyfish

By William M. Graham and Toby F. Bolton

THE INTRODUCTION OF NON-INDIGENOUS SPECIES *is widely recognized as one of the most devastating impacts of human activity on natural systems. Invasive species are typically characterized by high rates of reproduction, and usually are tolerant of widely ranging environmental conditions. Because they often lack predators in their new environments, invaders may out-compete native species for critical resources. To compound their affect, invaders may in turn prey heavily on native species, spread exotic diseases, and alter the genetic makeup of closely related species.*

The reach of invaders certainly exceeds the natural system and the cost to human societies can be enormous. Invasive species inflict direct damage to industries including fisheries and agriculture, as well as the infrastructure on which these industries depend. While the costs of ecosystem modification, losses of indigenous species, damage to infrastructure, industry, and human health are difficult to estimate, available data suggest that 50,000 documented invasive species in the U.S. inflict an annual economic loss of about $137 billon per year. On a global scale, it is estimated that as many as 80 percent of endangered species worldwide are currently threatened by invasive species.

Though most research has focused on terrestrial and freshwater ecosystems, recent examples of marine invasions have demonstrated the ecological, economic, social, and health threats to systems that were once believed to be 'buffered' against impacts by invaders. However, the list of marine invaders continues to grow as our awareness and monitoring practices increase. Some recent invasions into coastal waters of the U.S. that have received recent attention include the European green crab (*Carcincus maenas*), the Chinese mitten crab (*Eriocheir sinensis*), the veined rapa whelk (*Rapana venosa*), a 'mystery' tunicate *Didemnum* sp., and even the tropical aquarium lionfish (*Pterois volitans*). While these important few examples received a great deal of attention, the vast majority of marine introductions likely go unreported because these 'open' systems are far more difficult to monitor than freshwater and terrestrial systems.

The primary means for moving a species between ocean basins is widely thought to be shipping traffic. Ballast water and hull fouling are two mechanisms by which the inadvertent transportation of non-indigenous species by ships occurs. Ships carry large volumes of ballast water containing an enormous variety of organisms that are regularly transported from one port and released at another. Likewise, whole communities of organisms may be attached to, or associated with, the hulls of ships. With the increase in speed, size, and container volume of modern ships, it is not surprising to see marine introductions accelerate in the past 20-30 years. This problem makes monitoring especially difficult if invasive species have complex life-histories where one portion of the life-cycle exists in attached form and another is in the water column as either plankton or nekton. Such is the case for most medusae that fall into the Hydrozoa and Scyphozoa (i.e., jellyfish).

GELATINOUS ZOOPLANKTON: BLOOMS, INVASION, AND ECOSYSTEM CONTROLS

The role of shipping was probably best documented when the North American ctenophore *Mnemiopsis leidyi* was delivered into the Black Sea in the early 1980s through ballast water exchange of a grain ship. Heavy predation on eggs and larvae by this relatively simple organism resulted in the collapse of the regionally important anchovy fishery and pointed to the control that gelatinous zooplankton can have on ecosystems. Gelatinous zooplankton exhibits the characteristics of many other invasive species: they can reproduce rapidly and grow rapidly and, being highly opportunistic, are able to take advantage of already perturbed ecosystems, as was the case in the Black Sea. The prudent management of the Black Sea anchovy fishery, coupled with the subsequent introduction

Figure 1. *Phyllorhiza punctata*. The 'Australian spotted jellyfish' found in the northern Gulf of Mexico. This specimen is approximately 45 cm in diameter and harbors numerous small fish that use the medusae for protection by swimming around its bell.

Figure 2. A large aggregation of the so-called Australian spotted jellyfish, *Phyllorhiza punctata* in the northern Gulf of Mexico, summer 2000. Each medusa is approximately 50 cm in diameter.

of a natural predator of *Mnemiopsis*, has resulted in major improvements. However, an ominous portent of this species' ultimate power is unveiled with the recent introduction of *Mnemiopsis* into the Caspian Sea.

The possibility that exotic jellyfish can become established in regions of important commercial fisheries is of particular concern because feeding rates, especially on eggs and larvae of commercially important fish, are typically high. Recently, a non-native jellyfish known as *Phyllorhiza punctata* appeared in spectacular numbers in the northern Gulf of Mexico during the summer of 2000 (see Figure 1 on page 10). Locally referred to as the Australian spotted jellyfish, (*Phyllorhiza punctata*) this jellyfish has a long and notorious record for invading new systems. It was first described from southeastern Australia and, subsequently invaded the Swan-Canning estuary near Perth, Western Australia (1830s); Pearl Harbor, Hawaii, U.S.A. (1941); Laguna Joyunda, Puerto Rico (1945); San Diego, California, U.S.A. (1990); Danajon Bank, Bohol Island, Philippines; and Bahia de Todos os Santos, Brazil (between 1991-1999). This well-documented history of invasion over such an extended period makes *Phyllorhiza* a particularly interesting organism to study for causes and consequences of marine invasions.

The size of the population of *Phyllorhiza punctata* that appeared in the northern Gulf of Mexico was astonishing: estimates of aggregations ranged up to 5.3×10^6 medusae over 150 km^2 (see Figure 2). The potential ecological and economic impacts of *P. punctata* were also high and it was feared that the ecology of the northern Gulf of Mexico may be altered permanently along with the valuable fishing industry that depends on it. These fears were fueled by the costs of *P. punctata* to the shrimp industry of Mississippi alone that were estimated to be on the order of $100 million in 2000. Even if this figure was an over estimate for Mississippi, the costs to the shrimp industry across the states bordering the northern Gulf of Mexico were likely much higher. During the years following the appearance of *P. punctata*, aggregations (albeit smaller that in 2000) reoccurred along regions of the Louisiana coast and isolated populations have been found along the coast of Alabama and Florida.

HOW WE CAN MONITOR SUBSEQUENT INVASIONS OF *PHYLLORHIZA*?

While it is certainly possible that large medusae are transported in ballast water, a more plausible explanation is that they are moved during their 'alternate' life-stage of an attached polyp on the hull of a ship. Agents other than the hull of a ship could be utilized for relocation as well. These include gas and oil drilling platforms, mariculture trade and practices, pet industries such as the 'live-rock' trade (see Figure 3 on page 12), and natural variations in oceanographic circulation patterns. In the case of *Phyllorhiza punctata* (and other large jellyfish), the transportation of the polyp stage attached to the hulls of ships would appear to be the most likely invasion route, but like many other invasive species, the actual mechanism of transportation remains unknown because it is rare that scientists actually find a 'smoking gun.'

The problem with tracking jellyfish invasions is that the small size of the polyp (on the order of a few millimeters in length) makes it difficult to find using visual means even with good microscopes and plenty of patience. Thus, we need to use other non-visual means to find polyps among a stand of fouling organisms. Our own ongoing investigations focus on using new molecular techniques such as quantitative real-time polymerase chain reaction amplification of DNA sequences or 'markers' unique to this species. In this case, we are developing a useful tool for monitoring hulls of ships (or other mobile structures).

WILLIAM M. GRAHAM received his Ph.D. from the University of California at Santa Cruz in 1994. After doing his post-doctoral work at U.C., Santa Barbara, he accepted a position at the Dauphin Island Sea Lab and the University of

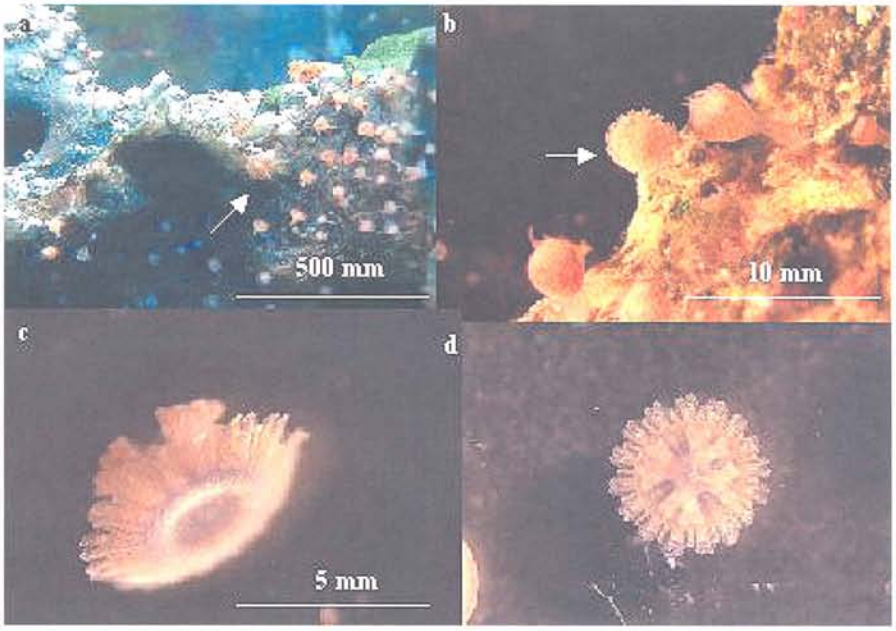

Figure 3. Polyps of the upside-down jellyfish, *Casseiopea* sp., found on 'live rock' purchased from an aquarium dealer in Florida. Live Rock is purchased as home aquarium decoration, and there are little if any regulations for how it is imported into the U.S. The origin of the material was traced to exporters in the Indo-Pacific (likely either Fiji or Indonesia). Polyps were not only viable, but were actively producing juvenile jellyfish.

South Alabama where he is currently an Associate Professor of Marine Sciences. He has published numerous research papers in the fields of biological oceanography and gelatinous zooplankton ecology. In 2000, he hosted the International Conference on Jellyfish Blooms in Gulf Shores, Alabama

TOBY F. BOLTON obtained a Ph.D. from Flinders University, South Australia in 1999. After conducting post-doctoral research at the Dauphin Island Sea Lab and at the University of South Florida, he accepted a faculty position in the School of Biological Sciences of Flinders University in his homeland Australia. He is currently undertaking research into the reproductive biology of marine invertebrates around southern Australia and also manages the Lincoln Marine Science Centre in Port Lincoln South Australia.

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Page 11: Courtesy of W. Strickland

Activity: Feasting with Natives

MATERIALS

- paper plate
- references
- a variety of food items (real, artificial, or pictures from food ads) that may include carrots, beef, chicken, corn, pork, lettuce, onion, pineapple, pumpkin, sweet pea, tomato, watermelon, white potatoes

OBJECTIVES

1. Students will appreciate that a large number of items we eat are not native to our area.
2. Students will become familiar with the origin of a few common meats and vegetables on menus in North America today.

DIRECTIONS

1. Distribute food items and paper plates to small groups of students. Ask them to discuss and choose which of these they think are native to the Americas.
2. Students should place on the paper plate items they have chosen. This is their "feast with natives."
3. Ask students which fruits, vegetables, and animals they believe are native to the Americas. You may use the lists below, as well as other references, to help you identify the origins of these foods.
4. Highlight the fact that a lot of what we eat today is native to places other than the Americas.

NATIVE HOMES

Carrots – Afghanistan of Central Asia.

Cattle – Europe.

Chickens (Domestic) - Southeast Asia.

Corn – Americas.

Hog – Europe and Southeast Asia. May have been domesticated in China.

Lettuce – Eurasia and North America. The garden lettuce we eat today was probably cultivated from the European wild lettuce.

Onion – Asia.

Pineapple – Central America and tropical South America.

Pumpkin – America.

Sweet Pea – Southern Europe.

Tomato – Andes of South America.

Watermelon – Africa.

White Potatoes - Andes area of Peru.
(Note: Sweet Potatoes are native to tropical areas of America.)

RESOURCES

"Cattle," "Corn," "Fowl," "Hog," "Lettuce," "Onion," "Potato," "Sweet Potato," "Pumpkin," and "Tomato," Microsoft Encarta Online Encyclopedia: **http://encarta.msn.com**

"History of Carrots." Dole Food Company, Inc.'s *5 A Day Fruit & Vegetable Encyclopedia:* **http://www.dole5aday.com/menu/nutrition/menu.htm**

"History of Pineapples." Dole Food Company, Inc.'s *5 A Day Fruit & Vegetable Encyclopedia:* **http://www.dole5aday.com/menu/nutrition/menu.htm**

"History of Potatoes." Dole Food Company, Inc.'s *5 A Day Fruit & Vegetable Encyclopedia:* **http://www.dole5aday.com/encyclopedia/potato/potato_history.html**

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Volume 21 • Number 2 • 2005

Louisiana's Coastal Wetland Loss: A Successful Invasive Species Control Program?

By Jeff Marx and Edmond Mouton

What role do nutria play in Louisiana's Coastal Wetland Loss? *In 2000-2001, Louisiana lost approximately 20,000 acres of marsh due to nutria vegetative damage. This loss of marsh in Louisiana is devastating to the infrastructure and all the citizens of the state, especially the people that depend on it for their livelihood, as well as the people that use it for recreation. It is vital to the people of Louisiana to protect the wetlands from destruction whenever possible. In order to remove the threat of land loss due to nutria, the Coastwide Nutria Control Program was developed.*

Louisiana has an abundance of natural resources directly related to coastal wetlands. Approximately 40 percent of the coastal wetlands in the continental United States are located in Louisiana. However, 90 percent of the total coastal marsh loss nationwide occurs in coastal Louisiana. Many factors, both man-made and natural, contribute to wetland loss. These include subsidence, salt water intrusion, sea level rise, erosion from wave action, tropical storms, and hurricanes as well as changes to the natural hydrology of the rivers and their deltas. Continued marsh loss will lead to a reduction in wildlife as well as sport and commercial fisheries, and decreased wetlands to buffer storm surge. The nutria (*Myocastor coypus*), native to South America, is another factor that can exacerbate the already considerable rate of marsh loss. The Louisiana Department of Wildlife and Fisheries (LDWF) has implemented a program to reduce the population of nutria with the goal of eliminating the vegetative damage they cause.

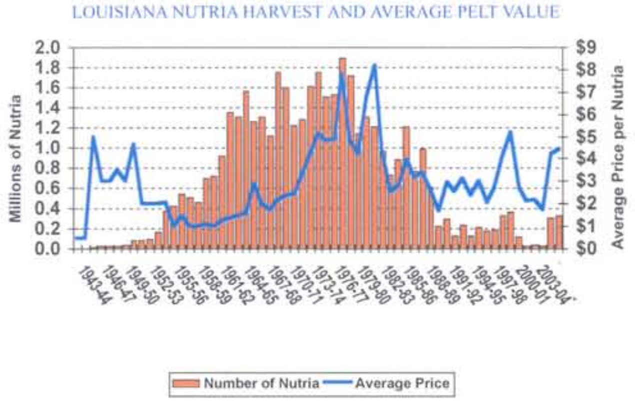
Nutria are large, semi-aquatic rodents and typically grow to an average of 12 pounds. Nutria consume approximately 25 percent of their body mass per day. Nutria are active both day and night, although they are primarily nocturnal and feed mostly at night. Nutria are prolific breeders with females giving birth to two litters a year with an average litter size of five. Nutria dig up and feed on the roots and basal portions of wetland plants. When the population of nutria exceeds the carrying capacity of the marsh, overgrazing occurs. This condition may result in exposed soil, which is termed an "eat out." Without the root system in place, the marsh soil is exposed to rain, tide, and storm action that may result in soil export out of the system. When the soil is lost, so is elevation and open water areas may be created.

In the 1930s, nutria were transported from South America and placed in captivity in Louisiana for potential fur production. Nutria were released, either accidentally or intentionally, and were able to establish populations in the coastal marshes. In the 1940s, nutria were errantly promoted as biological weed control agents and were subsequently dispersed across the southeastern portion of the state. It was thought that nutria would feed on water hyacinth but instead chose to feed on the native plants. Hurricanes also aided in dispersing nutria over a greater range. Nutria populations exploded in the 1950s and reports of damage in agricultural and some marsh areas increased. As a result of agricultural damage, nutria were removed from the list of protected wildlife in 1958 by the Louisiana legislature.

In the early 1960s, the demand for nutria fur increased and a market developed. Beginning in the mid 1960s the state promoted nutria fur as a renewable natural resource. From 1962 to 1982, an average of 1.3 million nutria per year were harvested from the state. Reports of nutria damage during this time were rare. However, in the mid 1980s the price for nutria fur declined rapidly as a result of changes in the international markets, and in turn, harvest declined.

There were several factors that contributed to the price decline of all furs, including nutria. First, by the 1980s the market in northern Europe was saturated. Followed by several

Nutria, *Myocastor coypus*



Annual harvest and average price of nutria from 1943 to 2004.* This figure includes the $4.00 incentive payment that began during the 2002-2003 harvest season.

mild winters during the 1980s in northern Europe. At the same time, trends in the fashion industry shifted away from fur to leather products. Also, animal rights activists in Europe impacted public opinion concerning furs. Finally, in the late 1980s and early 1990s, overproduction of ranch mink in the Scandinavian countries further reduced the demand for all fur both wild and farmed.

After the continued reduction in nutria harvest, coastal landowners began reporting vegetative damage in 1988. Coastal aerial surveys to detect wetland damage began in 1993 and have continued to the present. North south transects 1.8 miles apart were flown in a helicopter covering the fresh, intermediate, and brackish marshes. One observer navigated along each transect while the other recorded all pertinent information when vegetative damage was identified.

Information collected at each damage site during the flights included: 1) latitude and longitude, 2) acreage, 3) nutria abundance, 4) extent of vegetative damage, 5) impacted and adjacent plant species, and 6) number of nutria observed at each site. The earlier coastal surveys in the early 1990s showed an estimated 60,000 acres of marsh impacted. The first coast-wide damage survey in 1998 indicated that nutria grazing impacted 89,850 acres. The damage peaked in 1999 with 102,585 impacted acres. The damage decreased in 2000 and 2001 to 97,271 acres and 83,021 acres respectively. These surveys indicated that vegetative damage was occurring primarily in the southeastern portion of the state.

The LDWF was of the opinion that to increase harvest and control damage, a program was needed to increase the price paid for nutria. However, the department wanted an independent evaluation of all potential control methods available. In 2001-2002, Genesis Laboratories, Inc., of Wellington, Colorado conducted a comprehensive literature review. They considered a number of control methods, including chemical control, rodenticides, trapping, hunting, chemical repellents, induced fertility, and an incentive program. The contractor rated all methods on cost and chance for success and determined that an incentive program might be the best method for a coast-wide nutria control program. Eradication is not a viable option for several reasons. First, Louisiana tends to have mild winters, allowing nutria to feed and reproduce year round. Second, nutria are abundant along the Gulf coast and introductions from neighboring states would allow repopulation. Third, nutria habitat in Louisiana is vast, and to eradicate nutria from such a large area is not a feasible option.

The Coastwide Nutria Control Program (CNCP) was funded by the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA). CWPPRA was passed by Congress in 1990 and funds wetland enhancement projects nationwide, designating approximately $50 million annually for work in Louisiana. The CNCP began in January 2002 with the project goal to significantly reduce damage to coastal wetlands resulting from nutria herbivory by removing 400,000 nutria annually. The incentive is produced by providing a $4.00 per nutria economic incentive payment to registered participants. Registered participants must show proof of nutria harvest by bringing severed nutria tails to collection stations along the coast of Louisiana.

LDWF established the CNCP and is responsible for the following activities:

- registration of participants;
- validation of nutria tails and receipt processing;
- delivery of tails to an approved disposal facility;
- maintenance of compilation and records of participants, number, and origin of tails collected;
- incentive payments to program participants;

The brown areas have been denuded of vegetation from overgrazing by nutria.

A six-foot by six-foot fenced enclosure demonstrates that when nutria grazing is stopped, marsh grasses can recover.

- monitoring of vegetative damage through coast wide aerial surveys; and
- production of an annual report on the marsh vegetative condition and harvest to the CWPPRA Task Force.

The program area is the coastal region of south Louisiana with the northern boundary of the area along Interstate 10 from the Texas-Louisiana line to Baton Rouge, Interstate 12 from Baton Rouge to Slidell, and Interstate 10 from Slidell to the Mississippi-Louisiana line. Participants must obtain written permission from a landowner or land manager to harvest furbearing animals on property within the program area. Participants are required to purchase a trapping license and harvest nutria from the property where permission has been obtained. Nutria may be taken only during the Louisiana's open trapping season, late November to March.

Once a participant is accepted into the CNCP, he receives a registration packet containing program regulations, a registration card, and a schedule of collection times, dates, and locations. Participants deliver the nutria tails to a collection station, present their registration card, provide harvest information, and sign a voucher for the number of tails turned in. Participants receive the incentive payment two to three weeks later. The harvest of nutria during the remainder of the year would be inefficient and the operation of the program would be cost prohibitive.

During the first harvest season, (2002-2003), 308,160 nutria were harvested worth $1,232,640 to 342 participants. Thirty-one percent of the participants (105) turned in over 800 tails each and their combined harvest accounted for 81 percent of the season total. Approximately 90 percent of the harvest came from the southeast portion of the state. Sixty-six percent of the nutria were harvested by participants shooting with a .22 caliber rifle. Trapping was the other method used by participants and accounted for 34 percent of the nutria harvested.

In 2003-2004, there was an increase in the harvest with a total of 332,596 nutria, it was worth $1,330,384, and harvested by 346 participants. Thirty-five percent of the participants (121) turned in over 800 tails each and their combined harvest accounted for 81 percent of the season total. Again, the majority of the nutria harvest occurred in the southeastern portion of the state. There also was a change in the method of harvest. Shooting accounted for 52 percent of the nutria harvested while trapping accounted for 48 percent.

Individuals harvesting 800 or more nutria probably represent historic trappers. These individuals usually fished commercially for a living during the summer and trapped during the winter months. Many of the participants currently enrolled in the program have stated that the CNCP incentive for nutria provides important extra income during the winter months.

An annual aerial survey is flown during the spring. In 2002, the year prior to the implementation of the CNCP, nutria damage coast-wide was estimated at 79,400 acres. After two years of harvest, the number of impacted acres has decreased to 63,400 coast-wide. In 2001, it was estimated 20,000 acres of damaged marsh had converted to open water and was lost forever. In 2002, 3,938 acres of wetlands had converted to open water. After initiation of the control program in 2003, 274 acres converted to open water and in 2004 only 75 acres had converted to open water coast-wide.

The CNCP has committed funding to continue operation through 2006-2007 and may be funded for additional years. The program has demonstrated that it can increase the harvest of nutria from the coastal region of Louisiana. Prior to the CNCP, the harvests from 1999 to 2002 averaged only 24,779 nutria per season. The first year of the program produced an increase in harvest to 308,160 nutria and another increase the second year to 332,596 nutria. The increased harvest and the subsequent decrease in the amount of damaged acres and acres converted to open water is very encouraging and a good measure of success.

JEFF MARX is the biologist who oversees the "Coastwide Nutria Control Program" for the Louisiana Department of Wildlife and Fisheries where he has worked for four years. He has a bachelor's degree in biology from the University of Southern Mississippi.

EDMOND MOUTON is currently a Biologist Manager with the Fur & Refuge Division of the Louisiana Department of Wildlife & Fisheries. Edmond works as a statewide furbearer biologist; is involved in environmental monitoring and restoration in coastal Louisiana, and is presently involved with the "Coastwide Nutria Control Program."

Volume 21 • Number 2 • 2005

Green Crab–A Potentially Devastating Invasion and a Teachable Moment

By Andrea Copping

INVASION BY NON-NATIVE SPECIES *has been ranked as one of the most devastating ecological impacts to affect marine and fresh waters (Vitousek and Wilson, 1988; Lassuy, 1995). Once established, non-native introductions can rarely be eliminated. Like so many threats to aquatic ecosystems, prevention is more effective than cleanup. Unlike threats such as contamination and habitat loss, technical fixes and regulation may not be highly effective in reducing the threat of invasive organisms. Education and outreach have been identified as more powerful and effective in preventing introductions and managing established invasive species (van den Bergh et al., 2002).*

Species that are introduced into habitats where they are not native can result in habitat alteration and degradation. They may out-compete native species for food, space, and other resources, sometimes even causing the extinction of native species. Because species introduced from another region have not co-evolved with native northwest species, adapting slowly and smoothly to native habitats, they seldom have natural predators or competitors and may enjoy an unprecedented advantage over native species (Carlton and Gellen, 1993).

Not all non-native introductions are detrimental; some can be ecologically harmless and some are beneficial (such as the many agricultural introductions in this country). However, the outcome of an introduction is risky and complex, and the consequences cannot always be anticipated (Carlton, 1992).

The organism that has received the most attention in coastal and estuarine areas of the Pacific Northwest in recent years has been the European green crab *Carcinus maenas*.

MEET THE GREEN CRAB

The European green crab is small and, despite its name, often is not green in color. The crab measures 3 to 4 inches across the carapace and is most easily distinguished by five spines on either side of the front of the carapace (Jensen, 1995). Juvenile green crab can change color to match their surroundings. Adults are generally dark greenish with yellow markings; their underside is often bright red or yellow. Like all crab they hatch from eggs into planktonic larvae that drift with ocean currents for up to 80 days before settling to the bottom to take up life as juveniles that resemble small versions of the adult crab. Following a number of molts, the adult crabs emerge, mate, and subsequently, the females broadcast eggs that develop into the next generation. The life expectancy of an adult green crab is about three to four years.

The green crab is an able colonizer, efficient predator, and has the potential to significantly alter any ecosystem it invades. It has proven more resistant than many other crabs to exposure, temperature extremes, and changes in salinity levels. Green crab feed on the larvae of other crab species that can affect the population structure of other crabs. In the Pacific Northwest, the highly prized Dungeness crab can fall prey to green crab as juveniles, while adult Dungeness feed on adult green crab (Jensen et al., 2000). Their favorite prey, however, are bivalve shellfish. Green crab are held responsible for devastating the sift shell clam industry in the north east and are currently threatening California clam and mussel growing operations (Grosholz and Ruiz, 1995).

Green crabs are generally found in shallow water, beyond the range of octopus and other predators. They hide under rocks and in disturbed areas, making it difficult for birds to capture them. On the outer coast of Washington in Willapa Bay, green crabs are often associated with the roots of *Spartina* plants, another non-native invasive species (Dumbauld, 2002).

Green crab that have moved from their native range appear to be highly successful with the average size of the crab,

European green crab

Green crabs are often not green in color, but can change color to match their surroundings.

showing increases as it moves from one area to another. Green crab in Australia, South Africa, and the Atlantic coast are larger than their European relatives, while the Pacific coast crab have grown larger still. This increase in size is probably indicative of the availability of food resources and, on the Pacific coast, may reflect the milder winters that allow crab to survive and thrive from year to year (Grosholz and Ruiz, 1996).

HISTORY OF GREEN CRAB INVASIONS

The green crab is native to Europe and North Africa where it is an integral part of the intertidal and subtidal ecosystem. The crab has been widely introduced to many parts of the world, including Australia, South Africa, the Atlantic seaboard of the U.S., and more recently the Pacific coast of the U.S. The first introductions to the eastern seaboard occurred about 150 years ago with the first recorded sightings in the area from Cape Cod to New Jersey in the late 1870s. By 1900 the green crab had started to spread northward to Maine and into Nova Scotia in Canada, and southward into Chesapeake Bay (Yamada, 2001). The most likely vector for these early introductions was through the transport of live seafood and/or packing materials made from algae and seagrasses from the animal's native range. Australia also first experienced the green crab invasion during the nineteenth century. By 1980, established populations of green crab were found in South Africa, Japan, Tasmania, and California.

First sighted on the Pacific coast in 1989 in San Francisco Bay, the green crab began to spread south to Monterey and northward towards the Pacific Northwest. It was discovered in Coos Bay in southern Oregon in 1996, then in Washington and British Columbia in 1998-1999, arriving on the north west coast of Vancouver Island in the summer of 2000 (Yamada, 2001). Although the pathways of introduction are not known, there is considerable speculation among scientists and managers that ballast water discharges from shipping may have played a role, introducing the crab from one or more of its previous invasion sites (Cohen and Carlton, 1998). Spread of green crab along the west coast is thought to be controlled by ocean currents flowing near the coastline, carrying planktonic larvae to new estuaries. The exceptionally strong northward flowing coastal currents of 1998-1999, caused by a strong El Nino-Southern Oscillation, are thought to be responsible for the exceptional range expansion by the green crab.

RECENT HISTORY OF GREEN CRAB IN PACIFIC NORTHWEST ESTUARIES

The first sightings of green crab in Oregon estuaries occurred in 1996 in Coos Bay. Over the succeeding two years, green crab were found in estuaries further north and an established population was monitored in Coos Bay. The crab distribution then leapfrogged to Washington coastal estuaries with first sightings in Willapa Bay in late 1998. Subsequently a small number of adult green crab were found in Grays Harbor (the other major Washington coastal estuary) and in bays on the west side of Vancouver Island. Since 2000, there does not appear to have been an expansion of the green crab range, although an established population is clearly present in

Willapa Bay. Ongoing monitoring efforts are in place to ensure that the crab is not yet present in Puget Sound and inland marine waters.

USING GREEN CRAB AS A MODEL OF RESPONSE TO MARINE INVASIVES

In response to the detection of green crab in southern Oregon estuaries, and in advance of its inevitable arrival in northern Oregon and Washington state waters, Washington Sea Grant Program at the University of Washington and Oregon Sea Grant at Oregon State University organized a workshop to share information and to devise a response plan for green crab and other marine invaders in coastal Pacific Northwest waters. Held in Vancouver, Washington, in February 1998, the Green Crab Workshop brought together natural resource managers, researchers, shellfish growers, crab fishers, and non-governmental organizations. Speakers over the two days addressed the biology, invasive potential, and possible management of the organism. Scientists and natural resource managers with previous green crab experience were invited from the eastern U.S., California, and Tasmania to share their experiences with past invasions of the green crab, including the crabs' food and substrate preferences, and their impacts on native ecology. Local researchers and managers learned that the crab grows larger on the west coast than in its native habitat, and its food and substrate preferences appear to differ on the west coast from those on the east coast. Few natural controls seem to exist on the green crab outside of its native range, and they seem to alter the ecology of invaded areas within two years of establishment (Yamada, 2001).

In 1998, there were few managers or researchers in the Pacific Northwest with significant experience dealing with marine invasive species. It was unclear what mix of government agency management, outreach, education, and research would best prepare the region for dealing with green crab and similar invaders. The workshop began the process of organizing researchers and managers to respond to future invasions. The participants envisioned education programs that would enlist the public's help in recognizing and responding to new sightings, and created channels of communications to discuss new and looming invasive species threats to many marine resources.

Following the workshop, a volume on green crab was produced by Oregon and Washington Sea Grant programs, written by researcher Sylvia Yamada. The book, *Global Invaders: The European Green Crab* addresses the biology, ecology, and invasive potential of the crab (Yamada, 2001).

The rate at which green crab were spreading northward along the Pacific coast until 1998 lead researchers to assume the invasion would arrive in northern Oregon and southern Washington estuaries, including the Columbia River Estuary, in one to three years. Workshop organizers and participants alike thought they were prepared to deal with future invasions and were pleased to be out in front of an environmental threat. They were stunned to receive reports of green crab in coastal Willapa Bay, Washington, in July 1998—a mere five months later.

A TEACHABLE MOMENT

While interest in green crab and its future impacts in the Pacific Northwest were evident from the attendance of 120 scientists, managers, shellfish growers, and NGO members at the February 1998 workshop, the arrival of the organism in Washington state galvanized the community. There was an immediate demand for fact sheets, detailed identification guides, and up-to-the-minute reports of crab sightings.

The interest spread beyond the management, scientific and affected communities, with news stories appearing in major print, television, and radio markets in the Pacific Northwest and beyond. Funds rapidly became available to create education and outreach publications, and to hold identification workshops. Interest in the recommendations of the February 1998 workshop was intense. Washington Sea Grant Program took the lead in creating print materials, including a green crab identification card. The challenge of identifying green crab in the field is exasperated by its resemblance to certain native crab; reports out of Northern California included incidents of people destroying native crab, due to their misidentification as green crab. To help ensure accurate identification, the WSGP card includes color photographs, brief scientific descriptions and drawings, highlighting distinguishing features of green crab, and native crab species. Pacific Northwest fish and wildlife agencies and NGOs were instrumental in distributing educational materials and spreading the word about the potential impacts of green crab invasions on marine resources. WSGP also created and delivered a hands-on workshop for green crab identification. The workshop was repeated for citizens, tribal members, and industry who assisted agency staff in monitoring for green crab in Washington coastal estuaries and in Puget Sound.

GREEN CRAB AND OTHER INVADERS IN PACIFIC NORTHWEST TODAY

The European green crab has not become established throughout the Pacific Northwest; notably, green crab has also not been documented in Puget Sound and adjacent waters. Monitoring programs continue to have strong involvement by volunteer groups; resource managers, researchers, and shellfish growers as they continue to experiment with control mechanisms in estuaries where green crab are established.

The general public continues to be unaware of the threat that marine invaders may pose to ecosystem integrity, but the issue is firmly on the minds of Pacific Northwest natural resource managers. The high visibility of the green crab introduction helped move marine invasions from a theoretical environmental challenge to the status of a significant environmental threat, requiring cooperation among many interested parties.

ANDREA COPPING is Associate Director of the Washington Sea Grant Program at the University of Washington and Affiliate Faculty at the School of Marine Affairs. She is a biological oceanographer who has spent much of her professional career working on human impacts in the coastal environment. Dr. Copping is interested in the potential disruption of the Pacific Northwest marine ecosystem by non-native species, and the role that education can play in their management and control.

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EURASIAN WATERMILFOIL INVASIONS AND MANAGEMENT ACROSS THE UNITED STATES

BY DR. JOHN D. MADSEN

EURASIAN WATERMILFOIL IS A NON-NATIVE AQUATIC PLANT *from Europe and Asia that is green throughout the entire year. Growing completely underwater, with only the inflorescences above the water's surface, it can often be difficult to notice in early stages. Once mature, its dense canopy can interfere with boating, swimming, fishing, or other aquatic activities. Ecologically, it suppresses native plants and changes the equilibrium between predators, like bass, and their prey. Eurasian watermilfoil nuisance growths cost lake users millions of dollars a year to manage, and even more in other economic losses. While many management techniques are available, all are expensive and result in long-term management programs. The best option is to prevent the spread of this, and other, nuisance aquatic plants.*

Invasive plant species are widely recognized as a major concern to habitats across the country, including agricultural fields, pastures, rangeland, woodlots and forests, streamsides, and wetlands. In recognition of the importance of wetlands as habitats for fish and wildlife, much concern has focused on invasive species like purple loosestrife, melaleuca, salt cedar, and alligatorweed. Even wetland aficionados, however, forget that a wetland does not end at the surface of the water. An often-neglected community is that of the submersed aquatic plants, though this is often the most important community for fish spawning and nursery habitat. The submersed plant zone is being invaded by non-native species like hydrilla, egeria, and Eurasian watermilfoil, the topic of this paper. Eurasian watermilfoil is the most widely distributed invasive submersed plant in the United States.

EURASIAN WATERMILFOIL DESCRIPTION

Eurasian watermilfoil (*Myriophyllum spicatum L.*) grows completely under water (see Figure 1 on page 22), but can form a canopy of leaves and branches very close to the surface (see Figure 2 on page 22). It is a submersed evergreen perennial plant, with green shoots present throughout the year. Eurasian watermilfoil grows in water depths from one to 15 feet, from which it can grow to the surface. It occasionally grows in even deeper water, if water clarity is particularly high. Eurasian watermilfoil forms a dense root crown, from which numerous shoots grow towards the surface. The root crown and associated new shoots are the primary means by which Eurasian watermilfoil overwinters (see Figure 3 on page 22). As it grows to the surface, it branches repeatedly to form a very dense canopy with a profusion of leaves. The leaves are pinnately compound, with 14 to 24 pairs of thin tubular leaflets. These leaves typically occur in groups of four whorled at each node of the stem, though some variation can occur. The plant forms a short inflorescence, or flowering spike, above the surface of the water, composed of pollen-forming flowers on top and seed-producing flowers below (see Figure 4 on page 23). The flowers are wind pollinated. Stems and apical tips of Eurasian watermilfoil tend to be reddish, but variation in this color also occurs. Since Eurasian watermilfoil looks like some of the native Myriophyllum species, confusion in the identification of this nuisance invader frequently occurs. The native watermilfoil species provide valuable habitat for aquatic species, and rarely cause the same nuisance problems produced by Eurasian watermilfoil.

ECOLOGY OF EURASIAN WATERMILFOIL

Eurasian watermilfoil grows in a diverse range of aquatic habitats, including rivers, reservoirs, natural lakes and freshwater, and brackish estuaries. Eurasian watermilfoil can tolerate salinity as high as 13 ppt (approximately 33 percent of seawater), and growth is undiminished below salinities of 6 ppt (approximately 15 percent of seawater; Haller et al., 1974). In freshwater, it tolerates environments ranging from soft water, low alkalinity systems to hard water lakes, and trophic states from oligotrophic to eutrophic (Smith and Barko, 1990 and Madsen, 1998). The growth can vary across its range from being winter dormant in northern lakes to dormant in both winter and mid-summer (from heat stress) in the south (Madsen, 1997).

Eurasian watermilfoil requires light, nutrients, and carbon dioxide to grow. Since it forms a dense surface canopy, light can be collected from near the water surface in even relatively turbid water (Madsen et al., 1991a). Because it is a rooted plant, it derives most of its nutrients from the sediment rather than the water column. In most instances, nitrogen rather than phosphorus is limiting to growth (Smith and Barko, 1990). Carbon dioxide is taken from the water as either dissolved carbon dioxide or as bicarbonate (Grace and Wetzel, 1978).

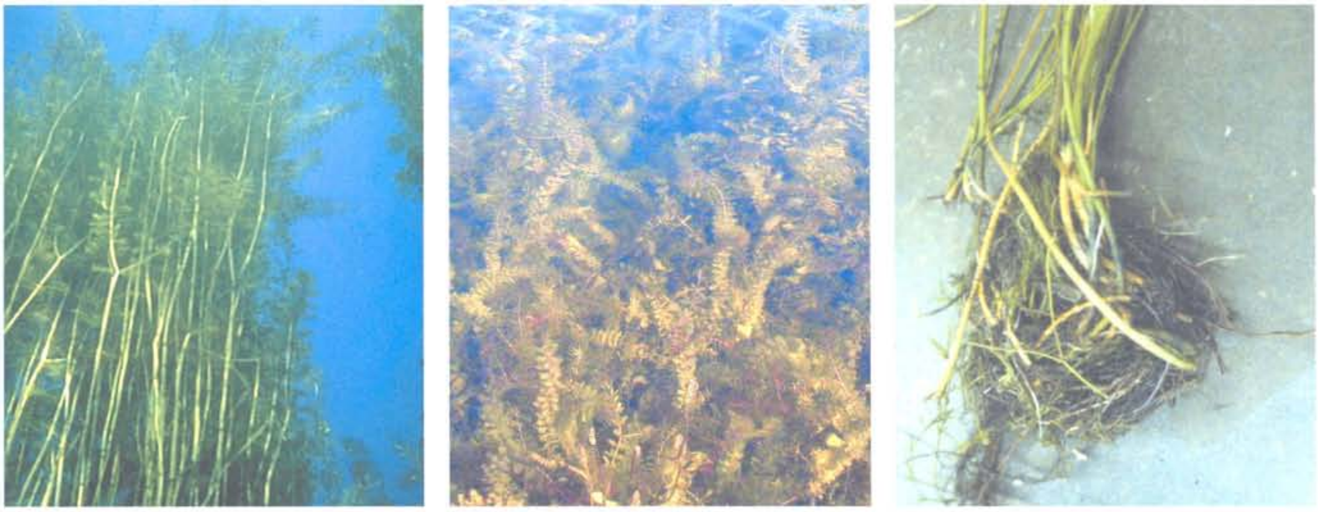

Figure 1 (left). Underwater view of the canopy of Eurasian watermilfoil in 12 feet water depth, in the clear waters of Lake George, New York. Figure 2 (middle). Eurasian watermilfoil growing close to the surface in the waters of Lake Hortonia, Vermont. Figure 3 (right). The dense root crown of Eurasian watermilfoil is how the plant grows and overwinters.

While seeds are produced, they generally do not appear to be an important source of new colonies (Hartleb et al., 1993). Seeds resist desiccation; so one possible mechanism of reproduction by seed is after drawdown (Standifer and Madsen, 1997). Reproduction is almost entirely by vegetative means, either through spread by stolons or fragments (Madsen et al., 1988 and Madsen and Smith, 1997). The plants produce fragments seasonally that act as dispersal units, and can survive for long periods of time before establishment occurs.

PROBLEMS CAUSED BY EURASIAN WATERMILFOIL

Eurasian watermilfoil invasions are not only problematic to human use of water resources, but also have negative ecological impacts on aquatic systems.

Human uses that are adversely affected by Eurasian watermilfoil infestations include recreational boating, shore and boat fishing, water skiing, and swimming (Newroth, 1985). Eurasian watermilfoil also increases sedimentation in reservoirs, and imparts unwanted taste and odor to drinking water. As with other submersed plants, it can increase the risk of flooding, reduce the flow of floodwater, impede hydroelectric generation, and foul water intakes (OTA, 1993).

Ecological impacts to aquatic habitats are somewhat more difficult to quantify than those to human uses. Dense Eurasian watermilfoil decreases both the diversity and abundance of native aquatic plants, causing localized extinction of species (Madsen et al., 1991b; Boylen et al., 1999). Eurasian watermilfoil reduces dissolved oxygen under the canopy, and may increase nutrient loading from sediments (Unmuth et al., 2000; Smith and Adams, 1986). Widespread growth of Eurasian watermilfoil in a lake may reduce macroinvertebrate density, and abundance (Cheruvelil et al., 2002). Fish communities and predator/prey equilibria may also be altered (Valley and Bremigan, 2001).

HOW EURASIAN WATERMILFOIL IS SPREAD

Eurasian watermilfoil spread throughout the United States is a combination of human intervention and natural processes, depending on the scale of dispersal (see Figure 5 on page 23). The initial transfer from Europe and Asia was completely by human transport. Some possible theories include the use of Eurasian watermilfoil as an aquarium plant, use as solid ballast in ships, or in the aquatic nursery trade. Interstate transfer of Eurasian watermilfoil was also predominantly human-vectored, though in some instances water flow could carry Eurasian watermilfoil across state boundaries. The most likely carrier of Eurasian watermilfoil between states or watersheds is on boats and boat trailers, with some transfer by means mentioned above (Johnstone et al., 1985). Inadvertent transfer with bait is also possible. Within a watershed or in-lake, transfer is likely done solely by water movement carrying fragments (Kimbel, 1982). Eurasian watermilfoil is a prolific former of autofragments, fragments created by an abscission layer in the stem, which are stem segment propagules (Madsen et al., 1988; Madsen and Smith, 1997). Thus, once Eurasian watermilfoil is in a lake or a watershed, it is difficult to prevent its spread by natural means. Wave action, boating, or other mechanical stresses that break the stem may also form stem fragments, which may form new colonies of Eurasian watermilfoil.

CURRENT DISTRIBUTION OF EURASIAN WATERMILFOIL

Eurasian watermilfoil was first found in the United States in the 1940s, with almost simultaneous introductions to California, Arizona, Ohio, and the Chesapeake Bay (Couch

Figure 4. Eurasion watermilfoil stems at the water surface with flower spikes extending into the air.

and Nelson, 1985; see Figure 6). Apparently, all these states acted as loci for spread, with populations found in a number of northeastern, midwestern, southwestern, and southeastern states by 1960. By the 1980s, numerous sites occurred throughout the United States with the apparent exception of the northern plains states. Currently, it is one of the most widespread invasive aquatic plants, occurring in at least 45 states and in three Canadian provinces (Jacono and Richerson, 2003). Given its adaptability to a wide range of environmental conditions, it is the invasive aquatic plant most likely to be found in any state of the U.S., in waters ranging from cool mountain lakes to brackish estuaries. Once established in a new state, it continues to spread to new lakes.

TECHNIQUES TO MANAGE EURASIAN WATERMILFOIL

Before managing a Eurasian watermilfoil infestation, a plan should be developed that includes defining the problem, setting management goals, determining resources and needs, assessing the problem, developing a method of assessing the management success, and informing the public. All management techniques should be considered based on their merits, and all aquatic plant management techniques have positive and negative attributes; there is no perfect and painless solution. All management techniques, including doing nothing, have some negative environmental impact. The techniques should be selected based on economic, environmental, and technical constraints.

A brief overview of management techniques specifically for Eurasian watermilfoil is provided in Table 1 on page 26, with more detail given elsewhere (Madsen, 2000). In addition, the Aquatic Ecosystem Restoration Foundation has recently published a Best Management Practices manual that includes Eurasian watermilfoil (AERF, 2004). Several lakes have management plans or guidance documents that are helpful; one recent effort for Houghton Lake (MI) is particularly thorough in its review of the literature (Getsinger et al., 2002)

Institutional controls should be part of an overall plan, but alone will not protect a lake from invasive species. A combination of regulations that prevent transport of species and public education about invasive species will help reduce the spread of problematic species. Before introduction of invasive species, concerned citizens should start monitoring their lakes for invasive plants, or ensure that the responsible entity is doing so, to serve as an early warning of invasion. Early response is the key to preventing widespread management problems.

A number of biological control organisms have been utilized for Eurasian watermilfoil. Grass carp do not prefer Eurasian watermilfoil, so they are a poor control option at best. Native insects (Madsen et al., 2000) and a native pathogenic fungus (Nelson and Shearer, 2002) have both shown some promise, but are still under development. The bottom line is

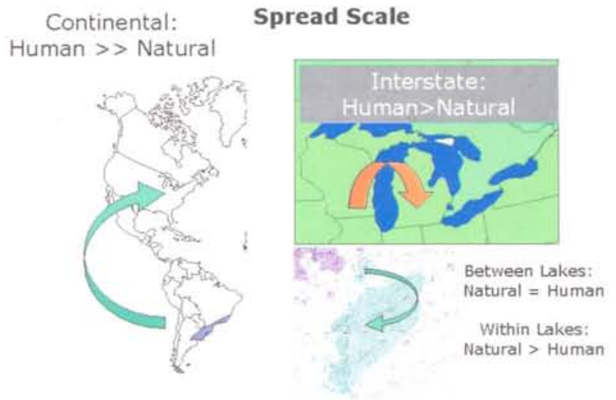

Figure 5. Scale of invasive plant spread determines whether human or natural processes predominate.

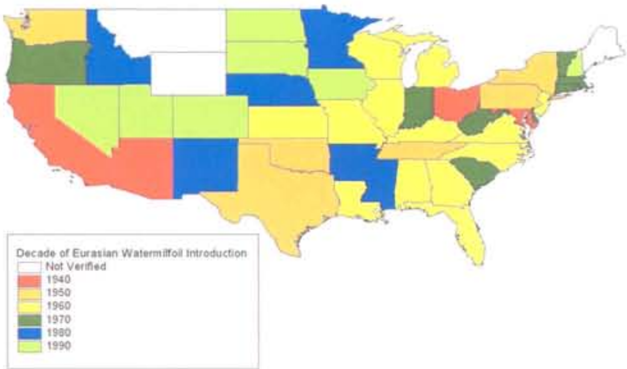

Figure 6. Estimated decade of introduction to each state in the U.S.

that there is not currently an operational biocontrol agent for Eurasian watermilfoil.

Herbicides are the most commonly used control technique for Eurasian watermilfoil. New herbicides have been approved or are in the process of registration by the U.S. E.P.A for use in aquatic environments for control of Eurasian watermilfoil. Currently, approved systemic aquatic herbicides are 2, 4-D, fluridone, and triclopyr. The contact herbicides diquat and endothall are also used on small infestations or along shorelines as a "spot" treatment.

Mechanical controls are also widely used for managing Eurasian watermilfoil. Of these, hand harvesting or hand implements are used on small segments of shoreline. Harvesters are commonly used to relieve the nuisance growth in larger areas offshore, with the plant material removed from the lake. While users get immediate relief from plant growth, this technique will not result in long-term control. Other techniques in use include rotovating, using an underwater tilling apparatus, and diver-operated suction harvesting, where SCUBA divers use a vacuum lift to remove plants by their roots.

Physical control techniques include a number of approaches, such as shading or dredging, to decrease the light available to plants. Of the physical techniques, the most affordable and effective is drawdown, particularly winter drawdown, in which the lake is drained during the winter period to desiccate and freeze the plant. Obviously, this technique is only feasible if the lake has a water control structure.

These are just some of the techniques available to manage Eurasian watermilfoil; more research is continuing on the management of this widespread nuisance plant. Whatever the management techniques selected, the goal is to reduce the abundance of this non-native invader and allow desirable native vegetation to grow and provide habitat for fish and wildlife.

DR. JOHN D. MADSEN is an Assistant Research and Extension Professor in the GeoResources Institute and the Department of Plant and Soil Sciences at Mississippi State University. Dr. Madsen is a past editor of the *Journal of Aquatic Plant Management*, past associate editor of *Wetlands*, and a former member of the editorial board of the *Journal of Freshwater Ecology*.

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MORE RESOURCES FROM THE BRIDGE:

Aquatic Ecosystem Restoration Foundation:
http://www.aquatics.org/

Aquatic Plant Management Society:
http://www.apms.org

Biological Control of Eurasian Watermilfoil:
http://www.fw.umn.edu/research/milfoil/milfoilbc.html

Mississippi State University, GeoResources Institute, Invasive Species Page:
http://www.gri.msstate.edu/lwa/invspec.php

Sea Grant Non-Indigenous Species Site:
http://www.sgnis.org/

University of Florida's Center for Aquatic and Invasive Species:
http://aquat1.ifas.ufl.edu/

USACE Aquatic Plant Control Research Program:
http://www.wes.army.mil/el/aqua/

U.S. Geological Survey Non-Indigenous Aquatic Species:
http://nas.er.usgs.gov/

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Pages 22-23 (top) Courtesy of Dr. John D. Madsen

Page 23 (bottom right) Couresty of Data from Couch and Nelson (1985), and Jacono and Richerson (2003).

Page 26 Table 1 modified from Madsen, 2000

TECHNIQUES TO MANAGE EURASIAN WATERMILFOIL

TECHNIQUE	DESCRIPTION	NOTES
INSTITUTIONAL		
Quarantine	Regulations restricting possession and transport	May reduce the spread of Eurasian watermilfoil
Education	Advertising, signage at boat launches	Alerting public about Eurasian watermilfoil
BIOLOGICAL		
Grass carp	Herbivorous fish	Not recommended for Eurasian watermilfoil
Milfoil weevil, other native insects	Herbivorous native insects	Some success, but mostly in research phase
Mycoleptodiscus terrestris	Pathogenic fungus	Some success in research and demonstration
Native plant community restoration	Planting native plants in infested areas	Restorative rather than a treatment
CHEMICAL		
2,4-D	Selective systemic herbicide	Generally effective for Eurasian watermilfoil
Diquat	Broad spectrum contact herbicide	Effective for small treatments
Endothall	Broad spectrum contact herbicide	Effective for small treatments
Fluridone	Slow-acting systemic herbicide	Requires very long contact time
Triclopyr	Selective systemic herbicide	New aquatic herbicide for Eurasian watermilfoil
MECHANICAL		
Hand-removal	Direct hand pulling or use of hand tools	Effective for individual plants
Cutting	Cut weeds without removal	May spread Eurasian watermilfoil
Harvesting	Cutting and removing weeds	May spread Eurasian watermilfoil
Diver-operated suction harvesting	Diver-operated vacuum lift to remove plants	Effective for small beds or plots
Rotovating	Underwater tiller that disrupts root crowns	May spread Eurasian watermilfoil
PHYSICAL		
Dredging/Sediment Removal	Mechanical sediment removal to deepen water	Extremely expensive for only plant control
Drawdown	"De-water" water body for an extended period of time	Effective for controlling Eurasian watermilfoil
Benthic barrier	Use natural or synthetic sheet or barrier over plants	Effective in small beds, but expensive

Table 1.

INVASIVE *SPARTINA* IN WEST COAST ESTUARIES

BY KIM PATTEN

ESTUARINE WATERS SUSTAIN A LARGE COMMUNITY OF CONSUMERS, *from single-cell plankton, worms, crabs, oysters, fish, and birds to humans. They are highly productive, critical habitat for migratory wildfowl and endangered and threatened species of fish. They also support multi-million dollar shellfish industries. Along the Atlantic and Gulf Coasts of the United States, a perennial, deep-rooted saltmarsh grass called smooth cordgrass (*Spartina alterniflora*) dominates the harsh intertidal habitat of the low salt-marsh community, where it has a major role in physical and biological estuarine processes. Another native *Spartina *species, (*S. patens*) salt meadow cordgrass, is found in the higher salt-marsh community. These two grass species form the ecological backbone of east coast tidal marshes (see Figure 1). Outside its native range, however, smooth cordgrass is particularly well adapted at colonizing the open intertidal mudflats of geologically young estuaries like those on the west coast of North America (see Figure 2 on page 28). It transforms the wide expansive mudflats into emergent monotypic marshes (see Figure 3 on page 28). As a consequence, many of the Pacific coast's most valued estuaries hang in a precarious ecological balance due to the invasion of *Spartina.

Invasive *Spartina* species are a problem in many other estuaries of the world. It is listed among the 100 World's Worst Invasive Alien Species (visit: http://www.issg.org/booklet.pdf). Besides *S. alterniflora*, several other *Spartina* species are problematic. *S. anglica* has invaded estuaries in Puget Sound, Washington, Europe, Australia, and New Zealand. A hybrid of *S. alterniflora* with the California native *S. foliosa* has become the dominant *Spartina* species in San Francisco Bay. These hybrid swarms (*S. alterniflora* and *S. foliosa*) are more vigorous and reproductively fit than either of the parents. *S. densiflora* and *S. patens* are minor problems in several west coast estuaries.

Willapa Bay, Washington, currently has over 15,000 acres of tideflats infested with invasive *Spartina*. San Francisco Bay, California and Puget Sound, Washington, both have several thousand acres of *Spartina*-infested tidelands. These infestations pale compared to more than 200,000 acres of invasive *Spartina* in the estuaries of China.

METHOD OF INTRODUCTION AND SPREAD

The ability of this species to accumulate large volumes of tidal sediments as a pioneer species has led to its deliberate introduction in several parts of the world (Northern Europe, Australia, New Zealand, and China) for land reclamation. In fact, most of the initial infestation of invasive *Spartina* has occurred as a consequence of intentional planting for the purpose of stabilizing mudflats, reducing source areas for channel silting, protecting coastlines from erosion, and for livestock feed. Other invasion pathways to new locations include seeds contained within ship ballast water, and on water currents dispersing float mats containing seeds. Erosion and re-establishment of the rhizome root mat have been noted to be a source for its establishment in lower intertidal zones where tidal energy would normally have occluded seedlings from establishing.

The *Spartina* originally introduced in 1894 to Willapa Bay, Washington, occurred as discarded packing material in shipments of eastern oysters (*Crassostera virginica*). It wasn't

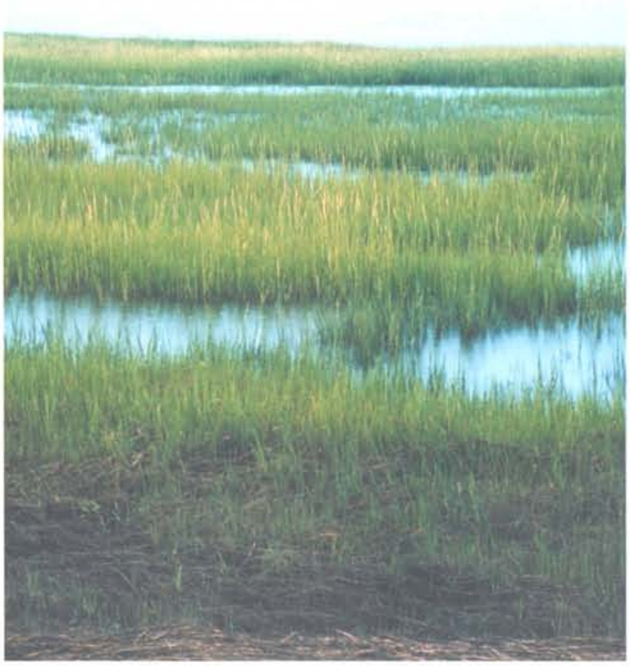

Figure 1. East coast salt marsh with *Spartina alterniflora* (far shore) and *S. patens* (near shore).

Figure 2. A section of Willapa Bay, showing the typical flat expansive mudflat. This is an empty niche ready for an opportunistic species to invade.

Figure 3. A former mudflat and oyster nursery bed in Willapa Bay, which has converted into a *Spartina* meadow.

for another 60 to 70 years that it was recognized as an alien plant and potentially harmful, and as is typical with many invasive plant species, few efforts were made to control it until its exponential expansion became obvious. This wasn't until 100 years after its initial invasion.

Once established, *Spartina* spreads clonally from underground rhizomes. As rhizomes intermingle, circular clonal patches (see Figure 4) coalesce to form large dense meadows, often reaching 6 to 7 feet in height. In fertile substrate, the rhizomatous rate of spread is up to a 30 percent increase per year. *Spartina* can flower and set seed within the second year of growth. Seeds are set in late summer/fall and germinate later in the winter and spring. Most seeds drop within a short distance of the mother plant, but they may float for extended periods either by themselves or within floating wracks of *Spartina* stems. Greatest seed production occurs in large swards of *Spartina*, where flowers have a better chance of receiving the wind-borne pollen. Seeds are short-lived and are not reported to be viable beyond the first year. After a long time of colonization has elapsed, higher fecundity tends to occur as the species reaches critical mass for wind pollination and as it becomes genetically adapted to the environment (earlier flowering for example). The most rapid and successful seeding recruitment usually takes place in sites fairly close to the mother plants, in areas with softer sediment and low tidal energy, or where the seeds are trapped by any type of vegetative stubble on tide flats. The ability of invasive Spartina to undergo rapid evolution, hybridize, and undergo genome duplication (polyploidy) has lead to its tremendous success as an invader.

IMPACTS OF INVASIVE *SPARTINA*

- Trapping of sediment by Spartina stems dramatically increases sediment accretion rates. This increased accretion changes estuarine bathymetry resulting in modified water circulation and reduced tidal flows, altering marsh hydrology and increasing flooding during heavy tides. This increase in tidal height ultimately changes the entire habitat and structure of the estuary.
- By covering bare mudflats with a thick canopy and dense root mat, Spartina displaces epi-benthic macroalgae and eelgrass (see Figure 5 on page 29) and changes the primary productivity of mudflats. The thick canopy and root mass (see Figures 6a and 6b on page 29) prevents access to benthic prey from shorebirds and the thick root mat inhibits the extraction of shellfish for commercial and recreational purposes.
- Hybridization with native *Spartina* species in San Francisco Bay and hybrid swamping of pollen will likely result in regional extinction of native *S. foliosa* by genetic assimilation. This is likely to become the first naturally dominant plant species to go extinct in its own ecosystem since the passage of the Endangered Species Act of 1973.
- Loss of mudflat habitat to *Spartina* invasion will seriously impact shorebirds on the Pacific Flyway route. Not only is there a change in prey abundance and value, but access to prey through the dense canopy is impossible. Even if *Spartina* is controlled, the change in habitat (such as tideflat elevation and benthic infauna) is so significant that shorebirds fail to return to utilize the affected tideland. The Audubon Society has called the loss of shorebird habitat in Willapa Bay due to invasive *Spartina* one of the most serious threats to shorebird habitat in North America.
- Commercial shellfish production is seriously impaired. Manila clam habitat in the upper tidal land becomes unusable. Eventually, the deeper intertidal oyster beds become invaded. With reduced tidal flows, impaired access and changed bathymetry, these shellfish beds become unusable (see Figure 7 on page 30).

Figure 4. Circular clonal patches of *Spartina*, seedlings and young plants. These will coalesce into a meadow within a few years.

Often by the time regulatory permission for control is granted, what was only a few hundred acres of Spartina *has turned into many thousands of acres.*

Figure 5 (left). *Spartina* choking out native eelgrass–a valuable habitat for fish and waterfowl. Figured 6a (middle) and 6b (right). Impenetrable canopy and root mat of *Spartina* that prevent access and utilization by shorebirds.

- Numerous endangered species are directly affected by *Spartina*. Examples include *S. patens* directly competing for space with the federally-listed marsh plant (*Cordylanthus mollis* sp. *mollis*). *Spartina* chokes tidal channels which the endangered California clapper rail (*Rallus longirostris*) uses to forage. *Spartina patens* and *S. densiflora* colonize middle and upper marsh, displacing native pickleweed marsh, habitat of the endangered salt marsh harvest mouse.
- *Spartina* has caused failure of numerous estuary restoration projects by undermining efforts to recover native species and habitat. Some current recommendations suggest that restoration of tidal areas in highly infested areas of an estuary be postponed until exotic cordgrass is removed.

The problem of invasive *Spartina* is best summarized in the permanent laws (Revised Code of Washington (RCW)) of the State of Washington that were recently enacted to deal with the *Spartina* issue (RCW 17.26). This law states that the State of Washington "...is facing an environmental disaster that will affect other states as well as other nations. The spread of *Spartina* threatens to permanently convert and displace native freshwater and saltwater wetlands and intertidal zones, including critical habitat for migratory birds, many fish species, bivalves, invertebrates, marine mammals, and other animals. The continued spread of *Spartina* will permanently reduce the diversity and the quantity of these species and will have a significant negative environmental impact. *Spartina* poses a significant hydrological threat. Clumps and meadows of *Spartina* are dense environments that bind sediments and lift the intertidal gradient up out of the intertidal zone through time. This process reduces flows during flood conditions, raises flood levels, and significantly alters the hydrological regime of estuarine areas. *Spartina* removal shall include restoration to return intertidal land and other infested lands to the condition found on adjacent unaffected lands in the same tidal elevation."

CURRENT MANAGEMENT STRATEGIES

In estuaries where *Spartina* is currently not established, frequent inspection and rapid removal is critical. Once established, *Spartina* control becomes a costly and long-term problem. Efforts to manage, control, or eradicate invasive *Spartina* in west coast estuaries have been fraught with ecological and political contentiousness based on conflicting values in habitat and land/resource stewardship. State regulatory agencies have required very cautious management strategies to assure that the fragile estuarine ecology or endangered or threatened species are not damaged by any of the control approaches. For example, the possible use of the *Spartina* canopy by juvenile salmonids for predator avoidance during out-migration or nesting of clapper rails within *Spartina* has restricted the timeframe when control efforts can occur in Washington and San Francisco Bay, respectively.

Potential collateral damage to the fragile estuarine environment that may occur with *Spartina* control treatment has been a major concern of many environment groups and regulatory agencies. Environmental Impact Statements (EIS) and Environmental Assessments (EA) are usually required prior to any control effort being launched. Several examples of the types of documents can be found at http://www.Spartina.org/project.htm. Often by the time regulatory permission for control is granted, what was only a few hundred acres of Spartina has turned into many thousands of acres. Some countries, like New Zealand, have realized it is more prudent to immediately eradicate an invasive species than to first engage in lengthy reviews of all possible ecological concerns. They are willing to assume the short-term risk resulting from the control effort, rather than allowing the species to geometrically increase beyond what can be eradicated or cost-effectively controlled.

Most short-term risk aversion has focused on concerns with chemical control. A risk assessment of the herbicides used for *Spartina* control indicated that the herbicide residue found in

Figure 7. Commercial oyster beds invaded by *Spartina*. This photograph was taken during the winter and shows the residue dead stubble.

Figure 8. Digging to remove *Spartina* is limited to small plants. Care must be taken to remove all the rhizomes to prevent re-growth.

the sediment and water was well below the range considered harmful (8,000- to 1,000,000-fold below the concentration required to kill 50 percent of the population's most sensitive aquatic invertebrates and fish species).

Management strategies implemented for *Spartina* have included biological, mechanical, and chemical controls. A complete set of management tools is listed in Table 1 below. For biological control of *Spartina* in Willapa Bay, the planthopper (*Prokelisia marginata*) has been the most promising natural enemy because of its known potency against *Spartina* and its narrow host range. To date, plant death has been limited to greenhouse conditions, while field work has shown reduced seed set and plant growth.

Mechanical control efforts, like digging (see Figure 8), tilling, compacting, or disking, have been implemented in several sites with control ranging from poor to good depending

METHOD	ADVANTAGES AND LIMITATIONS
Mechanical- Tilling	Good efficacy, but requires expensive start-up for large amphibious tiller (~$250,000) is slow (<0.5 ac/hr) and expensive (>$1000/ac).
Mechanical: Crushing or Compacting	Good efficacy in very soft sediment where growing points are pushed 10 to 20 cm below the mudline. Poor efficacy on firm terrain. Requires multiple years of treatment to achieve control. Implementation is slow @~2-6 ac/hr, and requires expensive amphibious tracked vehicles ($40,000 to $80,000).
Mechanical: Mowing	No control other than preventing seed production if done multiple times during the growing season.
Mechanical: Digging	Only useful for small seedlings before extensive rhizome growth has occurred. Removal of all rhizomes on small clones (<3 feet in diameter) requires massive amounts of effort and time.
Mechanical: Weed Mats	Mowing to mudline followed by weed mats well beyond the root-line works well in areas infested with only a few clones.
Herbicide: Glyphosate (Rodeo, Aquamaster, AquaNeat)	Glyphosate has been used extensively for *Spartina* control over the past 10 years. Efficacy has been highly variable in the field, ranging from none to excellent. Most consistent control is achieved at the highest label rate, a canopy that is free of any sediment, and a dry time before tidal inundation of the canopy of more than 12 hours.
Herbicide: Imazapyr (Habitat)	Imazapyr has only recently received aquatic registration. It has been very effective at low rates (6 pt of product/ac) under a range of estuary conditions, including short dry time. It is proving to be the control method of choice for most resources managers. Imazapyr can be applied aerially over several hundred acres per day at ~$300/ac.
Biological Control	Efforts are still in the research phase with a leaf hopper. Field data indicate some reduction in plant growth and seed production. Other insect herbivores from the native host range specializing on *Spartina* are being considered/evaluated.

Table 1. Currently used methods for *Spartina* management and usefulness.

Figure 9. Herbicide application for *Spartina*, using an amphibious track vehicle equipped with GPS tracking, GIS mapping, and smart spray nozzles that only operate when they detect chlorophyll.

on the method, timing, and substrate. Mowing as a control tool by itself, however, has not been successful and is not widely used. Herbicides have been the most cost-effective means of control and continue to be the most viable management alternative available to resource agencies. When used under recommended conditions, herbicides provide long-term control of *Spartina*. Because most treated areas will have some minor amounts of vegetative regrowth and re-infestation with new seedlings, several years of spraying are required to thoroughly rid a site of all *Spartina*.

Precision agriculture technology, such as smart sensor spray nozzles that only spray when they detect chlorophyll, has been incorporated into the chemical control efforts to greatly improve accuracy and reduce non-target applications (see Figure 9.). These sprayer units are equipped with GPS tracking systems and GIS mapping systems that accurately record exact spray locations and spray rates by the second.

Accurately mapping the location and spread of *Spartina* over time has been a critical major focus for stakeholders involved in *Spartina* management. Orthorectified aerial infrared photographs (see Figure 10a) are frequently used for this purpose. They can accurately (one meter) provide data needed to map progress in the control effort, rate of vegetative growth, and areas of new infestations. Their expense and the time delay in obtaining orthorectification can limit their usefulness. Results can also be confounded (false negatives) when control efforts only provide temporary knockdown of *Spartina*. On-the-ground mapping techniques using GPS and GIS have been very useful to help define outer ranges and locations of meadows and clone fields. Other mapping techniques include the use of infra-red airborne laser LiDAR (Light Detection and Ranging) to detect subtle differences in tideflat elevations. This information can be combined with tide charts, *Spartina* locations, and plant heights, to provide a predictive model for canopy exposure (see Figure 10b). This allows the resource manager to optimize his/her spray timing to assure maximum dry tide of the herbicide on the plant canopy before tidal inundation.

In Willapa Bay alone, over $10 million were spent in the past decade on *Spartina*. This program still has a long way to go before it can achieve the ultimate goal of eradication. Because *Spartina* seeds have viability for less than one year, continual effort to control all outliers and prevent new infestations from occurring for the next five to ten years should result in eradication. This is in sharp contrast to many other aquatic invasive species where longevity of propagules makes a successful eradication effort unlikely.

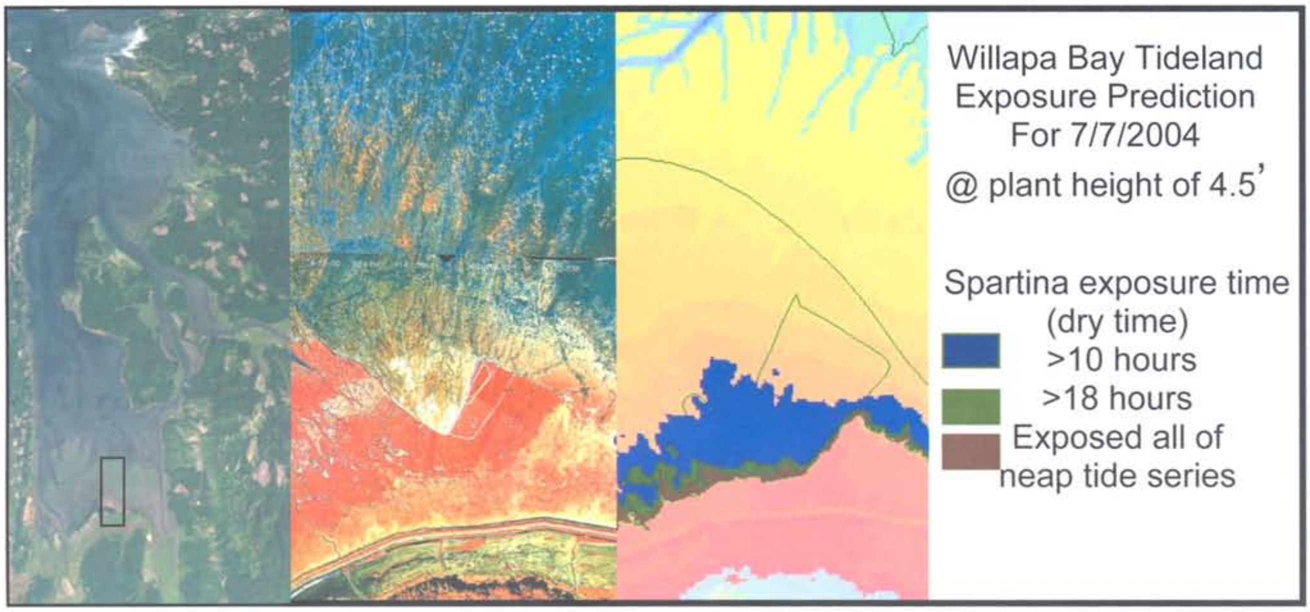

Figure 10a (left) and 10b (right). Aerial infrared photographs and map showing predictive *Spartina* exposure times above the tide, based on mudflat elevations, plant height, and tides. Long dry time exposures are ideal for achieving herbicide efficacy.

Figure 11. A section of tidelands (formerly open mudflats) completely covered by *Spartina*. One year after *Spartina* was killed on these tidelands, they were able to rapidly and irreversibly convert into salt marsh. The native salt marsh on the right has a light green tinge, while the newly forming salt marsh in the middle of the photo is darker green.

RESTORATION OF *SPARTINA* AFFECTED TIDELANDS

The job of managing invasive species does not end with the control of the problem species. Land managers need to strive towards restoring the affected habitat to its original state if feasible. Where *Spartina* has resulted in the rise of the mudflat elevation by several feet, this restoration effort may take many decades to accomplish or may never be feasible. An example of such irreversible changes in mudflat structure, and therefore function, is demonstrated in Figure 11 shown above. In this instance, a large *Spartina* meadow has been killed, but because the elevation of the landscape has risen over 18 inches, the tideland can not revert back to its original mudflat condition and instead is converting over to a salt marsh. This rapidly expanding salt marsh, although a valuable habitat for many species, is not a very desirable habitat for shorebirds and has no value for supporting shellfish production.

Because change in habitat caused by aquatic invasive species is often irreversible, it is critical that their control occur as expeditiously as possible.

CONCLUSION

Invasive aquatic species have a profound effect on the highly diverse and productive environments of estuaries. *Spartina* is a great example of a plant that is highly valued and considered sacrosanct in its native range along the Atlantic and Gulf Coast estuaries. In many west coast estuaries, however, *Spartina* currently poses one of the greatest natural threats. It rapidly transforms valuable mudflat habitat to a monoculture of tall grass that is unusable by shorebirds and for commercial shellfish production. Once established, its control is very costly and it is likely that irreversible habitat loss will occur. Early detection and rapid removal is the key to preventing the establishment of *Spartina* or any other invasive species.

DR. KIM PATTEN is an Extension Professor with Washington State University and directs the Washing State University Long Beach Research and Extension Unit. His programs focus on pest management in cranberries, shellfish, and aquatic invasive weeds. He has spent the past 12 years conducting research on *Spartina* management, with an emphasis on developing new chemical and mechanical control techniques. His current emphasis is on restoration of *Spartina* affected tideland for shorebird usage.

PHOTO CREDITS:

Page 27: Courtesy of Jeffrey Schardt

Page 28 (right): Courtesy of F. Grevstad

Page 31 (bottom left): Map Courtesy of T. Alcock, Olympic Natural Resource Center, University of Washington

Page 31 (bottom right): Infrared Photo Courtesy of Washington Department of Natural Resources

THE INVASIVE *MELALEUCA* By Susan Snyder

Melaleuca quinquenervia is an Australian tree,
Brought to drain Florida's freshwater sea.
The purpose: to create more real estate
For attracting more people to live in the state.

Water, absorbed by the roots of these trees,
Is transpired to the air from its long, narrow leaves.
An acre of trees has great draining power;
It drains more than 2,000 gallons of water an hour.

Since they were brought here, 100 years have passed by,
And much of the land, once wet, is now dry.
Native forests and marshes and swamps disappear
As the water table falls, and more *Melaleuca* appear.

Spreading at 51 acres per day,
Melaleuca appears to be here to stay.
Because many wetlands have been destroyed,
Wildlife is stressed, and people annoyed.

We slash it, burn it, to get rid of the wood;
But, cutting and burning the trees isn't good.
When stressed, more seeds are produced, you see...
Numbering up to 20 million per tree.

Using herbicides works, but the process is slow.
Can we win the battle? We don't know.
With habitat gone, native species are too.
Introducing the *Melaleuca* was the wrong thing to do.

Aquatic Invasive Species Online Resources

GIVE STUDENTS AN ESCAPE!

Exotic Species Compendium of Activities to Protect the Ecosystem (ESCAPE) is a collection of multidisciplinary activities developed from the Exotic Species Day Camp Project for Educators. This package includes 36 user-friendly lessons that incorporate experiments, art, music, and games. *ESCAPE* introduces students to issues such as exotic aquatics, spread and transport, harmful effects exotic aquatics pose, and importance of environmental knowledge and responsibility of each student as an environmental steward. Three downloadable activities can be found at www.iisgcp.org/edu/escape/.

This project was a collaboration by programs in the Great Lakes Sea Grant Network, including Illinois-Indiana, New York, Ohio, Michigan, and Minnesota.

SCIENCE AND SOCIAL STUDIES JOIN FORCES TO EDUCATE STUDENTS!

The study of exotic species is an ideal topic for an interdisciplinary approach that combines the social and natural sciences. *The Exotic Aquatics on the Move* CD-ROM contains 27 teacher-developed activities for K-12 education that align with National Geography Education Standards and focus on important geographical factors such as origin, distribution, movement, consequences, and solutions. Five sample lessons can be downloaded at www.iisgcp.org/edu/br/index.html.

This project was a collaboration among Sea Grant Programs in Illinois-Indiana, Ohio, New York, Louisiana, and Washington.

STUDENTS TAKE ACTIVE ROLE TO PROMOTE COMMUNITY AWARENESS!

Community Stewardship Projects on Aquatic Exotic Species provides summaries for 15 community stewardship projects created by students. Each objective raises the awareness of local citizens to problems caused by numerous invasive aquatic species that intrude on the natural habitat of native species. The publication offers a broad sampling of approaches people can use to inform others in their communities. The guide is available free of charge or the complete PDF can be downloaded at www.iisgcp.org/edu/br/.

This project was a collaboration among Sea Grant Programs in Illinois-Indiana, New York, Louisiana, and Washington.

AWARD WINNING EDUCATIONAL KIT AT YOUR FINGERTIPS!

The *Zebra Mussel Mania Traveling Trunk* is an award-winning educational kit and curriculum that allows elementary and middle school students to explore the effects of alien species, particularly the zebra mussel, on ecosystems and local economies. The curriculum guide contains 10 activities, which include basic concepts and fundamental skills across the curriculum: science, language arts, mathematics, social studies, and fine arts. Students learn about native mussels, shellfish biology, mussel classification, the historical importance of native mussels, and the current effects of the zebra mussel invasion on the environment and society.

Illinois-Indiana Sea Grant has a network of lending centers across the country that make the *Zebra Mussel Mania Traveling Trunk* readily available to teachers (for a detailed description of this project and list of local lending centers, please visit http://www.iisgcp.org/edk-12/mania/mania.htm). *The Zebra Mussel Mania Traveling Trunk* is also available for purchase.

INFORMATION "FAST FOOD" ON AQUATIC NUISANCE SPECIES!

Exotics To Go CD-ROM includes over 20 publications in PDF format, focusing on the understanding of exotic species, ways to stop their spread, and the impacts these species have on the environment. Also included in the CD are seven PowerPoint presentations ready to serve up knowledge on species such as zebra mussels, purple loosestrife, several fish, and two waterfleas. This CD helps organizations such as lake associations, natural resource agencies, extension educators, and teachers distribute accurate, timely, and critical information about these aquatic nuisance species. Available for $2.50 at http://www.iisgcp.org/pubs/br/cd.htm.

This project was coordinated by Illinois-Indiana Sea Grant and production of the CD was implemented by Minnesota Sea Grant. Information for this project was gathered from all programs in the Great Lakes Sea Grant Network.

Ordering information for the following, except Exotics to Go CD-Rom *can be viewed at www.iisgcp.org/edu/br/.*

AQUATIC INVASIVE SPECIES RESOURCES

Posters

Native Freshwater Plants Photo Mural (fully laminated, 62 in X 23 in) and Invasive Non-Native Plants Photo Mural (fully laminated, 62 in X 23 in)

- Contact: APIRS Photo-Mural, Center for Aquatic and Invasive Plants, 7922 NW 71 Street, Gainesville, Florida, 32653, http://aquat1.ifas.ufl.edu/welcome.html
- Cost: Free to K-12 U.S. teachers with a letter of request on letterhead.

***Stop Ballast Water Invasions* Poster and Brochure**

- Contact: Karen Hart McDowell, Project Coordinator Sea Grant/SFEP, 1515 Clay Street, Suite 1400, Oakland, California, 94612, Phone: (510) 622-2398 Email: kdhart@ucdavis.edu, http://ballast-outreach-ucsgep.ucdavis.edu/
- Cost: Free

Materials and Videos

A Primer on Invasive Species I Coastal and Marine Waters (new document)

- Contact: Florida Sea Grant Program, PO Box 110409, University of Florida, Gainesville, Florida, 32611-0409, www.FLSeaGrant.org

Aquatic Nuisance Species Report: An Update on Sea Grant Research and Outreach 2000 (TB-046)

- Website: Aquatic Nuisance Species Publications – Ohio Sea Grant, http://www.sg.ohio-state.edu/publications/topics/fts-nuisance.html

Preserved Lamprey (22" +)

- Contact: Carolina Biological Supply Co. Phone: 800/334-5551 http://www.carolina.com/
- Cost: $5.60

Non-Indigenous Species Activities for Youth by John Guyton, Ed.D., Dave Burrage, & Rick Kastner, Ph.D., Mississippi State University Extension Service Coastal Research and Extension Center. 1999. MASGP - 97 - 030, Download from: http://www.msstate.edu/dept/crec/nis.html

Non-native Invasion Video (Product Code: 750.312)

- Contact: GPN Educational Media, P.O. Box 80669, Lincoln, Nebraska, 68501, Phone: (800) 228-4630, http://gpn.unl.edu/
- Cost: $39.95

Wetland and Invasive Plants of the Southeast - A Coloring Book (ISBN 0-9700046-0-5; IFAS, Catalog # SP-276)

- Contact: IFAS Publications, PO Box 110011, Gainesville, FL 32611-0011, Phone: 352-392-1764, http://ifasbooks.ufl.edu/
- Cost: $4.95 (plus tax and shipping and handling)

2005 NMEA CONFERENCE

The 2005 National NMEA Conference will be held July 11-16 in Kahului, Maui, Hawai'i. Registration will begin July 11. Field trips are scheduled for July 12 and 13. The Marine Science Symposia and Concurrent Sessions will take place July 14-16. Activities will be centered at Maui Community College (MCC) and the adjoining Maui Arts & Cultural Center. For additional details visit the "Tentative Schedule" on the conference website (see bottom).

Field Trips

There is a wide selection of field trip activities on and in the water, including scuba diving, snorkeling, surfing, sailing, outrigger canoe paddling, kayaking, rebuilding a native Hawaiian fishpond, surveying coral reefs and fish populations, studying dolphins, and learning underwater digital photography.

On the drier side, participants may choose to hike through the crater at the top of Haleakala, or hiking into the lush forests. There is also a geological tour of Haleakala and a drive through the coastal jungles along the Hana Highway. Participants' families may register for field trips at the activity desk at NMEA Central.

Symposia & Sessions

The morning Marine Science Symposia will focus on Cutting Edge Research, Conservation & Sustainability, and Multidimensional Marine Science including cultural and artistic aspects. (See the website for more information about the local speakers featured at the symposia.) Afternoon concurrent session presentations will cover a broad variety of hands-on educational activities at all levels as well as topics in technology, science, humanities, and the arts. Global scientific literacy will be explored in the One World-One Ocean international strand.

For further information about accommodations and scholarships as well as more details about the conference, please visit the website www.hawaii.edu/maui/oceania/NMEA05.html. We look forward to seeing you on the sunny shores of Hawaii. Aloha!

WWW.HAWAII.EDU/MAUI/OCEANIA/NMEA05.HTML

AQUATIC INVASIVE SPECIES RESOURCES, WEBSITES AND CDS

MAJOR WEBSITES:	SUMMARY OF CONTENTS:	WEBSITE ADDRESS:
Sea Grant Non-Indigenous Species (SGNIS)	Comprehensive information on numerous ANS. Links to other ANS and exotics websites.	http://www.sgnis.org
Great Lakes Information Network (GLIN)	Current information from newspapers, scientific papers, conferences, press releases and education curricula.	http://www.great-lakes.net/
National Aquatic Nuisance Species Clearinghouse	Collection of technical publications dealing with the impacts, biology, spread, and control of ANS.	http://www.entryway.com/seagrant/
OTHER PROMINENT WEBSITES:		WEBSITE ADDRESS:
ANS Task Force	Prevention and spread of ANS. Updated conference and meeting dates, information about prevention initiatives, control programs, and scientific reports/publications.	http://anstaskforce.gov/index.htm
Earthwave Productions, Inc.	Specific to zebra mussels. Video offer. Focuses on how boaters/anglers and others can prevent spread of ANS.	www.earthwave.org/zmussel.htm
Great Lakes Fishery Commission	Biology and feeding habits of sea lamprey and techniques for control. Provides links to other ANS topics.	http://www.glfc.org/
Great Lakes Sea Grant Network	General ANS information. Many links to other sources.	http://www.seagrant.wisc.edu/greatlakes/GLnetwork
Great Lakes Sport Fishing Council	How anglers can prevent spreading ANS. List of resources for more information about ANS.	http://www.great-lakes.org/
National Biological Control Institute	Secondary information regarding biological control and ANS. Updated schedule of relevant conferences, meetings, and events	http://www.aphis.usda.gov/nbci/nbci.html
NOAA, Great Lakes Environmental Research Laboratory (GLERL)	GLERL's exotic species research program. Emphasis on zebra mussels. Includes links to numerous other government sites.	http://www.glerl.noaa.gov
University of Minnesota Sea Grant Program	Information on zebra mussels, round goby, Eurasian ruffe and other ANS affecting the Lake Superior/Great Lakes region.	http://www.seagrant.umn.edu
University of Minnesota Eurasian Watermilfoil Biocontrol Web Site	Biological control of Eurasian Watermilfoil. Numerous research references, providing links to complete bibliographies.	http://www.fw.umn.edu/research/milfoil/milfoilbc.html
University of Minnesota Ruffe Home Page	Directory to web-based information regarding the Eurasian ruffe. Many good links. Last updated in 1998.	http://www.fw.umn.edu/individuals/fgh/ruffe/
University of Florida, Center for Aquatic and Invasive Plants	Information, services, and products for educators and researchers about invasive aquatic plant species of the Southeastern U.S.	http://aquat1.ifas.ufl.edu/
University of Michigan Sea Grant Program	Zebra mussels, round goby, Eurasian ruffe, purple loosestrife and other ANS affecting the Great Lakes region.	http://www.msue.msu.edu/seagrant/sgezmans.html
National Invasive Species Council	Gateway to federal efforts concerning invasive species	http://www.invasivespecies.gov

OTHER PROMINENT WEBSITES:		WEBSITE ADDRESS:
Ohio Sea Grant Program	Research information dealing with numerous ANS of the Great Lakes region.	http://www.sg.ohio-state.edu
University of Wisconsin Sea Grant Program	Information about a variety of ANS affecting the Great Lakes Region.	http://www.seagrant.wisc.edu/
Center For Great Lakes Environmental Education	Resources, materials, and information regarding the environmental issues affecting the Great Lakes and St. Lawrence Seaway.	http://www.greatlakesed.org/
Weeds Gone Wild	Numerous links to reliable websites dealing with exotic plants.	http://www.nps.gov/plants/alien/moreinfo.htm
Round Goby Research Page	Identification and biology of round goby. Web links for more information about the goby and other ANS.	http://webnotes1.uwindsor.ca:8888/users/corkum/Goby.nsf/Study_Description?OpenForm
Aquatics Exotics News	ANS updates and informative/educational articles as they pertain to the Northeastern U.S..	http://www.ucc.uconn.edu/~wwwsgo/aen.html
Group on Aquatic Alien Species (GAAS)	Publications, references, and information on projects regarding Russia's ANS. International networking efforts to stop spread of ANS.	http://www.zin.ru/projects/invasions/
U.S. Fish and Wildlife Service Web Site	National efforts to stop the spread of ANS. Provides reliable links and contact information.	http://invasives.fws.gov
Wayne State University	Zebra mussel research at Wayne State University. Research summaries, publications, glossary, links to related sites, and slide show.	www.science.wayne.edu/%7Ejram/zmussel.htm
Western Zebra Mussel Task Force (WZMTF)	Overview of zebra mussels. Provides links to other ANS sites.	http://www.usbr.gov/zebra/wzmtf.html
Zebra Mussels and Water Pollution	Teacher-written lesson plan for an activity about zebra mussels.	http://www.iit.edu/~smile/bi9410.html
USGS Nonindigenous Aquatic Species	Research information about non-indigenous species. Includes extensive database.	http://www.fcsc.usgs.gov
The Nature Conservancy Wild Land Invasive Species Program	Controlling the spread of invasive weeds. Includes photographs for aid in identification.	http://tncweeds.ucdavis.edu/
Aquatic Nuisance species in Utah	ANS in Utah.	http://www.nr.state.ut.us/dwr/ans.htm
Non-indigenous species in the Gulf of Mexico Ecosystem	ANS, especially zebra mussels, specifically affecting the Gulf of Mexico.	http://www.gmpo.gov/nonindig.html
U.S. Department of Agriculture	National and individual state lists of invasive plants.	http://plants.usda.gov
Congressional Research Service	Information about the economic damage of introduced species.	http://www.cnie.org/nle/biodv-21.html
Purple Loosestrife	Purple loosestrife facts and information	http://consci.tnc.org/library/pubs/dd/loosestrife.html
Great Lakes Commission on Aquatic Nuisance Species	Information about all ANS in the Great Lakes region.	http://www.glc.org/ans/anspanel.html

OTHER PROMINENT WEBSITES:		WEBSITE ADDRESS:
Invading Species Homepage	Educational materials i.e., traveling trunk, targeting a variety of ANS.	http://www.ofah.org/invading/invading.htm
Invasive Plants of Canada Project	ANS information as it pertains to the provinces of Canada. Provides ANS fact sheet and links to relevant sites.	http://infoweb.magi.com./~ehaber/ipcan.html
Ducks Unlimited Canada Purple Loosestrife	Facts about purple loosestrife and control methods.	http://www.ducks.ca/purple
Vegetation Management Guideline Purple Loosestrife	Effective purple loosestrife control methods.	http://www.inhs.uiuc.edu/edu/VMG/ploosestrife.html
Biological Control Laboratory University of Guelph	Biological control information. Emphasis on purple loosestrife.	http://www.uoguelph.ca/~obcp/
Biological Control of Purple Loosestrife: A Guide for Rearing Leaf-Feeding Beetles	Purple loosestrife information and how to rear your own leaf-eating beetles.	http://www.extension.umn.edu/distribution/horticulture/DG7080.html
Biological Control of Non-Indigenous Plant Species (Cornell University)	Technical information about biological control of invasive species. Specific project information and resources available.	http://www.dnr.cornell.edu/bcontrol/weeds.htm
Biological Control: A Guide to Natural Enemies in North America (Cornell University)	How natural predators can be used to control invasive species	http://www.nysaes.cornell.edu/ent/biocontrol/weedfeeders/wdfdrintro.html
Cooperative Agriculture Pest Survey & NAPIS' (page on Loosestrife)	Provides purple loosestrife information through numerous links. Runs slow.	http://www.ceris.purdue.edu/napis/pests/pls/index.html
Weed Science	Directory of websites and links on weeds.	http://www.agric.wa.gov.au/progserv/plants/weeds/links.htm
American Fisheries Society Position on Introductions of Aquatic Species	Good summaries of the negative impacts introduced species have on natural environments.	http://www.afsifs.vt.edu/afspos.html
Center for Research on Introduced Marine Pests	Information on Australia's introduced marine pests.	http://www.ml.csiro.au/~spinks/CRIMP/
Non-indigenous Estuarine and Marine Organisms	Introductions of non-natives into the Baltic Sea.	http://www.ku.lt/nemo/mainnemo.htm
Hawaiian Ecosystems at Risk Project	Deals with Hawaii's problems of introduced species.	http://www.hear.org/
Aquatics Exotics News	Numerous links and up-to-date information on exotics.	http://www.ucc.uconn.edu/~wwwsgo/aen.html
COMPACT DISCS:	**CONTACT:**	
Sea Grant Non-Indigenous Species (*SGNIS*) CD	Available from the University of Minnesota Sea Grant Program, 2305 E. 5th Street, Duluth, MN, 55812-1445, or phone: 218/726-8712, http://www.d.umn.edu/seagr/	
Zebra Mussel Information System CD	Available from the U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS, 39180, phone: 601/634-2972	

Prepared by: Doug Jensen*, Exotic Species Information Center Coordinator, Steve Lovejoy and Connie Haugen, Interns
*University of Minnesota Sea Grant Program, 2305 East Fifth Street, Duluth, MN 55812-1445, (218) 726-8712 or email djensen1@d.umn.edu