Research to Support Integrated Management Systems of Aquatic and Terrestrial Invasive Species

Annual Report 2011

A collaborative effort between Mississippi State University's Geosystems Research Institute and the U.S. Geological Survey and National Biological Information Infrastructure

GRI Report #5051

Preface

The research and outreach programs described in the following report are the result of an ongoing partnership between the U.S. Geological Survey Biological Resources Discipline, the National Biological Information Infrastructure, and Mississippi State University. Funding for these programs was provided by an award from USGS BRD to MSU under cooperative agreements 08HQAG0139 and G10AC00404, a Gulf Coast Cooperative Ecosystem Studies Unit Cooperative and Joint Venture Agreement. The MSU program was managed by the Geosystems Research Institute. The USGS Invasive Species Program manager was Sharon Gross and the NBII Invasive Species Information Node manager was Annie Simpson.

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For comments or questions, contact Dr. John D. Madsen at jmadsen@gri.msstate.edu.

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Introduction

Invasive species are a widespread and increasing problem for terrestrial and aquatic ecosystems in the United States, degrading their biodiversity and the ecosystem services they provide to our society. As a result, over the past decade federal and state agencies and nongovernmental organizations have begun to work more closely together to address it.

While awareness of the problem is becoming more widespread, efforts to address the threat are often piecemeal and fragmented, and new tools to deal with the problems are needed. In particular, the states in the Mid-South Region (AL, AR, LA, MS, and TN) need assistance in developing additional capacity, expertise, and resources for addressing the invasive species problem.

This report presents the final status on a program of planned research, extension, and regional coordination implemented by the Geosystems Research Institute (GRI) of Mississippi State University (MSU) in collaboration with the U.S. Geological Survey (USGS). We pursued three areas of directed, peer-reviewed research to enhance the management of invasive species: aquatic invasive plants, developing a National Early Detection and Rapid Response webpage, and the renegade biocontrol agent, cactus moth (*Cactoblastis cactorum*). For each area, a program of extension and outreach has been developed to deliver the information from our research to those who can best make use of the results, both through traditional printed information and web-based information solutions. Our current webpage effort, the Cactus Moth Detection and Monitoring Network (www.gri.msstate.edu/cactus_moth), has been operating for seven years and garnered significant attention as the one source for pricklypear cactus and cactus moth location information nationwide. The Invasive Plant Atlas of the Mid-South (IPAMS), a national database with a regional focus, is available at www.gri.msstate.edu/ipams. While USDA CSREES (now NIFA) funded the program, we have listed USGS BRD and NBII as partners in the effort. In 2010, we have also added program elements that are more oriented to biodiversity and visualization.

John Skogerboe, US Army Engineer Research and Development Center, analyzes water sample for Rhodamine WT as part of a herbicide dissipation study on Big Detroit Lake, MN, which is one of the collaborative efforts on invasive species management in which GRI was engaged in 2011.

Ryan Wersal applying Rhodamine WT in the Ross Barnett reservoir, as part of a dissipation study for the Pearl River Valley Water Supply District. Rhodamine dye is used to examine how quickly water diffuses from a given location, which assists in selecting an herbicide, formulation, concentration, and application approach for control of invasive aquatic plants.

Specialists in USGS and other entities that are providing information, perspective, and/or oversight for the project are identified as collaborators. The research addresses invasive species issues that are often complex and require long-term cooperation.

The funding for this effort will be terminated in May 2012, with no funding added after the summer of 2010. Therefore, this is the last report of this effort. However, the web pages for cactus moth and the Invasive Plant Atlas of the MidSouth will continue, and we will continue to pursue research and outreach on invasive species issues.

John Madsen, buried in a backlog of publications and memos, contemplates the end of the USGS project.

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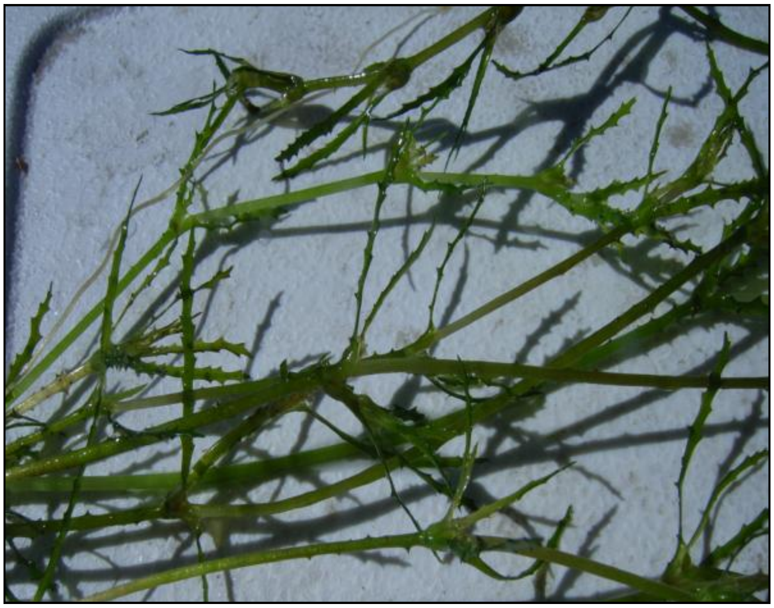
Task 1. Aquatic Plants



Spiny naiad (*Najas marina* L.) is an aquatic plant currently found in the USA. Some debate remains regarding it’s native range, but it is now largely cosmopolitan. Spiny naiad is one of several species causing nuisance problems to water pumping stations on Lake Havasu, Arizona/California.

Underwater photo of Eurasian watermilfoil (*Myriophyllum spicatum* L.) from Noxon Rapids Reservoir, Montana. GRI completed post-treatment sampling this summer for a multi-agency management program for Sander County, Montana.

Task 1.1. GIS Model of Invasive Aquatic Plant Distribution and Abundance based on Watershed Nutrient Loading Rates

PI: John Madsen
Collaborators: Louis Wasson, MSU; Randy Westbrooks, USGS

Utilizing Land Use Land Cover and Stream Gauge Data to Determine Habitat Suitability for Invasive Aquatic Plants in Mississippi

Louis Wasson, Ryan Wersal and John Madsen
Geosystems Research Institute

Land use often influences the invasibility of a given habitat by providing the necessary growth requirements for plants species thereby making the habitat more suitable. As their name in implies, aquatic plants require water for plant growth and therefore their distribution is dependent upon where water is within the landscape. What we currently lack however, is information on how present and past land use practices surrounding waterbodies is influencing invasive species habitat selection and spread. Therefore, the objectives of this study were to see if water column nutrient levels and surrounding land use can be used as a location predictor of aquatic invasive species.

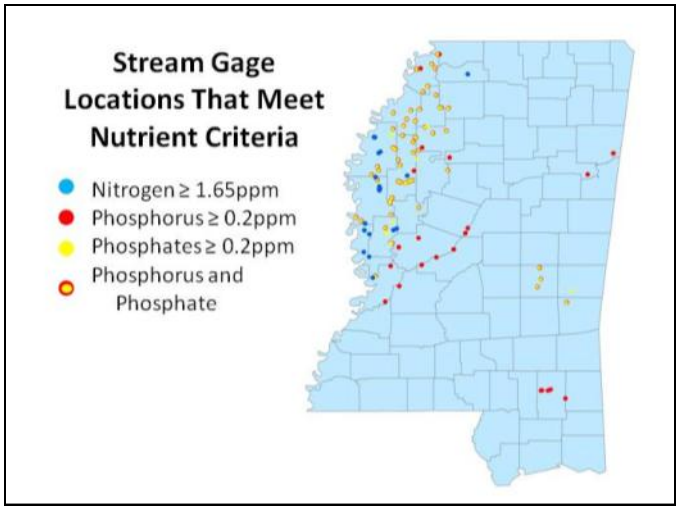


Figure 1. Locations of stream gauges in Mississippi used in modeling plant distribution.

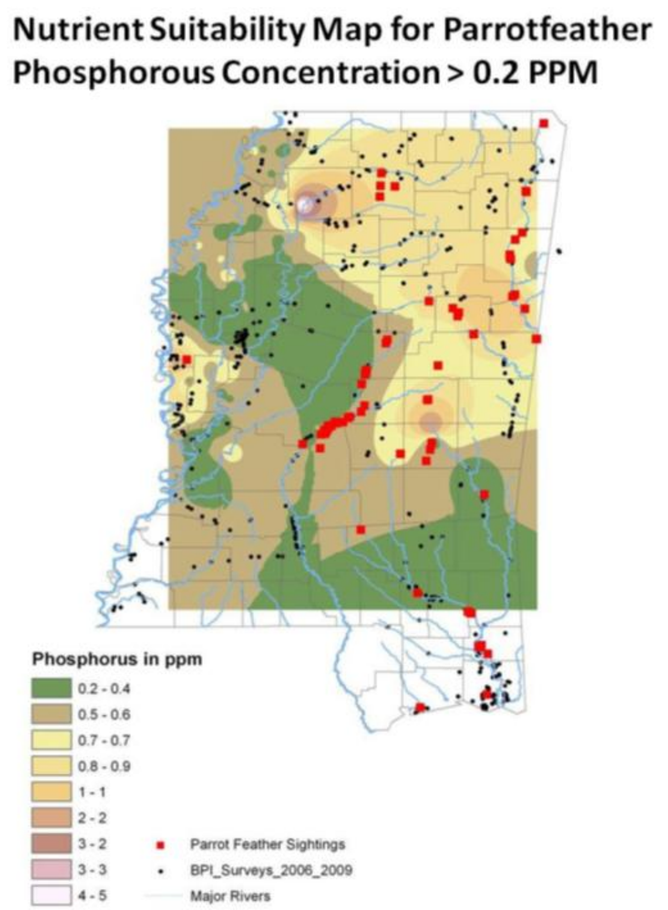


Figure 2. Water column nutrient suitability for parrotfeather in Mississippi.

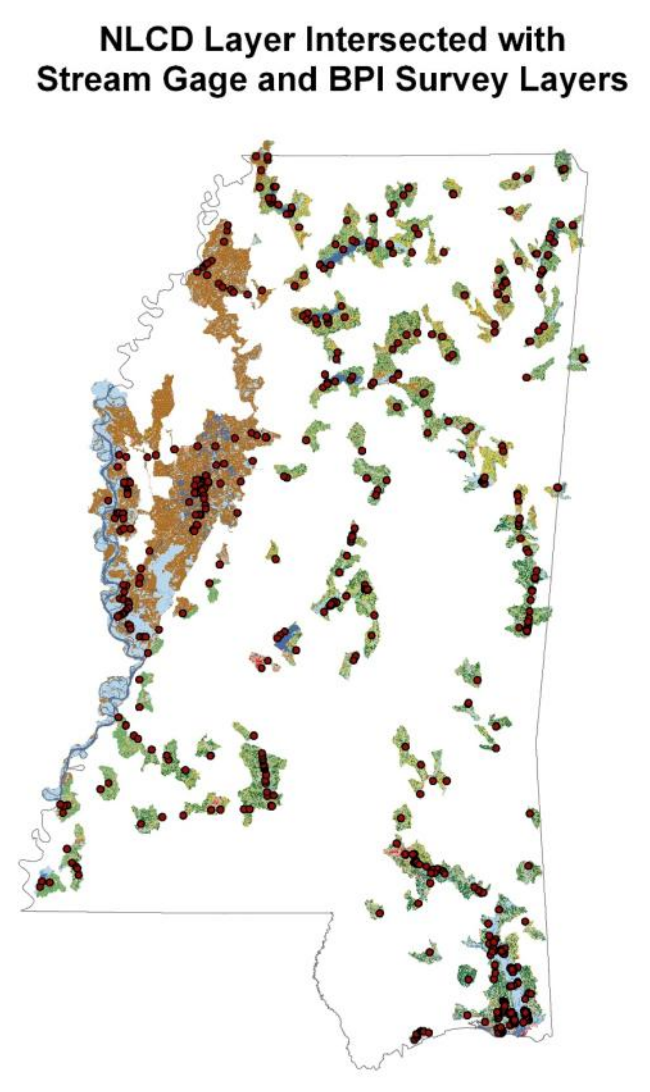


Figure 3. GIS layer map of stream gauge nutrient data combined with plant distribution data.

Task 1.1. GIS Model of Invasive Aquatic Plant Distribution and Abundance based on Watershed Nutrient Loading Rates (Cont.)

In order to address this we developed water column nutrient thresholds for aquatic plants by conducting controlled growth studies using varying rates of nitrogen and phosphorus additions to the water column.

These studies indicated that an optimum threshold for growth of invasive species was > 1.6 and > 0.2 part per million (ppm) for nitrogen and phosphorus respectively.

Utilizing these nutrient thresholds we obtained spatial stream gauge data from Mississippi using a search tool developed by the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CAUSHI). The tool allowed for rapid searching, locating and downloading of all stream gauge data throughout the state. Stream data were then imported into Hydro Desktop to extract nutrient data from the different sources and reformat to ensure data consistency. Since nutrient levels in streams, rivers, and reservoirs fluctuate temporally, a 5-year average was calculated using Hydro Desktop for each stream gauge in Mississippi that met nutrient thresholds (Figure 1).

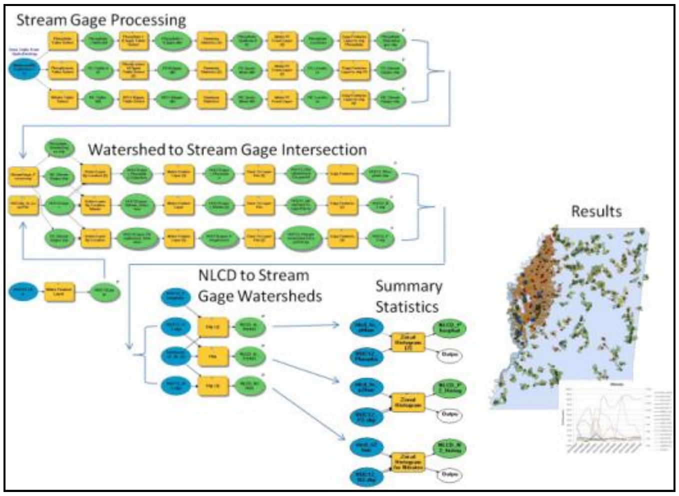


Figure 4. Graphic representation of the Arc Model Builder program.

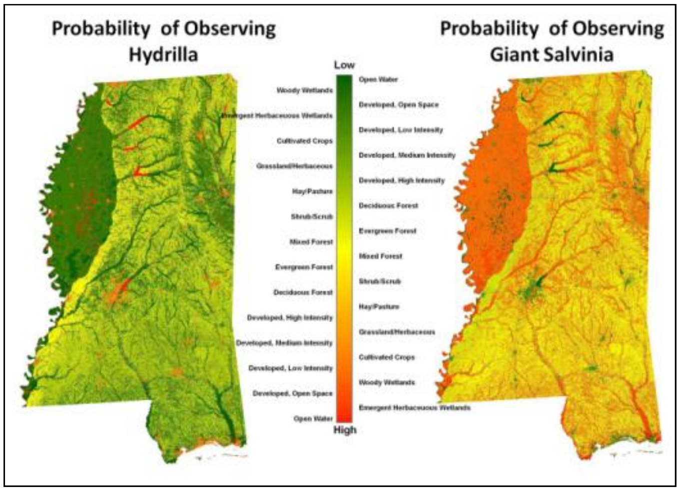


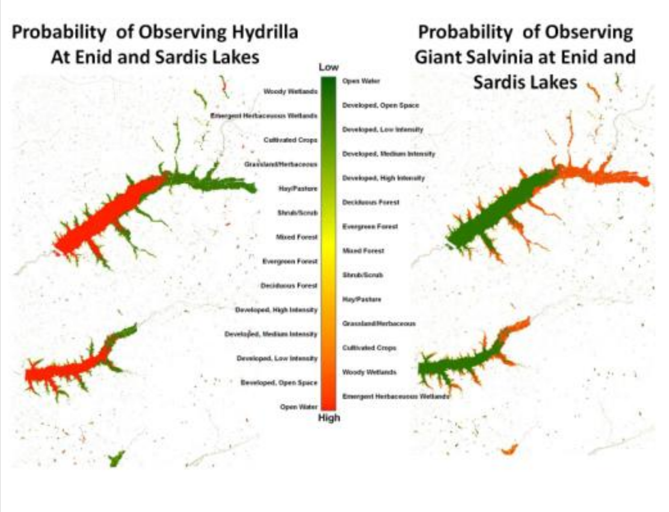
Figure 5. Probability of observing species based on land cover classes, as developed from the Model Builder program. Hydrilla (*Hydrilla verticillata* (left)) and giant salvinia (*Salvinia molesta* (right)) statewide.

An initial model was constructed using ArcGIS model builder to create an interpolated surface map that displayed predicted nutrient concentrations that would favorable to aquatic invasive species based upon nutrient thresholds (Figure 2). A visual assessment of the model was made utilizing statewide survey data from 2006-2009 (n=851 points). Survey data were overlaid onto the interpolated surface map which showed that parrotfeather (*Myriophyllum aquaticum*) was predominately observed in high nutrient areas of Mississippi (Figure 2).

However, stream gauges are not uniformly distributed across the state with gauges typically located at the exit point of an associated watershed. To gain a better understanding of water column nutrient concentrations it became necessary to try and include surrounding land use in the original model described above. Therefore, using the National Land Cover Dataset (NLCD), land use was extracted as it related to the watershed associated with a given stream gauge and survey point (Figure 3). The conceptual model of the GIS data selection process is depicted in Figure 4.

Using the GIS selection process, hydrilla (*Hydrilla verticillata*) and giant salvinia (*Salvinia molesta*) survey data were paired with its corresponding land use code and subjected to a logistic regression model to estimate the probability of observing each species within a given habitat type for Mississippi. The probabilities were then used to predict and map habitat types in Mississippi that would be most suitable for hydrilla and giant salvinia growth. Based the results of the model, the probability of observing hydrilla was greatest in open water habitats that were near development (Figure 5).

Task 1.1. GIS Model of Invasive Aquatic Plant Distribution and Abundance based on Watershed Nutrient Loading Rates (Cont.)


Probability of Observing Hydrilla At Enid and Sardis Lakes

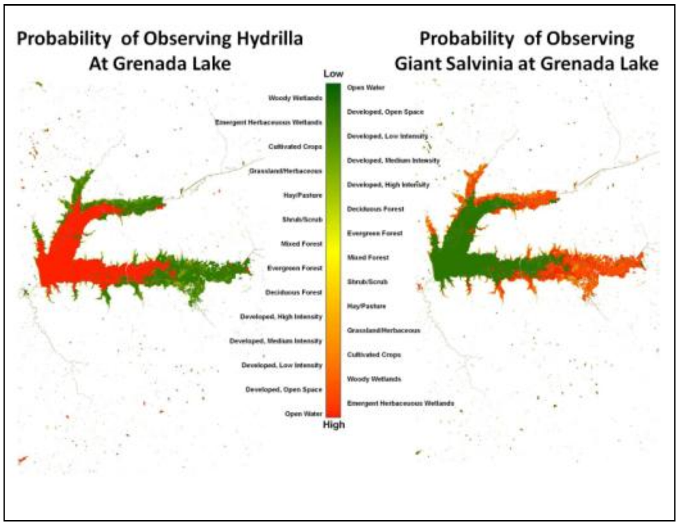
Probability of Observing Giant Salvinia at Enid and Sardis Lakes

Figure 6. Probability of observing hydrilla (left) and giant salvinia (right) in Enid and Sardis Lakes.

As a submersed species, hydrilla is often spread from lake to lake by fragments caught on watercraft, trailers, or other equipment that was used in invested waters. In contrast, giant salvinia had the greatest probability of being observed in emergent herbaceous and woody wetland habitats (Figure 5). Giant salvinia is a floating aquatic fern that requires quiescent nutrient rich water for growth. Wetland habitats often have high inputs of organic material that serve as a continual source of nutrients.

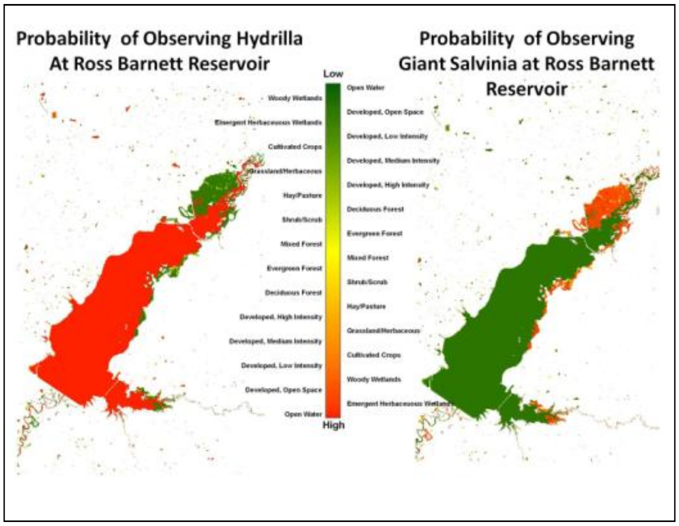
This relationship with habitat suitability, land use and nutrient availability can be seen clearly when looking at water bodies in Mississippi. Ross Barnett Reservoir, Sardis Lake, Enid Lake, and Grenada Lake are the largest freshwater impoundments in Mississippi and areas that experience high recreational traffic. Similar to the statewide suitability map, the probability of observing hydrilla in a given lake is greater in the open water areas, whereas, there is a higher probability of observing giant salvinia in more remote or protected areas of each water body (Figures 6-8).

In combining stream gauge nutrient data, associated land use, and field survey data the resulting model created a predictive tool to identify suitable habitat for invasive aquatic plants. Using Model Builder in ArcGIS allows for ease of model transfer between potential users, and ease of updating when new data become available. The model can also be tailored for individual species as species specific data become available. The model performed well across large spatial areas such as the state and lake scale, however additional methods are needed to more accurately map at finer scales. The inclusion of a buffer zone around streams and rivers would add more land cover area into the model and the resulting output could increase the predictive capability and better identify suitable habitat for a given species. Survey effort can then be matched to the invasion potential in a given area as part of an Early Detection and Rapid Response program.


Probability of Observing Hydrilla At Grenada Lake

Probability of Observing Giant Salvinia at Grenada Lake

Figure 7. Probability of observing hydrilla (left) and giant salvinia (right) in Grenada Lake.


Probability of Observing Hydrilla At Ross Barnett Reservoir

Probability of Observing Giant Salvinia at Ross Barnett Reservoir

Figure 8. Probability of observing hydrilla (left) and giant salvinia (right) in Ross Barnett Reservoir.

Task 1.2. Nonindigenous Aquatic Plant Database Plant Observation Entry

PI: John Madsen
Collaborator: Pam Fuller, USGS Caribbean Science Center

Utilizing an Online Database to Track Aquatic Invasive Plants

Ryan M. Wersal and John D. Madsen
Geosystems Research Institute

The Geosystems Research Institute (GRI), Mississippi State University has been coordinating data entry for invasive aquatic plants into the Non-indigenous Aquatic Species (NAS) database since 2010. The GRI conducted species specific location entry, updated maps, native range information, fact sheets, and managed the alert system for aquatic plants. Being a nationwide database, the NAS system contains the most recent and easily accessible data available regarding the location invasive aquatic plants.

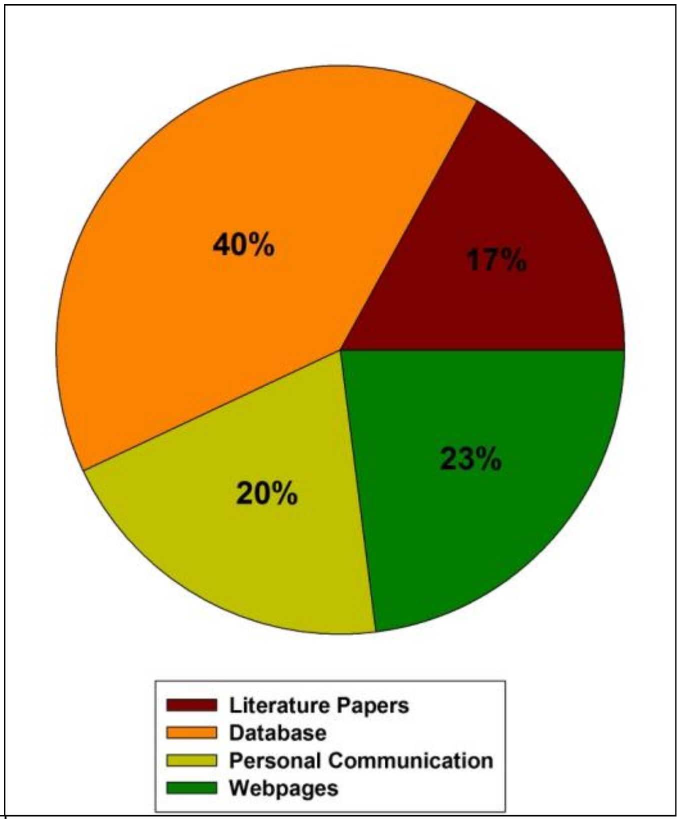


Figure 1. The proportion of species locations entered into the Non-indigenous Aquatic Species database from different sources since 2010.

The GRI entered 579 species locations from a variety of sources. A total of 98 entries were from literature sources such as journal articles or agency reports, 232 entries from plant database sources, 115 entries from personal communications such as emails, and 134 entries from internet website sources (Figure 1). The 579 species entries resulted in 23 national species alerts including Red root floater (*Phyllanthus fluitans*) a new species to the United States. An alert was generated for *Elodea canadensis* in Alaska, although a native species, elodea is becoming problematic in Alaska where it occurs. Additionally, an alert was generated for a sighting of *Egeria densa* in Mississippi. This is only the second known population of this species in Mississippi. Species alerts generated within the NAS system are emailed to over 100 individuals nationwide.

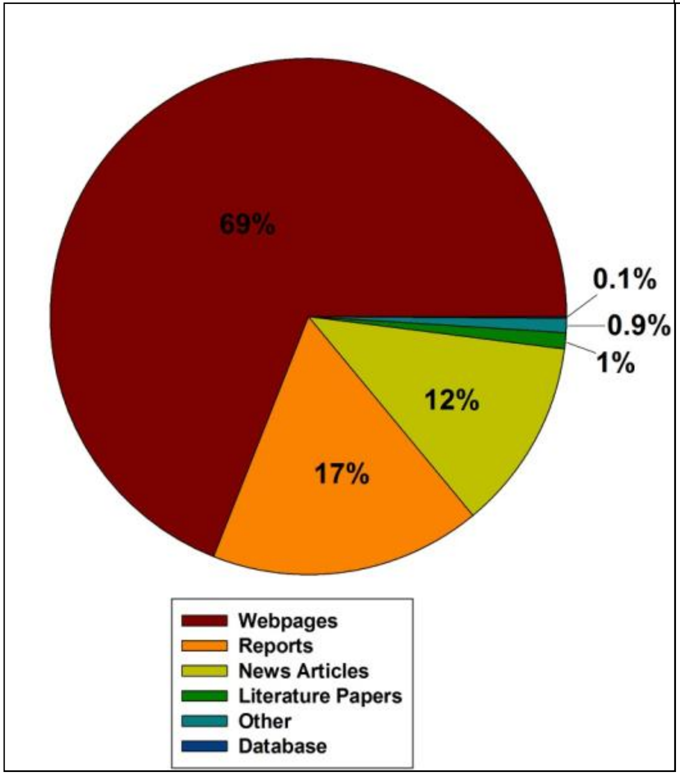


Figure 2. The proportion of reference material entered into the Non-indigenous Aquatic Species database from different sources since 2010.

In addition to entering location data and managing the alert system, GRI staff also entered 305 new references into the reference data base. Reference information included reports, webpages, news articles, journal papers, databases, and other non-categorized references. The majority of reference material was obtained from webpages followed by reports and news articles (Figure 2).

Task 1.2. Nonindigenous Aquatic Plant Database Plant Observation Entry (Cont.)

Species locations and reference material were then used to update existing factsheets in the NAS system or develop new factsheets for previously unreported invasive aquatic plant species. New factsheets were developed for parrotfeather (*Myriophyllum aquaticum*), Cuban bulrush (*Oxycaryum cubense*), and West Indian spongeplant (*Limnobium laevigatum*).

To facilitate future training of data entry into the NAS system, the GRI developed a draft training manual and provided the file to Pam Fuller (USGS) for further development.

Figure 1. Cuban bulrush growing on mats of other plants in the Ross Barnett Reservoir, MS.

Species of Concern to the Southeastern United States

Cuban bulrush. Cuban bulrush or Cuban club-rush (*Oxycaryum cubense*) is a non-native rush from the West Indies or South America, and was brought to the United States likely by migratory birds or in ship ballast. Cuban bulrush can be described as an epiphytic plant, as it requires a raft of other aquatic vegetation to attach to (Figure 1). Once Cuban bulrush gets established on other vegetation, it rapidly outgrows and eventually kills the other plants creating a monotypic self sustaining population of Cuban bulrush. Cuban bulrush reproduces sexually through the production of achenes, or more commonly via vegetative means. It was previously described to be a vigorous invasive plant with growth rates similar to giant salvinia and water lettuce.

Cuban bulrush has been present in the Southeastern United States for almost 100 years, though until recently, little attention has been given to this species. There are currently five specimen records in the database from Mississippi, Alabama, and Louisiana, though a new population was recently observed in the Ross Barnett Reservoir, MS. Cuban bulrush has begun to displace other non-native aquatic plants, most notably waterhyacinth, in the Tennessee Tombigbee Waterway in Mississippi and Alabama. In 2009, it was reported for the first time in the Ross Barnett Reservoir near Jackson Mississippi. It is unclear how Cuban bulrush was introduced into the Ross Barnett since the reservoir is not connected to the Tennessee Tombigbee Waterway (the closest infestation).

Figure 2. A mature South American spongeplant from California.

Given its rapid growth rate, ability to out compete species such as waterhyacinth, and potential means of long distance dispersal; Cuban bulrush will be a species to closely monitor in the future.

South American spongeplant. South American sponge plant (*Limnobium laevigatum*) is currently only located in the San Joaquin River, CA and was first identified in 2007 by the California Department of Food and Agriculture, and the United States Department of Agriculture (Figure 2). The plant has since spread downstream into the San Joaquin Delta and established several infestations within the river and delta area. The plant is a popular component in water gardens and the aquarium industry, thus it is widely available and easily transported. Seedlings float, are very small, and can be confused with duckweed species.

Task 1.2. Nonindigenous Aquatic Plant Database Plant Observation Entry (Cont.)

Although South American spongeplant is not in the southeastern United States, its close relative frogsbit (*Limnobium spongia*) is wide spread in this region and inhabits areas that would be suitable for South American spongeplant invasions. Currently, there are very little data regarding this species basic biology and ecology, and no data regarding management.

Figure 3. Red root floater growing with duckweed (*Lemna minor*), giant duckweed (*Spirodela polyrhiza*), *Salvinia* sp., and water lettuce (*Pistia stratiodes*). Photo by Michael Sowinski, Florida Fish and Wildlife Conservation Commission.

Red root floater. In April 2011, red root floater (*Phyllanthus fluitans*) was added as a new species to the NAS system. Red root floater was first observed in 2010 in several areas within and around the Peace River in Desoto County, Florida and represent the first natural populations in North America for this plant species. Red root floater is a free floating aquatic plant from South America, and like South American spongeplant, is often used in water gardening and the aquarium industry, which are likely the pathways for its introduction into Florida (Figure 3).

Little information exists regarding the ecology and management of this species. As a free floating aquatic plant, it has the potential to overtake large expanses of water similar to giant salvinia, water lettuce, and waterhyacinth. Slow moving freshwater areas along the Gulf Mexico, including habitats in Alabama, Mississippi, and Texas could be at risk from this species; though the temperature limits of this species have yet to be determined and therefore spread could be farther north than anticipated. Other invasive aquatic plants from South America, such as parrotfeather (*Myriophyllum aquaticum*), have established populations as far north as New York on the east coast and the state of Washington on the west coast.

Figure 4. Typical hydrilla growth in lakes.

Hydrilla. In August 2011, hydrilla (*Hydrilla verticillata*) was found growing in Lake Cayuga, NY. The first report of hydrilla was in the southern end of the lake, but as of September 2011, the plant has spread to the popular boating area called Cayuga Inlet. There are only three other locations of hydrilla in the state of New York with the first specimens recorded in 2008 from San Souci Lake, Lotus Lake, and Creamery Pond.

Hydrilla (Figure 4) can be spread by stem fragments, tubers, and turions. Additionally, there are two biotypes of hydrilla, moneceous hydrilla (primarily in the northern portion of the United States) and dioecious hydrilla (primarily in the southeastern United States). Outside of Florida, dioecious hydrilla has been confined to larger reservoirs in Georgia, Alabama, and Mississippi that are popular fishing locations, or waterways that are used for commercial shipping. However, the rapid growth of hydrilla (both monecious and dioecious) and its many mechanisms of dispersal will allow it to spread to new areas of the United States in a short amount of time if control measures are not implemented to manage new insipient populations such as Lake Cayuga.

Task 2. National Early Detection and Rapid Response Toolbox Development

Densely-packed rosettes of waterlettuce (*Pistia stratiotes*) cover the surface of a pond on the campus of Mississippi State University. While prized as a water garden plant, this nonnative is also invasive. Photo by Debbie McBride, Mississippi State University

Michael Cox (left), Ryan Wersal (front) and Wilfredo Robles (right, standing) during training on plant monitoring methods at the R. R. Foil Plant Science Center (e.g., North Farm), Mississippi State University. Photo by John Madsen.

Task 2.1. GRI Invasive Species Program and EDRR Toolbox Webpage

PI: John Madsen
Co-PI: Clifton Abbott

GRI Invasive Species Program and EDRR Toolbox Webpage

John D. Madsen and Clifton Abbott, Geosystems Research Institute

A new webpage on the Geosystems Research Institute site has been launched that collects all the resources of the invasive species program into one location. The Invasive Species Program page, available at http://www.gri.msstate.edu/research/invspec/, has direct access to items of interest on invasive species. Tabs include areas for fact sheets, databases, case studies, habitat modeling, newsletters, publications, outreach, and other links.

Invasive Species Program

MISSISSIPPI STATE UNIVERSITY

Provided below are useful resources developed by the Invasive Species Program at Mississippi State University's Geosystems Research Institute. GRI researchers actively study invasive plants that take over agricultural and natural areas, with expertise for studies ranging from regional impacts through use of remote sensing and GIS, to cellular and molecular studies of plant uptake, and genetic composition. GRI brings together multidisciplinary research teams comprised of university and government researchers to address diverse questions on the management of invasive species.

These resources were made possible by funding through a grant from the United States Geological Survey and the National Biological Information Infrastructure.

Contact PI: John D. Madsen, PhD
Geosystems Research Institute, Mississippi State University

The Invasive Species Program webpage, at http://www.gri.msstate.edu/research/invspec/, will ease the locating of information that is the result of GRI activity on invasive species.

The Fact Sheets section includes 54 fact sheets on invasive species developed by GRI. Databases include links and descriptions for the two GRI databases (IPAMS and CMDMN), as well as our partner IPANE and the USGS Nonindigenous Aquatic Species program page, for which we have been providing aquatic plant content. The Case Studies tab is currently under development, but will have pages for specific species or geographic locations on which GRI has worked. Habitat Modeling will have data and models related to niche modeling efforts. The Newsletters tab has all of our Cactus Moth Update and Invasive Species Update newsletters. The Publication Database brings the viewer to the GRI publication database. Searches can be made for specific species, topics, authors, or "invasive species" in general. The database includes peer-reviewed journal articles, reports, and presentation abstracts. Most of the reports and journal articles are available for download from this site. The Outreach tab details training workshops for the Invasive Plant Atlas of the MidSouth, and in the future will include other outreach efforts.

We will continue maintaining and improving this webpage to serve as a single site for current information on invasive species research at Geosystems Research Institute.

Task 3. Invasive Insects: Cactus Moth *(Cactoblastis cactorum)*

Joe Bravata of USDA APHIS searches for cactus moth in Louisiana. Photo by Victor Maddox.

Mapping and data collection was conducted in the Sonoran Desert in Southern Arizona by Victor Maddox (pictured with *Opuntia engelmannii* Salm-Dyck ex Engelm. on right and *Cylindropuntia* spp.)

Task 3.1. Early Detection and Reporting of Cactus Moth

PI: Richard L. Brown
Co-PI: John Madsen, Victor Maddox
Collaborators: Randy Westbrooks, USGS NWRC; Joel Floyd, USDA APHIS PPQ; John C. Stewart, USDA APHIS PPQ, Thomas Simonsen, Natural History Museum, London; Sangmi Lee, MSU

Identification of the Cactus Moth Pupa and Differentiation of the Male and Female Sexes

Richard L. Brown and Sangmi Lee
Department of Entomology

Surveys for cactus moths have concentrated on detection of egg sticks or presence of caterpillars associated with *Opuntia* cactus and the use of pheromone traps for detection of adult moths. However, surveys for detecting cactus moth pupae have not been as employed. This may be due to the lack of information on characters of the cactus moth pupa that can be used to differentiate it from the pupa of native *Melitara* species and other Lepidoptera.

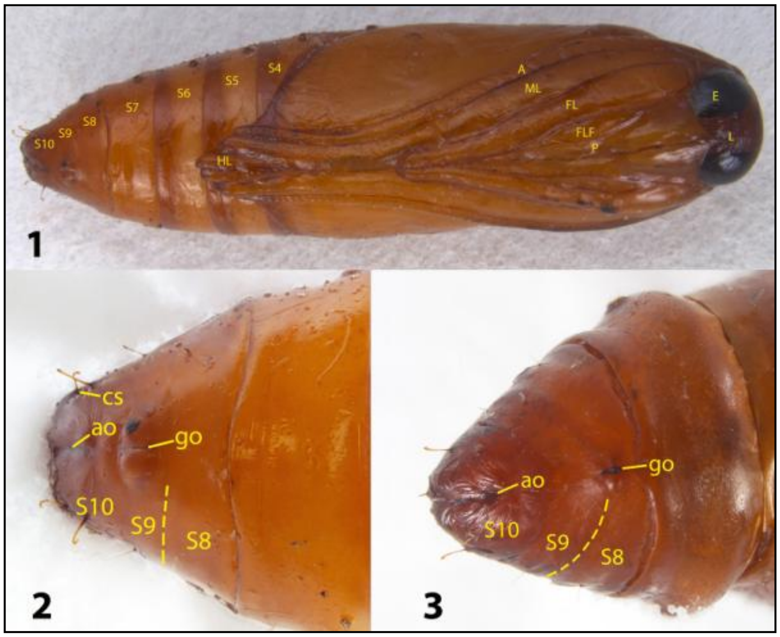
Upon completion of the larval phase, the cactus moth typically pupates at the base of the plant in the leaf litter, beneath dead cladodes or rocks, or in the soil. The pupa is enclosed in a cocoon that has loose silk on the outside and more compacted silk on the inside. In southeastern U.S., the cactus moth may be present as a pupa for 3-4 months at a given site during the three generations that are present during a year.

Descriptions of pupae of most Lepidoptera in North America are lacking. The pupa of the cactus moth has never been described. Differentiation of the pupa of the cactus moth from other cactus feeders and other Lepidoptera has been constrained from lack of information.

Current research on Cactus moths and native *Melitara* has required the differentiation of sexes of the pupae in order to compare pupal weights and to segregate the sexes for mass rearing to conduct other experiments. The differences in sexes of pupae of many Lepidoptera have been documented, but these differences have not been previously illustrated for the cactus moth.

Thirty three pupae of the cactus moth and three pupae of the native *Melitara prodenialis* were examined to document differences between the male and female sexes and between the two species. Pupae were photographed with a Leica auto-formatting system.

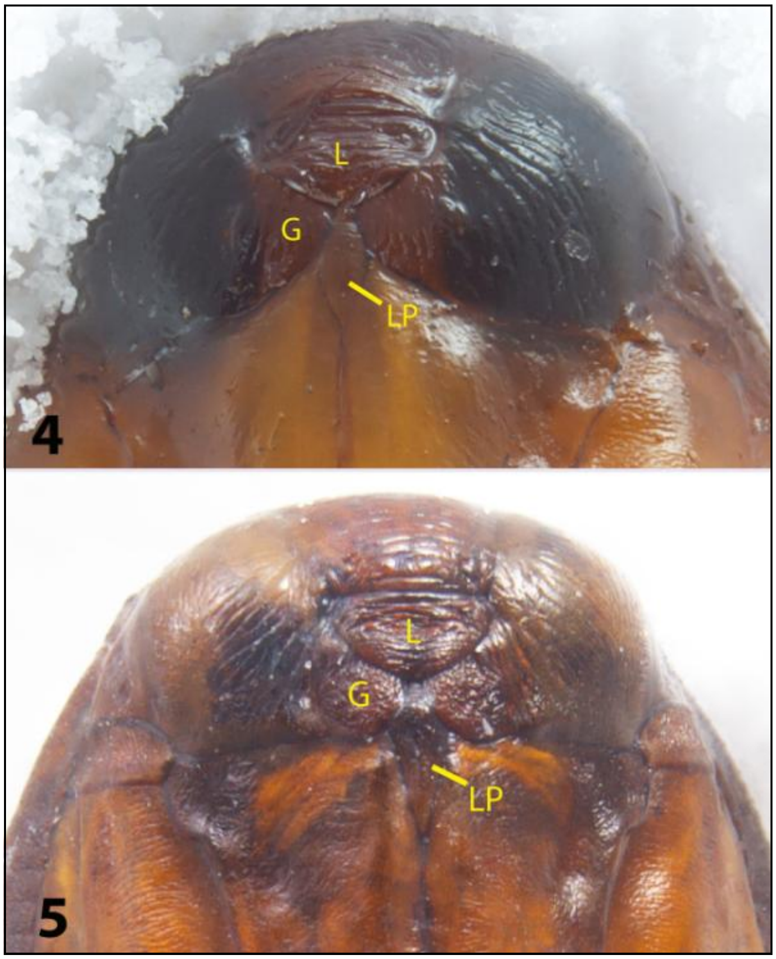
A ventral view of the pupa (Fig. 1) shows that the apices of the hind legs (HL) extend beyond the apices of the antennae (A) and middle legs (ML). The length of the antenna (A) relative to the middle leg varies from being nearly subequal to being much shorter. The fore leg (FL) is about 2/3 the length of the middle leg, and the fore leg femora (FLF) is distinct as a separate segment. The proboscis (P) of the maxilla does not extend beyond the apices of the foreleg. The compound eye (E) and labrum (L) are distinct. Abdominal segments S4−S10 are visible in the ventral view.



Figures 1-3. The ventral view of the pupa shows the immature parts of cactus moths.

Sexual differences. The male and female sexes of pupae can be differentiated by the position of the genital orifice (go) on the ventral side. The male pupa has the genital orifice at the middle of segment 9 (Fig. 2), whereas the female has the genital orifice at the caudal end of segment 8 (Fig. 3). Both sexes have the anal orifice (ao) on segment 10. The caudal region bears 8-10 hooked cremastral setae (cs) in both sexes. These hooked setae attach to the silk cocoon and hold the pupal exuvia to allow emergence of the adult. Removal of pupae from cocoons for rearing may result in adults being unable to shed the pupal exuvia.

Species differences. The pupa of the cactus moth differs from that of *M. prodenialis* by having the gena (G) on the ventral side triangular and the labial palpus (LP) curved laterally, whereas the gena is rounded and the labial palpus is angled laterally in the native species (Figs. 4−5). The most distinctive difference between the pupae of the two species is the punctate tergites of the abdomen in the dorsal view (Fig. 6) in the cactus moth, whereas these tergites are striate in the native species (Fig. 7).



Figures 4-5. The pupa of the invasive cactus moth has several differences from its closest native species.

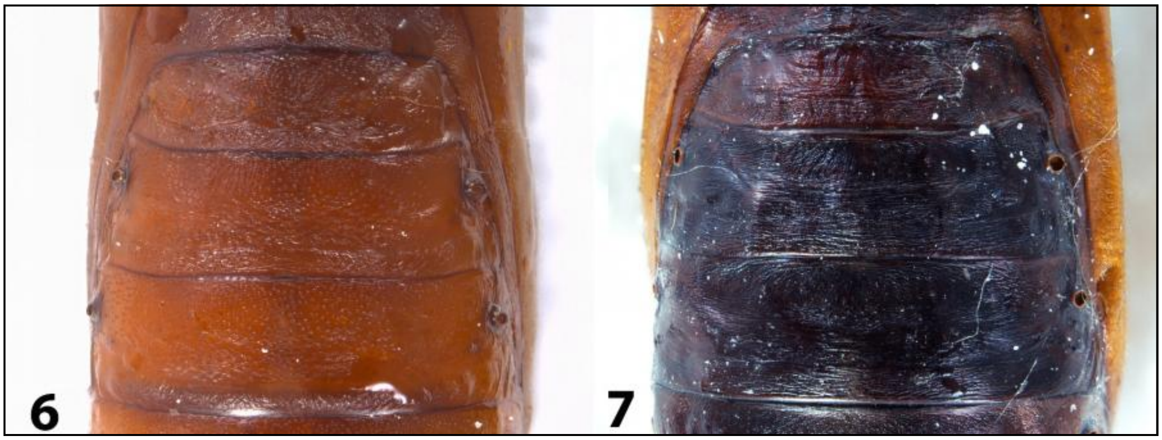


Figure 6-7. The invasive cactus species, left, and the native species, right.

Task 3.1. Early Detection and Reporting of Cactus Moth (Cont.)

PI: Richard L. Brown
Co-PI: John Madsen, Victor Maddox

Collaborators: Randy Westbrooks, USGS NWRC; Joel Floyd, USDA APHIS PPQ; John C. Stewart, USDA APHIS PPQ, Thomas Simonsen, Natural History Museum, London; Sangmi Lee, MSU

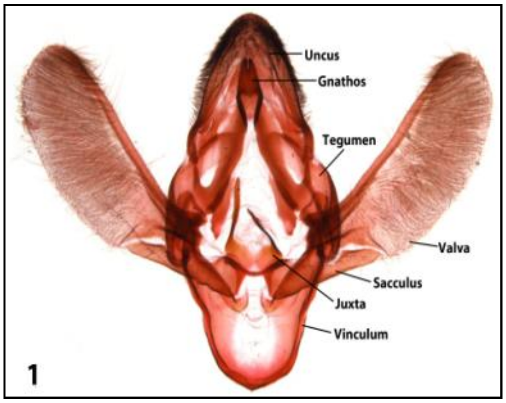


Figure 1. Male genitalia of *Cactoblastis cactorum*.

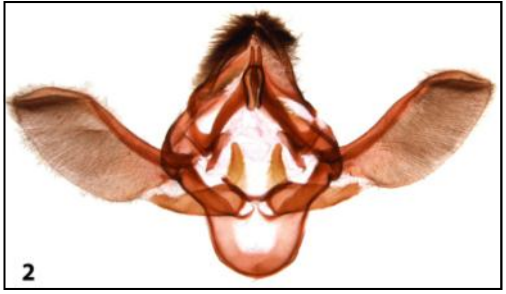


Figure 2. Male genitalia of *Melitara prodenialis*.

The Use of Genitalic Characteristics for Identification of the Cactus Moth

Identifications of the adults of the Cactus Moth, *Cactoblastis cactorum*, can be problematic because the color and pattern of the forewing are similar to those of native species of *Melitara* and *Alberada*. The genus *Melitara* includes one species in eastern U.S. and six species in western U.S., and these feed on various species of prickly pear cacti. *Alberada* includes five species in western U.S., and so far as known, feed only on cholla cacti. Pheromone traps used in surveys for the cactus moth are not specific for *Cactoblastis*, and native species of cactus feeders have also been captured. A principal character for differentiating the cactus moth from superficially similar native species has been the male antenna, which is simple in *Cactoblastis* and bipectinate (with short projections) in both *Melitara* and *Alberada*. However, the head or antennae may be separated from the body in traps where the sticky surfaces contact each other, and genitalic characters are required for making a positive identification. Females of *Cactoblastis* and *Alberada* are similar in having a simple antenna, and females of *Melitara* only slightly differ in having very short projections. Identification of females reared from pupae collected in the field requires examination of genitalia. Instructional videos for making dissections and slide mounts of male and female genitalia are available on YouTube (with a search for cactus moth) and at the following URL: http://mississippientomologicalmuseum.org.msstate.edu//Researchtaxapages/CactusMoths/Videos_CactusMoths.html.

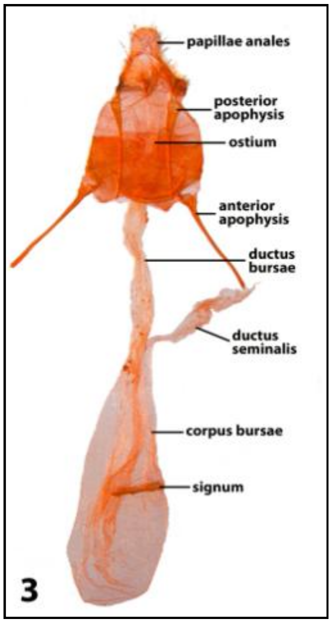


Figure 3. Female genitalia of *Cactoblastis cactorum.*

The male genitalia of *Cactoblastis* (Fig. 1), *Melitara* (Fig. 2) and *Alberada* share a similar uncus that is hooded and densely setose, a broad tegumen, and a vinculum with a lightly sclerotized medial area. The phallus (not shown) is similar among the three genera. The valvae, used for holding the female during mating, are similar in shape (the apical fold in Fig. 2 is an artifact of slide mounting), although the shape varies among the constituent species. The heavily sclerotized dorsal margin of the valva is relatively narrower, compared to its length, in *Cactoblastis* and *Alberada* than in *Melitara*. The sacculus is separated from the remainder of the valva by a narrow membranous band in *Cactoblastis*, whereas this membranous band is broad in *Melitara* and *Alberada*. The dorsal processes of the juxta are narrow in *Cactoblastis*, but are broad in *Melitara* and *Alberada*. The most distinctive difference between these genera is the form of the gnathos, whose apex is divided into two lobes in *Melitara* and *Alberada*, but these lobes are fused in *Cactoblastis*, ventrally rounded, and only bifid dorsally.

The female genitalia of *Cactoblastis* (Fig. 3), *Melitara*, and *Alberada* have similar papillae anales for oviposition of the egg stick and apophyses for muscle attachment. *Cactoblastis* is unique in having a ductus seminalis arising at the inception of the ductus bursae and the corpus bursae combined with the presence of a long, band-like, sclerotized signum in the corpus bursae, where the spermatophore is stored after mating. Females of *Alberada* have a ductus seminalis that arises anteriorly on the corpus bursae just posterior to a small rounded signum. Females of *Melitara* have a small rounded signum in only two species, and in these two species, the ductus seminalis arises from the corpus bursae posterior to the signum.

Task 3.2. Distribution of *Opuntia* in the Region

PI: Victor Maddox
Co-PI: John Madsen, Richard Brown
Collaborators: Randy Westbrooks, USGS NWRC; Joel Floyd, USDA APHIS PPQ; Ron Weeks, USDA APHIS PPQ

The Cactus Moth Detection and Monitoring Network: Progress Made and Work Left Undone

Victor Maddox and John Madsen

The road ahead in the battle to prevent cactus moth from moving into Texas may be difficult (Figure 1). As federal cuts continue, so does the threat of the cactus moth. In difficult economic times, even more emphasis is focused on non-government resources to combat invasive species like cactus moth. The need still exists, while personnel and funds are diminished. It is during these times that strong volunteer and partnership networks may be most critical.


Figure 1. Pricklypear (*Opuntia sp.*) near Devils River on land managed by The Nature Conservancy where Corbin Neill monitors pricklypear for cactus moth as part of the CMDMN. Photo by Corbin Neill,TNC.


Figure 2. Pricklypear cactus (*Opuntia* spp.) species presence (blue) and absence (red) locations in the United States.

The establishment of the Cactus Moth Detection and Monitoring Network (CMDMN) (www.gri.msstate.edu/cactus_moth) was initiated just a few years ago with a multi-faceted goal that included a network of collaborators to assist in a common goal of combating the cactus moth. With the system established and functional, the greatest test may lie ahead in the face of difficult economic times. With budget cuts at the federal level, many agencies are looking for ways to reduce personnel and programs and cactus moth programs are no exception.

Since we initiated work in 2005, we have collected 12,428 data points of the presence or absence of pricklypear cactus species (*Opuntia* spp.) and cactus moth (*Cactoblastis cactorum*); all of which are in an accessible database at http://www.gri.msstate.edu/cactus_moth. These data include 3,856 locations with pricklypear cactus and 8,572 locations without pricklypear cactus (Figure 2). We have also logged 130 locations with cactus moth (*Cactoblastis cactorum*), extending mostly along the coast or peninsular Florida, from South Carolina to Louisiana (Figure 3). We have also established a network of 74 sentinel sites, using volunteers to monitor for the arrival of cactus moth (Figure 4). Throughout this time, we have worked closely with state, regional, and national staff of USDA APHIS and USDA ARS to monitor, assess, and survey for new populations.


Figure 3. Locations at which cactus moth (*Cactoblastis cactorum*) was found in the United States.

The road ahead may be the most challenging for the CMDMN since its inception only a short while ago. With an initial investment in training volunteers strategically across the southern U.S., the real test lies ahead in maintaining volunteer connectivity, maintenance, and a response team with little or no funding. These may be trying times for networks of this type, but time will tell if they can fill in the voids left by federal cuts in personnel and programs. This is a time to look within ourselves and ask what we can do for our country. Volunteer networks can empower us to do more than we could do alone by allowing us to be part of a larger effort. Now is the most critical time to volunteer, because government cannot do it alone.


Figure 4. Locations of sentinel sites in the United States, at which volunteers monitor for the arrival of cactus moth.

Task 3.3. Environmental-based Habitat Models for Invasive Species

PI: Gary N. Ervin
Co-PI: John Madsen
Collaborators: Christopher Brooks, MSU Biological Sciences

Biology Graduate Student Examining Dietary Influences of North America *Opuntia* on Native and Invasive Cactus Moth Fitness

Tyler Schartel, Christopher Brooks and Gary N. Ervin

In order to better understand how host plants influence the spread of cactus moths, we are planning to conduct experiments to evaluate the demographic responses of cactus moths to various aspects of host quality. These experiments will focus on the influence of macronutrients (proteins, lipids and carbohydrates) on moth survivorship and reproduction. Our goal is to develop the experimental approach using a native cactus moth before we implement our approach with *Cactoblastis cactorum*.

Figure 1. Laboratory-reared adult *Melitara prodenialis* mating inside a mesh butterfly enclosure kept in the Brooks/Ervin lab.

We have begun to rear the native eastern cactus borer (*Melitara prodenialis*) in our laboratory space in order to obtain the eggs necessary for our experimental design (Fig. 1). Rearing is occurring in our laboratory space in Harned Hall, and we have already collected our first group of egg sticks. Moths have been reared on *Opuntia pusilla* which was collected in July and August 2011 at Town Creek Campground, West Point, Mississippi (33.60667°N, 88.49195°W). Plants were dissected and a total of 91 *M. prodenialis* larvae were collected, with up to 9 individuals observed within one cladode (cactus stem segment). These larvae then were placed in a growth chamber to continue development. A total of 24 larvae died prior to pupation. Of the surviving individuals, 5 larvae are preparing to overwinter within their respective cladodes. The remaining 62 live individuals began to pupate, were removed from the growth chamber, and were placed in a mesh butterfly enclosure inside the laboratory. To date, a total of 16 adult moths have eclosed and they have produced 10 eggsticks, totaling 213 eggs.

Figure 2. Male parasitoid wasp (*Temelucha sinuata*) that emerged from a field-collected parasitized *M. prodenialis*. These parasitoids emerged in approximately equal numbers as adult *M. prodenialis* moths.

In addition to these adult moths, a total of 19 parasitoid wasps (*Temelucha sinuata*) have also been collected from within the enclosure (Fig. 2). The collection of these parasitoids represents the first record of *T. sinuata* occurring in Mississippi, and one of two collections east of the Mississippi River (the other having been collected by Travis Marsico as a part of this project in 2009). We currently are working on a manuscript with Dr. Marsico to report these new parasitoid records and the observed levels of parasitism in the field.

Task 3.4. Habitat modeling of and susceptibility to *C. cactorum* among west Gulf Coast *Opuntia* species

PI: Gary Ervin
Co-PI: John Madsen
Collaborators: Christopher Brooks, MSU Biological Sciences

Habitat Modeling of and Susceptibility to *Cactoblastis cactorum* among west Gulf Coast *Opuntia* Species

Gary Ervin and Chris Brooks

In order to determine the potential risk of spread for *Cactoblastis cactorum* it is necessary to determine the potential for cactus communities along the western edge of the invasion front to support populations of the moth. In order to evaluate future risk of spread we would ideally assemble different species of *Opuntia* and conduct replicated rearing experiments on each. However, the taxonomy of the *Opuntia* is not well resolved, making the identification of hosts to species difficult, and we know little about how variation in environmental conditions across locations might alter host suitability.


Figure 1. Brice Lambert (undergraduate student) works with Gary Ervin to assemble mesh cages prepare the quarantined rearing room for our experiment.

Our approach to overcoming these impediments was to focus on locations along the Gulf coast instead of species. Using records for the locations of different *Opuntia* stands from the Cactus Moth Detection & Monitoring Network database. We collected cactus pads at 21 sites from St. Mary Parish, LA to Corpus Christi, TX during June and July 2010. Photos were taken of each plant for potential identification in the future. A minimum of three (3) cladodes were taken from each presumed species at each site and transported back to Starkville, MS for planting.

Previous experience has shown that un-rooted cladodes respond differently than rooted plants to herbivory by *C. cactorum*. To minimize such effects, we placed all collected cladodes into sand-filled pots and allowed them to grow for approximately nine (9) months (July 2010 – April 2011) in a greenhouse on the MSU R. R. Foil Plant Science Research Center. At the beginning of our experiment we assembled a series of mesh-covered PVC cages in one of the climate-controlled, USDA-APHIS quarantine-approved, Insect Rearing Facility rooms in the Clay Lyle Entomology Building (Figure 1). In late April 2011, we moved experimental plants from the greenhouse to the Clay Lyle rearing room to provide a brief acclimation period prior to adding *C. cactorum* caterpillars. Due to losses that occurred during growth in the greenhouse, only nine of the original 21 sites were represented by a minimum of three individual rooted host plants. We knew from previous experience that at least three plants could be consumed by a set of 20-30 *C. cactorum* larvae; thus, we set up the experiment to use only these nine host plant collections.

Eggs were collected from Mexico Beach, a public beach near Panama City, Florida, and provided by Anastasia Woodard (Arkansas State University Ph.D. student). All eggsticks used in the experiment were collected from a single *Opuntia stricta* plant, and eggsticks were broken into multiple pieces such that each one contained approximately 30 larvae. The eggs then were randomly assigned to cages and glued onto the surface of one of the cladodes so that larvae would have access to the host plant immediately upon hatching. Undergraduate student Brice Lambert managed the experiment, checking plants and insects regularly between May 2011 and September 2011. When caterpillars were about to deplete one plant, a second potted plant (from the same original parent plant) was added to the cage so that there was always a supply of food available.

Task 3.4. Habitat Modeling of and Susceptibility to *C. cactorum* among West Gulf Coast *Opuntia* species (Cont.)

Data are still being compiled, but we have some preliminary results that indicate a high variability in larval developmental period when grown in plants from across the Gulf Coast (Figures 2, 3). Hatched larvae failed to enter the cladodes of three plants, but once they entered the survival was similar across plants. Unfortunately, none of the variation appears to relate to geographic position along the Gulf Coast. We will continue analyzing these data and plan to begin to construct a short manuscript in the coming months.

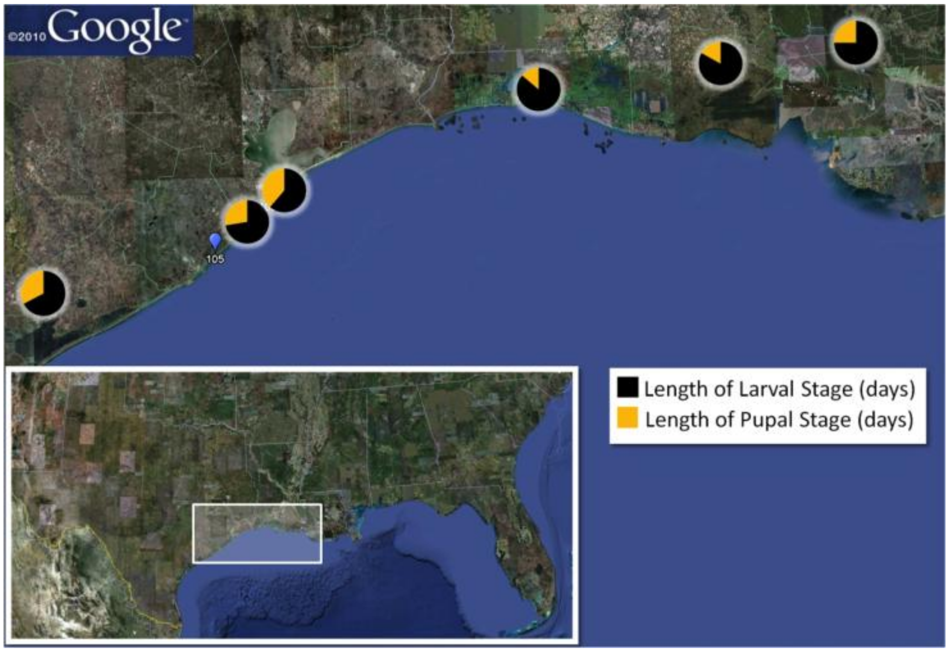


Figure 2. The relative lengths of larval (black) and pupal (orange) stages for moths reared on *Opuntia* host plants collected from six of our nine study locations (indicated by location of pie charts).

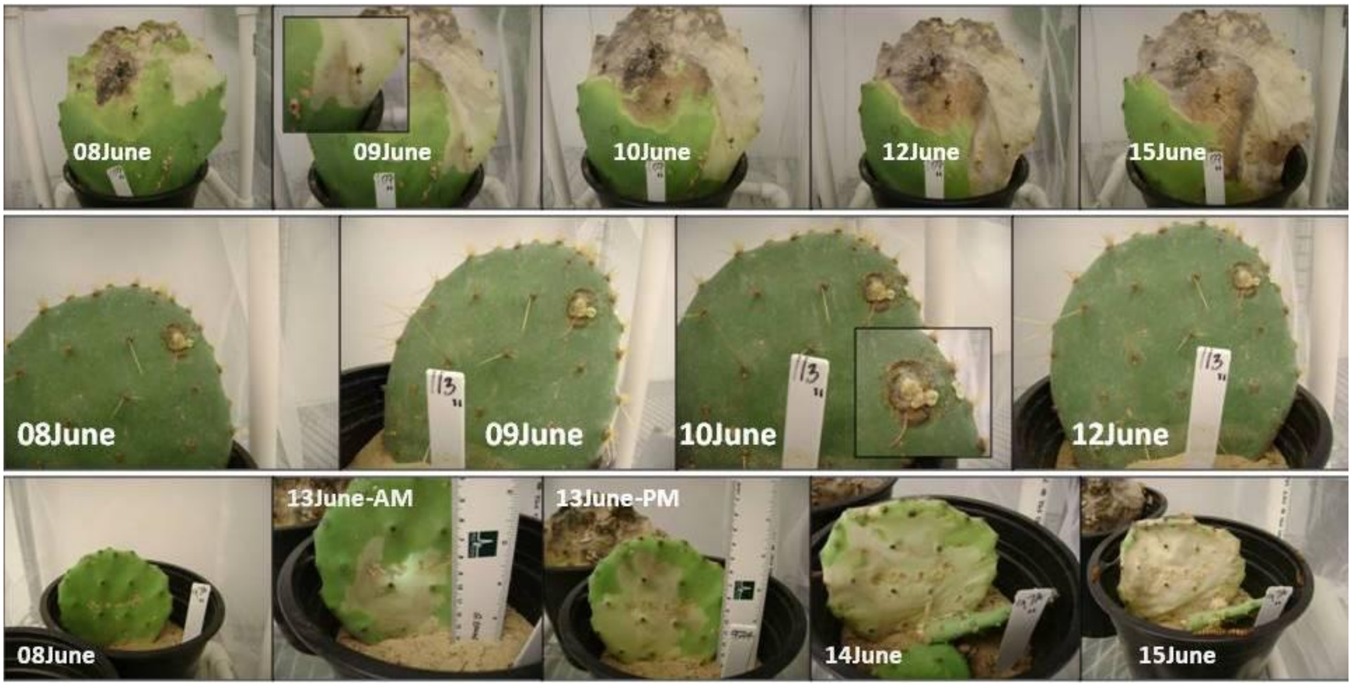


Figure 3. Progression of damage in three experimental *Opuntia* plants infested with *C. cactorum* larvae. Each row represents sequence of feeding in a single pad beginning on June 8, 2011.

Task 3.5. Cactus Moth Detection and Monitoring Network

PI: Clifton Abbott
Co-PI: Richard Brown, Victor Maddox, John Madsen
Collaborators: Randy Westbrooks, USGS NWRC; Joel Floyd, USGS APHIS PPQ; Ron Weeks, USDA APHIS PPQ, and Annie Simpson, NBII

Cactus Moth Detection and Monitoring Network: A Website—An Online System

Clifton Abbott

Cactus moth *(Cactoblastis cactorum)* is a very destructive nonnative moth wreaking havoc across the gulf coast on pricklypear cactus populations. The Cactus Moth Detection and Monitoring Network (CMDMN) has been identifying cactus populations throughout the coastal states and monitoring the spread of the destructive moth. The leading edge of the moth's progression across the gulf coast is still in south Louisiana. The goal is to keep the moth from progressing any further.

Identification

EggSticks
Infestation by *Cactoblastis* may be indicated by the presence of egg-sticks, which resemble cactus spines. However, native cactus-feeding Lepidoptera lay similar egg sticks that currently cannot be distinguished reliably from those of the cactus moth. Identification has to wait until the larvae appear.

Larvae
The mature larvae are more distinct with a characteristic orange to red color interrupted by dark banding or spots on the body and are relatively easy to distinguish from those of native species. However, younger stages of *Cactoblastis* are similar to those of native species and the two sometimes have been misidentified. Available larval identification keys are limited to differences in color of mature larvae. Also, records of some species may only be known from limited reference material. If you suspect the presence of the cactus moth, please view important information below.

Adult Moth
The adult cactus moths are non-descript brownish-gray moths that can only be definitively identified by a microscopic examination of dissected male genitalia, although the native species differ from *Cactoblastis* in having a more plumose antenna. Click on the moth image to the right for a comparison between the native moth *Melitara* and *Cactoblastis*. High resolution images are also provided for *Melitara* and the *Cactoblastis*.

They generally appear as typical pyralid moths with pronounced labial palps of the female, thus the name "snout moths". The forewings show a characteristic banding pattern, however other related Phycitinae have similar banding. If you suspect the presence of the cactus moth, please view important information below.

Additional Help for Identification
For more information and a key to the cactus feeding species in the Southeastern US, see:
Solis, M. Alma, Stephen D. Hight, and Doria R. Gordon. 2004.
Tracking the Cactus Moth, Cactoblastis cactorum Berg., as it flies and eats its way westward in the

Figure 1. Identification information for the cactus moth available from the CMDMN Website.

The CMDMN system currently contains 12,487 pricklypear surveys. 3,915 of these surveys are actual cactus populations with the remaining surveys being areas where cactus populations are not found. Cactus populations have been surveyed in 36 states, Puerto Rico, and Mexico. Six states are positive for the presence of cactus moth. A host of sentinel sites in six states are being monitored by volunteers to detect the moth's movement into new areas.

The Cactus Moth Detection and Monitoring Network website provides educational materials to arm the public in helping to fight the spread of the cactus moth. These materials include information on the moth itself, including origin information, identification information, information on the danger and the destruction this moth poses, and some biology information on the moth. Information on native moth species are also provided due to the close characteristics these moths share. Materials on the host pricklypear cactus are provided to aid in the identification of the host cactus and information on how to visually inspect the cactus for the presence of the moth. Resources are provided on control methods in case you have an infestation of the cactus moth.

Figure 2. CMDMN interactive map showing locations at which pricklypear cactus are found (Blue) and sites at which cactus moth are found (Red).

While CMDMN website does provide live and up-to-date maps imbedded within the text, it also provides a full-size interactive map to allow users to move around and view the cactus and moth data. The interface allows the user to view a comparison between the positive cactus locations and the negative locations while showing the moth locations. The map also includes the sentinel sites throughout the US.

The CMDMN system can be accessed from the website with a valid user account. This access allows the user to submit pricklypear reports (positive for the presence of pricklypear cactus or negative for the absence of pricklypear cactus), or visual observations of the cactus population for the presence of the moth. The visual observation can either be positive for the presence of the moth or negative. Repeat visual observations for a cactus population are encouraged, especially for those populations within the leading edge of the moth's progression.

The information provided through the CMDMN website is adaptable to mobile devices to allow the information to be accessed on the go. The website identifies the mobile device and sends the user to pages that are designed to fit on the device in a more manageable manner.

If you would like to help with this effort, volunteer information can be found at the CMDMN website: http://www.gri.msstate.edu/cactus_moth.

Task 4. Habitat Modeling for Species of Interest

An example of the diversity of *Opuntia* hosts observed during a December 2010 field research trip in South America by Chris Brooks and Gary Ervin. It is likely that at least six native South American species were observed during this trip. Photo by Gary Ervin.

Richard Brown (far left) and others listen as Dr. Jon Rebman (San Diego Natural History Museum) describes cacti and other desert plants during a field trip organized as part of the *Cactoblastis* symposium at the Entomological Society conference, San Diego, CA in 2010. Photo by Gary Ervin.

Task 4.1. Habitat Modeling Workshop and Web Tutorial

PI: Gary Ervin
Co-PI: Christopher Brooks

Habitat Modeling Workshop and Web Tutorial

Gary N. Ervin and Christopher Brooks

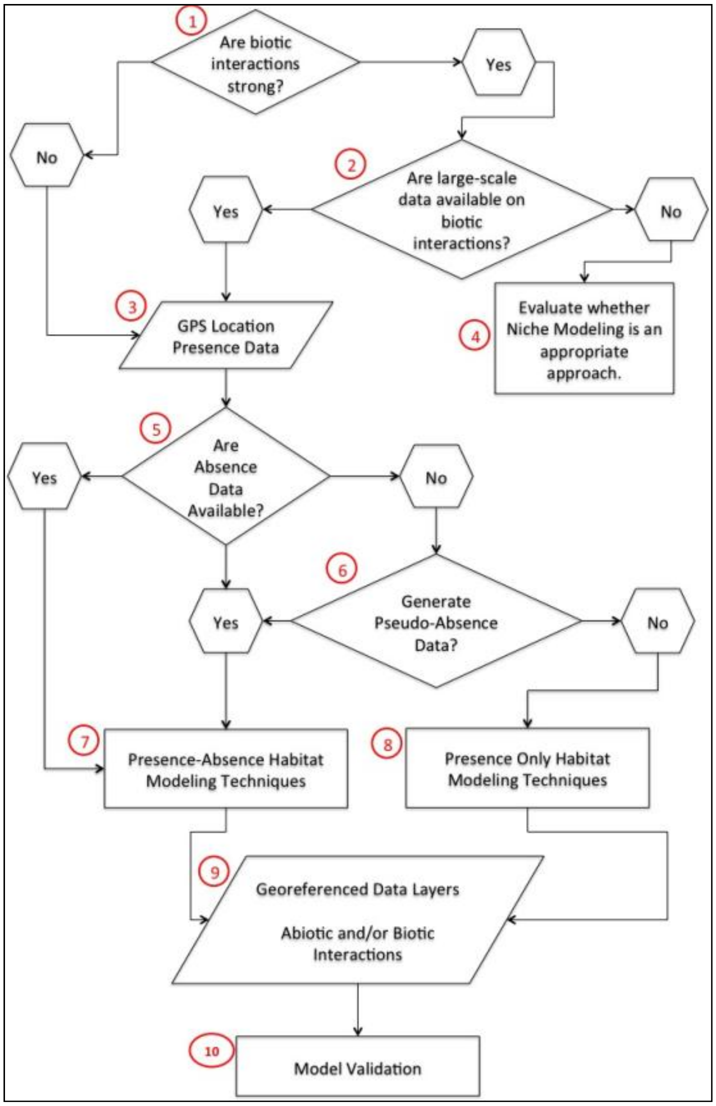


Figure 1. Our Environmental Niche Modeling (a.k.a. Habitat Modeling) web tutorial will be based on the conceptual process depicted here, representing a general, ecological question-based, modeling approach.

Environmental niche models (ENMs) have gained popularity during recent years as tools to investigate potential changes in species distributions resulting from such factors as climate change and species introductions. As mentioned in our report for Task 3.3 and in previous quarterly and annual reports, we have used this modeling approach (also referred to as niche modeling or species distribution modeling) in the study of invasive plants and insects, as well as with native plant species and native plant assemblages.

As part of the Geosystems Research Institute's Invasive Species Resources web page, we are developing an online ENM tutorial. This tutorial will be comprised of two sections (a "Case Studies" section and a "Habitat Modeling" section) and will include links to and brief descriptions of sources for original data layers and software such as those that are being used in our work or that may be of interest in others' modeling efforts. Our ENM web tutorial will include the following information, linked to a process chart representing a general, ecological question-based, modeling approach (Figure 1). Annotations for each element of the process chart would consist of discussions of the rationale associated with addressing each, along with descriptions of relevant tools, methods, or databases.

We begin the "Habitat Modeling" section of our tutorial with a question of the perceived importance of biological interactions because we have found in our own recent work that such interactions sometimes can override effects of the abiotic environment and lead to inaccurate ENM interpretations (Brooks et al., *In press*). The answer to this first question (element 1 in Figure 1) then leads to elements related to the availability of different types of georeferenced ***data*** (elements 2, 3, 5, and 9), ***methods*** to be implemented (elements 6, 7, 8, and 10), and ***conceptual issues*** related to the approach under certain conditions (element 4).

Information linked from each of the elements in this ENM process chart includes:

A. Conceptual issues

Element 1. Some species may be much more strongly influenced by environment than by biological interactions. Where this is the case, one may safely proceed to use environment-driven ENM. However, when it is hypothesized that biological interactions are important (such as in the invasion of an introduced consumer), ENMs ought to incorporate some measure of interaction between the invader and distribution of its potential resources.

Task 4.1. Habitat Modeling Workshop and Web Tutorial (Cont.)

Element 4. When it is hypothesized that biotic interactions are important but data that might be used to represent such interactions are unavailable, a key decision that should be made is whether ENM is an appropriate tool. Models based only on abiotic data are unlikely to provide appropriate estimates of the species' expected distribution in these cases.

B. Data

Element 2. Large-scale biotic data may be represented in many ways, but all would consist of georeferenced data layers that represent a species' distribution across the area wherein models would be developed. These data would focus on species that are hypothesized to interact in important ways with the species for which ENMs are being developed.

Element 3. This is one of the two essential sets of data around which all habitat modeling studies are based: georeferenced data on the known distribution (occurrences) of the target species.

Element 5. In some ENM approaches, absence data are a required piece of information. Where such data are unavailable, it is sometimes ecologically permissible to construct sets of pseudo-absence data that represent points at which the species could be reasonably assumed to be absent. Element 6 deals with methods for producing pseudo-absence data.

Element 9. The second essential set of information for building ENMs is a database of influential environmental variables, either collected or transformed to a spatial grain (spatial grid cell size) that is relevant for the species or system being modeled.

Patrones en la diversidad de especies exóticas y aplicaciones para programas de monitoreo

Gary N. Ervin

Departamento de Ciencias Biológicas
Universidad Estadal de Mississippi

Figure 2. Ervin delivered this presentation ("Patterns in exotic species diversity and applications for monitoring programs") at the 2010 congress of the Mexican Weed Science Association, in Cancun. Presentations such as these will be provided through the "Case Studies" section of the GRI Invasive Species Resources page.

C. Methods

Element 6. Sometimes it is feasible and ecologically defensible to produce a set of pseudo-absence data for analyses where presence-absence analytical approaches are available (such as binary logistic regression). Pseudo-absence points can be established in areas where it is reasonably valid to assume the target species was not present during surveys. For example, if transects are searched for presences of the target species, random absence points might be placed within the transect area at specified distances from occurrence points, with the assumption that no unobserved individuals of the target were present.

Element 7. This will link to an annotated listing of a few of the more reliable presence-absence ENM tools, with hyperlinks to detailed methodological literature and downloads, where such are available.

Element 8. This will link to an annotated listing of a few of the more reliable presence-only ENM tools, with hyperlinks to detailed methodological literature and downloads, where such are available.

Element 10. Model validation and assessment are carried out through diverse means. Our ENM tutorial will provide information on some assessment and validation approaches appropriate to each of the ENM tools discussed under elements 7 and 8.

The "Case Studies" section of our ENM tutorial will include examples of application of some of the modeling tools presented in the "Habitat Modeling" section, as well as a bibliography of key references on ENM approaches. In addition to descriptions of ENM studies and the bibliography of papers and reports, we will provide a few relevant presentations to help illustrate select ENM case studies (e.g., Figure 2).

Literature Cited

Brooks, C. P., G. N. Ervin, L. Varone, and G. Logarzo. In press. Native ecotypic variation and the role of host identity in the spread of an invasive herbivore, *Cactoblastis cactorum* (Berg). *Ecology*.

Task 4.2. Landscape Genetic Habitat Modeling for Invasive Species

PI: Gary Ervin
Co-PI: John Madsen
Collaborators: Christopher Brooks, Lisa Wallace, Mark Welch, MSU Biological Sciences

Landscape Genetic Habitat Modeling for Invasive Species

Gary Ervin and Christopher Brooks

This portion of the research is aimed at incorporating knowledge of invasive species genetics into distribution modeling, with the ultimate goal of identifying genetic signals correlated with invasiveness (e.g., faster rates of spread) or with success under different environmental conditions. We targeted this research initially on cogongrass, which has a longer history of invasion in the southeastern United States than the other species we are studying from both a landscape ecology and genetic perspective (i.e., South American cactus moth). That longer history of invasion presumably has provided a greater opportunity for cogongrass to “sample” environmental heterogeneity across the region and potentially to have come to something more resembling an equilibrium between genetic and environmental influences on distribution and spread.

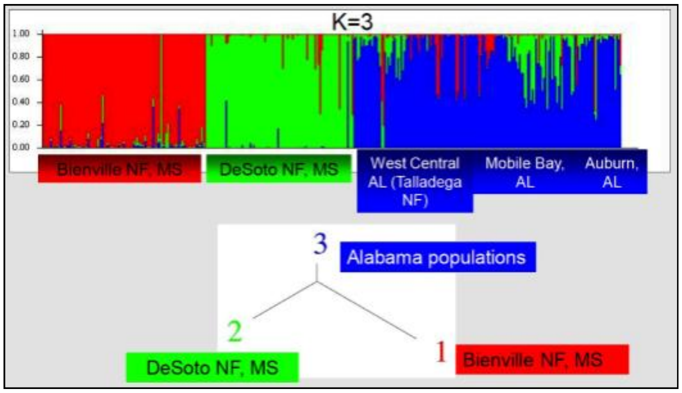


Figure 1. Analyses of cogongrass genetic data, using the program STRUCTURE, demonstrated that population differentiation clearly exists among the sampled populations, which could be best segregated into three groups (K=3). Genetic differentiation was evident between populations in MS and AL (AL in blue), as well as between the two MS populations (in red and green). Greater genetic distance between Desoto NF and Bienville NF (illustrated in the unrooted tree at the bottom of the figure) suggested that they are less related to each other than either is to the populations sampled in AL.

Mississippi and Alabama are the two states that received documented, direct introductions of cogongrass from Asian populations in the early 20th century. Because of this, our population genetic work began with a detailed investigation of population genetic diversity in southern MS and AL. In the current research, we utilized a molecular and population genetics approach referred to as Amplified Fragment Length Polymorphism (AFLP) to detect genetic patterns within and among cogongrass populations.

We found significant partitioning of genetic variation among 18 sampled cogongrass populations in these two states, with 65% of variation attributable to within-population variation and the remaining 35% partitioned among populations. The highest occurrence of rare alleles was found in one population in Alabama, north of Mobile Bay, suggesting that population to be older and possibly experiencing population expansion, correlated with the higher prevalence of genetic “uniqueness.”

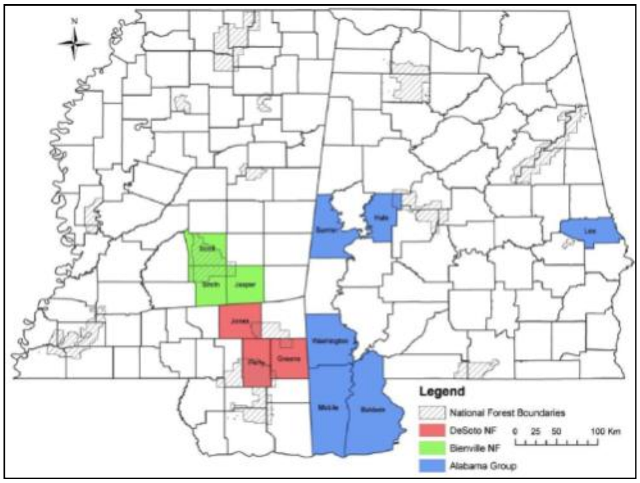


Figure 2. Map of MS and AL, showing areas from which cogongrass was sampled for these analyses. Color coding for the counties indicates groups identified in the genetic analyses (see previous figure).

Significant population structure also was found between the two states (Figure 1). An F_{ST} value (measure of genetic distance) of 0.44 ($p<0.001$) for grouped samples between Mississippi and Alabama suggest that cogongrass populations in the two states are greater than 40% distinct, genetically speaking. This is supported by other of our results that suggest populations in Mississippi fall into two distinct genetic groups that have greater genetic distance individually from each other than to all populations in Alabama (Figure 1, 2). This suggests asymmetrical migration of alleles and therefore, different patterns of genetic mixing within and between the two states (or regions of the states represented in these analyses). These data suggest that populations in Mississippi and Alabama have experienced differing histories of introduction, establishment, and spread in the last century, a conclusion supported by documented introductions of cogongrass into the region.

Task 4.2. Landscape Genetic Habitat Modeling for Invasive Species (Cont.)

Currently, we are preparing to submit DNA samples from the entirety of the southern U.S. range of cogongrass for sequencing (anticipated in November 2011). Analyses of those data will follow a similar approach to the above analyses, with the aim of discovering patterns of genetic diversity and relatedness from Texas to Florida and South Carolina. Included in this second set of samples are individuals thought to represent Brazilian satintail (*Imperata brasiliensis*), a congeneric species with cogongrass (*Imperata cylindrica*) and a species with which it is thought cogongrass may have hybridized since arrival in the United States. We anticipate these population-level analyses may yield some insight into that hypothesis and possibly suggest whether such hybridization may have contributed to greater invasiveness in cogongrass.

Once we complete these genetic analyses, it will be possible to categorize sampled cogongrass populations based on their genetic relatedness, and then to carry out habitat modeling for genetic groups, as well as with the population as a whole. These analyses can function in the same way that our recent genetic and niche modeling research with the South American cactus moth helped provide information on the ecology of that invasion. That is, we can use genetically informed models to examine hypotheses about invasion success of cogongrass in different parts of its range, based on known biological linkages among related sub-populations.

Another useful piece of information we have gained from this population genetic approach in cogongrass is that development of suitable genetic markers for previously un- or understudied species is a time-consuming process. Although the marker system developed for cogongrass appears to be robust (statistically and biologically), it has required an enormous amount of time for development. One result of this is that we have not pursued the similar set of investigations in our cactus moth system. Despite this, we currently have a relatively powerful genetic dataset for the cactus moth that, thus far, have proven highly informative at the biological and spatial scales we have applied it.

Our recently published genetic analysis (Marsico et al. 2011) was used, in part, to guide our niche modeling analyses (Brooks et al., *In press*) that now are being used to conduct and design further investigations into mechanisms that appear to influence the moth's invasion. Part of that work is described above in section 3.4. However, another project that is nearing completion aims to combine our genetic knowledge with previously published morphological studies of the moth in its native range (McFayden 1985), to determine how closely genetics and this aspect of morphology correlate.

McFayden (1985) used external pigment patterns in six instar larva to describe ten larval morphotypes in the insect's native range. We hypothesized that the geographic distribution of larval morphology in the native range would correspond to our previously identified genetic patterns and that all larvae in Florida would share a common morphology, owing to their shared genetic similarity. The four morphological groups described by McFayden (1985) in Argentina also were found in our study, and their geographic distribution roughly matches what we observed for mitochondrial DNA sequence data (Figure 3).

Figure 3. Morphological analyses of South American cactus moth collections (*C. cactorum*) from Florida and Argentina agree with our previous genetic analyses. North American collections (kes110, kes261) appear clearly to be associated with one of the South American morphotypes (5e). Two of the thirteen morphological characters examined by McFayden (1985) are indicated on specimens 5b, 5e, and kes261.

Literature Cited

Brooks, C. P., G. N. Ervin, L. Varone, and G. Logarzo. In press. Native ecotypic variation and the role of host identity in the spread of an invasive herbivore, *Cactoblastis cactorum* (Berg). *Ecology*.

Marsico, T. D., L. E. Wallace, G. N. Ervin, C. P. Brooks, J. E. McClure, and M. E. Welch. 2011. Geographic patterns of genetic diversity from the native range of *Cactoblastis cactorum* (Berg) support the documented history of invasion and multiple introductions for invasive populations. *Biological Invasions* 13: 857-868

McFayden, R. E. 1985. Larval characteristics of *Cactoblastis* spp. (Lepidoptera: Pyralidae) and the selection of species for biological control of prickly pears (*Opuntia* spp.). Bulletin of Entomological Research 75: 159-168.

Task 5. Invasive Plant Atlas of the Mid-South (IPAMS)

Dr. Victor Maddox instructs volunteers at a 2009 workshop event in Louisville, MS. Photo by John Madsen.

Arkansas Master Gardeners packed our November 2011 workshop in Little Rock, Arkansas. Photo by John Madsen.

Task 5.1. Web-based Database of Invasive Plant Species Locations (IPAMS)

PI: John Madsen
Co-PI: Gary Ervin, Clifton Abbott, and Victor Maddox
Collaborators: John Byrd, MSU; Randy Westbrooks, USGS NRWC; Annie Simpson, NBII, and Les Mehrhoff, University of Connecticut (IPANE)

Invasive Plant Atlas of the Mid-South (IPAMS)

John D. Madsen and Victor Maddox

Initiated in January 2007 with a grant from the USDA CSREES AFRI program, the Invasive Plant Atlas of the MidSouth (IPAMS) has had three goals: 1) research on the relationship between land cover and invasive plant distribution, to develop predictive capability to find new infestations; 2) developing training workshops for citizen scientists, to train them in identifying 40 invasive plant species for the MidSouth and entering occurrence data in a web-based database; and 3) developing a web-based database (http://www.gri.msstate.edu/ipams) which will provide invasive plant information, including best management practices, and allow the entry and display of location data. All three of these goals have been accomplished; this report focuses on the second goal of the status of citizen science workshops.

Figure 1. John Madsen presents the IPAMS system to volunteers at the Mississippi Vegetation Management Association annual meeting in Louisville, MS in 2009. Photo by Debbie McBride.

Table 1. Invasive Plant Atlas of the MidSouth workshop locations, dates, hosts, and number of registered attendees.

Location	Date	Host	Registered Attendees
Louisville, MS	11/13/09	Mississippi Vegetation Management Association	40
Biloxi, MS	12/4/09	USDA Natural Resource Conservation District	11
Hattiesburg, MS	11/3/10	Mississippi Exotic Pest Plant Council	10
Shreveport, LA	09/22/11	Louisiana Master Gardeners	32
Mobile, AL	10/4/11	Alabama Master Gardeners	21
Arkadelphia, AR	10/11/11	Henderson State University	7
Baton Rouge, LA	10/17/011	LSU AgCenter and Louisiana Master Gardeners	45
Covington, TN	10/19/11	Tennessee Master Gardeners	28
Little Rock, AR	11/14/11	Arkansas Master Gardeners	82
Birmingham, AL	11/16/11	Birmingham Botanical Gardens and Alabama Master Gardeners	36
Total Trainees			312

Task 5.1. Web-based Database of Invasive Plant Species Locations (IPAMS) (Cont.)

Table 2. A typical agenda for an IPAMS workshop.

8:00-8:15	Registration and Introduction. John Madsen, Geosystems Research Institute, Mississippi State University
8:15-8:45	IPAMS Project Summary, Definition of Invasive Plants, Contacts, Field Survey Methods and the Field Survey Data Form, Using GPS. John Madsen, Geosystems Research Institute, Mississippi State University
8:45-9:45	Identifying the IPAMS Species, part 1. Victor Maddox, Geosystems Research Institute, Mississippi State University
9:45-10:15	Break
10:15-11:15	Identifying the IPAMS Species, part 2. Victor Maddox, Geosystems Research Institute, Mississippi State University
11:15-11:45	Registering on IPAMS, Filling in data, other resources on the IPAMS website, and additional IPAMS information. John Madsen, Geosystems Research Institute, Mississippi State University
11:45-12:00	Workshop Evaluation

We developed a training manual for volunteers; which includes the presentations for the training workshop, fact sheets for the forty species, and other relevant materials (Madsen and Maddox, 2009).

We also developed an identification guide for volunteers to use in verifying the identities of the plants in the field (Madsen et al. 2009). The identification guide is laminated, to allow field use, and is small enough to bring into the field. Both of these resources are available for download from the IPAMS webpage and the GRI publication page (http://www.gri.msstate.edu/resources/pubs.php). These resources, and the fact sheets for the forty species, are also available on the GRI Invasive Species Resources page (http://www.gri.msstate.edu/research/invspec/).

We have held ten formal workshops on the complete system, training a total of 312 registered attendees (Table 1). Additional individuals have been trained as part of university classes and informal sessions. In addition, Victor Maddox has trained hundreds of Master Gardeners in the identification of invasive plants and introduced them to IPAMS through two-hour sessions on plant identification.

A typical workshop agenda spans four hours, separated into four talks (Table 2). The first talk introduces the data fields (using the NAWMA standard), field survey techniques, and using the GPS. Following this talk, two one-hour presentations are given on identifying the forty species. Following the species identification talk, a final session presents how to register in the IPAMS database, how to fill in the data online, and explains Early Detection and Rapid Response (EDRR).

While the funding for IPAMS through USDA NIFA is now complete, we will continue the IPAMS training program and webpage. The volunteers are eager for this type of training, with several requests each year for training programs throughout the MidSouth. We anticipate small grants to help support this effort.

Figure 2. Participants at the IPAMS volunteer workshop at the Birmingham Botanical Gardens in November 2011. Photo by John Madsen.

Literature Cited

Madsen, J. D., and Maddox, V. L. (2009). Invasive Plant Atlas of the MidSouth Training Workshop Manual. GRI Report #5040, Mississippi State University: Geosystems Research Institute.

Madsen, J.D., Ervin, G., Maddox, V., Madsen, N., Byrd, J., McBride, D., and Stroud, B. (2009). Invasive Species Field Identification Guide. Mississippi State University: Geosystems Research Institute.

Task 5.2. IPAMS Web Site Enhancement and Development - Accessible by Mobile Devices

PI: Clifton Abbott
Co-PI: John Madsen, Gary Ervin
Collaborators: Annie Simpson, NBII

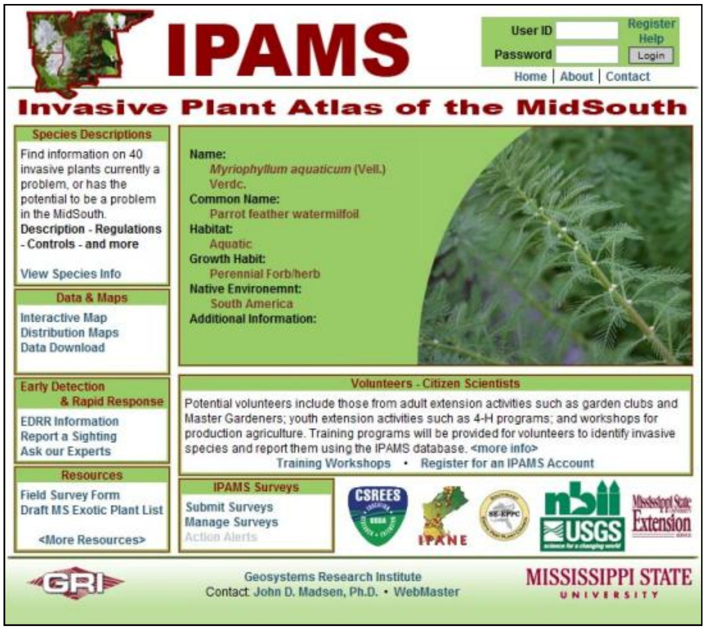
Invasive Plant Atlas of the Mid-South: A Network of Volunteers

Clifton Abbott

One of the goals for the Invasive Plant Atlas of the Mid-South (IPAMS) is to develop a web-based database system allowing the submission and display of location data for invasive plant species. In addition, the website will provide invasive plant information on 40 targeted species, including best management practices, and early detection and rapid response resources and training resources for citizen scientists.

To date, the system is running with over 115 users working together to find and report invasive species. IPAMS currently allows data to be submitted for 548 different invasive species and currently has data for 257 of those species. There are currently 11,643 surveys with data covering 39 different states and Puerto Rico. IPAMS provides an interactive map that allows the user to subset the data based on several different criteria, giving the user a powerful analysis tool.

IPAMS workshop training materials and identification field guides are available from the website.



Find information on 40 invasive plants currently a problem, or has the potential to be a problem in the MidSouth.
Description - Regulations - Controls - and more

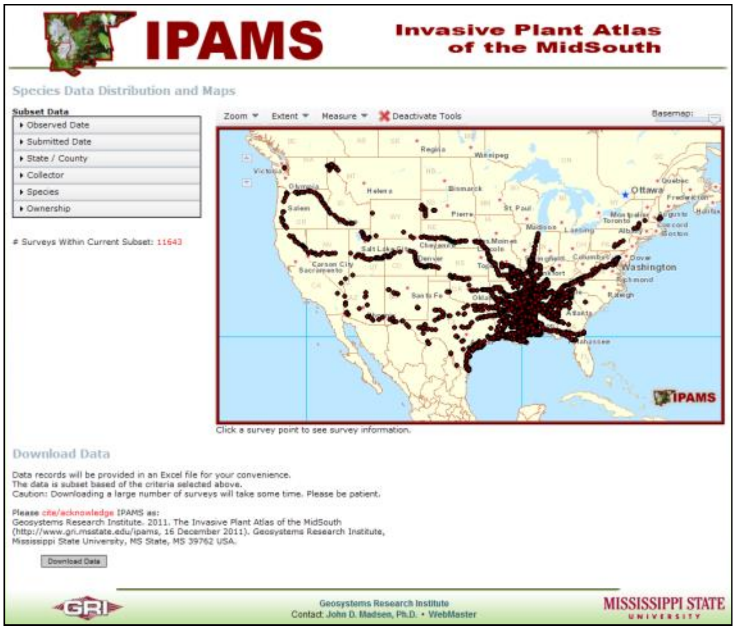
Name: *Myriophyllum aquaticum* (Vell.) Verdc.
Common Name: Parrot feather watermilfoil
Habitat: Aquatic
Growth Habit: Perennial Forb/herb
Native Environemnt: South America
Additional Information:

Potential volunteers include those from adult extension activities such as garden clubs and Master Gardeners; youth extension activities such as 4-H programs; and workshops for production agriculture. Training programs will be provided for volunteers to identify invasive species and report them using the IPAMS database. <more info>
Training Workshops • Register for an IPAMS Account

Geosystems Research Institute
Contact: John D. Madsen, Ph.D. • WebMaster

Figure 1. The Invasive Plant Atlas of the MidSouth website home page.

The IPAMS website provides three avenues for the user to interact with the system. First, the user can “Ask Our Experts” a question about invasive plants or alternatives to invasive species, etc. Second, the user can report a sighting of an invasive species. The user might not be a volunteer with the system but might have come across a population of an invasive species and wanted to report that sighting. Third, the user can volunteer to help locae and report invasives across the region. They can register their username and get right to work. Once in the system, the user can submit or edit their surveys in the system.



\# Surveys Within Current Subset: 11643

Click a survey point to see survey information.

Data records will be provided in an Excel file for your convenience.
The data is subset based of the criteria selected above.
Caution: Downloading a large number of surveys will take some time. Please be patient.

Please cite/acknowledge IPAMS as:
Geosystems Research Institute. 2011. The Invasive Plant Atlas of the MidSouth (http://www.gri.msstate.edu/ipams, 16 December 2011). Geosystems Research Institute, Mississippi State University, MS State, MS 39762 USA.

Geosystems Research Institute
Contact: John D. Madsen, Ph.D. • WebMaster

Figure 2. Species Distribution map on the Invasive Plant Atlas of the MidSouth web page.

The information provided on the IPAMS website is adaptable to mobile devices to allow the information to be accessed on the go. The website identifies the mobile device and sends the user to pages that are designed to fit on the device in a more manageable manner.

The Invasive Plant Atlas of the MidSouth can be visited at http://www.gri.msstate.edu/ipams. If you would like to help with this effort, volunteer information can be found at the IPAMS website.

Task 6. Bioinformatics and Biodiversity

Thomas Naberhaus (R) showing the newest version of Butterflies and Moths of North America (BAMONA) database to Richard Brown (L) and Sangmi Lee at Big Sky Institute in July 2009.

Richard Brown and Sangmi Lee attended the Cooperative Agricultural Pests Survey (CAPS) National Conference, December 1-3, 2010, and provided demonstrations and identification aids for the cactus moth and other exotic species of Lepidoptera. More than 200 attendees from all states attended this conference.

Task 6.1. Collaboration with the ITIS and BAMONA

(Integrated Taxonomic Information System and Butterflies and Moths of North America)

PI: Richard Brown
Co-PI: John Madsen, Clifton Abbott, Sangmi Lee
Collaborators: Thomas Naberhaus, Big Sky Institute, Bozeman, MT; Elizabeth Sellers, NBII, and Jen Carlino, NBII

Improving Distribution Data for BAMONA and Nomenclature of Species Names for the Integrated Taxonomic Information System (ITIS)

Richard L. Brown and Sangmi Lee

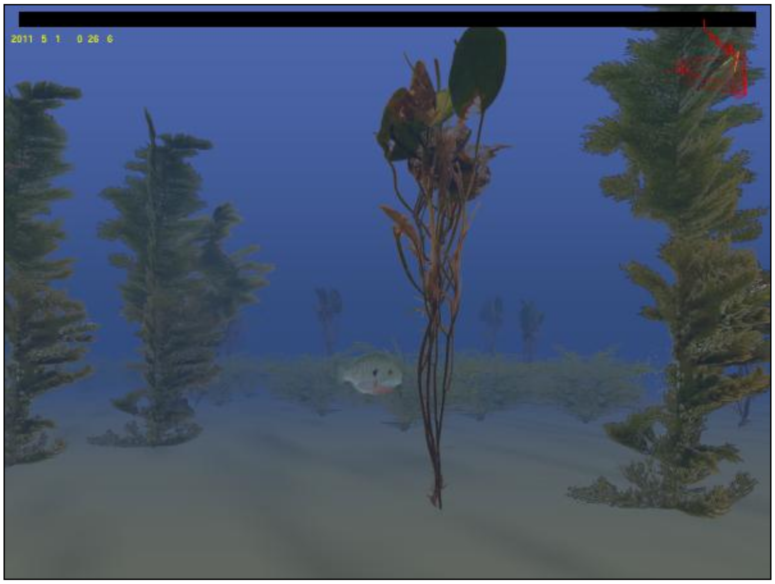
During 2010−2011 the Mississippi Entomological Museum collaborated with the Big Sky Institute at Montana State University to provide distributional data of specimens for incorporating into distribution maps of the Butterflies and Moths of North America (BAMONA) website and with the Integrated Taxonomic Information System (ITIS) to up-date the nomenclature of Lepidoptera.

The BAMONA website includes the taxonomic, biological, and distributional information for species of butterflies and moths, but distributional data were lacking for many of the families of small sized moths. During 2011 data for 17,182 specimens of moths were captured, edited, formatted and exported to BAMONA. These data were databased from 1,281 specimens of Elachistidae from 109 counties in 30 states, 315 specimens of Psychidae from 35 counties in 9 states, 6,009 specimens of Tortricinae from 211 counties in 39 states, and 9,577 specimens of Gelechiidae from 189 counties in 38 states.

Training was obtained at the Smithsonian Insitution by staff of ITIS (Fig. 1) for using the Taxonomic Workbench software. The nomenclature of 2,676 species names in eight families of moths was updated to include many names of species that have been described in recent years and verify current status of names. These families include Gelechiidae, Cosmopterygidae, Xylorictidae, Chimabachidae, Glyphidoceridae, Coleophoridae, and Pelopodidae. All names were formatted to include information on author and original publication of species name, synonyms, homonyms, geographical distribution, and author and date of publication including the most recent nomenclatorial status. After merging with data downloaded from the ITIS online database, duplications was eliminated and all mandatory required data fields were checked by several query tools with Microsoft Access.

Figure 1. Staff of ITIS in November, 2010, from left to right: Daniel Perez, Gerald Guala, Armanda Treher, David Mitchell, Sara Alexander, David Nicolson, and Thomas Orrell.

Task 7. Visualization and Biological Informatics



A virtual bluegill swims among virtual coontail (*Ceratophyllum demersum*, left and right) and virtual American pondweed (*Potamogeton nodosus*).

Dr. Rachel Schultz photographs a water celery (*Vallisneria americana*) plant for developing the virtual littoral zone program.

Task 7. Visualization of Invasive and Native Aquatic Plant Structure in the Littoral Zone Environment

PI: Eric Dibble (Ecology), Phil Amburn (Computation)
Co-PI: John Madsen

Waterscape—A Virtual Environment for Invasive and Native Aquatic Plant Structure

Eric Dibble, Phil Amburn, Rachel Schultz and Derek Irby
Department of Wildlife, Fisheries and Aquaculture and Geosystems Research Institute

Critical issues are facing our aquatic habitats including infestation by invasive species. These invaders, including aquatic plants, can disrupt relationships between animals and native vegetation leading to the collapse of fisheries and unusable recreational areas. Unlike kudzu in a forest, we do not necessarily see the extent of an infestation until a lake is choked with vegetation. Researchers explore these areas using scuba gear, but very few other people have access to this equipment and training. Therefore, most people only have a vague understanding of the issue, but there is a critical need for action to stop the spread and persistence of invasive aquatic plants.

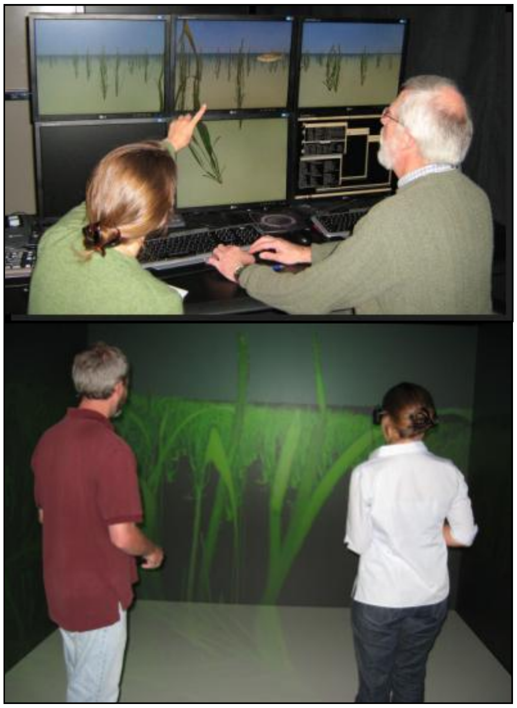


Figure 1. On-screen demos helped the ecologists get realistic densities and modify the 3-D model. Top, Drs. Rachel Schultz (left) and Eric Dibble examine the model progress; below, Derek Irby and Rachel Schultz observe simulated plant invasion in the VERTEX.

August 2010 a collaborative effort was initiated between a team in the Geosystems Research Institute and the Department of Wildlife, Fisheries and Aquaculture at Mississippi State. The intent of this work was to develop a visualization system to simulate and analyze an underwater environment of diverse native plant life and provide a wide range of people a chance to see what they routinely cannot see. The goal was to visualize the influence that invasive species have on the native aquatic community and the effects that the diversity and densities of aquatic vegetation has on fishes and their macro-invertebrate prey (Figure 1).

The team compiled 2-diminsional data from previous field studies, and have integrated the information in to a 3-diminsional model that describes and illustrates changes in vegetated habitat structure caused by exotic invasive plant species. Appropriate data were gathered by reviewing peer-reviewed literature published during 1996-2011 and from the available research that focuses on structural alteration of plant habitat due to exotic plant invasions, and the ecology of freshwater macrophytes, phytophyic fishes, and invertebrate populations. In addition to the literature review we analyzed underwater video recordings collected from previous experiments *in*

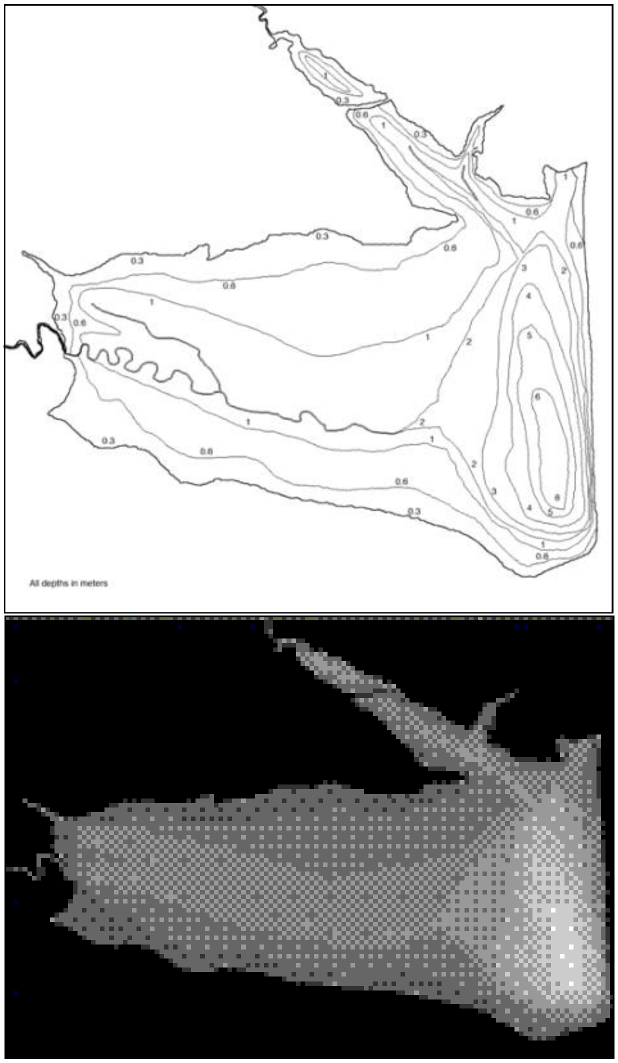


Figure 2. Model reservoir used for the waterscape based on Oktibbeha County Lake, MS.

Task 7. Visualization of Invasive and Native Aquatic Plant Structure in the Littoral Zone Environment (Cont.)

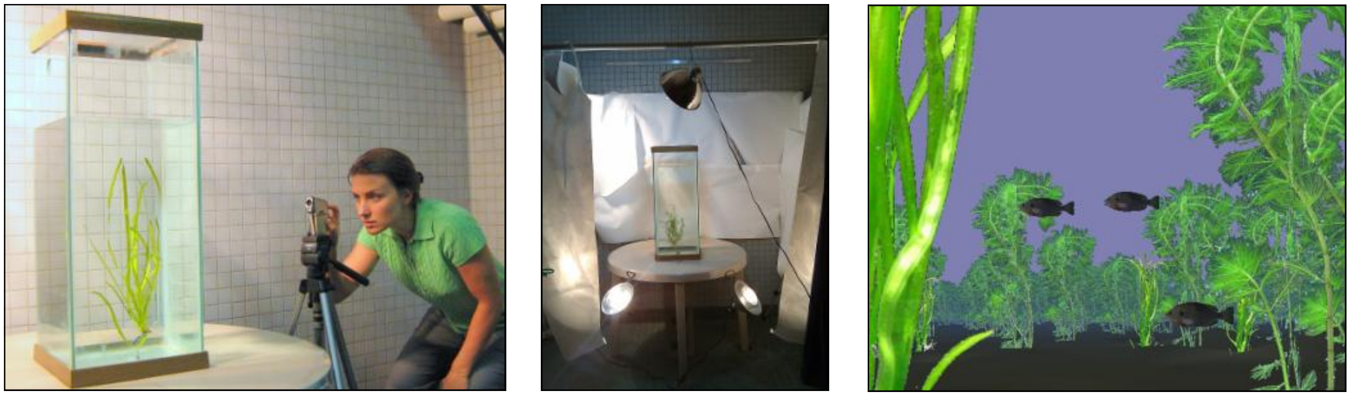


Figure 3. Left: Dr. Shultz photographing aquatic plants suspended in aquaria; center: aquaria setup used for gathering plant photo-data; right: digital data of plants integrated into visual simulation.

situ to describe swimming and foraging patterns of freshwater fishes in vegetated habitats. Information from this analysis was then compiled and integrated into the 3-dimensional model. Our synthesis of available data for integration into the 3-dimensional model helps to visually describe critical habitat in native aquatic systems.

The team developed new modeling and visualization software that uses a control file to create a realistic waterscape that specifies the composition of plants and ecology of the system. We chose to use a typical southern reservoir invaded by hydrilla (*Hydrilla verticillata)* as the model. The model system was based on Oktibbeha County Lake near Starkville, MS (Figure 2). We photographed plant species typical of southern reservoirs and entered them into the waterscape as texture maps along with fishes (i.e., bluegills and bass). We incorporated data from the scientific literature we reviewed on community dynamics, (i.e., density and distribution of ranges of native plants and fishes, hydrilla infestation rate, and population dynamics for invasion stages).

The virtual model simulated a real waterscape with realistic density and distribution of native aquatic plants in a notional southern reservoir. To characterize a biological invasion, we chose a common plant invader of southern reservoirs, *Hydrilla verticillata* (hereafter hydrilla), and compiled published data on its modes of introduction, rates of spread, and monoculture density. Then, in a virtual environment, we are using this data to create a realistic, time-dependent simulation of the introduction hydrilla and the subsequent invasion of the native plant community. Time-dependent simulation level of detail was incorporated into the demonstration using Open GLL and 3-D demonstration. The team used the digital data to generate a virtual environment by using Virtual Environment for Real-Time Exploration (VERTEX). The VERTEX system is a CAVE device located at Mississippi State University.

The team was able to capture video from segments in the MSU VERTEX, a CAVE device that surrounds the users in a 3D, virtual environment (Figure 3). After capturing and editing these segments it enabled us to develop an educational video describing an invasion within a typical southern reservoir. This video presents simulation of the ecology of a real invasion that demonstrates characteristics of plant introduction, rates of spread, and response by native plant and fish species.

As a result of our literature review to gather data for the visual model we also were able to explore how potential mechanisms of impact may deviate from current models in the ecological literature describe plant-fish interactions, and assess how traits that enable macrophytes to invade are linked to effects on fish and macroinvertebrate communities. The team found that in certain instances, invasive macrophytes increased habitat complexity, hypoxia, allelopathic chemicals, facilitation of other exotic species, and inferior food quality leading to a decrease in abundance, richness, etc. of native aquatic fish and macroinvertebrate species. However, mechanisms underlying invasive macrophyte impacts on fish and macroinvertebrate communities (i.e., biomass production, photosynthesis, decomposition, and substrate stabilization) were not fundamentally different than those of native macrophytes. We identified three

Task 7. Visualization of Invasive and Native Aquatic Plant Structure in the Littoral Zone Environment (Cont.)

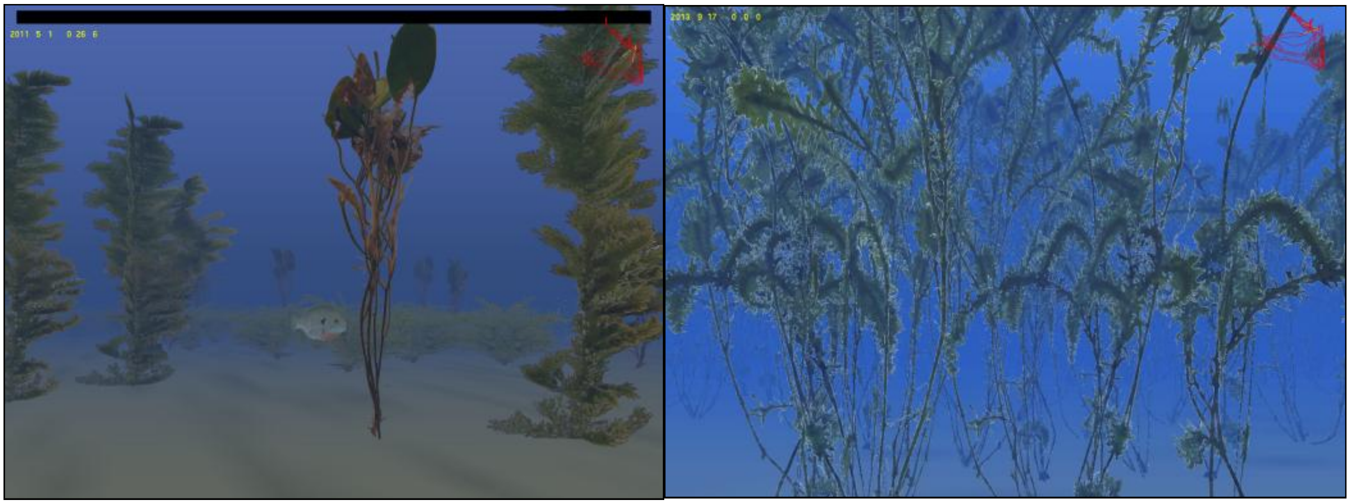


Figure 3. Screen shots of the waterscape taken from two separate times reflecting the transition from, left, the native plant community to, right, hydrilla infestation.

invasive traits largely responsible for negative effects on fish and macroinvertebrate communities: increased growth rate, allelopathic chemical production, and phenotypic plasticity allowing for greater adaptation to environmental conditions than native species. We suggest that information on invasive macrophytes (including invasive traits) along with environmental data could be used to create models to better predict impacts of macrophyte invasion. However, effects of invasive macrophytes on trophic dynamics are less well known and more research is essential to define system level processes.

The team identified areas we feel would further improve our knowledge of how invasive macrophytes influence fish and macroinvertebrate communities. Currently researchers have focused on responses of sport fishes to invasive species; therefore a diversification of research effort to assess impacts on phytophylic fishes (especially rare and threatened species) is necessary to assess what different responses fish species have to invasions. For instance, fishes with declining populations (i.e. killifish, darters, and rare minnows) were positively associated with plant biovolume of a native macroalgae (*Chara* sp.). In the event of an invasion, *Chara* would likely be replaced by invasive macrophytes, but fish response to this change would be difficult to predict. Furthermore, most studies focused on only one component of aquatic communities; however, interactions among community components are likely and research into impacts of invasive macrophytes on trophic relationships among plankton, macroinvertebrates, and fishes in early life and adult stages would give insight into these dynamics.

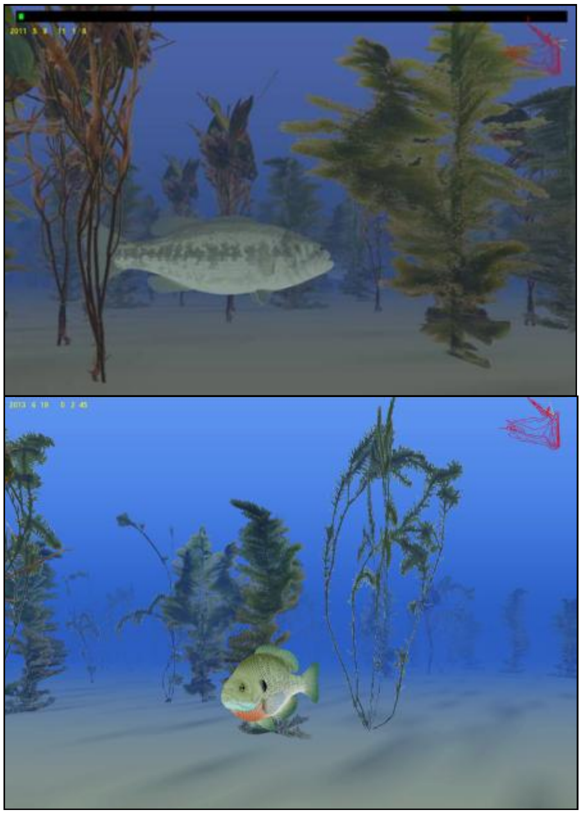


Figure 5. A virtual bluegill, top, and largemouth bass, bottom, swims through a virtual habitat of virtual plants, in a MSU virtual reality model.

Results from this work aids in the collaboration between ecologists and visualization experts, and the demos in the 3D virtual waterscape and a video we feel will reach a broad audience about the threat of invasive aquatic plants. While we have shown how to use a virtual waterscape as a demonstration, it can also be used for exploration of aquatic dynamics. For example, college courses can use this tool to test out hypotheses about plant-fish interactions. Furthermore, researchers may be able to integrate this tool with geographical information systems to better understand the mechanisms responsible for the impacts by invasive aquatic plants in native ecosystems.

Task 8. Regional and National Collaboration

Chip Welling (Invasive Species Program, Minnesota Department of Natural Resources) discusses how the invasive flowering rush (*Butomus umbellatus*) is forming a turf-like mat in the shallows of Curfman Lake, Detroit Lake, MN. Photo by John Madsen, GRI.

Scott Watson, Research Associate with the Geosystems Research Institute, hold a rake full of spiny naiad (*Najas marina*) from Lake Havasu, an impoundment on the Colorado River bordering Arizona and California. Photo by John Madsen, GRI.

Spiny naiad (*Najas marina*) is armed with large spine-like hairs on the stem and leaves. Photo by John Madsen, GRI.

Task 8.1. Collaboration - Idaho

PI: Wes Burger
Co-PI: John Madsen, David Shaw

Managing Flowering Rush (*Butomus umbellatus*) in Drawdown Areas of Pend Oreille Lake, Idaho

Tom Woolf, Idaho State Department of Agriculture; and Ryan Wersal and John Madsen, Geosystems Research Institute, Mississippi State University

Flowering rush (*Butomus umbellatus*) was found north of the Clark's Fork delta in both 2007 and 2008 and represents a unique population for Lake Pend Oreille (Ling Cao 2009). The majority of flowering rush in the Lake Pend Oreille system is located in the Clark Fork River delta area. This area is owned by the USACE and serves as a source of infestation to other parts of the lake and Columbia River system. Small populations have been found taking hold throughout the lake and downstream of Albeni Falls Dam on the Pend Oreille River in Washington. Flowering rush is an expanding problem in this region and currently there are no proven tools to effectively kill it.

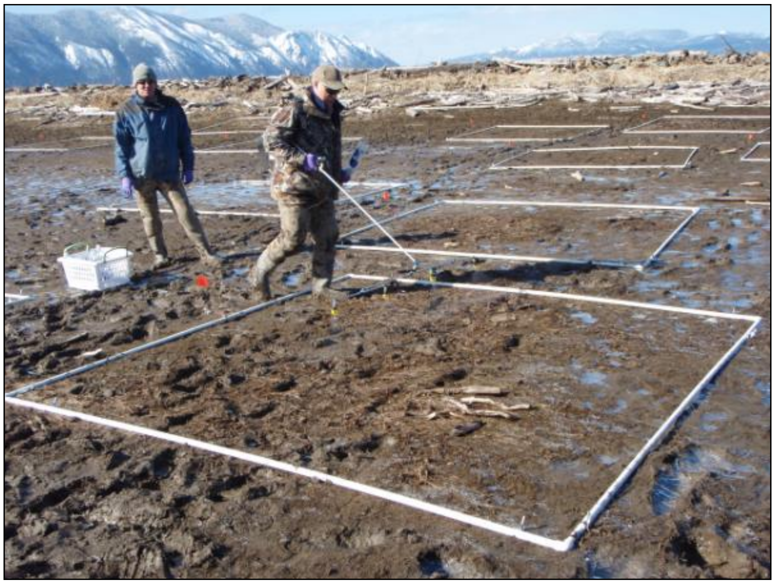


Figure 1. John Madsen applying herbicide to the bare ground plots at Pend Oreille Lake, Idaho. Photo by Tom Woolf.

As part of the normal water management regime, Lake Pend Oreille undergoes a drawdown (≥ 11 ft) every fall and winter for flood control and to help protect infrastructure from ice damage. During this time, flowering rush plants are exposed and are easily accessible to implement management techniques. To date there is no published peer reviewed literature that can provide reliable control recommendations for flowering rush. Anecdotal reports suggest that foliar herbicide applications will control emergent plants; however, submersed plants are typically not controlled. There has been no attempt to our knowledge of conducting subsurface herbicide applications to target submersed flowering rush plants; but given water exchange characteristics and the overall water volume to treat this may be unfeasible in Lake Pend Oreille. Thorough evaluations of management techniques are needed to determine a viable approach to managing flowering rush in Lake Pend Oreille and other lakes in this region. Treatment of flowering rush during times of lake drawdown represents a potential opportunity to effectively treat this plant. Due to concerns regarding endangered species in the Lake Pend Oreille system, only a small number of herbicides were applied to the drawdown area "in-field".

Figure 2. US Army Corps of Engineers Albeni Dam Project office resource manager Betsy Hull (right) and her intern Taylor (left) dig flowering rush rhizomes. Photo by John Madsen.

Materials and Methods

The field evaluation was conducted in 3 m x 3 m plots that were established in March 2011, in Lake Pend Oreille during the winter drawdown period. Plots were delineated using a frame constructed from PVC pipe and held down with sandbags. Additionally, the coordinates of each corner of every frame were recorded using a GPS

Task 8.1. Collaboration - Idaho (Cont.)

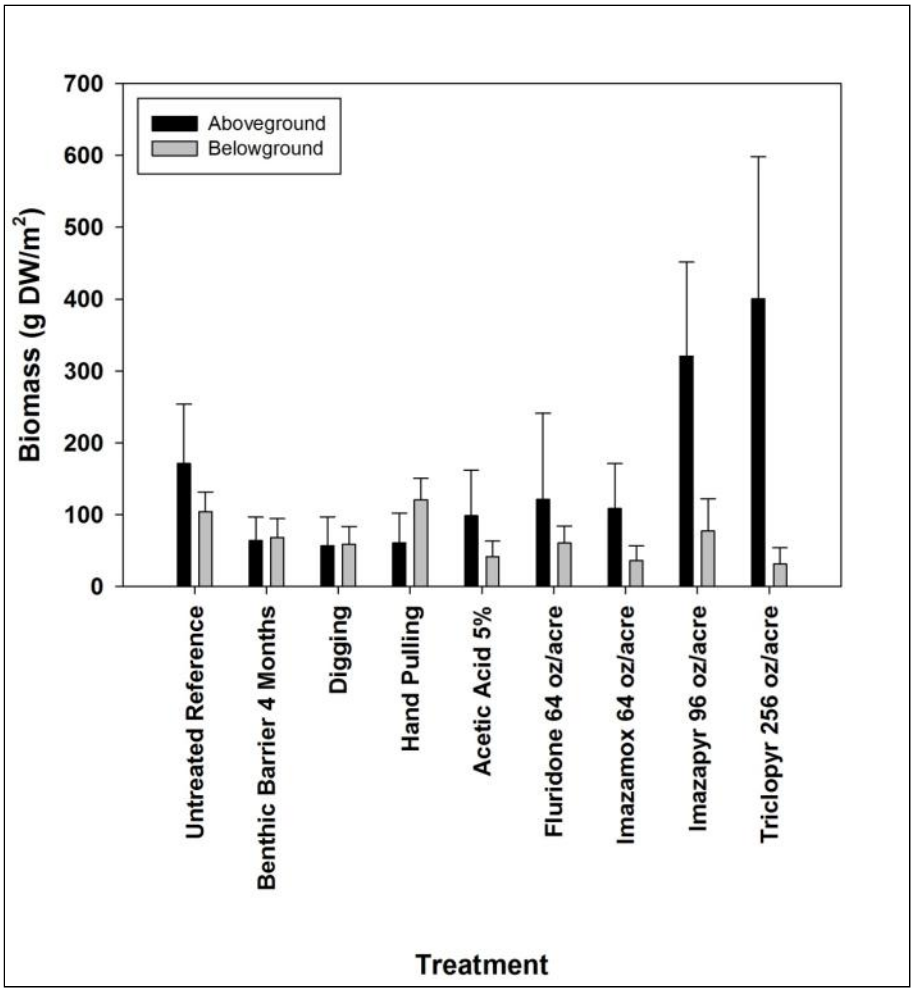


Figure 3. Field plot mean (± 1 SE) flowering rush biomass 16 weeks after implementation of management techniques in field plots in Lake Pend Oreille, ID.

device. Once the plots had been established, management techniques were randomly assigned to each plot and pretreatment belowground biomass was collected using a PVC coring device (Madsen et al. 2007).

Management techniques included the maximum labeled rates for bare ground applications of imazapyr, triclopyr, fluridone, imazamox, and acetic acid; other techniques included hand pulling, digging, and benthic barrier (deployed for 4, 6, and 12 months, only 4 month barrier data are included in this report). Each treatment including an untreated reference was replicated in 4 plots. Herbicides were applied using a CO_2 pressurized backpack spray system with a 5 nozzle boom and 8002 flat fan spray tips (Figure 1). Applications were made based on a spray volume of 100 gal/acre. Hand pulling consisted of pulling only visible plants within the designated plots; no attempt was made to excavate underground plant structures. Manual digging was completed using a shovel. Benthic barriers were affixed to a PVC frame and placed on the sediment in respective plots. Sand bags were used to hold the benthic barrier in place. In addition to biomass data, the total time of utilizing each management technique was recorded in each plot to assess labor for each technique.

At 16 WAT, the 4 month benthic barriers were removed and two biomass samples collected in all plots for each management technique using a PVC coring device (0.10 m^2). All biomass samples were separated into above and belowground tissues, dried, and weighed to determine biomass. Percent control, stem density, and biomass were determined pretreatment and 16 WAT. Field data were subjected to a Kruskal-Wallis non-parametric Analysis of Variance to determine treatment effects. Time data for each management technique were averaged and reported.

Results and Discussion

Flowering rush biomass was not reduced by any management technique with respect to untreated reference plots in the field treatment plots(aboveground p=0.46, belowground p=0.12) (Figure 3). Belowground biomass of all management techniques was lower than pretreatment belowground biomass (635.03 g DW/m^2); although, biomass in reference plots were also lower. High variability in the results is likely due to the clumped growth pattern of the flowering rush population in the Clark Fork Delta area of Lake Pend Oreille, the sampling intensity utilized in the study (i.e. 2 samples per plot), and pretreatment samples were collected during the winter drawdown whereas the 16 WAT samples were collected when there was 5-7 ft. of water on the plots (Figure 4); all of which likely increased the variability in biomass samples.

The lack of efficacy may be attributed to the environmental conditions in the area following treatment. Due to a high

Task 8.1. Collaboration - Idaho (Cont.)

snowpack and high projected runoff for the spring of 2011 the water levels in Lake Pend Oreille were kept low for a longer period of time than was originally projected. As a result, plots were treated three weeks prior to the lake level rising to the point of inundating the plots. This time lag between treatment and inundation accompanied with cold rainy conditions may have led to delayed plant growth and lack of observed efficacy in the field evaluation.

The time in implementing management techniques is depicted in Table 1. The application of herbicides took on average 38 seconds for each plot, whereas the other techniques required 12-30 minutes per plot. If differences in efficacy were detected, the differences in implementation time could have implications for cost effectiveness and labor requirements.

Table 1. Average time of management technique implementation in field plots in Lake Pend Oreille, ID.

Management Technique	Average Time (Minutes)	# of People	Person Minutes
Herbicide	0.6	1	0.6
Hand Pulling	23.2	2	46.4
Digging	12.6	1.5	18.9
Benthic Barrier	30.0	2	60.0

Additional samples need to be collected 1 year after treatment in all plots to assess below-ground biomass during the same time and conditions when the initial pretreatment samples were collected.

Acknowledgements

The authors would like to acknowledge the support of a number of groups and individuals who supported this project: Herbicide for the field plot trials were provided by SePro Corporation. Plot establishment and evaluation was supported by Brad Bluemer and Lorie Jasmine (Bonner County), Duke Guthrie (Boundary County), John Selby (Cygnet Enterprises) and Betsy Hull (USACE Albeni Falls).

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Figure 4. Flowering rush growing submersed in Pend Oreille Lake off the delta of the Clark Fork River.

Task 8.2. Collaboration - Montana

PI: Wes Burger
Co-PI: John Madsen, David Shaw

Plant Community Response in Small Plots One Year after Treatment with Triclopyr and Endothall in Noxon Rapids Reservoir, MT, 2011

Ryan M. Wersal and John D. Madsen

Figure 1. A weighted thatch rake was used to determine the species present at each point. In this case, elodea (*Elodea canadensis*) was found at this point. Photo by John Madsen.

Aquatic plants are important to lake ecosystems (Madsen et al. 1996, Wetzel 2001) and are essential in promoting the diversity and function of an aquatic system. Littoral zone habitat and associated plants may be responsible for a significant proportion of primary production for the entire lake (Ozimek et al. 1990, Wetzel 2001). Littoral zone habitats are prime areas for the spawning of most fish species, including many species important to sport fisheries (Savino and Stein 1989). Furthermore, aquatic plants anchor soft sediments, stabilize underwater slopes, remove suspended particles, and remove nutrients from overlying waters (Barko et al. 1986, Madsen et al. 2001). The introduction of non-native plants into littoral zone habitats often alters the complex interactions occurring in these areas (Madsen 1998). Dense stands of non-native plants are often responsible for reduction in oxygen exchange, depletion of dissolved oxygen, increases in water temperatures, and internal nutrient loading (Madsen 1998).

Eurasian watermilfoil (*Myriophyllum spicatum* L.) is a non-native invasive species that, when present, has been associated with declines in native plant species richness and diversity (Madsen et al. 1991, Madsen et al. 2008). Eurasian watermilfoil also poses nuisance problems to humans in the form of increasing flood frequency and intensity, impeding navigation, and limiting recreation opportunities (Madsen et al. 1991). Furthermore, the establishment of Eurasian watermilfoil and subsequent spread is likely perpetuated by the ease of fragmentation (both physical and physiological) of this plant, water movement within the reservoir, and high watercraft traffic that moves fragments to new areas.

Although the impacts form Eurasian watermilfoil are numerous, controlling this species is often difficult and unpredictable. Flowing water, such as the Lower Clark Fork River, further complicates the use of herbicides as water flow will increase the dilution and dissipation of the herbicides. Herbicide applications in run of the river reservoirs are often subject to more extreme perturbations than those of natural lakes. Run of the river reservoirs have variable water -exchange patterns, typically tied to dam operations, which will impact aqueous distribution of herbicides resulting in reduced chemical exposure times against target plants and unacceptable effectiveness (Getsinger et al. 1997).

The use of auxin mimicking herbicides such as 2,4-D and triclopyr, and the contact herbicide endothall have been used extensively for Eurasian watermilfoil control. Additionally, herbicide concentration exposure time (CET) relationships have been designed under controlled conditions to guide management decisions on choosing the correct herbicide concentration with respect to contact time (Netherland et al. 1991, Netherland and Getsinger 1992). However, little data exists with respect to combining a contact herbicide with a systemic herbicide to reduce the exposure time requirements and maintain plant control. Mesocosm trials of herbicide combinations resulted in reduced contact time needed for effective Eurasian watermilfoil control, while maintaining the benefits of the longer term control afforded by the systemic herbicide (Madsen et al. 2010). Though small scale trials have been conducted, there has been limited field assessment of this herbicide combination. Pursuant to this, effective herbicide concentrations used in field situations still need to be determined; and the selectivity spectrum of non-target plants to this combination is still unknown.

Therefore, our objectives of this study were to:

1) Demonstrate at the field scale the effectiveness of combining triclopyr with endothall for control of Eurasian watermilfoil and curlyleaf pondweed in flowing systems.

Task 8.2. Collaboration - Montana (Cont.)

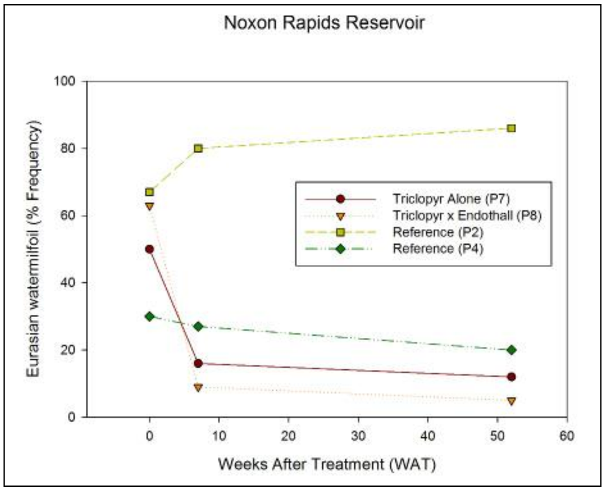

Figure 2. Eurasian watermilfoil percent frequency in plots 7 (treated with triclopyr), 8 (treated with a combination of triclopyr and endothall), 2 (untreated reference), and 4 (untreated reference) in Noxon Rapids Reservoir for pretreatment, 7 and 52 weeks after treatment (WAT).

2) Evaluate the aquatic plant community response to herbicide treatments one year after treatment.

Materials and Methods

Point Intercept Assessments. Pretreatment (0 weeks after treatment (WAT)) point intercept surveys were conducted on July 20, 2010 using a 50 m grid to assess the plant community in four plots on Noxon Rapids Reservoir prior to herbicide application. The four plots selected were based on surveys conducted throughout the reservoir in 2008 and 2009 (Wersal et al. 2009, Wersal et al. 2010). Plots 2 (23.8 acres) and 4 (28.5 acres) served as our untreated reference plots, meaning no herbicides were placed in these plots. Plot 7 (28.3 acres) was treated with triclopyr alone, and plot 8 (15.8 acres) was treated with the combination of triclopyr + endothall. Additional surveys of each plot occurred at 7 WAT and 52 WAT to assess herbicide efficacy on Eurasian watermilfoil and curlyleaf pondweed; as well as to assess non-target effects on the entire aquatic plant community.

Survey methods were similar to those utilized during recent projects in the Pacific Northwest (Madsen and Wersal 2008, Wersal et al. 2010). A total of 36, 38, 35, and 37 points were surveyed in Plots 2, 4, 7, and 8 respectively. Surveys were conducted by boat using Global Positioning System (GPS) technology to navigate to each point. Survey accuracy was 1-3 m (3-10 ft) depending on satellite reception. At each survey point, a weighted thatch rake was deployed to determine the presence of plant species (Figure 1). Spatial data were recorded electronically using FarmWorks Site Mate® software (Hamilton, IN). The software allowed for in-field geographic and attribute data collection. Data were recorded in database templates using specific pick lists constructed exclusively for this project. Site Mate® provided an environment for displaying geographic and attribute data and enabled navigation to specific locations on the lake.

Statistical Analyses. Plant species presence was averaged over all points sampled and multiplied by 100 to calculate percent frequency. Changes in the occurrence of plant species between the pretreatment survey and 7 WAT and 52 WAT surveys were determined using the McNemar's test. The McNemar's test is used to assess the differences in the correlated proportions within a given data set between variables that are not independent, i.e. sampling the same points pre- and post-treatment (Stokes et al. 2000, Wersal et al. 2006). All comparisons were made back to pretreatment plant occurrence. Native species richness was calculated for each plot and subjected to a general linear model. If a significant difference in species richness was detected, means were separated using a Fisher's Protected LSD test. All analyses were conducted at a $p < 0.05$ significance level.

Results and Discussion

Plot 7 (Triclopyr Only)

The presence of Eurasian watermilfoil in Plot 7 significantly declined from 50% before herbicide treatment to 16% 7 WAT and 12% 52 WAT (Figure 2). This represents 70% and 76% control respectively for the 7 and 52 WAT surveys.

No significant impact was observed from the herbicide application on native plant species at either the 7 WAT or 52 WAT surveys (Figure 3). Native species richness was not different between survey times as well. The presence of elodea in this plot increased from the pretreatment survey to the 52 WAT survey, suggesting that as Eurasian watermilfoil was removed Elodea was able to re-colonize those areas. Similar results were observed in Hayden Lake, ID when applications of 2,4-D and triclopyr were made for Eurasian watermilfoil control (Wersal et al. 2010). The use of triclopyr alone resulted in very selective control of Eurasian watermilfoil for at least a full year after treatment, a result due to the CET achieved after treatment (Wersal and Madsen 2011).

Plot 8 (Triclopyr and Endothall)

Eurasian watermilfoil in plot 8 significantly declined by 7 WAT and control was maintained to 52 WAT with the

Task 8.2. Collaboration - Montana (Cont.)

combination of triclopyr + endothall (Figure 2). Eurasian watermilfoil was observed at 63%, 9%, and 5% of survey points during the pretreatment, 7 WAT, and 52 WAT surveys respectively (Figure 2). These results represent 92% reduction in Eurasian watermilfoil occurrence out to 52 WAT.

The combination of triclopyr + endothall was much less selective in plot 8, as there were impacts to the native plant community (Figure 3). Native species richness metrics for both the 7 and 52 WAT surveys were lower than what was estimated during the pretreatment surveys. The presence of elodea increased during the 52 WAT survey, again likely due to opening new areas for expansion and growth by the herbicide application. Although, the combination herbicide treatment was effective there will be a trade-off in selectivity when compared to using triclopyr alone. Given the estimated half-life for dye and herbicide in plot 8 (Wersal and Madsen 2011), triclopyr applied alone would have been much less effective. In areas where there is potential for high water exchange, the combination treatment would be necessary to maximize control.

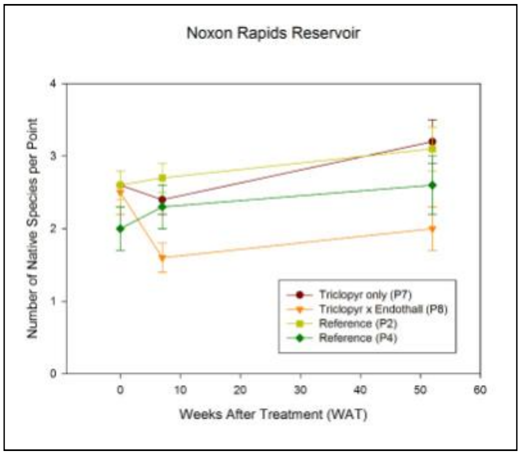

Figure 3. Average number of native species per point in plots 7 (treated with triclopyr), 8 (treated with a combination of triclopyr and endothall), 2 (untreated reference), and 4 (untreated reference) in Noxon Rapids Reservoir for pretreatment, 7 and 52 weeks after treatment (WAT).

Plots 2 and 4 (Untreated Reference Plots)

The plant community in plot 2 has changed little over the course of the study. Eurasian watermilfoil was found at survey points during the post treatment surveys where it was not observed during previous surveys, suggesting that the population in plot 2 is expanding, though statistical differences in presence have not been detected (Figure 2). Species richness did not change between any of the surveys.

The presence of Eurasian watermilfoil in plot 4 did not change between the pretreatment survey and the 7 and WAT surveys (Figure 2). Therefore, the reductions observed in Eurasian watermilfoil in plots 7 and 8 can be attributed to the herbicide applications.

Conclusions

Herbicide applications were effective at reducing the presence of Eurasian watermilfoil in the treated plots, 76% and 92% for plots 7 and 8 respectively to 52 WAT. Control of Eurasian watermilfoil is achievable in flowing water systems if there is an understanding of water exchange characteristics at a given site. Water exchange is likely to be site specific within Noxon so additional studies are needed, especially upstream, to develop a water exchange data set for portions of the reservoir to base management decisions on.

Our data indicate that Eurasian watermilfoil can be selectively removed from areas of Noxon, and that native species will rapidly re-colonize areas once inhabited by Eurasian watermilfoil. Furthermore, these data suggest that Eurasian watermilfoil control can be maintained for at least two growing seasons with a single herbicide application. Achieving multiple year control would allow for the treatment of additional areas without having to continually re-treat in the same plots. Though this will depend upon site location, water flow, and distance from other Eurasian watermilfoil infestations that would re-colonize an already treated area.

The combination herbicide treatment was less selective than applying triclopyr alone. Using triclopyr alone would not have been effective in plot 8, as the necessary exposure time would not have been met to achieve acceptable results. Therefore, the use of triclopyr alone will not be conducive to all places in the reservoir, especially in areas of increased water-exchange; these areas will need the combination treatment to meet CET requirements. The potential short term impacts of herbicide applications on the native plant community should not overshadow the long-term effects that Eurasian watermilfoil will have if left unmanaged (Figure 4). Species such as leafy pondweed (*Potamogeton foliosus*) and elodea which are widespread in Noxon recovered by 52 WAT to levels similar or greater than what was observed during the pretreatment survey in plot 8. There is a native propaglue bank present in Noxon that will allow the native community to recover following Eurasian watermilfoil management.

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Figure 4. Topped-out Eurasian watermilfoil (*Myriophyllum spicatum*) in Noxon Rapids Reservoir. Photo by John Madsen.

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Task 9. Coordination and Reporting

Victor Maddox digging pricklypear cactus on Petit Bois Island in Mississippi. Photo by Maurice Duffel, USDA APHIS.

Tom Woolf of the Idaho State Department of Agriculture laying out research plots on the drawn-down littoral zone of Pend Oreille Lake, Idaho near the mouth of the Clarks Fork River. We are evaluating management techniques in drawdown areas for control of flowering rush (*Butomus umbellatus*). Photo by John Madsen.

Task 9.1. Coordination and Reporting

PI: John Madsen

Collaborations: Partnerships for Invasive Species Management

John Madsen, editor

The funding from USGS Invasive Species Program and NBII has been extensively leveraged over the past seven years. The base funding has supported developing programs and applications which, in turn, allow us to work with others on complementary projects and programs. All of us in the invasive species program have either found partners who share our interests and desire for invasive species management, or through the visibility afforded by this research program, the partners have sought us out to assist them. These partners may be governments at the international, national, state, or local level; nongovernment organizations, private corporations, and, of course, the hundreds of volunteers that have worked with us on the Cactus Moth Detection and Monitoring System and the Invasive Plant Atlas of the MidSouth.

I anticipate that many, if not most, of these partnerships will continue after our USGS / NBII funding has terminated.

The following is a listing of significant collaborations:

Christopher Brooks and **Gary Ervin** have continued their collaborations with Varone and Logarzo (USDA-ARS, Buenos Aires, Argentina) and Carpenter and Hight (USDA-ARS, Tifton and Tallahassee). They currently are planning a research proposal to investigate the roles of environment versus host species on growth, survival, and reproduction of *C. cactorum* in the US and Argentina.

Figure 1. Ryan Wersal presenting at an invasive aquatic plant workshop hosted by Mississippi Exotic Pest Plant Council (MS EPPC). Photo by Julie Marcy.

Gary Ervin was invited to serve on graduate student committees at Arkansas State University (*Cactoblastis cactorum* research; doctoral dissertation) and University of Texas-PanAm (invasive grass research; Master’s thesis).

Gary Ervin served as co-PI on a grant proposal with Drs. Teresa Feria and Andrew McDonald (University of Texas-PanAm). The proposal, submitted to the National Science Foundation in July 2011, was entitled: Integrating Species Interactions with Ecophysiological Profiles to Improve Predictions of Current and Future Plant Invasions.

Gary Ervin has ongoing collaborations with his former postdoctoral student, Travis Marsico, who currently as Assistant Professor in the Biology Department at Arkansas State University, Jonesboro, Arkansas. These involve serving on student committees, as well as developing papers and conference presentations on collaborations related to cactus moth research.

Gary Ervin, **Victor Maddox**, and/or **John Madsen** participated in the monthly Invasive Species Working Group teleconferences throughout 2011.

Victor Maddox worked with USDA APHIS PPQ eastern and western regions to survey for pricklypear cactus and cactus moth, as well as hold training seminars in Louisiana and Texas.

Victor Maddox, **John Madsen**, and **Ryan Wersal** presented at a workshop on invasive aquatic plants, hosted by Mississippi Exotic Pest Plant Council and the Mississippi Cooperative Weed Management Association.

Task 9.1. Coordination and Reporting (Cont.)

Fig. 2. Ryan Wersal (left) and Jonathan Fleming (right) used kayaks to survey rivers in Montana for Eurasian watermilfoil (*Myriophyllum spicatum*), as sponsored by MT DNRC.

John Madsen and **Ryan Wersal** worked with former PhD student Wilfredo Robles and other members of the Southern Weed Science Society to plan and implement an aquatic plant management workshop for Puerto Rican territorial regulators and resource managers. The workshop, chaired by Dr. Robles of the University of Puerto Rico, was held during the 2011 annual meeting of the Southern Weed Science Society in San Juan, Puerto Rico.

John Madsen and **Ryan Wersal** are finalizing an agreement with the Food and Agriculture Organization (FAO) of the United Nations, to write a review of the importance of aquatic plants under the International Plant Protection Convention.

John Madsen and **Ryan Wersal** participated with local agencies in two separate American Reconstruction and Recovery Act (ARRA) grants to state and local governments, sponsored by the US Army Engineer Research and Development Center. In Idaho, we partnered with Tom Woolf of the Idaho State Department of Agriculture on studies for controlling flowering rush (*Butomus umbellatus*) in drawn-down areas of Pend Oreille Lake, Idaho. In Montana, we worked with Sanders County, Montana and the Eurasian watermilfoil Task Force on management of Eurasian watermilfoil in Noxon Reservoir.

John Madsen collaborated with John Skogerboe and Kurt Getsinger (U.S. Army Engineer Research and Development Center) and Michelle Marko (Concordia College, Moorhead, MN), on flowering rush ecology and management studies for the Pelican River Watershed District and the Minnesota Department of Natural Resources.

John Madsen served on the board of the newly-formed North American Invasive Species Network.

We all participated in meetings with Dr. Jerry Cook of Sam Houston State University to explore potential joint funding on a multistate project.

John Madsen participated in a US Army Engineer Research and Development Center workshop, organized by Kurt Getsinger and Heidi Sedivy, on managing invasive plants in flowing waters of the Pacific Northwest, held in Spokane, WA.

John Madsen collaborated with Renata Claudi of RNT Consulting on a research project investigating the growth of nuisance forming aquatic plants in Lake Havasu, Arizona and California, for the Central Arizona Project.

John Madsen attended the starting workshop for the new USGS bioinformatics initiative, Biological Information Serving our Nation (BISON).

John Madsen organized and **Ryan Wersal** presented at an applicator workshop associated with the MidSouth Aquatic Plant Management Society, in Guntersville, AL.

Ryan Wersal and **John Madsen** contracted with the Montana Department of Natural Resource Conservation to survey reservoirs and rivers in western Montana for the presence of Eurasian watermilfoil.

Ryan Wersal and **John Madsen** collaborated with Kurt Getsinger of USAERDC on a study of managing small patches of Eurasian watermilfoil in Noxon Reservoir, Montana, supported by Sanders County (MT) and the Montana Weed Trust.

Invasive Species Publications for 2011

Peer-Reviewed Journals

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Ervin, G. N. In press. Indian fig cactus (*Opuntia ficus-indica* (L.) Miller) in the Americas: An uncertain history. *Haseltonia*.

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Fleming, J. P., Madsen, J. D., & **Dibble, E. D**. 2011. Macrophyte Re-Establishment for Fish Habitat in Little Bear Creek Reservoir, Alabama, USA. Journal of Freshwater Ecology. 26(1), 105-114.

Fleming, J. P., Madsen, J. D., & **Dibble, E. D**. 2011. Development of a GIS Model to Enhance Macrophyte Re-establishment Projects. Applied Geography. 32, 629-635.

Huenemann, T., **E. Dibble**, and **J. Fleming**. 2011. Influence of turbidity on the foraging of largemouth bass in aquaria. Transaction of the American Fisheries Society (In Press).

Kovalenko, K.E., **E.D. Dibble**. 2011. Effects of invasive macrophyte on trophic diversity and position of secondary consumers. Hydrobiologia 663: 167-173.

Marsico, T. D., Wallace, L., Ervin, G. N., Brooks, C., McClure, J. E., & Welch, M. E. 2011. Geographic Patterns of Genetic Diversity from the Native Range of *Cactoblastis cactorum* (Berg) Support the Documented History of Invasion and Multiple Introductions for Invasive Populations. Biological Invasions. 13, 857-868.

Sauby, K.E., T.D. Marsico, **G.N. Ervin and C.P. Brooks**. 2011. Accepted, pending revisions. Host plant identity and associational susceptibility affect the prevalence of the invasive moth, *Cactoblastis cactorum*. *Florida Entomologist*.

Schultz R., and **E. Dibble**. 2011. Effects of invasive macrophytes on freshwater fish and macroinvertebrate communities: the role of invasive plant traits. Hydrobiologia (in press).

Wersal, R. M., Cheshier, J**., Madsen, J. D.,** & Gerard, P. D. 2011. Phenology, Starch Allocation, and Environmental Effects on *Myriophyllum aquaticum*. Aquatic Botany. 95, 194-199.

Wersal, R. M., & Madsen, J. D. 2011. Comparative Effects of Water Level Variations on Growth Characteristics of *Myriophyllum aquaticum*. Weed Research. 51(4), 386-393.

Wersal, R. M., & Madsen, J. D. 2011. Influences of Water Column Nutrient Loading on Growth Characteristics of the Invasive Aquatic Macrophyte *Myriophyllum aquaticum* (Vell.) Verdc. Hydrobiologia. 665(1), 93-105.

Invasive Species Publications for 2011 (Cont.)

Conference Presentations

Brooks, C. P. 2011. Integrating models and data: The intersection of math, statistics and biology. Mathematics & Statistics Research Experience for Undergraduates, Mississippi State University, June 2011. Invited.

Ervin, G. N. 2011. Combining biological databases and predictive modeling in conservation planning. Department of Biological Sciences, Arkansas State University, Jonesboro, AR, February 16, 2011. Invited.

Lucardi, R. and **G. N. Ervin.** 2011. Multi-scale ecological understanding of cogongrass: Landscape genetics and habitat modeling. Natural Areas conference workshop: Biology and control of cogongrass (*Imperata cylindrica*), Tallahassee, FL, November 1-4, 2011. Invited.

Garcia, B. M., S. A. del Alto, T. P. Feria, A. Felicisimo, J. Goulovob, **G. N. Ervin, and C. P. Brooks**. 2011. Potential distribution of the Prickly–pear moth *Cactoblastis cactorum* in south Texas and north Mexico. 96th Meeting of the Ecological Society of America, Austin, TX, August 8-12, 2011.

Garcia, C. I., T. P. Feria, A. McDonald, K. Summy, and **G. N. Ervin.** 2011. Potential distributional effects on the invasive grass, Panicum maximum, due to climate change. 96th Meeting of the Ecological Society of America, Austin, TX, August 8-12, 2011.

Lambert, B., **G. N. Ervin**, and **C. P. Brooks**. 2011. Comparing morphological variation to genetic variation in an invasive herbivore, *Cactoblastis cactorum* (Berg). Southeastern Ecology and Evolution Conference, Auburn University, Auburn, AL, March 25-27, 2011.

Lambert, B., **G. N. Ervin**, and **C. P. Brooks**. 2011. Comparing morphological variation to genetic variation in an invasive herbivore, *Cactoblastis cactorum* (Berg). Biology Undergraduate Research Program, Mississippi State University Department of Biological Sciences, April 8, 2011.

Lucardi, R., **G. N. Ervin**, **L. Wallace,** and C. Bryson. 2011. Population genetic analysis of cogongrass (*Imperata cylindrica*) in Mississippi and Alabama. Southeast Exotic Pest Plant Council conference, Lexington, KY, May 3-5, 2011.

Lucardi, R., **G. N. Ervin**, **L. Wallace,** and C. Bryson. 2011. Population genetic analysis of an invasive species: Cogongrass (*Imperata cylindrica* (L.) P. Beauv.) in Mississippi and Alabama. 96th Meeting of the Ecological Society of America, Austin, TX, August 8-12, 2011.

Marsico, T. D., **G. N. Ervin,** and **C. P. Brooks**. 2011. Putting hypothesized native-range phylogeographic patterns of *Cactoblastis cactorum* to the test using genetic and climatic data. Fifth International Biogeography Society Meeting, Heraklion, Crete, Greece, January 8, 2011.

Maddox, V. L., Madsen, J. D., & Chapin, R. 2011. Formation of the Mississippi Cooperative Weed Management Area: A New Vision for an Old Problem. Southern Weed Science Society. 64th Annual Meeting of the Southern Weed Science Society, Caribe Hilton, San Juan, Puerto Rico.

Madsen, J. D. 2011. Something Green in Your Pond. 5th National Aquaculture Extension Conference. Memphis, TN.

Schultz, R., E. Dibble, **P. Amburn, and D. Irby.** 2011. Taking the plunge without a wetsuit: using a 3-D visualization to explore invasive macrophyte effects on aquatic communities. Ecological Society of American, August 2011, Austin, TX.

Invasive Species Publications for 2011 (Cont.)

Getsinger, K. D., **Madsen, J. D., Wersal, R. M.,** Skogerboe, J. G., Nawrocki, J., & Richardson, R. J. 2011. Aquatic Herbicide Trials for Selective Control of Eurasian Watermilfoil and Curlyleaf Pondweed in Noxon Rapids Reservoir: 2009-2010. Western Aquatic Plant Management Society Annual Meeting. Denver, CO.

Madsen, J. D., Wersal, R. M., & McLaurin, C. S. 2011. Sensitivity of Native Aquatic Plant Species to Imazamox (Clearcast) and Penoxsulam (Galleon). Western Aquatic Plant Management Society Annual Meeting. Westminster, CO.

Madsen, J. D., Cheshier, J., Phuntumart, V., Thum, R., & Welch, M. 2011. Morphological and Genetic Taxonomic Analysis of Native and Nonnative Watermilfoil in Reservoirs of the Lower Clark Fork River System. Western Aquatic Plant Management Society. Westminster, CO.

Madsen, J. D., Wersal, R. M., & McLaurin, C. S. 2011. Sensitivity of Native Aquatic Plant Species to Imazamox and Penoxsulam. Midwest Aquatic Plant Management Society Annual Meeting. Grand Rapids, MI.

Cheshier, J., & Madsen, J. D. 2011. The Life History of Common Reed: Phragmites Australis (Cav.) Trin. Ex Steud. Weed Science Society of America. Portland, OR.

Madsen, J. D. 2011. Mississippi Invasive Species Programs: Finding Partners and Building Networks. 2011 Texas Invasive Plant and Pest Conference. Ladybird Johnson Wildflower Center, Austin, TX: Texas Invasive Plant and Pest Council.

Madsen, J. D. 2011. Aquatic Weed Control. National Roadside Vegetation Management Association. Little Rock, AR.

Fleming, J. P., Spickard, M. R., **Dibble, E. D., & Madsen, J. D.** 2011. Aquatic Community Responses to Different Plant Control Strategies in the Mississippi Alluvial Valley. 51st International Aquatic Plant Management Society Meeting. Baltimore, MD.

Heilman, M. A., **Madsen, J. D., Wersal, R. M.,** & Netherland, M. D. 2011. Overview of Emerging Use Patterns for Management of Invasive Aquatic Vegetation with the ALS Herbicides Imazamox (Clearcast) and Penoxsulam (Galleon). Aquatic Plant Management Society 51st Annual Meeting. Baltimore, MD: July 24-28 2011.

Madsen, J. D. 2011. Flowering Rush (*Butomus umbellatus* L.): An Invader on the Move. Aquatic Plant Management Society 51st Annual Meeting. Baltimore, MD: July 24-28 2011.

Madsen, J. D. 2011. To Manage or Not to Manage **-** That Is the Question. Aquatic Plant Management Society 51st Annual Meeting. Baltimore, MD: July 24-28 2011.

Marko, M., Olson, C., Dusek, S., Salo, E., & **Madsen, J. D.** 2011. Phenology of Flowering Rush and Hardstem Bulrush in Detroit Lakes. Aquatic Plant Management Society 51st Annual Meeting. Baltimore, MD: July 24-28 2011.

Fleming, J. P., Madsen, J. D., & Dibble, E. D. 2011. Conceptual Model and Deductive GIS Methodology to Identify Suitable Macrophyte Habitat. Association of American Geographers 2011 Annual Meeting. Seattle, WA.

Madsen, J. D., Cheshier, J., Phuntumart, V., Thum, R., & Welch, M. 2011. Morphological and Genetic Taxonomic Analysis of Native and Nonnative Watermilfoil in Reservoirs of the Lower Clark Fork River System. Midwest Aquatic Plant Management Society Annual Meeting. Grand Rapids, MI.

Madsen, J. D. 2011. Economic and Ecological Impacts of Invasive Aquatic Plants. Southern Weed Science Society 64th Annual Meeting. San Juan, Puerto Rico.

Madsen, J. D. 2011. Advantages and Disadvantages of Aquatic Plant Management Techniques. Southern Weed Science Society 64th Annual Meeting. San Juan, Puerto Rico.

Invasive Species Publications for 2011 (Cont.)

Madsen, J. D., Ervin, G. N., Wersal, R. M., & Fuller, P. 2011. Two Web-Based Databases for Invasive Aquatic Plant Locations and Information. Southern Weed Science Society 64th Annual Meeting. San Juan, Puerto Rico.

Lambert, B., **Ervin, G. N., & Brooks, C.** 2011. Comparing Morphological Variation to Genetic Variation in an Invasive Herbivore, *Cactoblastis cactorum* (Berg). Southeastern Ecology and Evolution Conference, Auburn University, Auburn, AL.

In-House

Woolf, T. E., **Madsen, J. D., & Wersal, R. M.** 2011. Flowering Rush Control Project for Lake Pend Oreille, Idaho: Preliminary Summary on Mesocosm and Field Evaluations Preliminary. Mississippi State University: Geosystems Research Institute.
Wersal, R. M., & Madsen, J. D. 2011. Plant Community Response in Small Plots One Year after Treatment with Triclopyr and Endothall in Noxon Rapids Reservoir, MT, 2011. GRI Report # 5049. Mississippi State University: Geosystems Research Institute. 21.

Wersal, R. M., & Madsen, J. D. 2011. Evaluating Plant Response to Triclopyr Applied Alone and in Combination with Endothall in Noxon Rapids Reservoir for 2010: Phase 2. GRI Report #5046. Mississippi State University: Geosystems Research Institute.

Madsen, J. D., Amburn, P., Brown, R. L., Dibble, E. D., Ervin, G. N., Shaw, D. R., Abbott, C. F., Baker, G., Bloem, K., Brooks, C., Irby, D., Lee, S., Maddox, V. L., Rose, R., Schulz, R., Wallace, L., Wasson, L. L., Welch, M., Wersal, R. M., McBride, D. W., & Madsen, N. 2011. Research to Support Integrated Management Systems of Aquatic and Terrestrial Invasive Species: Annual Report, 2010. GRI Report #5047. Mississippi State University: Geosystems Research Institute.

Cox, M. C., **Madsen, J. D., & Wersal, R. M.** 2011. Aquatic Plant Distribution Assessment within the Littoral Zone of the Ross Barnett Reservoir, MS in 2010: A Six Year Evaluation. GRI Report #5044. Mississippi State University: Geosystems Research Institute.

Cox, M. C., & **Madsen, J. D.** 2011. Estimation of Alligatorweed (*Alternanthera philoxeroides* (Mart.) Griseb.) and Waterhyacinth (*Eichhornia crassipes* (Mart.) Solms) Distribution in the Ross Barnett Reservoir Using Remote Sensing Techniques. GRI Report #5045. Mississippi State University: Geosystems Research Institute.

Technical Report

Mudge, C. R., **Wersal, R. M.,** & Nelson, L. S. 2011. Evaluation of Commercially Available Herbicide Mixes for Control of Rosette Stage Yellow Starthistle (*Centaurea solstitialis* L.). APCRP Technical Notes Collection (ERDC/EL TN-11-3). Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Maddox, V. L., & Kelly, L. S. 2011. Selecting Landscape Trees with Special Comments on Invasive and Native Plants. Mississippi State University: Extension Service of Mississippi State University.

Maddox, V. L., & Kelly, L. S. 2011. Selecting Landscape Shrubs with Special Comments on Invasive and Native Plants. Mississippi State University. Publication 2651: Extension Service of Mississippi State University.

Parkinson, H., Mangold, J., Jacobs, J., **Madsen, J. D.,** & Halpop, J. 2011. Biology, Ecology, and Management of Eurasian Watermilfoil (*Myriophyllum spicatum* L.). Montana State University: Montana State University Extension Service. EB0193, 9.

Invasive Species Publications for 2011 (Cont.)

Professional Presentations

Madsen, J. D. 2011. Identification of Common Aquatic Plants and Weed Problems in the MidSouth. Aquatic Plant Management Applicator Workshop,. Guntersville, AL: MidSouth Aquatic Plant Management Society Annual Meeting.

Madsen, J. D. 2011. Non-chemical Control of Aquatic Plants and Developing a Management Plan. Invasive Aquatic Weed Symposium. Stoneville, MS: Mississippi Exotic Pest Plant Council.

Madsen, J. D. 2011. The Ecology of Aquatic Plants and Its Implications for Lake Management. USACE Workshop: Control of Invasive Aquatic Plants using Herbicides in Flowing Water Systems in the Northwest. Spokane, WA: US Army Corps of Engineers.

Madsen, J. D. 2011. Understanding Eurasian Watermilfoil. USACE Workshop: Control of Invasive Aquatic Plants using Herbicides in Flowing Water Systems in the Northwest. Spokane, WA: US Army Corps of Engineers.

Lucardi, R., **Ervin, G. N., Wallace, L.,** & Bryson, C. 2011. Population Genetic Analysis of Cogongrass (*Imperata cylindrica*) in Mississippi and Alabama. Southeast Exotic Pest Plant Council Conference, Lexington, KY.

Lambert, B., **Ervin, G. N., & Brooks, C**. 2011. Comparing Morphological Variation to Genetic Variation in an Invasive Herbivore, *Cactoblastis cactorum* (Berg). Biology Undergraduate Research Program, Mississippi State University Department of Biological Sciences.

Maddox, V. L. 2011. Invasive Plant Identification and Management. 14th Annual Jackson Garden & Patio Show, Mississippi Trade Mart, Jackson, MS.

Madsen, J. D. 2011. Invasive Species Research and Extension at GRI. Mississippi - Texas Invasive Species Work Group. Mississippi State University: Geosystems Research Institute.

Madsen, J. D. 2011. Strengths and Weaknesses of Aquatic Plant Management Techniques. Aquatic Plant Management Forum. Guntersville, AL.

Madsen, J. D. 2011. Economic and Environmental Impacts of Invasive Aquatic Plants. Aquatic Plant Management Forum. Guntersville, AL.

Madsen, J. D. 2011. Non-chemical Control Practices for Invasive Plants. Current Topics Seminar. Mississippi State University: Department of Plant and Soil Science.

Maddox, V. L. 2011. Invasive Species Identification and Management. Mississippi Horse Park, Starkville, MS: Everything Garden Expo.

Maddox, V. L. 2011. Identification and Management of Invasive Plant Species. 10th Annual Gulf Coast Garden and Patio Show, Mississippi Coast Coliseum, Biloxi, MS.

Ervin, G. N. 2011. Combining Biological Databases and Predictive Modeling in Conservation Planning. Department of Biological Sciences, Arkansas State University, Jonesboro, AR.

Madsen, J. D., Cox, M. C., & **Wersal, R. M**. 2011. Aquatic Plant Distribution Assessment within the Littoral Zone of the Ross Barnett Reservoir, MS in 2010: A Six Year Evaluation. Board of Directors Meeting. Jackson, MS: Pearl River Valley Water Supply District.

Marsico, T. D., **Ervin, G. N., & Brooks, C.** 2011. Putting Hypothesized Native-Range Phylogeographic Patterns of *Cactoblastis cactorum* to the Test Using Genetic and Climatic Data. Fifth International Biogeography Society Meeting, Heraklion, Crete, Greece.

Items of Pride

Awards and Recognitions

Madsen, J. D. (2011). Presidential Award. Guntersville, AL: MidSouth Aquatic Plant Management Society.

Undergraduate **Brice Lambert** won 3rd place in the MSU Biology Undergraduate Research Symposium and placed 1st in Life Sciences in the MSU Honors College Research Symposium for his poster on cactus moth morphological comparisons between North America and Argentina.

Gary Ervin was selected to receive the 2011 Phil and Kari Oldham Mentor Award from the MSU College of Arts & Sciences.

Thesis and Dissertation

Prince, J. M. (2011). Modeling Eurasian Watermilfoil (*Myriophyllum spicatum*) Habitat with Geographic Information Systems. PhD Dissertation, Crop Science, Mississippi State University: ProQuest/UMI.

Cox, M. C. (2011). Distribution and Management of Invasive Plant Species in the Ross Barnett Reservoir. M.S. Thesis, Weed Science, Starkville, MS: Mississippi State University. 87.

Appendices

Appendix 1

Greenhouse and Mesocosm Aquatic Plant Research Facilities at Mississippi State University

John Madsen,
Geosystems Research Institute

Figure 1. Thirty-six 30-gallon aquaria are used for small scale experiments in the aquatic plant greenhouse.

The Geosystems Research Institute, in conjunction with the Department of Plant and Soil Sciences and the R. R. Foil Plant Research Facility, has developed two contained research facilities dedicated to studying the biology, ecology and management of aquatic plants. Located on the R. R. Foil Plant Research Facility ("North Farm"), the facilities were developed using project funds for aquatic plant research. These facilities include a greenhouse and mesocosm tank area, both of which are locked to limit access.

Figure 2. Twenty-four 150-gallon tanks are used for experiments and holding samples of aquatic plants in the aquatic plant greenhouse.

Figure 3. The mesocosm facility employs a wide range of tank sizes, from 50 to 500 gallons.

The greenhouse has been modified to hold thirty-six 30-gallon aquaria and twenty-four 150-gallon tanks (Figures 1, 2). The greenhouse is used for small-scale, low replicate studies of the biology and management of aquatic plants, including curlyleaf pondweed and Eurasian watermilfoil. Tropical aquatic plants sensitive to cold weather have also been overwintered in this facility.

The mesocosm facility currently has over 500 tanks ranging from 50 to 500 gallons, to allow large replicated manipulative experiments (Figure 3). Air and filtered irrigation pond water are delivered to each tank. During the summer, shade cloth is suspended above the tanks to help moderate water temperatures, without reducing light to limiting levels (Figure 4). The mesocosm facility has been used for federal and state government contracts, as well as contracting with private companies and nongovernment organizations. The facility allows a

Appendix 1 (Cont.)

wide range of manipulative experiments, including the effects of altering environmental parameters on plant growth, examining life history and phenology, and management strategies including biological, chemical, mechanical and physical techniques (Figure 5). Plant growth responses are often quite dramatic (Figures 6, 7). These facilities will be quite important to developing management techniques for invasive aquatic plants. The combination of having a secure facility to prevent the spread of plants, and being able to manipulate the environmental conditions or replicate the concentration and exposure time of approved aquatic herbicides will assist in developing managements approaches for Mississippi, the MidSouth, and the United States. To pursue this objective, we have obtained a permit to hold Mississippi State Noxious Weeds from the Mississippi Department of Agriculture and Commerce, Bureau of Plant Industry.

Figure 4. Shade cloth is used in the summer to reduce water temperature, without limiting light availability to the plants.

Figure 5. Ryan Wersal manipulating pH in a study of salvinia response to pH and nutrients.

Figure 6. Salvinia growth under normal pH and high nitrogen.

Figure 7. Salvinia growth under low pH and low nitrogen.

Appendix 2

Publications and Presentations, 2004-2011

Breakdown of Publications by Year

Table 1. Publications and Presentations for the Invasive Species Program since 2004.

Year	Journal articles	Presentations	Other publications	Total
2004		10	3	13
2005	2	43	23	68
2006	9	66	17	92
2007	13	78	20	111
2008	9	53	9	71
2009	6	59	40	105
2010	6	52	14	72
2011	15	47	12	74
Total	60	408	138	606

Peer-reviewed Journal Articles

2004
None.

2005
Slade, J. G., E. D. Dibble, P. C. Smiley Jr. 2005. Relationships between littoral zone macrophytes and the fish community in four urban Minnesota lakes. Journal of Freshwater Ecology 20: 636-640.

Madsen, J.D. 2005. Eurasian watermilfoil invasions and management across the United States. Currents: The Journal of Marine Education, 21(2):21-26.

2006
Bried, J. T., G. N. Ervin. 2006. Abundance patterns of dragonflies along a wetland buffer gradient. Wetlands. 26:878-883.

Bruce, L. M., A. Mathur, J.D. Byrd. 2006. Denoising and Wavelet-Based Feature Extraction of MODIS Multi-Temporal Vegetation Signatures. GIScience & Remote Sensing. 43:170-180.

Ervin, G. N., M. Smothers, C. Holly, C. Anderson, J. Linville. 2006. Relative importance of wetland type vs. anthropogenic activities in determining site invasibility. Biological Invasions. 8:1425-1432.

Ervin, G. N. 2006. Managing invasive species in the face of natural disaster: Obstacles and opportunities. Wildland Weeds. 10: 9-10.

Ervin, G. N., L. C. Majure, J. T. Bried. 2006. Influence of long-term GTR impoundment on stand structure, species composition, and hydrophytic indicators. Journal of the Torrey Botanical Society. 113: 468-481.

Appendix 2 (Cont.)

Ervin, G. N., B. D. Herman, J. T. Bried, D. C. Holly. 2006. Evaluating non-native species and wetland indicator status as components of wetlands floristic assessment. Wetlands. 26: 1114-1129.

Holly, D. C., G. N. Ervin. 2006. Characterization and quantitative assessment of rhizome penetration by cogongrass (*Imperata cylindrica* (L.) Beauv.). Weed Biology and Management. 6: 120-123.

Madsen, J. D., R. M. Wersal, M. Tyler, P. D. Gerard. 2006. The distribution and abundance of aquatic macrophytes in Swan Lake and Middle Lake, Minnesota. Journal of Freshwater Ecology. 21: 421-429.

Wersal, R. M., J. D. Madsen, B. R. McMillan, P. D. Gerard. 2006. Environmental factors affecting the biomass and distribution of *Stuckenia pectinata* in the Heron Lake System, Minnesota, USA. Wetlands. 26: 313-321.

2007

Bried, J. T. and G. N. Ervin. 2007. Intraspecific models and spatiotemporal context of size–mass relationships in adult dragonflies. Journal of the North American Benthological Society 26: 680-692.

Bried, J. T, B. D. Herman, and G. N. Ervin. 2007. Conservation umbrella potential of wetland plants and dragonflies: a quantitative case study using the Umbrella Index. Journal of Applied Ecology 44: 833-842.

Ervin, G. N. 2007. An experimental study on the facilitative effects of tussock structure among wetland plants. Wetlands 27: 620-630.

Gray, C. J., J. D. Madsen, R. M. Wersal, K. D. Getsinger. 2007. Eurasian Watermilfoil and Parrotfeather Control Using Carfentrazone-ethyl. Journal of Aquatic Plant Management. Vol. 45. 43-46.

Holly, D. C., G. N. Ervin. 2007. Effects of intraspecific seedling density, soil type, and light availability upon growth and biomass allocation in cogongrass, *Imperata cylindrica*. Weed Technology. Vol. 21. 812-819.

MacGown, J. A., J. G. Hill, L. C. Majure, and J. L. Seltzer. 2008. Rediscovery of *Pogonomyrmex badius* (Latreille) (Hymenoptera: Formicidae) in Mainland Mississippi, with an Analysis of Associated Seeds and Vegetation. Midsouth Entomologist, In press.

Madsen, J. D., R. M. Wersal, T. E. Woolf. 2007. A New Core Sampler for Estimating Biomass of Submersed Aquatic Macrophytes. Journal of Aquatic Plant Management. Vol. 45. 31-34.

Majure, L. C. 2007. Noteworthy collections: Mississippi. Castanea. Vol. 72. 121-122.

Majure, L. C. 2007. The Vascular Flora of the Chunky River (Mississippi). The Journal of BRIT. Vol. 1. 1179-1202.

Theel, H. J., E. D. Dibble, and J. D. Madsen. 2007. Differential influence of a monotypic native aquatic plant bed on a macroinvertebrate assemblage; an experimental implication of exotic plant induced habitat. Hydrobiologia. (In Press; DOI10.1007/s10750).

Theel, H. J., and E. D. Dibble. 2007. Simulation of an exotic aquatic macrophyte invasion and its influence on foraging behavior of bluegill. J. Freshwater Ecology. In Press.

Wersal, R. M., J. D. Madsen. 2007. Comparison of imazapyr and imazamox for control of parrotfeather (*Myriophyllum aquaticum* (Vellozo) Verdecourt). Journal of Aquatic Plant Management. Vol. 45. 132-136.

Appendix 2 (Cont.)

2008

Ervin, G. N. 2009. Using GAP data in invasive plant ecology and management. US Geological Survey Gap Analysis Bulletin 16: Accepted.

Ervin, G. N. 2009. Distribution, habitat characteristics, and new county-level records of *Baccharis halimifolia* L. on a portion of its present US range boundary. Southeastern Naturalist, In press.

Ervin, G. N. 2008. Applying the state-of-the-art to advance the state of our understanding in integrated hydrophyte ecology. *Verhandlungen Internationale Vereinigung für theoretische und angewandte Limnologie* (Proceedings of the International Society of Theoretical and Applied Limnology) 30: 128-132.

Holly, D. C., G. N. Ervin, C. R. Jackson, S. V. Diehl, G. T. Kirker. 2008. Effect of an invasive grass on ambient rates of decomposition and microbial community structure: A search for causality. Biological Invasions, Accepted – DOI: 10.1007/s10530-008-9364-5.

Madsen, J. D., R. M. Stewart, K. D. Getsinger, R. L. Johnson, R. M. Wersal. 2008. Aquatic plant communities in Waneta Lake and Lamoka Lake, New York. Northeastern Naturalist. Vol. 15. 97-110.

Madsen, J. D., R. M. Wersal. 2008. Growth regulation of *Salvinia molesta* by pH and available water column nutrients. Journal of Freshwater Ecology. Vol. 23. 305-313.

Madsen, J. D., R. M. Wersal, K. D. Getsinger, and L. S. Nelson. 2008. Sensitivity of wild rice (*Zizania palustris* L.) to the aquatic herbicide triclopyr. Journal of Aquatic Plant Management 46:150-154.

Majure, L.C. 2008. New records of *Geranium molle* and *Erodium cicutarium* (Geraniaceae), from Mississippi and other important collections from the state. The Southeastern Naturalist, In Press.

Majure, L.C. and G. N. Ervin. 2008. The *Opuntia* (Cactaceae) of the state of Mississippi, United States. Haseltonia, 14:1-16.

Theel, H. J., E. D. Dibble, and J. D. Madsen. 2008. Differential influence of a monotypic and diverse native aquatic plant bed on a macroinvertebrate assemblage; an experimental implication of exotic plant induced habitat. Hydrobiologia 600:77-87.

2009

Holly, D. C., Ervin, G. N., Jackson, C. R., Diehl, S. V., & Kirker, G. T. 2009. Effect of an invasive grass on ambient rates of decomposition and microbial community structure: A search for causality. Biological Invasions. DOI: 10.1007/s10530-008-9364-5. 11(1855), 1868.

Simpson, A., Jarnevich, C., Madsen, J. D., Westbrooks, R., Fournier, C., Mehrhoff, L., Browne, M., Graham, J., & Sellers, E. 2009. Invasive species information networks: collaboration at multiple levels for prevention, early detection, and rapid response to invasive alien species. Biodiversity. 10(2), 5-13.

Ervin, G. N. 2009. Distribution, habitat characteristics, and new county-level records of *Baccharis halimifolia* L. on a portion of its present US range boundary. Southeastern Naturalist. 8, 293–304.

Ervin, G. N. 2009. Using GAP data in invasive plant ecology and management. US Geological Survey Gap Analysis Bulletin. 16, 34-41.

Dibble, E. D., & Kovalenko, K. 2009. Ecological Impact of Grass Carp: A Review of the Available Data. Journal of Aquatic Plant Management. 47, 1-15.

Wersal, R. M., & Madsen, J. D. 2009. Combinations of diquat and a methylated seed oil surfactant for control of common duckweed and watermeal. Journal of Aquatic Plant Management. 47(1), 59-62.

2010

Robles, W., Madsen, J. D., & Wersal, R. M. 2010. Potential for Remote Sensing to Detect and Predict Herbicide Injury on Waterhyacinth (*Eichhornia crassipes*). Invasive Plant Science and Management. 3, 440-450.

Bryson, C. T., Krutz, L. J., Ervin, G. N., Reddy, K. N., & Byrd, J. D., Jr. 2010. Ecotype Variability and Edaphic Characteristics for Cogongrass (*Imperata cylindrica*) Populations in Mississippi. Invasive Plant Science and Management. 3, 199-207.

Wersal, R. M., Madsen, J. D., Woolf, T. E., & Eckberg, N. 2010. Assessment of herbicide efficacy on Eurasian watermilfoil and impacts to the native submersed plant community in Hayden Lake, Idaho, USA. Journal of Aquatic Plant Management. 48, 5-11.

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