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Herbicide efficacy assessment on waterhyacinth and aquatic plant community monitoring in Lake Columbus, Mississippi

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ABSTRACT

Large-scale waterhyacinth control programs commonly rely on herbicides as a major management tool. Quantitative surveys are helpful for documenting the efficacy and success of control methods and assessing the reestablishment of aquatic vegetation following treatment. Lake-wide aquatic vegetation surveys were conducted during 2005 and 2006 using the point-intercept method to document the frequency of occurrence of exotic and native aquatic plants in Lake Columbus, Mississippi. Surveys were performed before and after broadcast herbicide applications of 2,4-D for waterhyacinth control. Prior to herbicide application, the frequency of exotic plant species was significantly higher ($p = 0.0004$) than native plant species, with waterhyacinth being the most frequently occurring exotic plant recorded. After herbicide treatment, the frequency of occurrence of waterhyacinth was significantly reduced ($p = 0.02$) from 29 to 7%, a 76% reduction in the presence of waterhyacinth. After herbicide treatments, there was an increase ($p < 0.05$) in native aquatic plant species over the following 10 months after the applications. Native species increased from 5% before treatment to 16% after treatment. Native plant species found after herbicide treatments included pennywort (*Hydrocotyle ranunculoides*), duckweed (*Lemna minor*), frog's bit (*Limnobium spongia*), and American pondweed (*Potamogeton nodosus*).

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These data indicate that native species can recolonize areas previously inhabited by waterhyacinth after control techniques have been successful.

Key words: 2,4-D, *Eichhornia crassipes*, frequency of occurrence, herbicide, invasive plant species, native plant species.

INTRODUCTION

Aquatic plants provide many ecological benefits to the function of freshwater systems. Aquatic plants support fish and invertebrate populations by providing habitat and refuge against predators (Moss et al. 1998, Ferrer-Montaño and Dibble 2002) as well as providing a food source to vertebrate communities (Wersal et al. 2005). These ecological interactions may be disrupted by the introduction of exotic invasive aquatic plant species. The exotic species waterhyacinth (*Eichhornia crassipes* [Mart.] Solms), was introduced to the United States from South America, and is considered one of the "world's worst weeds" (Holm et al. 1991) because its presence causes economic losses and affects ecological interactions. In the state of Mississippi, waterhyacinth is the most abundant aquatic plant in lakes Columbus and Aliceville (Ferrer-Montaño and Dibble 2002, Robles and Madsen 2006); consequently, the implementation of a management plan has been recommended for waterhyacinth control (Robles and Madsen 2006).

A successful management plan should include an accurate monitoring program that assesses both beneficial and harmful aquatic vegetation. Assessment is critical to documenting the success of the management plan with respect to control efficacy, evaluating different plant control techniques, and determining non-target plant injury or recovery. Ideally, an assessment method needs to incorporate both target and non-target plant response, collect data that are objective and can be quantitatively analyzed, and is labor and cost effective.

The point-intercept sampling method, a commonly used survey technique to acquire ground-truth data in a water body (Madsen 1999), obtains aquatic plant species presence and absence data by navigating the lake in an evenly spaced grid of points aided with global positioning systems (GPS). This survey method has been useful for providing frequency of occurrence estimates and spatial distribution of aquatic plants (Case and Madsen 2004, Wersal et al. 2006). Furthermore, the effectiveness of chemical control programs has been evaluated in the Ross Barnett Reservoir in Mississippi, Lake Gaston in North Carolina, and lakes Pend Oreille and Hayden in Idaho using point-intercept surveys (Madsen 2007, Madsen and Wersal 2008, Wersal et al. 2008, 2010). With the exception of Ross Barnett Reservoir (Wersal et al. 2008), point-intercept surveys have not been widely used to assess aquatic vegetation or management efforts in the state of Mississippi. In fact, few assessment or monitoring activities occur with respect to vegetation management in Mississippi. The information from surveys such as those described above is needed to document the efficacy of management techniques performed as well as the recovery of native aquatic plant species, and to show natural resource agencies the value of implementing such monitoring efforts in their programs.

Therefore, the objectives of this study were to (1) determine the frequency of occurrence of exotic and native aquatic plant species in Lake Columbus using point-intercept surveys and (2) detect changes in the frequency of occurrence of waterhyacinth after herbicide application. The results from this study may serve to document changes in the frequency of occurrence of native species, as well as other exotic aquatic plant species not affected by herbicide treatments, after waterhyacinth is controlled, and serve as a guide for future monitoring programs in Mississippi.

MATERIALS AND METHODS

Lake Columbus (Figure 1) is located in Lowndes and Clay counties (33°32'31"N; 88°29'27"W) in northeastern Mississippi. This man-made lake is 1208 ha in size and impounded by a dam. Lake Columbus is part of the Tennessee-Tombigbee Waterway and facilitates commercial transportation between the Gulf of Mexico and the Tennessee River (Auerbach et al. 1985, Green 1985,). It is also used for recreation (e.g., fishing) and provides wildlife habitat (Green 1985).

Lake Columbus was surveyed in July 2005, May 2006, and November 2006 to estimate the frequency of occurrence of aquatic plant species. The July 2005 survey was performed prior to herbicide treatments, and the May 2006 and November 2006 surveys were performed after herbicide treatments. Each survey was conducted using a point-intercept sampling method, which uses GPS technology to sequentially navigate the entire lake (Madsen 1999). Using GIS software (ESRI 2005), a 400 m by 400 m grid of points was created over the

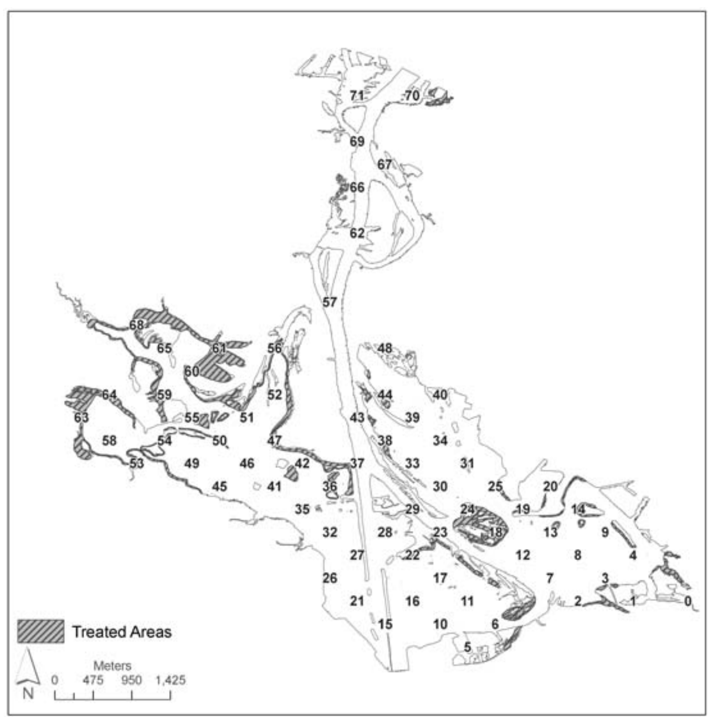

Figure 1. Point intercept survey locations on Lake Columbus, Columbus, MS. Shaded areas indicate the total treatment area sprayed with the herbicide 2,4-D during 2005–2006 for the control of waterhyacinth.

entire lake. This information was transferred to a handheld computer (HP iPAQ, model 2110) with GPS capability. The GPS receiver (Holux, model GR-271) was capable of 3 m position accuracy, and all data were projected in Universal Transverse Mercator (UTM, zone 16 N). Farmworks Site Mate software® (Farm Works 2004) was used to conduct each survey.

At each survey point, the presence and absence of aquatic plant species were identified and recorded for each sampling date. One rake toss was performed at each survey point by deploying the rake over the side of the boat and allowing the rake to sink to the bottom to ensure documentation of submersed aquatic plant species presence (recorded as "1") and absence (recorded as "0"). Similar survey methods were used in Idaho to evaluate herbicide efficacy and impacts to the submersed native plant community (Wersal et al. 2010). Although the map shows 72 points (Figure 1), only 68 points were accessed by boat. Points 8, 20, 22, and 64 were eliminated from the survey; therefore, all subsequent analyses were based on surveys with 68 points.

Herbicide applications were conducted from July to September of 2005 and 2006. Approximately 200 ha (17% of the total surface area of Lake Columbus) of waterhyacinth were treated by helicopter and air boat using the 2,4-D amine at 4 kg acid equivalent (a.e.)/ha. The 200 ha included many coves and shorelines where waterhyacinth was the most abundant species and were areas that served as nurseries for waterhyacinth, resulting in the re-infestation of areas that were previously managed. Twenty-four surveyed points (35% of all points) were located within herbicide-treated areas.

The Proc Freq procedure was used to obtain the frequency of occurrence of each aquatic plant species present at the lake (SAS 2003). To facilitate statistical comparisons within each survey between exotic and native aquatic plant species, a new dataset was created where each survey point included the presence or absence of exotics and native species. For instance, a 1 was recorded if an exotic species was observed at a given point regardless of species; if there were no exotics a value of 0 was recorded. This was repeated for native plant species. If both an exotic and a native plant species were present, then a 1 was recorded for each category (i.e., exotic or native). Differences in the distribution of native and exotic plant species were determined using McNemar's Test for dichotomous response variables. The test assesses differences in the correlated proportions within a given dataset between variables that are not independent (Stokes et al. 2000, Madsen et al. 2008, Wersal et al. 2010). A pair-wise comparison was made between survey times using the Cochran-Mantel-Haenszel statistic (Stokes et al. 2000, Wersal et al. 2006) to test for changes in the presence of waterhyacinth by controlling for time. This analysis allowed the documentation of change in waterhyacinth presence over time in relation to herbicide applications.

RESULTS AND DISCUSSION

Aquatic Plant Community

Exotic and native aquatic plant species found in Lake Columbus (Table 1) show that with the exception of waterhyacinth, none of the aquatic plant species exhibited herbicide injury, as indicated by qualitative (visual) means. During the pre- and post-treatment surveys, the aquatic plant community was composed on average of 55% exotic species and 45% native species. The free-floating exotic waterhyacinth was the most commonly occurring aquatic plant species during all 3 surveys with a frequency of occurrence up to 29% in July 2005 (Table 1).

The submersed exotic species hydrilla (*Hydrilla verticillata*) was first recorded in 2006 at 3% of the points surveyed (Table 1). Although the presence of hydrilla was reported on this lake in 2005 (Madsen et al. 2006), its extent was not

TABLE 1. FREQUENCY OF OCCURRENCE (%) OF EXOTIC (E) AND NATIVE (N) AQUATIC PLANT SPECIES IN LAKE COLUMBUS, MS.

Aquatic Plant Species	Growth Form+	Exotic or Native	Frequency of Occurrence (%) Survey Month July 2005	May 2006	Nov. 2006
Alternanthera philoxeroides (Mart.) Griseb.	E	E	0	3	0
Ceratophyllum demersum L.	S, FF	N	1	7	0
Eichhornia crassipes (Mart.) Solms	FF	E	29*	15*	7*
Hydrilla verticillata (L.f.) Royle	S	E	0	3	1
Hydrocotyle ranunculoides L. f.	E	N	0	3	0
Justicia americana (L.) Vahl.	E	N	3	10	9
Lemna minor L.	FF	N	0	6	4
Limnobium spongia (Bosc.) Steud.	FF	N	0	3	1
Ludwigia grandiflora (Michx.) Greuter & Burdet	E	E	1	4	1
Myriophyllum aquaticum (Vell.) Verdc.	E	E	0	1	0
Myriophyllum spicatum L.	S	E	1	1	0
Nelumbo lutea (Willd.) Pers.	FL, E	N	1	1	1
Oxycaryum cubense (Poepp. & Kunth.) Palla	E	E	1	3	3
Potamogeton nodosus Poir.	FL	N	0	7	0
Salvinia minima Baker	FF	E	0	1	1

*Indicates significant decrease for a given species between surveys at $p < 0.05$ according to Cochran-Mantel Haenszel Test.
+Growth forms are represented as emergent (E), floating-leaved (FL), submersed (S), and free-floating (FF)

quantified until surveys were performed in 2006, perhaps because large-scale spread was being mediated by shading effects of waterhyacinth. After waterhyacinth was controlled, hydrilla quickly grew to the water surface and began lateral expansion, which was largely attributed to increased light availability (Barko and Smart 1981). The hydrilla canopy allowed better detection during the May 2006 survey when hydrilla was growing only in the northern portion of the lake; however, recent surveys in 2008 (Robles et al. 2008) reported that hydrilla had also spread to the southern portion of the lake.

The emergent exotic plant, Cuban club-rush (*Oxycaryum cubense* [Poepp. & Kunth.] Palla), was found growing rooted in mats of waterhyacinth and frog's bit (*Limnobium spongia* [Bosc.] Steud.) and forming large floating islands in many locations within the lake. Waterhyacinth and frog's bit, as well as debris from dead vegetation, provided buoyancy for Cuban club-rush, which allowed the formation of these floating islands. A similar association between waterhyacinth and Cuban club-rush was previously reported in Mississippi (Bryson et al. 2008). Frequent in the state of Florida, floating islands are composed mainly of Cuban club-rush, frog's bit, pennywort (*Hydrocotyle* spp.), and organic matter and are categorized as "floating-type tussocks" (Mallison et al. 2001).

Along the lake's shoreline, American water-willow (*Justicia americana* [L.] Vahl.) was the most commonly found native aquatic plant species during each survey, with a frequency of occurrence up to 10% in May 2006 (Table 1). American lotus (*Nelumbo lutea* [Willd.] Pers.) was also found in every survey, albeit at a much lower frequency of occurrence (1%) than American water-willow, and occupied the same shoreline area of the lake. Other natives such as coontail (*Ceratophyllum demersum* L.) and duckweed (*Lemna minor* L.) were not consistently found during each survey; however, these species were found growing at the same survey points as waterhyacinth and hydrilla.

Herbicide Treatments

Prior to herbicide treatments, the frequency of occurrence of exotic plant species was higher ($p = 0.0004$) than after treatment, with waterhyacinth the most abundant species within this group (Table 1; Figure 2). Despite a 29% frequency of occurrence, treated populations of waterhyacinth in Lake Columbus were reduced ($p < 0.01$) to 7% after herbicide treatments, a 76% reduction in occurrence, due to its susceptibility to 2,4-D (Joyce and Haller 1984). The reduction of waterhyacinth likely resulted in an increase of native plant species, which is supported by a significant increase in native species observed in 2006 ($p = 0.02$; Figure 2). The increase in native species between the July and May surveys was largely due to increases in American water-willow, frog's bit, duckweed, and American pondweed. Although there was an increase in native plant occurrences, large areas formerly occupied by waterhyacinth before herbicide treatments were being colonized by infestations of Cuban club-rush, hydrilla, and waterprimrose (*Ludwigia grandiflora* [Michx.] Greuter & Burdet) after herbicide treatments. This indicates that areas that have undergone management activities will be repopulated with aquatic plants; however, if other exotic species are abundant in the area, these exotic species will likely populate the new habitat openings. Following herbicide treatments, Cuban club-rush became well established in many areas, forming extensive floating tussock islands along with frog's bit.

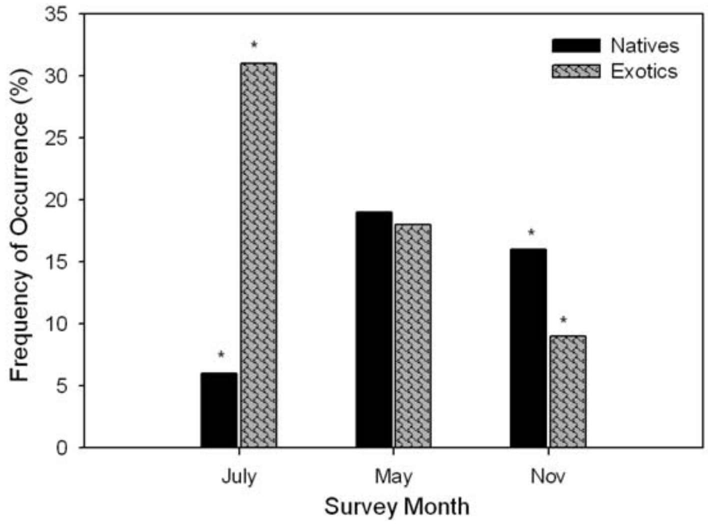

Figure 2. Native and exotic aquatic plant species frequency of occurrence in Lake Columbus, MS. An asterisk (*) indicates significant difference between the 2 groups within each survey at $p < 0.05$, according to (McNemar's Test).

Management Implications

Broadcast applications of 2,4-D resulted in a 76% reduction in the presence of waterhyacinth in Lake Columbus. Based on surveys conducted in 2006, an increase in the frequency of native plant species suggests their potential for recovery in the lake. Native aquatic vegetation, specifically American water-willow, was the most frequently occurring native plant in Lake Columbus after waterhyacinth was controlled with herbicide. Conversely, the frequency of occurrence of other native aquatic plant species important for fish habitat, such as coontail (Ferrer-Montaño and Dibble 2002) and American pondweed (*Potamogeton nodosus* Poir.; Dibble and Harrel 1997), remained low despite the herbicide treatment and subsequent removal of waterhyacinth. The reason for low reestablishment of coontail and American pondweed is unknown; however, it is suggested that their growth and spread is limited to continuous water fluctuation in Lake Columbus. For instance, as water level fluctuates, free-floating rootless aquatic plants like coontail are more prone to be dislodged and washed away than uprooted plants. Moreover, as water level rises, floating leaves of American pondweed may cause the stem to be pulled out of the sediment. Although these are hypothetical explanations, further research is needed to determine the response in plant growth form (i.e., floating vs. submersed leaves) to changes in water regimes in run-of-the-river reservoirs. When hydrilla was managed with herbicide treatments in Lake Gaston, North Carolina, native submersed aquatic vegetation remained unchanged in this man-made impoundment (Madsen 2007), whereas reestablishment of native emergent aquatic vegetation was successful in marshes of Alabama and Georgia when alligatorweed (*Alternanthera philoxeroides* [Mart.] Griseb.) was controlled with herbicides (Allen et al. 2007).

Remaining waterhyacinth quickly formed dense surface mats in combination with newly established exotics like hydrilla and Cuban club-rush, which may have limited the reestablishment of native species (Penfound and Earle 1948, Hofstra et al. 1999, Bryson et al. 2008). This suggests that a more holistic management approach may be necessary when several exotic plant species are abundant. The removal of one species, for example waterhyacinth, susceptible to 2,4-D likely resulted in the growth of Cuban club-rush and hydrilla, two species not known for their susceptibility to 2,4-D. Management programs may need to consider an integrated approach or use herbicide combinations that will address the presence of these other exotic plant species and prevent their further spread.

Our data indicate that point-intercept surveys can provide an efficient and quantitative assessment of an aquatic plant community and herbicide treatments within a waterbody. We recommend additional vegetation surveys be conducted to document the long-term trends within the aquatic plant community and recovery of waterhyacinth after treatments. These trends will indicate the frequency of waterhyacinth control needed in a management program. Future herbicide treatments are contingent upon additional funds because treatments conducted during this study were part of a short-term management budget. Although hydrilla was localized in some areas of Lake Columbus, its establishment and spread (Robles et al. 2008) cannot be overlooked, and herbicide treatments are recommended to prevent further nuisance problems with this species. Currently, only hydrilla occurring in primary navigation channels is being managed with contact herbicides. Future research is needed to determine appropriate management techniques to address both waterhyacinth and hydrilla. Additionally, aquatic plant relationships, such as the formation of floating islands dominated by Cuban club-rush, require further research because they may present additional problems with navigation and disruption of ecological interactions.

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