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A Framework for Assessing Economic Benefits of Invasive Aquatic Plant Management in Louisiana

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INTRODUCTION

People benefit from a wide range of aquatic ecosystem goods and services (EGS), and non-native invasive plants impact many of these benefits. EGS' are the socially valued aspects or outputs of ecosystems that arise from self-regulating or managed ecosystem structures and processes (Murray et al. 2013). Derived from aquatic ecosystems, EGS benefits include recreational opportunities, navigation, food supply, flood control, and fish and wildlife habitat, among other uses. Non-native invasive species reduce or eliminate these benefits by altering the ecosystem structures and processes on which EGS depend. For example, dense vegetative growth of aquatic invasive plants may impede commercial navigation or reduce the probability of a recreational angler catching a fish.

To counter these negative effects, multiple agencies in the U.S. spend millions of dollars annually on aquatic invasive species (AIS) control. In 2012 alone, the U.S. Army Corps of Engineers (USACE) spent \$95 million on AIS control and management and Early Detection Rapid Response (EDRR) in public waters (National Invasive Species Council 2014). Despite these investments, large-scale analyses comparing AIS management costs with beneficial outcomes, such as improvements in EGS, are rare or outdated. The major challenges to such economic analyses are twofold: 1) multiple stakeholders (i.e., local, state and federal governments, and private entities) may simultaneously conduct invasive species control - resulting in disjointed records of activities or non-standardized data collection; and 2) scientific evidence needed to quantify ecosystem impacts of invasive species is often lacking (an exception is Smart et al. 2009), even

though observational evidence of harm may be strong.

This Information Exchange Bulletin presents a framework to analyze the benefits and costs of aquatic weed control, using the example of water hyacinth (*Eichhornia crassipes* (Mart.) Solms) in Louisiana, and includes preliminary analysis of costs and treatment effectiveness. Although this Information Exchange Bulletin examines a particular case study, the methodology presented is transferable to other species and control programs. Water hyacinth is a particularly useful case study species because, in contrast to many other AIS, substantial data are available (from 1974 – present) to inform analysis of control costs and EGS impacts. Furthermore, because the species is widespread in Louisiana, the types of harm are diverse, and the magnitude of harm is potentially substantial.

The control benefits of water hyacinth are analyzed by examining the differences between distribution and seasonal growth with management, and its likely distribution and seasonal growth without management. These differences are used to analyze treatment effectiveness in terms of reducing plant extent or density and effects on human uses and values. A main objective of the analysis is to estimate monetary values for as many changes in EGS benefits—due to control—as possible. However, if important benefits cannot be monetized, they will be quantified with non-monetary benefit indicators, as described in the methods below. Finally, the costs of management are assessed using data gathered from multiple agencies. This economic analysis effort is ongoing, and this bulletin is the first to describe the methods and preliminary results.

CASE STUDY - WATER HYACINTH CONTROL IN LOUISIANA

Water hyacinth is a floating aquatic plant native to the Amazon basin in South America. Outside of its native range, it can display aggressive growth, spread, and plants can interlock to form large impenetrable mats (Figure 1). It is widely considered one of the worst nuisance plants in the world and has invaded freshwater

systems in five continents (Villamagna and Murphy 2010).

Water hyacinth negatively impacts aquatic EGS in direct and indirect ways. The majority of impacts stem from its ability to cover water surfaces with large amounts of biomass, which serve as barriers to atmospheric gas exchange of dissolved oxygen and carbon dioxide. Dense mats also shade underlying waterbodies, which reduce light penetration needed

for subsurface photosynthesis and exacerbate dissolved oxygen concentration reduction. These conditions lead to reduced diversity and abundance of phytoplankton and submersed aquatic plant species (Mitchell 1985), while lowered, dissolved oxygen negatively impacts fish and invertebrate communities (Villamagna and Murphy 2010). These structural and functional changes in aquatic, primary producer communities can negatively affect primary and secondary consumers. Large infestations may also directly impede commercial navigation, recreational boating, and fishing. In addition, blocked waterways and drainage canals can lead to increased flooding incidents. Water hyacinth also clogs surface water intakes and pipes for public water and industrial supply, crop irrigation systems, and hydropower systems (Villamagna and Murphy 2010; UNEP Global Environmental Alert Service 2013).

HISTORY OF WATER HYACINTH CONTROL IN LOUISIANA

Water hyacinth was initially introduced into the United States in Louisiana at the 1884 Cotton States Exposition in New Orleans as an ornamental plant (Wunderlich 1962). By 1899, just 15 years after its introduction, water hyacinth became such an impediment to navigation in the southeastern states that the U.S. Congress authorized USACE to clear infestations in navigable waters (Sanders et al. 1985). USACE was responsible

Figure 1. A close-up of a water hyacinth plant and a water hyacinth infestation at Lake St. Joseph, LA during summer 2012.

for controlling water hyacinth in Louisiana through its Removal of Aquatic Growth (RAG) and Operations and Maintenance (OM) programs until 1959, when Public Law 85-500 authorized the cost-share program, between USACE and states (at a 30 % contribution), to manage noxious aquatic plants (Sanders et al. 1985). In Louisiana, the Louisiana Department of Wildlife and Fisheries (LDWF) was tasked with monitoring and controlling water hyacinth. Louisiana's program benefited from the federal Aquatic Plant Control Program of 1965, which increased funding to control aquatic plants and led to new research efforts through USACE Aquatic Plant Control Research Program (APCRP), established in 1973. Although primary management responsibilities for Louisiana have been with USACE and the LDWF, other state programs and local water management agencies have contributed to previous control efforts in Louisiana by providing funding and in-kind support.

Mechanical removal and herbicide application were the primary treatment strategies until the early 1970s (Figure 2) when biological control agents were introduced. Biological control, or the intentional introduction of a host-specific organism to suppress a target species, was seen as a potentially more cost-effective, sustainable control method over traditional, mechanical, and chemical controls, due, in part, to their ability to self-sustain and to reach otherwise inaccessible areas (Manning 1979). Herbicide control, primarily through the use of 2, 4-D, has continued to the present. These treatments are targeted to public use areas where boaters have complained about impacts

Figure 2. A USACE shredder boat used to clear waterways in Louisiana. This type of boat was used until the early 1970's.

Figure 3. The water hyacinth weevil, *Neochetina bruchi*.

of water hyacinth on navigation (Alexander Perret, LDWF, personal communication, January 22, 2015).

Two weevil species, *Neochetina eichhorniae* Warner and *Neochetina bruchi* Hustache (Figure 3), a moth, *Sameodes albiguttalis* (Warren), and a fungus, *Cercospora rodmanii*, were introduced into Louisiana beginning in 1974 (Manning 1979; Sanders et al. 1985). Of the four agents, *N. eichhorniae* was the most successful at establishing and dispersing throughout the state, and it has persisted in most areas despite the lack of new releases since the 1980s. New agents, such as the water hyacinth leafhopper (*Megamelus scutellaris* Berg.), continue to be released, but establishment has not yet been confirmed (Grodowitz et al. 2014). Water hyacinth-infested areas are still regularly treated with herbicides, while mechanical treatment has not been widely used since the early 1970s.

METHODS

To quantify economic benefits of water hyacinth management, the authors applied a standard economic approach, which was modified to capture EGS. The benefits will be compared to costs through either a cost-benefit or cost-effectiveness analysis, depending on how many of the EGS can be successfully valued. Many EGS were identified, but valuing the benefits from treatment required that appropriate economic data, such as damage costs or “willingness to pay” data for service users, be available. Where appropriate data for monetization are lacking, non-monetary benefit indicators will be used to capture potential benefits.

The study area includes the state of Louisiana, divided into the river basins that the LDWF currently use to report vegetation survey data (Figure 4). Surveys have been conducted biannually from 1975 to present. Commercial and recreational fisheries, commercial navigation, drinking water supply, and recreational hunting are a few EGS in the

state that water hyacinth effect. In addition, these EGS have the best monetization potential. Other affected EGS, such as support for waterfront property values, flood damage avoidance, and nonuse values of species or ecosystems (e.g., existence values), will likely be discussed qualitatively due to lack of data to quantify biophysical changes and value changes due to water hyacinth.

The economic analysis includes four main steps: 1) Quantify the effectiveness of water hyacinth control relative to a no-action scenario; 2) Connect changes in water hyacinth density and distribution to changes in EGS benefits; 3) Estimate costs of water hyacinth control; and 4) Estimate net benefits or cost-effectiveness of water hyacinth control.

I. QUANTIFY EFFECTIVENESS OF WATER HYACINTH MANAGEMENT RELATIVE TO A NO-ACTION SCENARIO

To understand the effects of water hyacinth management on EGS, a “counterfactual,” no-action scenario is needed to represent water hyacinth growth and distribution that would have occurred without those efforts. The no-action scenario is being generated by adapting an existing model that uses climate-based habitat suitability characteristics to evaluate potential water hyacinth spread over the landscape (Robinet et al. 2012). The modified spread model uses one process to account for the growth rate of water hyacinth at a site and another process to distribute the plant across the landscape. The published model was modified to include the effect of over-winter mortality, which is shown as a function of days below freezing. The no-action scenario will be calibrated to local data, but will also leverage data available from multiple sites worldwide in order to estimate plant spread outcomes that are not directly observable in the case study area due to ongoing control efforts.

Once the baseline no-action scenario has been developed, it will be compared to observed water hyacinth distribution to evaluate differences in EGS by location due to control efforts. Currently, biological control and herbicides are in widespread use to manage the plant, so it is not possible to completely separate the effects of the two types of control. Likewise, long-term survey data of water hyacinth distribution are being used to capture the effectiveness of both treatment types on water hyacinth’s growth rate statewide, after controlling for such factors as weather, flooding events, etc. In addition, data on treatment effort by waterbody (LDWF 2015) will be used to generate outcomes of treatment by location.

Figure 4. Louisiana river basins as classified by the Louisiana Department of Wildlife and Fisheries and used for biannual vegetation surveys. For survey reporting purposes, Terrebonne and Barataria were combined and Calcasieu and Mermentau were combined into single river basins. The Mississippi River was added as one of the vegetation survey basins in 2009. To be able to compare data across all study years, data for the Mississippi River basin were split evenly between the Ouachita River and Terrebonne-Barataria basins.

II. CONNECT CHANGES IN WATER HYACINTH DISTRIBUTION TO CHANGES IN EGS BENEFITS

The reduction in infestation density and extent due to management is linked to changes in EGS benefits using three functions (Figure 5). First, in the response function, the treatment's impact on the ecological outcome of interest is estimated. The ecological outcome reflects an ecological structure or process that supports a benefit.

Figure 5. Determining EGS benefits from management activities.

For instance, in the case of recreational fisheries, the response function would estimate how the abundance and distribution of game fish species are likely to change with water hyacinth cover. Second, the ecoservice production function establishes whether a change in an ecological outcome affects people. For recreational fishing, the authors will evaluate whether changes in fish abundance and distribution (and physical impediments to fishing) translate into reduced catch rates, given preferred fishing locations and methods of access (i.e., boat or shoreline, and boat type). Third, in the benefit/damage function, the economic benefits or damages due to EGS changes are quantified, typically in monetary units. For recreational fishing, the change in the total value of fishing days would be estimated.

Non-monetary benefit metrics will be used to capture benefits that cannot be valued. These metrics may be a single metric or an index that evaluates the magnitude of change to people as a function of the level of ecological change, the number of people affected, and their capacity to substitute for the loss of an EGS. For example, all other factors being equal, if unaffected fishing sites are readily available to anglers then the loss of use of a single site will generate less harm than if unaffected sites are scarce.

III. ESTIMATE COSTS OF WATER HYACINTH MANAGEMENT OVER PROJECT TIME

To calculate total costs of water hyacinth management during the study period, data on research, labor, materials, equipment, and administration are collected and consolidated. Data sources include the USACE New Orleans District's (MVN) annual reports on aquatic plant control from the RAG program and OM, water hyacinth herbicide contracts between USACE MVN and private companies, annual and project reports from USACE

APCRP, and published and unpublished data from LDWF. All management costs reflect activities conducted on public waters and do not include management on private lands by local/private entities. All costs are adjusted for inflation to allow accurate comparisons between years, and are reported as 2014 dollars.

When LDWF costs of management were missing, they were estimated from USACE costs using known cost-share formulas. USACE and LDWF shared management responsibility within the state at an approximate ratio of 70:30 from 1959–1985. With the Water Resources and Development Act of 1985, the cost-share ratio changed to 50:50 until 1999 when USACE MVN RAG budget was significantly cut (Figure 6). LDWF spending was generally highest in the mid-80s to mid-90s and leveled off thereafter, except for an anomalous peak in 2009. For some years, costs could not be estimated since 1) both USACE and LDWF budgets were missing, and 2) cost of management documentation was lacking. These years are shown as gaps in the data.

Figure 6. USACE Removal of Aquatic Growth (RAG) and LDWF aquatic plant removal spending (2014 \$) during study period.

IV. ESTIMATE ECONOMIC EFFECTS OF WATER HYACINTH MANAGEMENT

The benefits of the water hyacinth management program will be evaluated through a cost-benefit analysis or cost-effectiveness analysis over the analysis period of 1975–2014, depending on data availability. If major benefits are not monetizable due to data limitations, the cost-effectiveness of program actions will be assessed by comparing the magnitude of a change to the dollar spent (e.g., fishing days gained per dollar spent) (Durden and Fredericks 2009). Any monetary values used in the analysis, including past, present, and future costs or benefits are calculated as present values by applying a discount rate to future values and a price index and interest rate to past values. These adjustments to dollar values allow appropriate comparison of past, present, and future cost or benefits.

INITIAL RESULTS OF TREATMENT EFFECT AND COST ANALYSIS

EFFECTIVENESS OF MANAGEMENT OVER TIME

In the years following initial introductions of biological control agents in Louisiana, both the total statewide area of hyacinth and its seasonal growth in multiple river basins decreased substantially (Figure 7, 8). In 1974, the statewide area of water hyacinth was 1.1 million acres and by 1980 it had declined to 301,100 acres (Cofrancesco et al. 1985), while the area treated with herbicides remained approximately the same during this time period (Figure 7). Since the mid-1980s, total acreage of water hyacinth in the state has remained relatively low and constant (Figure 7). In addition, annual seasonal production of water hyacinth decreased and remained low in most river basins, especially in the southern part of the state, during the same time period (Figures 8A and 8B).

Ongoing modeling (results not shown) suggests that even after correcting for overwinter mortality of water hyacinth, seasonal production declined significantly. The results suggest that water hyacinth, where present, is not spreading as quickly or extensively as before introduction of the biological controls. While the impact of the weevil *N. eichhorniae* has been suggested as the primary cause of this decrease in acreage, other factors including improved and repeated herbicide applications,

a drought in 1980, extreme weather events (e.g., tropical storms and hurricanes), and biophysical factors (e.g., weed competition), may have played important roles in this reduction (Goyer and Stark 1984; Sanders et al. 1985; Sanders and Theriot 1986). The authors will examine a number of these potential influences in a later report.

COSTS OF MANAGEMENT OVER TIME

Documentation of water hyacinth control costs is available from 1964 to present for herbicide, mechanical, and biological control approaches. The cost documentation also covers research and program administrative costs. However, because data on water hyacinth acreage is only available from 1974 onward, and biological control cost data are only available from 1975, the authors generally limited the analysis to the period 1975–2014. However, the authors made an exception here for the use of herbicides to manage water hyacinth, so that an illustration of long-term trends in spending per acre could be shown. Since mechanical treatment has not been used widely since the early 1970's, spending on it is excluded from analysis. Additionally, costs associated with water hyacinth herbicide research are likely overestimates. Due to the lack of available documentation, the authors were unable to partition research dollars between multiple target weed species in some years. However, herbicide research is a small portion of total spending, so this issue does not have a significant effect on results. All of the costs presented in this section include administrative overhead costs that were adjusted to 2014 dollars.

Total spending on water hyacinth management and research from 1975–2014 was approximately \$111 million (Table 2), although this is an underestimate since data were missing for certain years (four years of LDWF and USACE RAG budgets were not available or could not be estimated). Costs are broken down by category in Table 2.

From 1964 to 2011, USACE and LDWF used herbicides to treat an annual average of about 26,400 and 21,900 acres, respectively, at a combined average annual cost of \$84/acre, with missing data years excluded. The two agencies' herbicide use varied by year budget, but spending per acre for herbicide treatment showed an overall decline through time (Figure 9).

Figure 7. Water hyacinth statewide acres and acres treated with herbicide by USACE and LDWF. The large spike in hyacinth acres in 1975 is thought to be the result, in part, of the opening of Morganza spillway in 1973, which alleviated Mississippi River flood pressures on the old river control structure, but spread water hyacinth into previously uninfested areas of the Atchafalaya Basin.

For biological control, a large portion of the money spent in the state is captured in the USACE Large-Scale Operations Management Test (LSOMT) program, in which different biological control agents were released into various sites throughout Louisiana between 1975 and 1980 to test their effectiveness for controlling water hyacinth (Sanders and Theriot 1986). The annual average cost for this program was about \$356,000 over a six-year period (Table 2). The costs associated with large-scale rearing and labor and equipment costs associated with the release of biological control agents (including the release of insect agents, by helicopter, at various remote locations in the state) are missing from this estimate, largely incurred by the state of Louisiana in the 1970's (Manning 1979). However, costs for this effort are unavailable, so they are not included in the analysis.

Because a number of other states may potentially benefit from all aspects of water hyacinth research, the

authors proportioned research costs among states for each of the management technologies (i.e., biological control, herbicide control, and integrated control) based on the areal extent of available water hyacinth habitat per state (Table 1). To identify the amount of habitat in different states, the authors clipped water hyacinth habitat suitability GIS data, provided by Darren Kriticos (CSIRO, personal communication, October 9, 2014), to national water body 1:1,000,000-scale GIS data (USGS National Atlas of the United States 2014). Louisiana has approximately 5.8 million acres, or 23 % of the total available water hyacinth habitat in the U.S. Therefore, USACE has spent a total of approximately \$14.9 million researching herbicide, biological and integrated control (Table 2) for water hyacinth from 1975 – 2014 with 23 %, or \$3.43 million assigned to Louisiana.

A

B

Figure 8. Changes in seasonal water hyacinth production (from spring to late summer/fall) in southern Louisiana (A) and northern Louisiana (B). Note the different scales. The gaps in the lines represent years when data were not collected.

Figure 9. Overall cost per acre (2014\$), for USACE and LDWF combined, to treat water hyacinth using herbicides in Louisiana over time. Since LDWF costs and/or acres treated were missing for a number of years, values for these years were estimated based on cost-share ratios between USACE and LDWF. Inline gaps represent missing data that could not be estimated with available data and information.

Table 1. Water hyacinth habitat area and percentage by state.

State	Acres of Suitable Hyacinth Habitat	Percentage of Total Acres
Hawaii	6,800	0.03%
Nevada	195,200	0.78%
California	960,400	3.82%
Virginia	52,600	0.21%
Arizona	257,500	1.02%
Oklahoma	72,600	0.29%
North Carolina	1,622,100	6.46%
Texas	1,796,000	7.15%
Alabama	656,100	2.61%
Mississippi	686,900	2.73%
Georgia	2,788,100	11.10%
South Carolina	1,972,200	7.85%
Arkansas	359,400	1.43%
Louisiana	5,789,700	23.05%
Florida	7,906,400	31.47%
Total	25,122,033	100.00%

Table 2. Spending allocated to research and management of water hyacinth in Louisiana.

Cost Category	Organization	Cost (2014 \$)	Costs per year (2014 \$)*	Number of years*	Time period
Herbicide Research† (APCRP)	USACE-ERDC	\$1,580,651	\$112,904	14	1976–1989
Biological Control Research‡ (APCRP)	USACE-ERDC	\$1,162,496	\$77,500	15	1975–2014
Integrated Control Research (APCRP)	USACE-ERDC, MVN	\$699,516	\$58,293	12	1976–1989
Large Scale Operations Management Test (LSOMT)	USACE-ERDC, MVN	\$2,136,150	\$356,025	6	1975–1980
USACE Herbicide Application	USACE	\$84,802,683	\$2,494,196	34	1975–2012
State Herbicide Application	LDWF	\$20,498,629	\$590,220	35	1975–2013
Total		\$ 110,880,124			

*Only includes years when data were available and the cost category was funded.

† Includes multiple target species in addition to water hyacinth

‡ Total research costs have been apportioned to Louisiana based on the % water hyacinth habitat present in Louisiana relative to the entire country (Table 1).

CONCLUSIONS OF COST ANALYSIS

The largest expenditures in water hyacinth control in Louisiana from 1975–2014 were the application of herbicides (\$84 million and \$20 million by USACE and LDWF, respectively), with much lower spending on the operational release of biological control agents (~\$2 million) and funding for research (Table 2). The cost analysis reveals that costs per acre for herbicide usage have decreased over time. This decrease is due, in part, to improvements in the efficiency of herbicide spray programs (Sanders et al. 1985) and reduced costs of herbicides as patents expired and less expensive generic product alternatives became available. Although the release of biological control agents can reduce the interannual growth of water hyacinth (Figure 8 and Haag 1986), there is little evidence from the cost data that the presence of these agents has contributed to a reduction in per-acre management costs (i.e., through reduced plant density or increased plant susceptibility to herbicide).

EXPECTED OUTCOMES OF ECONOMIC ANALYSIS

The EGS benefits from water hyacinth management are likely to be non-linear functions of water hyacinth distribution. At low levels of invasion, other species (e.g.,

fish) generally can adapt, and aquatic system users can substitute uninvaded sites for invaded sites. However, as distribution increases, other species and users will have to expend more time and effort to find substitute sites, thereby directly decreasing EGS benefits. The authors will use such understanding to generate realistic estimates of benefits from management programs including benefits to commercial navigation, water supply, recreational hunting, and nonuse values of species and ecosystems.

Overall, the completed analysis will provide evidence for the economic benefits of water hyacinth management in Louisiana and establish a framework that can be used to further analyze the benefits and costs of other invasive aquatic plant management activities. The work includes new data analysis to evaluate the ecological effectiveness of water hyacinth management. It will provide USACE, and other stakeholders involved in invasive species management, an opportunity to better document and communicate the benefits of these programs. The research will also identify approaches for future data collection within control programs to enhance future analysis of program benefits.

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