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Using the West Indian Manatee (Trichechus manatus) as a Mechanism for Invasive Aquatic Plant Management in Florida

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ABSTRACT

West Indian manatees (*Trichechus manatus* L.) are opportunistic, herbivorous aquatic mammals that occupy the warm, shallow coastal waters throughout the southeastern United States. Manatees are known to feed on large quantities of diverse plant types. Presently within the state of Florida, manatees are an endangered species facing environmental and anthropogenic threats. Several different organizations work to rescue and rehabilitate these animals for an eventual return to the wild. Also within Florida, invasive aquatic plants are becoming increasingly problematic, creating both negative economic and environmental impacts. Each year, efforts are made to control these exotic plant species through several different methods. However, physical, mechanical, chemical and biological means to contain nonindigenous plants each have their drawbacks. There is a need for a natural, integrated approach to invasive aquatic plant management. The opportunity for manatees to control exotic plant species within the Florida ecosystem exists, but is improbable because of inadequate population densities. This study builds on this potential examining the use of manatees held in captivity as a tool for management by utilizing the physical collection of targeted nonindigenous plants to supplement the diet of rehabilitated manatees. Provisions are augmented with nutrients that manatees may not obtain from other sources typically found in captive diets. Early introduction of natural plants may allow for an easier transition to normal feeding patterns upon release and may condition animals to continue consumption of exotic plants in the wild. Each step has the potential to contribute to the reduction of invasive aquatic plants in Florida, and presents a cost-effective feeding alternative for manatee rehabilitation facilities. This method promotes a native Florida species as a natural solution to the problem.

Key words: invasive aquatic plant management, biological control, *Trichechus manatus*, manatee, *Eichhornia crassipes*, *Pistia stratiotes*, herbivory.

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INTRODUCTION

West Indian manatees (*Trichechus manatus* L.) are large aquatic mammals endemic throughout the islands of the Caribbean, west to Central America and south to Brazil. Their native range also extends north to the southeastern United States where they inhabit warm, shallow, coastal waters. They are the largest species of manatee, averaging 2.7 to 3.5 m long and weighing 400 to 550 kg. The West Indian manatee is divided into two subspecies, the Antillean manatee (*Trichechus manatus* L. ssp. *manatus* Harlan) and the Florida manatee (*Trichechus manatus* L. ssp. *latirostris* Harlan). Because the two subspecies are genetically unique and separate from each other, having low genetic diversity among their endemic populations (Garcia-Rodriguez et al. 1998, Vianna et al. 2006, Hunter et al. 2010, Pause Tucker et al. 2012) and slow reproductive rates (O'Shea and Hartley 1995, Marmontel 1995, Odell et al. 1995, Rathbun et al. 1995, Reid et al. 1995, Marmontel et al. 1996), manatees are vulnerable to extinction. Since their population numbers are threatened, manatees in Florida have been classified as endangered and are protected under Florida State Law and United States Federal Law, as they face threats from natural and anthropogenic factors. In January of 2014, a synoptic aerial survey counted 4,824 manatees in Florida waters (FWC 2014).

In Florida, manatees are not the only organisms facing human-induced threats. Aquatic ecosystems across the state are facing the dilemma of invasive exotic plants becoming increasingly problematic within the environment. In ecosystems where nonindigenous plants prevail, there are few constraints that inhibit their growth (Rejmanek 2000, Malik 2007; FWC 2012). These introduced plants compete with Florida's natural aquatic vegetation for habitat and nutrients (Gordon, 1998) and can grow into dense infestations clogging waterways and causing navigational issues for boaters (Light and Dineen 1994, Schmitz et al. 1997). Of the world's most invasive plant species, 8 out of 33 are aquatic species (Zedler and Kercher 2004). Characteristic of other invasive species, exotic plants thrive in habitats similar to that of their native range (Rejmanek and Richardson 1996, Holm 1997). One factor limiting these species where they occur naturally is predation from herbivores. In Florida, however, there are no native species that feed upon these nonindigenous plants. Because of limitations to the natural processes to control growth, invasive plants have become established and infest 94% of Florida's public waterways (FWC 2012). To combat this problem, the Florida Fish and Wildlife Conservation Commission (FWC) created the Aquatic Plant Management Plan. This plan oversees eradication and control efforts of 24 invasive aquatic plants within 1.26 million acres of public waterways in Florida, and focuses on three species: water hyacinth, [*Eichhornia crassipes* Mart.) Solms] (Pontederiaceae); hydrilla, [*Hydrilla verticillata* (L. f.) Royle] (Hydrocharitaceae); and water lettuce *Pistia stratiotes* L. (Araceae) as removal priorities (FWC 2012).

Current methods of control include physical and mechanical means through direct removal of plants from waterways, chemical control through herbicides to inhibit growth, and the use of biological mechanisms through the introduction of other organisms known to feed on targeted plants. However, each mechanism that is presently used produces drawbacks. Physical and mechanical techniques require a great deal of time and effort to harvest and extract each plant, and complete eradication is limited to small-scale areas. Chemical control involves the addition of defoliants and herbicides to eliminate undesired plants, but these chemicals can have unintended toxic effects to native plants and other life-forms (Johnson and Finley 1980, Bus and Gibson 1984, Mitchell et al. 1987, Marris et al. 1991, Readman et al. 1993, Biradar and Rayburn 1995, DiTomaso 1997, Giesy et al. 2000, Williams et al. 2000, Tsui and Chu 2003, Relyea 2005). Copper-based herbicides have even been linked to high liver concentrations of copper in manatees (O'Shea 1983, O'Shea et al. 1984). The use of biological agents has also been employed and is most practical when they only target exotic plants and leave native plants unharmed (AERF 2005). Often times, these introduced species feed on a broad range of plant species (Shireman and Smith 1983, Sutton 1985, Sutton and Vandiver 1986) including native plants (Taylor et al. 1984) which can cause negative environmental impacts within an ecosystem including the alteration of water quality (Bernstein and Olson 2001), changes in invertebrate, amphibian and fish communities (Zimpfer et al. 1987, Bettoli et al. 1990, Bettoli et al. 1993, McKnight and Hepp 1995, Murphy et al. 2002) and depletion of vegetation consumed by other herbivores (Zimpfer et al. 1987, McKnight and Hepp 1995). Other introduced biocontrol agents that only target the specific plants they are known to feed upon in their native range have proven to be effective; however, this can also be a limiting factor (Hill and Cillers 1999) as they are limited by population size and range. Furthermore, each of these methods of management can be very costly (Perrings 2002, Rockwell 2003, Pimentel 2003, Lovell and Stone 2005, Pimentel et al. 2005).

Within Florida, aquatic plant management efforts are overseen by the Florida Fish and Wildlife Conservation Commission. These duties are often contracted out to regional water management districts, and projects are funded through joint federal, state, local and private cooperatives. During the 2011 to 2012 fiscal year, the State of Florida spent $3.45 million controlling 27,740 acres of floating invasive plants like water hyacinth and water lettuce, $12.36 million on treating 30,300 acres of hydrilla, and another $2.5 million on managing invasive aquatic plants other than hydrilla on 10,170 acres within Florida public waterways (FWC 2012). Though expensive, maintaining efforts to suppress these introduced plant species is of both economic and ecological importance (Lovell and Stone 2005, Villamagna and Murphy 2009). Florida's freshwater recreation generates $1.9 billion in annual fishing revenue, accounts for over 19,500 jobs, and generates $55 million in annual taxed revenue (FWC DATE). Exotic plant control is critical for avoiding floods and for supporting navigation and recreation within public-use waterways, and is also essential for the conservation of native plants to maintain Florida ecosystems. To accomplish this, there is a need for a natural, integrated approach to invasive aquatic plant management.

As the only herbivorous marine mammal, manatees have developed adaptations to fill a unique niche. These adaptations include use of their prehensile lips and perioral bristles to grasp plants while feeding (Marshall et al. 1998, Marshall et al. 2000), unique dentition that is useful to begin the digestion processes (Miller et al. 1980, Domning 1983, Domning and Hayek 1984, Fortelius 1985), and an enlarged gastrointestinal tract to accommodate a substantial volume of consumed vegetation (Kenchington 1972, Snipes 1984, Reynolds and Rommel 1996). Manatees are opportunistic generalists that feed on a wide range of plant species including many of the aforementioned invasive plants (Hartman 1979, Bengtson 1981, Bengtson 1983, Best 1981, Etheridge et al. 1985, Ledder 1986, Hurst and Beck 1988), and can consume plant material equivalent to 4% to 9% [7.1%] (Bengston 1983, Etheridge et al. 1985) to 10% to 15% (Reep and Bonde 2006) of their body mass per day. There has been a wide range of reported estimates about the amount of food that manatees consume in a given day (kg d^{-1}): 9 (Crandall 1964), 12 (Hartman 1979), 28 (Best 1981), 42 to 56 (Lomolino 1977), 50 (Pinto de Silveira 1975) and 80 (Severin 1955). Differences in the amount of vegetation consumed are dependent on the animal's size and activity level, nutrient value of plants consumed, demands for bodily function, and availability of food plants. Because of these determinants, manatees could be used to curb the growth of invasive aquatic plants in Florida.

The use of manatees to control growths of aquatic plants was first conceptualized by W.H.L Allsopp's weed-clearing experiments in the South American country of Guyana (Allsopp 1960, Allsopp 1969). This practice has continued for several decades as manatees have been transported to aid in weed control in irrigation and drainage canals (Haigh 1991). Over the years, several other studies and reports have also detailed efforts in Guyana (Dill 1961, Bertram and Bertram 1963, Bertram and Bertram 1977, Spurgeon 1974, Vietmeyer 1974), the only country to use manatees specifically in this manner. In other parts of the world, investigations have taken manatees into consideration for the control of plant growth within Central America (MacLaren 1967, Klinge 1968, Cruz and Delgado 1986) and the United States (Sguros 1966). Some of these past studies, however, have run into problems related to population size and anthropogenic issues.

As manatee populations in Florida are challenged by natural and human-caused threats, many agencies and organizations are working to prevent the extinction of these endangered marine mammals through rescue and rehabilitation programs. With authorization from the United States Fish and Wildlife Service, several facilities are licensed to rehabilitate manatees in Florida. The Dolphin Research Center (Grassy Key, FL), Homosassa Springs Wildlife State Park (Homosassa Springs, FL), Lowry Park Zoo (Tampa, FL), Miami Seaquarium (Miami, FL), SeaWorld of Florida (Orlando, FL), The Living Seas at Disney's Epcot (Orlando, FL) and the South Florida Museum (Bradenton, FL) are all locations where manatees are rehabilitated in captivity; Lowry Park Zoo, Miami Seaquarium and SeaWorld are the primary care locations where critical care of injured, sick or orphaned manatees takes place. It is hoped that every manatee rescued will eventually be released back into the wild.

The Parker Manatee Aquarium located in Bradenton, FL at the South Florida Museum is a secondary care facility. The aquarium contains a 227 kl, state-of-the-art tank that houses rehabilitated manatees. At the South Florida Museum, manatees cared for receive food through a unique, comprehensive approach. Aquarium staff and volunteers work to gather untreated, exotic plants from collection sites, and then incorporate these plants into the animals' daily ration. Incorporating natural plants into the manatee's prerelease diet helps to condition the animals' GI-tracts to eating the kinds of coarse food that they will encounter once back in the wild. In 2010, a study by Siegal-Willott et al. examined the nutrient content of four seagrass species in comparison to romaine lettuce and suggested a reassessment of foods presently fed to captive manatees in Florida. Adding natural vegetation may address nutritional deficiencies found in an all-produce diet of foods normally fed to manatees in captivity. To evaluate efforts, this study details: a) the practicability of using this integrative approach for supplementation of nonindigenous plants into the diet of captive manatees; b) the effectiveness of this technique for exotic plant removal in the environment, and; c) how these efforts might be developed for added benefit. Studying the effectiveness of a unified physical and biological mechanism provides the potential for a unique, contemporary approach to invasive aquatic plant management through a native species.

MATERIALS AND METHODS

Initial study site

Collection of aquatic invasive plant species began at Myakka River State Park (MRSP) in Sarasota, Florida, United States (27°17′21″ to 27°17′26″N and 82°15′11″ to 82°19′0″W). Untreated plants were extracted from several locations along the Myakka River including Deer Prairie Slough (27°6′16.20″N to 82°15′52″W). Beginning in 2009, South Florida Museum staff collaborated with state park rangers to collect exotic plants at these sites. Collection sites were later developed at other locations.

Study system

Physical and biological methods were combined to obtain and manage invasive aquatic plants. Through physical collection, plants were gathered at collection sites. Initial efforts to extract individual plants by hand were in small, contained areas, and focused on the collection of *Water hyacinth* specifically. Collection began in the summer of 2009 and continued bimonthly into the fall season. After each effort to gather vegetation, plants were washed and dried, biomass was weighed (in kg) and recorded, and plants were then refrigerated prior to consumption. Complete removal of entire plants during collection assured the prevention of spreading exotic species during transit. Captive manatees were offered fresh plants in the days following collection as supply allotted; plants were replenished as stock diminished. As the study advanced, this process was also applied to other invasive plant species.

Expansion of study sites and focus species

As the success of invasive plant removal became apparent, the need for additional sites for gathering sufficient plants became imminent. Harvesting sites from 2009 were expanded in 2010 and 2011. Other sites utilized locations outside of MRSP, including public-use waterways and private ponds where invasive plants were left untreated. Initial collection sites that focused on the removal of water hyacinth showed promising results. With this development, the suitability of other exotic plant species was also investigated. Water lettuce and West Indian marsh grass, [*Hymenachne amplexicaulis* (Rudge) Nees] (Poaceae) were included in collection efforts and supplemented in the diet of manatees at the South Florida Museum to provide a cost effective alternative to purchased produce.

RESULTS

Initial trial results

Initial results provided promising outcomes for this approach. Though time consuming, physical collection efforts removed 226.9 kg of water hyacinth from locations within MRSP. The complete, intact plants accumulated were then incorporated into the diet of animals being rehabilitated at the South Florida Museum (Figure 1) employing native Florida manatees as an indirect biological control mechanism. Once sites within MRSP were cleared, collection expanded to other locations within the park along the Myakka River. As water hyacinth became scarce, efforts to gather other invasive plant species began in the park and surrounding areas. West Indian marsh grass (37.6 kg) and water lettuce (38.3 kg) were harvested and also introduced into the diet of captive manatees at the South Florida Museum. Upon the addition of these new species, consumption by manatees was examined. Manatees initially showed a preference for water lettuce and ignored West Indian marsh grass. With persistent presentation, the manatees eventually began experimenting and feeding upon the West Indian marsh grass. In 2009, two manatees consumed all

Figure 1. A captive manatee at the South Florida Museum consumes water hyacinth prior to its release back into the wild (photo by A.C. Allen).

226.9 kg of water hyacinth, 37.6 kg of lettuce collected, and roughly 21.2 kg of the 38.3 kg of West Indian marsh grass harvested (Table 1) to total 142.8 kg of natural vegetation per manatee. Availability of invasive plants declined into the fall as temperatures cooled.

Continued efforts and results

As the availability of invasive plants lapsed at MRSP, collection sites were established in surrounding areas and private ponds. The number of invasive species targeted and quantity harvested also expanded threefold with this endeavor. In 2010, 231.7 kg of water hyacinth, 43.9 kg of water lettuce, and 40.6 kg of West Indian marsh grass were harvested along with an additional 230.2 kg of water hyacinth, 52.6 kg of water lettuce, and 31.8 kg of West Indian marsh grass in 2011. All three plant species were combined as "natural vegetation" to analyze annual feeding of collected invasive plants with respect to proportion of diet. In 2010, a total of 316.2 kg (158.1 kg per manatee) of natural vegetation was consumed as part of the captive manatee diet at the South Florida Museum. In 2011, a total of 314.6 kg (157.3 kg per manatee) was consumed (Table 1). The incorporation of natural vegetation increased annually, and each year a larger proportion of manatee food consumption was observed: 1.27% in 2009, 1.38% in 2010 and 1.41% in 2011 (Figures 2A–C). These subtle increases, however, did not make up a significant proportion of annual consumption with natural vegetation producing only an average of 1.35% of the captive manatee diet over three years.

Cost-comparison analysis

To determine the cost-effectiveness of this endeavor, a cost-comparison analysis was used to determine overall

Table 1. Average annual diet of a captive manatee at the South Florida Museum.

	2009		2010		2011	
Type	Total (kg)	% Diet Composition	Total (kg)	% Diet Composition	Total (kg)	% Diet Composition
Romaine	9,906	88.10%	10,020	87.75%	9,858	88.22%
Kale	936.3	8.33%	955.7	8.37%	921.1	8.24%
Carrot	126.9	1.13%	138.9	1.22%	116.4	1.04%
Potato	131.6	1.17%	146.3	1.28%	121.3	1.09%
Natural[1]	142.8	1.27%	158.1	1.38%	157.3	1.41%
Total[2]	11,244	100.00%	11,419	100.00%	11,174	100.00%

[1]Natural category includes water hyacinth, water lettuce and West Indian marsh grass.
[2]Totals are divided by 2 to represent the estimated amount consumed per manatee; there were 2 consistent manatees during trial.

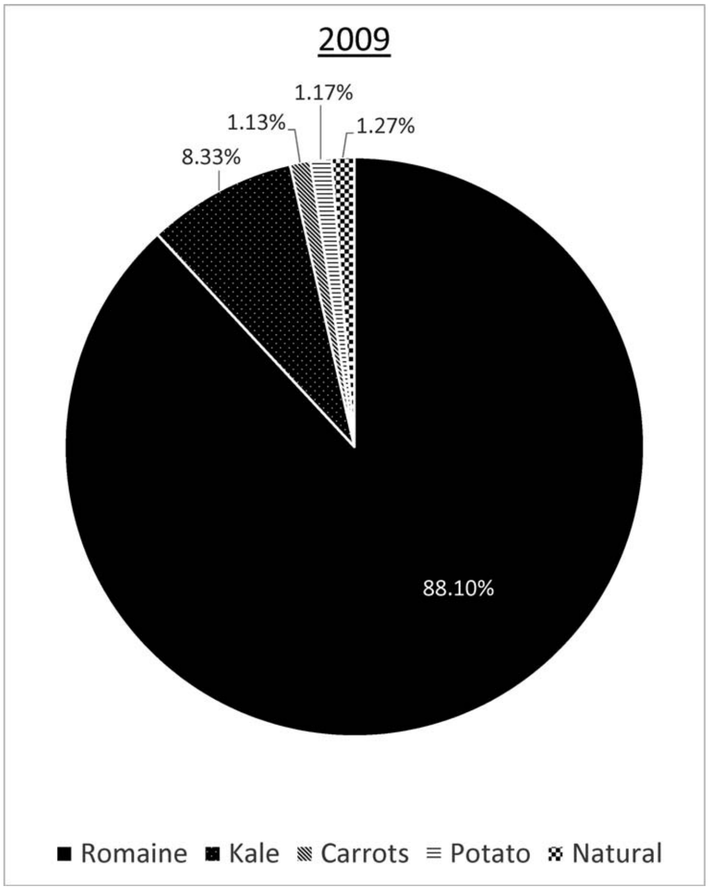

Figure 2A. Proportion of the captive manatee diet at the South Florida Museum in 2009.

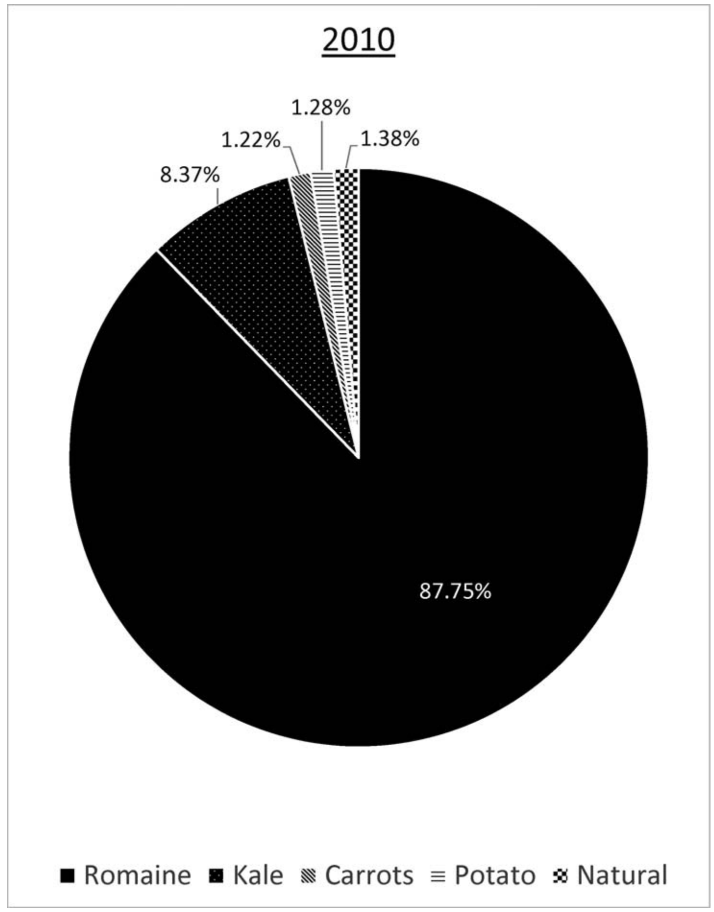

Figure 2B. Proportion of the captive manatee diet at the South Florida Museum in 2010.

economic benefit. In 2009, 28.75 hours were spent collecting and processing invasive aquatic plants, 29.5 hours in 2010, and 29.0 hours were spent in 2011. Annual cost per kilogram of natural vegetation was $1.02 in 2009, $1.00 in 2010, and $0.95 in 2011 resulting in a mean $0.99 per kg of natural vegetation (Figure 3). This cost included transportation, processing of the plants and staff compensation during collection efforts. To compare the cost of produce manatees normally consume in captivity, romaine and kale were considered as these varieties of vegetation made up the majority of manatees' diets at the South Florida Museum. The average weight of 10 boxes of romaine and 5 boxes of kale was obtained and then divided against the current cost paid per box. The resulting cost was $1.54 per kg of romaine and $2.65 per kg of kale (Figure 3). The price of romaine was roughly 1.6 times greater than the collection of natural vegetation, and the cost of kale was 2.7 times greater, thus making the collection of invasive aquatic plants a cost-effective alternative to purchased produce.

Invasive aquatic plants and the environment

There were environmental improvements seen from the removal of invasive aquatic plants, although the precise acreage impacted was not examined. Within MRSP, Deer Prairie Slough revealed a reduced volume of water hyacinth and did not return as a dense infestation in subsequent years (Figures 4A and 4B). Hydrology of the immediate area also showed improvement as an increase in water flow was observed, providing evidence that removal of these plants is beneficial to the health of the waterway. This was further demonstrated by observation of native species before and after collection. water lily, (*Nymphaea* L. sp.) (Nymphaeaceae) was seen in greater number and frog's bit. [*Limnobium spongia* (Bosc) Rich. ex. Steud.] (Hydrocharitaceae), which was not previously present, began to appear. Although the extent of native species recovery is unknown, similar outcomes were also seen in several other locations along the river where water hyacinth and water lettuce were collected. Each collection site was maintained by direct physical collection and received no treatment from herbicides. Private ponds, where infestations were removed, showed a considerable decline in regrowth in consecutive years as evidenced by a lesser amount of invasive biomass available to be harvested at these sites in following years. An increase in the number of collection sites compensated for the reduced availability of plants at other locations.

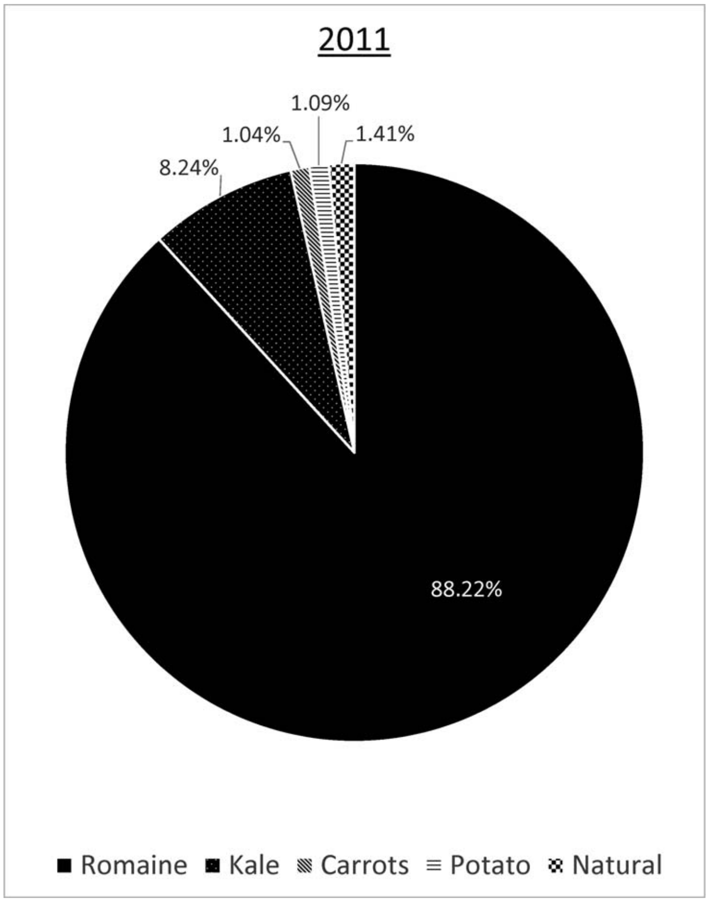

Figure 2C. Proportion of the captive manatee diet at the South Florida Museum in 2011.

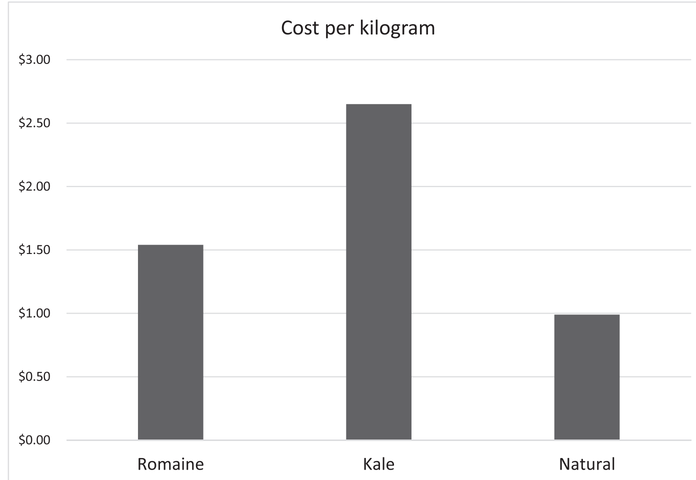

Figure 3. Average Cost per Kilogram of Food Types. Note: Cost of romaine and kale at wholesale cost from produce supplier. Cost of natural includes all endeavors to collect, process and prepare for manatee consumption.

DISCUSSION

Integrated methods

In efforts to manage aquatic invasive plants, it may be necessary to employ more than one specific method to obtain optimal results. Some pitfalls may be overcome through the combining of different techniques. Current methods show the most promise when applied in conjunction with other means to control aquatic invasive plants (Center et al. 1999a, Hatcher and Melander 2003, Major et al. 2003, Paynter and Flanagan 2004, Wiggers et al. 2004), and there is an ongoing need for alternative ways to approach management. Though combined management techniques presently in place make use of physical or mechanical means with the addition of chemicals or a nonindigenous species, a natural and native solution exists. This study applies physical control methods augmented with a native biological channel to provide a new, progressive combination to invasive aquatic plant management.

Direct application of manatees to invasive plant management

Capable of consuming large quantities of foliage (Bengston 1983, Etheridge et al. 1985), manatees present a potential for a native medium to manage nonindigenous aquatic plants. Data from past studies collected in other parts of the world suggest that dense populations of manatees may be useful to control infestations of aquatic plants (Allsopp 1960, Allsopp 1969, Dill 1961, Sguros 1966, MacLaren 1967, Klinge 1968, Andres and Bennett 1975, Haigh 1991). Although directly using manatees in weed control has proven to be semi-effective, some disadvantages and limitations were encountered in these studies. In Guyana, where manatees were kept in contained areas to aid in plant removal, manatees were either too numerous and required additional feeding, underpopulated and could not keep up with clearing the areas, or subject to poaching or death from collisions with boats and barges in heavily traversed areas (Haigh 1991). Similar to this study, Haigh (1991) reported the consumption of water hyacinth and West Indian marsh grass by manatees. Finding the right number of manatees necessary to clear an area of predetermined size may further restrict the application of these animals. Lomolino (1977) used ecosystem simulations to determine that 1.6 manatees per hectare would be required to be continuously present to reduce a fast-growing plant like water hyacinth to a manageable level. In other studies, ten manatees were introduced to an area near the Panama Canal in order to assist in weed control but proved ineffective (MacLaren 1967, Klinge 1968). More recently, Cruz and Delgado (1986) reported manatee use for weed control in Lake Yojoa, Honduras was not recom-mended. Prior to this, Sguros (1966) detailed efforts of five manatees that were used to clear canals near the Everglades in Broward County, FL, U.S.A. Manatees were reportedly able to clear a 1 km length of a canal 10 m wide in a three week span. Sguros (1966) also discusses the use of captive breeding to supply the manatees for this endeavor. Present laws in the United States and other countries prohibit captive breeding because of their status as an endangered species.

Past studies using wild manatees to contain exotic plants encountered problems with containment, poaching, and

Figure 4A. Water hyacinth collection site at Deer Prairie Slough prior to harvesting (photo by A.C. Allen).

Figure 4B. Same collection site one year later, with limited regrowth of water hyacinth (photo by A.C. Allen).

population size. Since they are an endangered species, inadequate population numbers prevent manatees from being an effective tool for invasive aquatic plant management in nature. One further complication of the direct use of manatees is the rate at which these animals ingest and consume vegetation. Manatees ingest about 7.1% of their body mass in 5 hours of chewing time (Etheridge et al. 1985). Etheridge et al. (1985) explored the rate of consumption by manatees in relation to their usefulness to control hydrilla in Crystal River, FL, USA. The study concluded that rates of consumption would fall short by an order of magnitude at present population levels (in 1985) making them ineffective (Etheridge et al. 1985). However, since this study, more manatees have occupied Crystal River as a source of warm water during winter months, and this population increases each year (Runge et al. 2004, Runge et al. 2007). Placing added importance on their protection, until present population numbers can reach the appropriate level, manatees will not be a viable solution in a natural ecosystem.

Diet alternative for captive manatees

By supplementing dietary requirements of manatees held in captivity with exotic plants harvested by physical means, a new methodology is created for the management of nonindigenous plants in Florida ecosystems. In captivity, manatees are commonly fed a diet primarily of romaine lettuce supplemented with kale and other vegetables. A study determined that the nutritional value of romaine in the diet of captive manatees required additional fiber (Harshaw 2012) and is not comparable to that of seagrass (Siegal-Willott et al. 2010). With a diet comprised mostly of food manatees do not regularly consume in the wild, there are likely to be nutrient deficiencies. Because of this, the practice of supplementing wild vegetation into the diet of captive animals is employed by several organizations that rehabilitate manatees within Florida, and a concerted effort is put forth at the South Florida Museum to give a more natural diet to animals prior to being released back into the wild. The inclusion of natural plants may be beneficial to add nutrients that manatees may not receive through the farmed, processed items they normally consume in captivity. Manatees will then become acclimated to natural food earlier in the rehabilitation process conditioning their GI-tract for an easier transition to feeding on coarser plants after release. Additionally, it may create preferential consumption of wild exotic plant species. Collecting and supplementing larger quantities of exotic plants is an economical substitution to the annual cost of purchased foods. Because manatees consume large quantities of food in captivity, they provide the potential for an extensive quota of exotic plants to be collected in order to fill this requirement providing dual benefit.

The indirect use of captive manatees to control invasive aquatic plants does have some disadvantages. Though this practice has expanded in recent years, the amount of vegetation collected does not make up a significant percentage (mean $\sim$ 1.35%) of the annual diet of animals at the South Florida Museum (Figures 2A–C). Highlighting the weaknesses of physical collection methods, exotic plant intake must markedly increase in order to accomplish this task. Temperature has a large impact on the growing season when some invasive aquatic plants species proliferate (Rejmanek and Richardson 1996); environmental factors inhibit accessibility and availability of targeted species and further complicate these endeavors. Because of this, employing captive manatees to manage invasive aquatic plant species in an expanded region is improbable but can be helpful in some confined areas.

Application of invasive aquatic plant management in the environment

This method has been shown to be an effective means of reducing the volume and potential spread of aquatic invasive plants in stagnant, small-scale or contained areas such as private ponds. During this study, regrowth of exotic species was not as strong in sequential years of collection; in some instances, infestations were removed in their entirety. While the large-scale use of this process in the environment possesses shortcomings because of time constraints, smaller sites are able to be cleared through physical collection; they may take an entire season depending on the size and plant density at the collection site. Post removal of water hyacinth at Deer Prairie Slough showed improvement to native plant communities and restoration of water flow to the immediate area. Since there was no treatment with herbicides at collection sites, this decline can be attributed in part to the endeavors of this study. Other biological entities such as the water hyacinth weevil (*Neochetina* sp.), which is an established species in Florida used to curb invasive water hyacinth (Center et al. 1999a, Center et al. 1999b, Hill and Cillers 1999, AERF 2005), could have contributed to this as well. For larger sites, and in moving bodies of water like rivers, it will be more difficult to clear out plants as they are dynamic to the movement of water. In these types of waters, seedlings can be disbursed to formerly cleared areas. Efforts may prove promising if they are initiated in areas upstream and no infestations arise beyond that point.

Further development

Further research needs to be done in order to examine the nutrient benefit and postrelease diet preferences of manatees. Increasing the amount of natural food fed to manatees in captivity will enhance the advantages found in this study. Expanding the number of species targeted for collection and developing improved collection techniques will allow for an increase in the quantity of exotic plants that can be harvested. This will enable a greater volume of these plants to be implemented into the diet of captive animals and will increase the overall efficiency of utilizing manatees as a mechanism for invasive aquatic plant management.

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