Rethinking Exotic Plants: Using Citizen Observations in a Restoration Proposal for Kings Bay, Florida

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ABSTRACT

The Kings Bay, Crystal River complex, located in Citrus County, Florida, is one of the world's largest spring-fed ecosystems and a critical warm-water refuge for endangered Florida manatees. Unfortunately, large areas of Kings Bay are currently in a state of ecological degradation characterized by smothering mats of the filamentous cyanobacterium *Lyngbya wollei*. The causes of this ecosystem shift are not well understood, although it is often suggested that human-caused nutrient loading into the Bay combined with intermittent saltwater intrusions from storm surges may be responsible. In this article, we present results from interviews with local citizens, a review of aquatic plant literature, and research into the history of ecological change in Kings Bay. Our work indicates that management efforts to eradicate invasive exotic aquatic species may also have played an important role in the dominance of *L. wollei*. We suggest that future restoration efforts should follow a logic of "alternative stable states" that focuses primarily on the recovery of desired ecosystem functions and relaxes the assumption that exotic plants should be minimized. The Kings Bay case study points toward a more adaptive conception of ecological restoration, one informed by local knowledge and open to the utilization of established exotic plants as a tool for maintaining or restoring important ecological attributes.

Keywords: adaptive management, alternative stable states, ecological restoration, Eurasian milfoil (*Myriophyllum spicatum*), Florida, hydrilla (*Hydrilla verticillata*), invasive species, local knowledge, *Lyngbya wollei*, water hyacinth (*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*)

The minimization or elimination of exotic species is one of the traditional goals of ecological restoration. However, many ecosystems are so drastically altered that eliminating established exotics may be cost-prohibitive or even impossible (D'Antonio and Meyerson 2002). Moreover, field studies indicate that some exotic species, particularly plants established in highly degraded areas, can provide functional services that are remarkably consonant with long-term conservation and restoration goals. Naturalized exotic plants have been found to facilitate restoration through various functional mechanisms, including rapid fixation of nitrogen in depleted soils (Parotta 1992), establishment of a protective canopy for forest understory development (Lugo 2004), and phytoremediation of harmful pollutants (Ma et al. 2001). In other cases, exotic plants targeted for eradication by ecosystem managers can provide primary feeding and breeding habitat for native fauna that these same managers are trying to protect (Chen 2001, Shapiro 2002). Eradication of one exotic plant species from a site does not necessarily result in the straightforward restoration of native communities, and may sometimes lead to the establishment of other exotic or invasive species more difficult to manage. This has led Ewel and Putz (2004) to suggest that strict adherence to the principle of minimizing exotic species within ecological restoration projects may at times be counterproductive.

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Alternative Stable States

Recent research concerning "alternative stable states" raises further questions about the general conclusion that exotic species constitute an *a priori* harm (Sagoff 2005). Limnologists have observed that some shallow aquatic ecosystems switch between alternative stable states (Blindow et al. 1993, Scheffer et al. 1993). In one stable state condition, large populations of macrophytes create and are dependent upon clear water. In contrast, the other stable state condition is characterized by cyanobacteria or algal communities that create and are able to thrive in highly turbid water. Switches between the two states are triggered by high-energy events, with wind, waves, and torrential rainfall from hurricanes among the most common natural disturbance factors for stable state switches in subtropical areas such as Florida (Bachmann et al. 1999).

This logic of alternative stable states has three important implications that should be considered by people involved in restoration. First, because a "forward switch" into a turbid algal state results in cascading changes to biotic assemblages and sediment structure, even substantial reductions of external nutrient loading will not lead to a straightforward recovery of the previous macrophyte community (Scheffer et al. 1993). Bachmann et al. (1999) suggest that efforts to restore submersed macrophyte communities in Florida's hypereutrophic Lake Apopka through nutrient reduction have been unsuccessful due to feedback loops that favor continued dominance by suspended algae. A second implication of this alternative steady states logic is that widespread herbicide use and similar disruptions caused by invasive plant control activities may catalyze a forward shift in stable state from macrophytes to algal dominance. Large-scale control of exotic macrophytes has been suggested as such a catalyst for forward shifts observed in several Florida lakes, including Lake Apopka (Clugston 1963, Chesnut and Barman 1974), Lake Okeechobee (Grimshaw 2002), and Lake Tarpon (Robison and Zarbock 1998). Third, an increasing number of studies indicate that highly productive macrophytes such as water hyacinth (*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*), and hydrilla (*Hydrilla verticillata*), which are often managed as undesirable invasive exotic weeds, may facilitate "reverse shifts" into desired submersed macrophyte communities (Hu et al. 1998, Canfield et al. 2000, Scheffer et al. 2003, Rodriguez-Gallego et al. 2004).

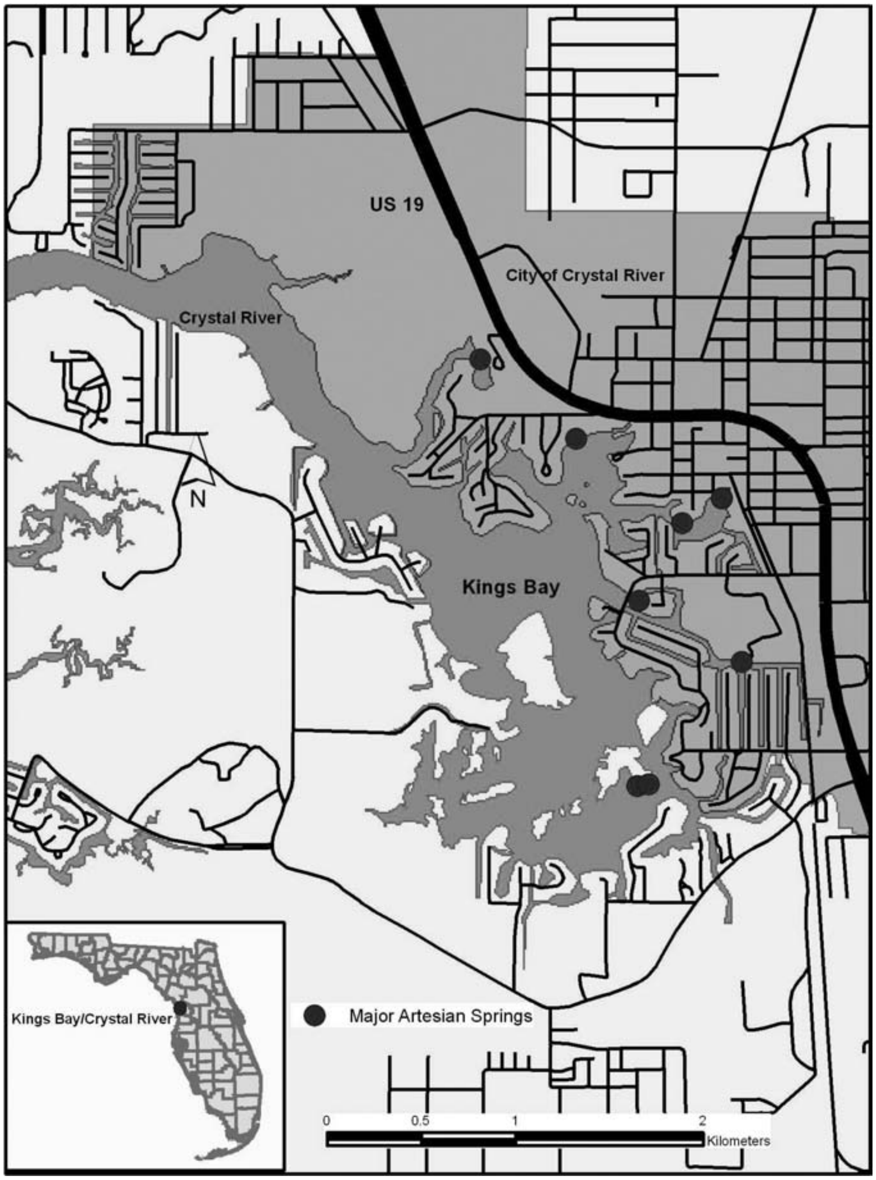
In this paper, we follow this line of reasoning through an interdisciplinary case study of Kings Bay, Florida. Kings Bay, the spring-fed headwaters of Crystal River, is famous as a critical warm-water refuge for endangered West Indian manatees (*Trichechus manatus*). Significant areas of Kings Bay are currently in a persistent state of ecological degradation characterized by smothering mats of the cyanobacterium *Lyngbya wollei*. The causes of this ecosystem shift are not well understood, although it is commonly suggested that human-caused nutrient loading and intermittent salt-water storm surges are to blame. Interviews with local citizens, a review of aquatic plant literature, and the history of invasive plant management in Kings Bay suggest, however, that past efforts to control invasive exotic species may have also played an important role in the current degraded state of the bay. Using alternative stable state logic in support of ideas articulated by local citizens, we assess the potential for a more adaptive management approach and, in particular, explore the idea that exotic plant species such as water hyacinth, water lettuce, hydrilla, and Eurasian water milfoil (*Myriophyllum spicatum*) could assist in achieving major ecological restoration goals for Kings Bay.

Kings Bay and Crystal River

The headwaters of the Crystal River, in Citrus County, Florida peninsula, lie in Kings Bay. The bay is a 243-hectare area of open water with depths generally ranging between 0.9 and 3 meters and containing at least 30 artesian springs (Jones et al. 1998). The combined discharge of these springs is approximately 2.39 billion liters per day, making Kings Bay one of the world's largest artesian spring complexes (Rosenau et al. 1977). The springs maintain a year-round water temperature of 22 °C and clear water, ecological conditions that have supported the growth of highly productive submersed aquatic plant communities, an important habitat for endangered manatees. Florida's manatee population, which is estimated at 3,000 to 3,500, is primarily threatened by collisions with boats and toxins associated with near-shore algal blooms (Bledsoe et al. 2006).

Nature-based tourism, much of which features manatee viewing, currently flourishes in the Crystal River region. However, there is widespread concern among government agencies and local citizens about ongoing ecological deterioration characterized by increased coverage by filamentous cyanobacteria such as *Lyngbya wollei* and associated declines of submersed macrophytes such as native tape grass (*Vallisneria americana*). While the replacement of submersed plant communities by filamentous cyanobacteria is in itself a cause for concern, *L. wollei*'s potential to release cyanotoxins that may adversely affect manatee health has prompted even greater alarm (Bledsoe et al. 2006). Virtually all displaced plant species are food sources for manatees (Campbell and Irvine 1977), while *L. wollei* apparently has little to no food value (Anonymous 2005). Other problems posed by *L. wollei* include its unattractive "slimy" appearance, emission of foul odors, association with decreased water clarity, and potential to cause severe allergic reactions in swimmers (Gross and Martin 1996, Munson 1999).

In 1988, the Kings Bay/Crystal River complex was listed by the Southwest Florida Water Management District (SWFWMD) on its Surface Water Improvement and Management (SWIM) priority list (SWFWMD 2004). Under the provisions of Florida law, the associated SWIM Plan serves as the operative research and planning document for setting and achieving ecosystem restoration and protection objectives. Primary goals listed in the plan are improved water clarity, reduction of *L. wollei*, prevention of sediment resuspension within the water column, re-vegetation of desirable submersed macrophytes, and protection of the endangered manatee population (SWFWMD 2000). Despite almost two decades of detailed scientific research and management effort



Kings Bay, the spring-fed headwaters of Crystal River, is famous as a critical warm-water refuge for endangered West Indian manatees and contains at least 30 artesian springs. The combined discharge of these springs is approximately 2.39 billion liters per day, making Kings Bay one of the world's largest artesian spring complexes. Map credit J.M. Evans

associated with the SWIM Plan, however, the clear consensus among local citizens and ecosystem managers is that Kings Bay continues to decline.

The Study

The genesis of this study was the lead author's participation from August to December 2004 in a project to assist the City of Crystal River in developing model stormwater and landscaping ordinances aimed at improving water quality. The University of Florida's Conservation Clinic sponsored this collaborative project. Development of the stormwater ordinances required working closely with local residents and agency representatives and participation in meetings held by the Kings Bay Water Quality Subcommittee—a citizen-based advisory group funded by the Waterfronts Florida Partnership of the Florida Department of Community Affairs (FDCA 2006).

During this project, Jason Evans was exposed to additional citizen concerns about the management of Kings Bay. Interest in better understanding and exploring these concerns led to the development of a qualitative research project. We pursued interviews with twenty-four involved citizens between April and August 2005 about their perception of the various problems facing the aquatic ecosystem in Kings Bay, their understanding of how these problems arose, and their insights into what might be done to help remedy these problems in the future.

Study participants were selected through a snowballing technique beginning with key informants identified through the Conservation Clinic project. These first participants were then asked to nominate other knowledgeable local citizens who then nominated additional people. While our non-random selection method means that our results may not be generalizable to the larger population of the Crystal River area, we did gain important knowledge from a subset of citizens who have deep interest in the Kings Bay ecosystem. Environmental ethicists and natural resource management theorists have argued that local knowledge is an important complement to expert knowledge and can even expose deficiencies in expert approaches (Holling et al. 1998, Fischer 2000). Local knowledge can also be the source of novel hypotheses for management and restoration (Norton 2005).

Interview Findings

In the interview sessions, most citizens cited increased nutrient loading, hydrologic alterations, and storm surges as important drivers in ecosystem change, which closely match those typically cited by agency managers and research scientists (SWFWMD 2000). Where citizen accounts diverged most clearly from the accounts of managers and scientists was in their observations that past aquatic exotic plant management activities in Kings Bay had directly contributed to the emergence of *L. wollei*. In addition, many citizens expressed a strong belief that increased

Increasing coverage of filamentous cyanobacteria such as *Lyngbya wollei* in Kings Bay is a cause for many concerns including replacing food plants for manatee, potentially releasing cyanotoxins that may adversely affect manatee health, emission of foul odors, decreased water clarity, allergic reactions in swimmers, and an unattractive "slimy" appearance.
Photo credit J.M. Evans

coverage of established exotic macrophytes such as water hyacinth and hydrilla would benefit Kings Bay by increasing water clarity, reducing *L. wollei*, and supporting manatees. Citizens expressed frustration that, in their view, little scientific or management attention has been given to observational accounts linking exotic plant control with proliferation of *L. wollei*. Citizens also stated frustration that ecosystem managers were unwilling to consider alternative management of exotic plants such as water hyacinth and hydrilla as a means of reducing the growth and spread of *L. wollei*.

We accompanied this investigation of citizen concerns with a general review of scientific literature on aquatic plants, focusing specifically on literature related to aquatic plant management and ecosystem change in Kings Bay. This literature review was supplemented by communications with several scientists who have research and management experience in the ecosystem. We combined the information gathered through citizen interviews, our scientific literature review, and communications with agency personnel to develop a narrative history of aquatic plant management and ecosystem change in Kings Bay from 1950 to 2005.

A Local History of Nuisance Aquatic Plants: 1950–2005

Management of "nuisance" aquatic plants has been an issue of great controversy and central importance within the Kings Bay ecosystem for many decades. Published literature on Kings Bay focuses largely on the introduction and spread of hydrilla in the early 1960s and then on persistent *L. wollei* blooms that began in the mid-1980s (SWFWMD 2004). However, several of our informants provided a deeper history, reporting that aquatic plant problems actually began with the proliferation of water hyacinth mats throughout many areas of Kings Bay and Crystal River in the early 1950s.

Water hyacinth

Known as the "world's worst aquatic weed" (Gopal 1987), water hyacinth is a free-floating macrophyte species native to South America that has become naturalized over the past century throughout many subtropical and tropical regions of the world. As described by several long-time citizens, the rapid expansion of floating water hyacinth mats throughout Kings Bay and Crystal River during the 1950s at times made navigation very difficult. These problems triggered an aggressive eradication program in the mid to late 1950s using broadcast herbicides.

Citizens suggested that water hyacinth had been known in Kings Bay and Crystal River for many years, but, unlike many other areas of Florida that had battled water hyacinth since the late nineteenth century, the plant was not considered particularly invasive before the 1950s. In fact, a variety of beneficial features associated with water hyacinth were noted in the interview sessions. Local fishermen reportedly considered the edges of water hyacinth mats to be superior nursery habitat for fish, and it was also noted that the attractive water hyacinth blooms can be a desirable aesthetic feature (see Tilghman 1962, 1963, Maltby 1963 for similar historical accounts on the St. Johns River). Even when describing the proliferation of water hyacinth, most informants noted their belief that the water clarity of Kings Bay remained as high as it had been previously or has been since. Interviewees also expressed the opinion that water hyacinth control operations were responsible for undesirable ecological changes, including significant declines in water clarity and the subsequent proliferation of another nuisance weed—hydrilla.

If these reports about water hyacinth in Kings Bay/Crystal River circa 1950s are accurate, there are fairly straightforward explanations for the plant's changed growth behavior and the observed ecosystem effects. This is because the 1950s marked the beginning of a period of large-scale shoreline and watershed development along Kings Bay, which is thought to have resulted in substantial increases of nutrient loadings from wastewater and fertilizer sources (SWFWMD 2004). In addition, significant shoreline alterations that destroyed fringing wetlands and greatly increased sediment loading into Kings Bay were also associated with this development period (SWFWMD 2004). Gopal (1987) notes that factors such as increased inputs of sediments and nutrients, disturbance of extant circulation patterns, and destruction of fringing marshes all provide ideal conditions for water hyacinth to enter into a period of exponential, or invasive, growth similar to that described by interview informants.

Such exponential growth would likely cause navigational problems similar to those reported by interviewed citizens. However, a review of aquatic plant literature also supports the observation that water clarity and submersed aquatic vegetation communities in open water areas remained relatively unchanged during the period of water hyacinth expansion. This is because water hyacinth is known to sequester large amounts of soluble nutrients (Agami and Reddy 1990, Tripathi et al. 1991, Panda and Kar 1996, Sooknah and Wilkie 2004), filter algae and other particulates in its fibrous roots (Kim et al. 2001), and suppress phytoplankton blooms through allelopathic mechanisms (Jin et al. 2003). In an experiment on China's Lake Taihu, Hu et al. (1998), for example, found that such feedbacks provided by water hyacinth improved water clarity and helped to maintain submersed plant communities in open water areas.

Citizen reports about the effects of water hyacinth control are also consistent with mechanisms noted in aquatic plant literature. While herbicides generally are quite effective in suppressing water hyacinth, the practice results in the deposition of large amounts of nutrients and other contaminants from the dying plants into the water column and bottom sediments (Reddy and Sacco 1981). Chemical control of water hyacinth is therefore often followed by large algae blooms (Clugston 1963, Brower 1980, Grimshaw 2002) or explosive growth of submersed plants such as hydrilla (USACE 1973).

Hydrilla

Citizen interviews and published literature both indicate that after water hyacinth control efforts in the 1950s, hydrilla soon became the dominant macrophyte species throughout large areas of Kings Bay and Crystal River. Hydrilla is a submersed macrophyte species native to Africa and Southeast Asia that has spread throughout the world, largely due to its historic popularity within the aquarium trade and prolific growth capabilities within a wide range of environmental conditions. The appearance of hydrilla in Kings Bay circa 1960 is thought to mark one of the first records of this exotic species within Florida (SWFWMD 2000).

Local citizens repeatedly asserted that the rapid growth and spatial extent of the hydrilla invasion resulted in a range of environmental and navigation problems that dwarfed those previously associated with water hyacinth. Although the growth and spread of hydrilla was likely inevitable after its introduction, work by Fontaine (1978) suggests that enriched sediments deposited by previously treated water hyacinth mats may have exacerbated the subsequent problems. Hydrologic disturbances and creation of "bare" aquatic habitat through the dredging of numerous canals along the eastern shore of Kings Bay in the 1960s and 1970s were additional factors that likely facilitated the rapid spread of hydrilla over this period.

Early hydrilla control efforts were varied and largely ineffective, including a now notorious attempt to control the plant (which was, at the time, misidentified as *Elodea* sp.) through the application of large amounts of sulfuric acid obtained from a nearby phosphate mine into various areas of Kings Bay (Phillipy 1966). Aquatic plant managers later acknowledged that this treatment method only temporarily affected hydrilla and likely had severe detrimental effects on fish and other biota (Friedman 1987). A more long-term hydrilla treatment program using a variety of copper-based herbicides was instituted in the 1970s, but many citizens and managers considered this program ineffective and counterproductive also (Dick 1989). Copper herbicide applications were discontinued in the late 1980s after highly elevated levels of copper were detected in Kings Bay's sediments and in the organs of deceased manatees (O'Shea et al. 1984, Facemire 1991, Leslie 1992, SWFWMD 2000). A hydrilla management program based upon shredding, mechanical harvest in navigational trails, and application of herbicides such as diquat, endothall, and fluridone was instituted in the late 1980s (Dick 1989, Cowell and Botts 1994). These methods remain the foundation of the current hydrilla management plan within Kings Bay (Anonymous 2005).

Lyngbya wollei

Noticeable blooms of filamentous algae such as *L. wollei* were first recorded in Kings Bay in the late 1970s and early 1980s (SWFWMD 2004), but, likely due to the dominance of hydrilla, the coverage and persistence of these blooms remained at low levels (Dick 1989). Large-scale *L. wollei* blooms throughout Kings Bay were first reported in September 1985, soon after temporary salinity increases associated with the storm surge of Hurricane Elena reduced the hydrilla population by over 90% (Dick 1989, SWFWMD 2004). Despite the historical problems associated with water hyacinth and hydrilla, interviewed citizens suggested that the emergent *L. wollei* invasion was almost universally regarded as having even more deleterious effects on wildlife habitat, recreational desirability, and overall aesthetics within Kings Bay (see also Dick 1989).

Interview accounts indicate that hydrilla populations began to recover and *L. wollei* blooms progressively lessened for several years after the 1985 storm surge (see also Cowell and Botts 1994). However, ongoing aquatic plant management activities and additional storm surges associated with the "Storm of the Century" in March 1993 resulted in further displacement of hydrilla (Bishop 1995, SWFWMD 2004). While the 1993 storm surge also resulted in temporary declines of *L. wollei* and increased coverage of more salt-tolerant macrophytes such as Eurasian milfoil and tape grass throughout many areas, *L. wollei* quickly rebounded to maintain an almost complete monoculture throughout the north central, northeastern, and southeastern portions of Kings Bay (Frazer and Hale 2001).

Over the past decade, management efforts to reduce *L. wollei* and restore native submersed plant communities—sediment dredging, replanting, mechanical harvesting—have had disappointing results. Most recently, SWFWMD has initiated a watershed education program, which is designed to reduce nutrient inputs into Kings Bay through voluntary behavioral change, as a priority management strategy for achieving goals outlined by the SWIM plan (SWFWMD 2004). While such a program may be valuable from the standpoint of public education, it is, for reasons discussed in more detail below, insufficient as a stand-alone restoration approach.

Scientific Research on *Lyngbya wollei* Dominance

The underlying factors that resulted in the establishment of the *L. wollei* community in Kings Bay have been widely studied and debated over the past two decades. SWFWMD (2004) describes *L. wollei* as an exotic species introduced sometime in the late 1970s and early 1980s; however, very little evidence exists to support this claim. Whitford's (1956) work indicates that *L. wollei* is, in fact, an indigenous cyanobacterium species that has mutated or become invasive over time due to changing ecological conditions (Gross and Martin 1996). There has also been much speculation that increased nutrient concentrations, nitrate-nitrogen as well as phosphorus, and salinity levels, are responsible for the emergence and persistence of *L. wollei* (Jones et al. 1998). Studies attempting to correlate Kings Bay's nitrate-nitrogen with *L. wollei* coverage, however, have generally found no significant relationship (SWFWMD 2004).

As we discovered through both the interview process and participation in public meetings, many longtime citizens associate the appearance of *L. wollei* in Kings Bay with the large-scale application of herbicides for hydrilla control in the 1970s and 1980s—an account that is also suggested by Cowell and Botts (1994). SWFWMD (2004) reports that the first noticeable blooms of *L. wollei* occurred in the late 1970s and early 1980s, an era in which copper herbicide formulations were most intensively used for hydrilla control in Kings Bay (O'Shea et al. 1984, Leslie 1992). Despite such vocal public concern and anecdotal evidence, the potential linkage between herbicidal treatment of aquatic macrophytes and the emergence of *L. wollei* monocultures has received little formal attention in Kings Bay research.

The merit of citizen observations is most clearly supported by studies noting that one of *L. wollei*'s distinctive ecological traits is its resistance to the herbicidal and algaecidal formulations—including copper, endothall, and diquat—historically used for hydrilla control in Kings Bay (Dyer et al. 1992, Gross and Martin 1996, Spencer and Lembi 2005). All of these herbicides are known to control many species of freshwater algae (Whitworth and Lane 1969, Leland and Carter 1984, Dubose et al. 1997). This suggests that an unintended consequence of large-scale hydrilla control may have been selection of resistant *L. wollei* strains to become a dominant component of the phytoplankton and periphyton communities. Such a mechanism is described by Cooke et al. (2005), who note that negative side effects of copper herbicide applications typically include the selection of copper-resistant algal strains, severe impairment of planktonic food chains, and sediment contamination. Given that severe copper contamination of Kings Bay's sediments is clearly documented (Facemire 1991, Leslie 1992), it is plausible that severe disruption of the algal community and preferential selection of resistant *L. wollei* forms may also have resulted from past hydrilla treatments.

In this scenario, herbicidal control methods would have freed *L. wollei* of algal competitors. Because copper herbicides are ineffective at long-term hydrilla control, the expansion of *L. wollei* likely was, as suggested by Dick (1989), prevented so long as hydrilla grew back quickly after chemical treatments. However, the destruction of hydrilla as a result of the storm surge events would have provided an ideal opportunity for *L. wollei* to expand and assert dominance throughout the ecosystem. The rapidity with which these changes could have occurred is underscored by *L. wollei*'s incredibly fast doubling time of 0.8 to 2 days in ideal conditions where it is provided with ample nutrients and released from competition (Tubea et al. 1981)—not unlike the conditions described after the storm surge. By way of comparison, water hyacinth's maximum doubling time, often regarded as the fastest measured among the world's macrophytes, is approximately 6 days (Bartodziej and Leslie 1998).

Regardless of the ultimate triggering mechanisms, the growing dominance by *L. wollei* represents a forward shift in stable state from macrophytes to filamentous cyanobacteria—a suggestion that is consistent with the finding that growth and accumulation of *L. wollei* is not significantly slowed by even quite dramatic reductions in nutrient loading and concentrations (Terrell and Canfield 1996, Cowell and Dawes 2004, Stevenson et al. 2004). With this in mind, SWFWMD's current focus on nutrient load reduction through public education is likely to have minimal effects on the future growth of *L. wollei*, even under the most ideal (and unlikely) scenarios of voluntary compliance. We suggest that the seemingly intractable nature of the *L. wollei* problem at Kings Bay calls for a break from traditional management paradigms and a move towards adaptive management.

Adaptive Management

Aquatic plant management activities at Kings Bay and other Florida waterways are founded in a provision of Florida law, which states that the goal of aquatic plant managers should be the establishment of "maintenance control" for invasive and nonnative species (Florida Senate 2006). While maintenance control can be an effective means of controlling invasive plant species and promoting restoration in some aquatic systems, the history and current state of aquatic plant management at Kings Bay has striking parallels with what Holling (1995) calls a condition of "management pathology." Holling argues that management pathologies result when managers achieve initial success in controlling a single target variable, and then focus on operational efficiency at the expense of ongoing monitoring for ecosystem changes. A common result of such narrow management focus, Holling argues, is an unnoticed homogenization of critical ecosystem components, which consequently makes the ecosystem much less resilient to disturbance.

The historical evidence suggests that a condition of management pathology has developed at Kings Bay around the minimization of exotic plants. The roots of this pathology can be traced back to successful efforts to control water hyacinth. However, this success was then followed by the more difficult problem of hydrilla, which has now been supplanted by an almost entirely unsuccessful effort to control *L. wollei*. Each change in ecosystem state observed at Kings Bay over the past 50 years is widely regarded as a condition of further degradation, leading to substantial frustration among ecosystem managers (Dick 1989) and local citizenry.

We argue that rigid adherence to maintenance control is counterproductive and call for a more flexible approach based upon adaptive management principles. The primary foundations of such an approach can be summarized as follows: 1) natural resources always change due to both human action and natural events; 2) some of these changes will be quite surprising; 3) new management uncertainties are bound to emerge from these surprises; 4) management actions should be treated as experiments from which new knowledge and hypotheses about the managed resource can be developed; 5) management policies should be continuously modified to reflect new understandings; and 6) local citizens should be intimately involved as partners in building basic knowledge and future goals for better managing the resource (Holling 1995, Norton 2005).

A first step towards an adaptive management approach in Kings Bay would be a reconsideration of the goal of restoring Kings Bay to pristine conditions. Current and predicted human development, not to mention the unpredictable impacts of climate change, make this goal unrealistic. A second step requires management agencies to incorporate the knowledge of local citizens into the design of restoration strategies and management experiments. Our interview research indicates that such a participatory approach would yield scenarios for utilizing exotic plant species in restoration. In the final section of this paper, we outline some of the scientific and normative rationales for considering a restoration approach that would tolerate, and even openly utilize, four notoriously invasive exotic species currently found in Kings Bay: water hyacinth, water lettuce, hydrilla, and Eurasian milfoil.

Adaptive Restoration Opportunities Provided by Four Notorious Macrophytes

We argue that an effective approach to ecological restoration for an ecosystem like Kings Bay may be to identify and utilize feedback mechanisms that would sustain the desired clear water macrophyte stable state, while relaxing the assumption that these feedbacks can only be provided by native species. This is not to say that the invasive exotic species should not be managed, or that efforts to promote recovery of native plants should be abandoned. Rather, the role of exotic plants as, for example, contaminant sinks, faunal habitat, transitional buffers, and aids in stable state succession should be recognized and openly incorporated into restoration efforts, rather than rejected on an *a priori* basis.

Water hyacinth

The idea of using water hyacinth to improve water quality and other ecosystem conditions has been advocated by residents of the Crystal River area for many years. Aquatic plant and ecosystem managers with current or past connection to Kings Bay resist any proposal to modify the current control strategy for water hyacinth, however, which is based upon maintaining low levels of the plant through chemical treatment. The long history of problems associated with water hyacinth overgrowth in Florida makes concerns about alternative management approaches understandable, but a growing number of research studies indicate that the water hyacinth could assist with ecosystem restoration in Kings Bay.

It is well known that water hyacinth is one of the most effective aquatic plants at sequestering several types of heavy metals (Lee and Hardy 1987, Lu et al. 2004), petroleum-based organic contaminants (Hu et al. 1998), and soluble nitrogen and phosphorus (Panda and Kar 1996, Sooknah and Wilkie 2004) known to be present in Kings Bay, suggesting that, at the very least, growth and harvest of water hyacinth could be utilized as a contaminant removal mechanism. Water hyacinth has also been found to greatly inhibit cyanobacteria production through synergistic mechanisms, including reduction of ambient nutrients and sunlight (Mahujchariyawong and Ikeda 2001), emission of allelopathic compounds (Gross 2003, Jin et al. 2003), direct filtration of algal cells in its fibrous roots (Kim et al. 2001), and habitat for zooplankton grazers. Perhaps even more importantly, water hyacinth is also known to be a preferential and nutritious food source for manatees (Lomolino and Ewel 1984). Thus, increased availability of water hyacinth in Kings Bay could reduce manatee grazing pressure on native submersed macrophytes such as tape grass (Lomolino 1977, Bengston 1983), which is an important factor in the failure of restoration plantings (Hauxwell et al 2004).

It is plausible that one or more of these functions provided by water hyacinth would have the effect of reducing *L. wollei* in Kings Bay. Also, while harvest of aquatic plants is often considered prohibitively expensive due to biomass disposal costs, harvested water hyacinth has been used for organic fertilizer, biogas, and weaving fiber (Lindsey and Hirt 1999, Shoeb and Singh 2000), most notably in Thailand (Morris 2001). The finding that mass harvest of floating macrophytes such as water hyacinth can be followed by a rapid shift to a stable state of submersed macrophytes gives further support for consideration of such a management program at Kings Bay (Scheffer et al. 2003).

Efforts to utilize an exotic species such as water hyacinth within an ecosystem restoration project are not without some risks. As we have described, however, improved water clarity and reduction of cyanobacteria resulting from increased water hyacinth coverage has been found in some cases to substantially benefit submersed macrophyte populations within open water areas (Hu et al. 1998, Rodriguez-Gallego et al. 2004). Moderate water hyacinth coverage has been shown to result in increased levels of dissolved oxygen (Furch 1995). Furthermore, Bartodziej and Leslie (1998) found that flowing water conditions under water hyacinth mats prevented oxygen suppression in the spring-fed St. Marks River, located in the Florida panhandle. The flowing water conditions in Kings Bay would likely have a similar effect on the oxygen profile under water hyacinths. Florida aquatic plant managers justify current maintenance control strategies by emphasizing risks associated with exotic species, and often refer to Joyce's (1985) finding that the sediment deposition rate of untreated water hyacinth mats is four times more than the rate of water hyacinth maintained at minimum levels by herbicidal control. However, a close reading of Joyce's (1985) study suggests that due caution should be used when extrapolating these results into typical field conditions.

Water Lettuce

Although water lettuce is officially listed and managed as an invasive exotic species within Florida, the botanical history of the plant raises considerable doubt about this classification. The explorer William Bartram observed and made drawings of water lettuce on the St. John's River and other areas of Florida in 1765 (Stuckey and Les 1984). Paleofloristic work indicates that water lettuce may have been present in Florida and most other subtropical areas of the world prior to European colonization (Stoddard 1989).

Regardless of its origins, the alternative management opportunities provided by water lettuce are similar to those listed above for water hyacinth. Manatees are known to consume water lettuce (Bengston 1983), and like water hyacinth, water lettuce is widely known as one of the most effective vascular plants for uptake of soluble nitrogen and phosphorus (Panda and Kar 1996, Sooknah and Wilkie 2004) and heavy metals (Sridhar 1986). Water lettuce may also help to control algae and cyanobacteria growth through allelopathic emissions (Aliotta et al. 1991) and filtration of algal cells in its fibrous roots (Kim et al. 2001). Optimal harvest of water lettuce from an aquatic system also removes significant amounts of sequestered contaminants from the water body, and can be followed by rapid recovery of a submersed macrophyte stable state (Scheffer et al. 2003). Research indicates that water lettuce biomass can be utilized to produce beneficial products such as biogas and organic fertilizer (Reddy and Rao 1987).

Hydrilla

We found that many Kings Bay residents who remember significant problems caused by hydrilla in Kings Bay after its appearance in 1960 now advocate for this notoriously invasive exotic species. Four consistent rationales were offered by informants: 1) hydrilla maintains water clarity; 2) hydrilla suppresses the growth of *L. wollei*; 3) hydrilla is a preferred manatee food; and 4) hydrilla provides good habitat and cover for desirable fish and wildlife species.

Hydrilla's role in maintaining water clarity and suppressing the growth of *L. wollei* within Kings Bay is well-established (SWFWMD 2004), leading SWFWMD to adopt a *de facto* policy of preferring hydrilla over *L. wollei* for the purposes of the SWIM Plan (A.H. Remley, SWFWMD, pers. comm.). Hydrilla's importance as a preferred and nutritious fodder for Kings Bay manatees is also well-documented (Campbell and Irvine 1977), and has led aquatic plant managers to acknowledge that maintenance control mandates for hydrilla may, at times, be trumped by the need to maintain adequate food supply for manatees (Anonymous 2005). While extremely dense populations of hydrilla can negatively affect fish and wildlife, recent research shows that up to 85 percent hydrilla coverage can benefit fish and wildlife populations (Netherland et al. 2005). Evidence that native tape grass, a frequent restoration target, can co-exist and even expand coverage in the presence of hydrilla (Rybicki and Carter 2002) gives even more reason for reconsidering the role of the plant.

However, the most far-reaching adaptive management opportunity provided by hydrilla in Kings Bay may stem from a better understanding of why this species has in large part ceased to be as invasive as it once so famously was within this ecosystem. A key component may be the 1992 discovery of *Cricotopus lebetis* living among hydrilla in Kings Bay (Cuda et al. 2002), the larvae of which significantly damage hydrilla stems and may restrict hydrilla growth. Indications that hydrilla in many areas of Florida is rapidly developing herbicide resistance (Michel et al. 2004) provide great impetus for better understanding the potential role of biocontrol agents. If *C. lebetis* is, in fact, effectively preventing hydrilla from becoming a severe navigational nuisance, habitat and functional benefits provided by hydrilla may justify abandonment of large-scale chemical control against this species in Kings Bay.

Eurasian Milfoil

Eurasian milfoil, a submersed macrophyte native to Europe, Asia, and northern Africa, is often considered one of the worst aquatic weeds within the United States (Madsen et al. 1991). Although Eurasian milfoil has not attracted as much citizen or management attention as other exotic macrophyte species in Kings Bay, recent aquatic plant surveys indicate that it now maintains the largest coverage of any submersed macrophyte species in the system (Frazer and Hale 2001, SWFWMD 2004). While there are indications that Eurasian milfoil stands may be having some adverse impacts on native macrophyte populations (Hauxwell et al. 2004), Eurasian milfoil's exudation of allelopathic chemicals that are inhibitory toward a wide variety of algal and cyanobacterium species (Gross 2003) may also be providing a buffer against further proliferation of *L. wollei*. Clearly, the importance of Eurasian milfoil as a primary food source for the wintering manatee population (Campbell and Irvine 1977) and the potential for aggressive control methods to result in establishment of *L. wollei* monocultures that may almost entirely eliminate native macrophytes should both be taken into close account as future aquatic management and restoration plans are developed.

Conclusion

In this study, we compiled a history of ecological change in Kings Bay based on citizen informants and a review of scientific research. We found that many local citizens associate invasive aquatic plant management activities with the emergence of a highly undesirable filamentous cyanobacterium species, *Lyngbya wollei*—an observational hypothesis that has credible support within the scientific literature. This research suggests that four notoriously invasive exotic macrophytes currently established in the Kings Bay ecosystem—water hyacinth, water lettuce, hydrilla, and Eurasian milfoil—perform functions that potentially could be utilized within a holistic and adaptive program of ecological restoration based upon the logic of alternative stable states. Consideration of such a restoration approach requires a rethinking of invasive exotic plants as tools for restoring important ecosystem functions rather than as *a priori* harms that should always be minimized.

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