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Adaptive Management of Nonnative Species: Moving Beyond the "Either-Or" Through Experimental Pluralism

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Abstract This paper develops the outlines of a pragmatic, adaptive management-based approach toward the control of invasive nonnative species (INS) through a case study of Kings Bay/Crystal River, a large artesian springs ecosystem that is one of Florida's most important habitats for endangered West Indian manatees (*Trichechus manatus*). Building upon recent critiques of invasion biology, principles of adaptive management, and our own interview and participant–observer research, we argue that this case study represents an example in which rigid application of invasion biology's a priori imperative to minimize INS has produced counter-productive results from both an ecological and social standpoint. As such, we recommend that INS control in Kings Bay should be relaxed in conjunction with an overall program of adaptive ecosystem management that includes meaningful participation and input from non-institutional stakeholders. However, we also note that adaptive management and INS control are by no means mutually exclusive, in Kings Bay or elsewhere. Instead, we suggest that adaptive management offers a means by which INS control efforts can emerge from—and be evaluated through—ongoing scientific research and participatory dialogue about the condition of specific places, rather than non-contextual assumptions about the harmfulness of INS as a general class.

Keywords Adaptive management · Invasion biology · Nonnative species · Invasive species · Crystal River · Florida springs · Manatee · Water hyacinth · Algal blooms

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1 Introduction

Today's ecosystem managers invest large amounts of time, money, and effort on programs that aim to control and/or eliminate invasive nonnative species (INS). On the face of it, the rationales for such control programs are quite compelling. For example, one influential study (Pimentel et al. 2000) estimates that INS annually cause over $100 billion of damages—an amount that includes estimates of damage to agriculture, forestry, and wildlife, as well as the direct costs of controlling INS—in the United States alone. Another study (Wilcove et al. 1998) concludes that INS currently represent the second greatest threat to the world's endangered species, just behind direct habitat destruction (e.g., deforestation) by modern humans. Ultimately, many invasion biologists (i.e., those who specialize in the study of INS) fear that the continued spread of INS threatens nothing less than the irrevocable destruction of native ecological assemblages across the globe, essentially replacing an evolutionary heritage of biodiversity with an impoverished, weedy world of "biosimilarity" (e.g., Hettinger 2001; Olden et al. 2004; Simberloff 2005).

Given such a backdrop, it is not at all surprising that INS control has emerged as a normative goal among ecosystem managers, ecologists, and, indeed, the wider environmental community. In recent years, however, a variety of academic critics have raised an increasing number of questions about the language, science, moral reasoning, and management prescriptions that characterize the underlying discourse of invasion biology. While some of these critics are largely reformist in the sense that they aim to strengthen the scientific credibility and maintain public support for INS control programs, others are hardened skeptics who pointedly dispute invasion biology's basic scientific and moral claims about how INS should be understood and managed. Boiled down to its most basic level, the debate between invasion biology and its most skeptical critics hinges on the following binary question: do INS represent an ecological bane that should be aggressively countered to preserve local and global biodiversity, as invasion biologists argue; or are INS ecologically innocuous or even beneficial to the extent that aggressive control activities are often unjustified and even ecologically destructive in their own right, as skeptics maintain?

In this paper, we engage this debate through a socio-ecological case study of Kings Bay, an artesian springs ecosystem located on the west coast of the Florida peninsula that provides critical habitat for a large population of endangered West Indian manatees (*Trichechus manatus*). Integrating recent critiques of invasion biology with principles of adaptive ecosystem management, we argue that the Kings Bay case study provides a clear example in which rigid application of invasion biology's a priori imperative to minimize INS has become counterproductive from both an ecological and social standpoint. As such, we argue that modification of current INS control policies in Kings Bay is justified by an adaptive and participatory approach that directly integrates local knowledge from non-institutional stakeholders into the research and management context. At the same time, we maintain that adaptive management and INS control are not mutually exclusive, in Kings Bay or elsewhere. Instead, we suggest that adaptive management offers a means by which INS control efforts can emerge from—and be evaluated through—ongoing scientific research and participatory dialogue about the condition of specific places, rather than non-contextual assumptions about the harmfulness of INS as a general class.

2 Conceptual Framework

In order to understand how the Kings Bay case study provides an example of why invasion biology can be helpfully conceptualized through adaptive management, it is necessary to first explore both invasion biology and adaptive management in a more general theoretical sense. First, we define important terms, discuss major ethical and empirical claims, and explore several lines of criticism associated with invasion biology as an applied scientific discipline. We give particular attention to an exchange between Mark Sagoff, a prominent critic of invasion biology, and ecologist Daniel Simberloff, a prominent defender of invasion biology, that highlights key fault lines regarding how facts, values, and the meaning of ecological change associated with INS can be interpreted. The second section of the conceptual framework then provides a brief account of adaptive management as both an interpretive theory and set of prescriptive principles. Applied directly to INS controversies, we suggest that adaptive management's participatory approach avoids the stark "either-or" problem of competing a priori judgments generally suggested by the Sagoff-Simberloff debate and, as discussed later in the paper, specifically manifested in the example of Kings Bay.

2.1 Invasion Biology and its Discontents

Formally defined, an INS is a species that meets both of the following criteria: (1) it was not present in a given region before some reference time period (i.e., is nonnative); and (2) it exhibits the ecological behavior of rapidly reproducing, spreading, and displacing extant species without direct human assistance (i.e., is invasive) in its new region. It is necessary to be clear about such a distinction from the outset, simply because discussion about invasion biology too often degenerated into confusion and outright error associated with the conflation of the logically distinct concepts of "nonnative" and "invasive" (i.e., assuming that all nonnative species are invasive, or, conversely, that all invasive species are nonnative (see Head and Muir 2004)). In fact, most nonnative species fail to survive without direct human assistance or are wholly uncompetitive with established native species, and thus are not INS for the simple reason that they are not invasive. Conversely, unambiguously native species are known to exhibit invasive behavior in certain circumstances, with a prominent example being native cattails (*Typha* sp.) that have displaced sawgrass marshes in nutrient-enriched areas of the Florida Everglades. Such invasive species are, of course, not INS because they are not nonnative.

Definitional quibbles aside, it is clear that human activity—particularly over the past century—has significantly increased the rate and extent of species introductions (both intentional and unintentional) across geographic space. This fact provides a primary rationale for considering INS in terms of both ecological science and, when coupled with a moral framework, environmental ethics (see Lodge and Shrader-Frechette 2003). From a scientific perspective, ecological theory suggests that nonnative species run a high risk of becoming invasive because the new geographic ranges into which they are introduced lacks co-evolved features (e.g., herbivores, predators, competitors, parasites, diseases, nutrient limitations, disturbance regimes, etc.) that presumably prevented these species from behaving invasively in their native ranges (Simberloff 2005). Based upon the premise that such invasiveness is a direct cause of measurable economic and environmental damages (e.g., Wilcove et al. 1998; Pimentel et al. 2000), policies for controlling INS can be coherently derived from moral frameworks as distinct as anthropocentric utilitarianism (i.e., preventing damages to human values), deontological eco-centrism (i.e., obligating humans to prevent, undo, or otherwise mitigate environmental changes that human activity has caused), and democratic theory (i.e., policies for controlling INS have, in fact, been adopted by many elected legislatures that presumably represent the will of the populace).

But given the ambiguity and complexity that such moral interplay between science and policy necessarily implies, it comes as no particular surprise that invasion biology has attracted a significant amount of criticism from natural scientists, social scientists, and professional philosophers. Perhaps the most common and general criticism is that invasion biologists often undermine their scientific and moral credibility through the outward use emotive and/or militaristic terms (e.g., "alien invaders," "noxious species," "biological pollution," "war against invaders") to describe INS and explain rationales for control programs (e.g., Jordan 1994; Gobster 2005; Larson 2005). More provocative commentators argue that such a vocabulary is not just scientifically suspect, but that it also reveals deep parallels between the tenets of invasion biology and xenophobia, nationalism, and even Nazism (e.g., Groning and Wolschke-Bulmahn 2003; Theodoropolous 2003). Theodoropolous (2003), one of the most outspoken and controversial critics of INS control, goes so far as to suggest that such language exposes invasion biology as a propaganda-based "pseudoscience" that cynically uses fear-mongering about nonnative species for the purpose of attracting funds to university programs, regulatory agencies, and pesticide manufacturers.

Although such criticisms have engendered debates and concerns even among proponents of INS control (see Jordan 1994; Gobster 2005; Larson 2005), there is good reason to believe that questions about language and metaphors do not seriously challenge the legitimacy of invasion biology's underlying empirical and moral claims. To take the most egregious example, the suggestion that invasion biology is morally abhorrent because botanists in Nazi Germany favored native species over nonnative species is dismissible through the simple invocation of the so-called *reductio ad Nazium* (as the argument goes, on-time trains would also be morally wrong if acceptance by Nazis is a sufficient standard for moral wrongness). The more general charge of preference for native species being nothing more than nativist xenophobia is answered at some length by Simberloff (2003, p. 189), who argues that xenophobia and nationalism have no necessary relationship with "the strongest ethical bases" for invasion biology's concerns about INS—namely, "that (INS) can threaten the existence of native species and communities and that they can cause staggering damage, reflected in economic terms, to human endeavor." Similarly, Jordan (1994) suggests that invasion biology can avoid charges of xenophobia and militarism by instead emphasizing the multicultural ideal that native species are an "oppressed and threatened group" that we, as moral beings, have a duty to protect from the impersonal and extinctive forces of global homogenization. Put another way, if militaristic and xenophobic-sounding language such as "war against the alien invaders" represents the primary problem with invasion biology, the obvious reformist position simply entails the adoption of language such as "restoring healthy ecosystems," "protecting endangered species," or "preserving historic landscapes" when explaining the rationales for INS control (see Gobster 2005; Larson 2005).

A recent paper by Sagoff (2005), however, offers a critical analysis of invasion biology that moves beyond superficial arguments about language and metaphor, and instead puts forth a series of direct and detailed challenges to the empirical and implied ethical bases for INS control. As a first prong of critique, Sagoff argues that the oft-cited claim that INS pose extreme extinction risks to native species (generally through citation of Wilcove et al. 1998) is, at least in most cases, based on an inductive fallacy. Citing work by Gurevitch and Padilla (2004), Sagoff points out that the vast majority of cases in which INS have been documented as a primary cause of extinction are characterized by the introduction of generalist animals into small islands and other "island-like" habitats (e.g., isolated lakes with endemic species, such as Africa's Lake Victoria). He then contrasts this specific finding with the observation that most INS control programs are directed at plants that have invaded continental land masses, noting that at least two logical distinctions that can be made between INS events that are known to cause extinction and the targets of most INS control programs: (1) animal versus plant, at the species level; and (2) island versus continental, at the ecosystem level. Absent species and site-specific information that may suggest otherwise, Sagoff thus argues that a primary justification for controlling INS—averting the risk of extinction—actually has very little empirical merit in the most common case of nonnative plants introduced into continental ecosystems.

A second prong of Sagoff's (2005) critique is aimed at the moral assumptions used to justify INS control efforts. Sagoff basically argues that invasion biology is plagued by an a priori interpretive bias that not only defines any documented effects of nonnative species as harmful, but also conflates costs associated with the *control of* INS with the supposed *damages caused by* these species. One basic problem with this reasoning is that defining all effects of INS as harmful gives rise to a vicious tautology: control of INS is justified by research suggesting that these species produce such and such harmful effects, but then many of these effects, in turn, are defined as harmful because they are produced by INS. Moreover, because ecological studies have often suggested that the success of INS can be viewed as a secondary symptom of other environmental changes (see Ewel and Putz 2004; Larson 2005), it stands to reason that simple focus on INS control may only treat symptoms and not get at the "root causes" of the observed harm. In practical terms, the ecological aftermath of INS control efforts may often not be restoration of a desired ecological community, but rather the unpredictable emergence of alternative ecosystem states and new dominant species that, in many cases, may be even more undesirable than the ones removed by previous management interventions (see Krajick 2005).

Sagoff (2005) extends this argument by pointing to empirical studies indicating that introduction of nonnative plants (including INS) tends to increase both species richness and biological productivity in most local areas, with the implication being that control activities may often be counterproductive in the sense that these seemingly desirable metrics are suppressed (see also Ewel and Putz 2004). In other words, defining costs of control as damages associated with INS seems, at best, to beg the question as to whether the control activities are a necessary or effective method for correcting harms. At worst, Sagoff's analysis implies that such a framework provides a self-justifying tautology for counter-productive control activities that are a source of harm in their own right.

Sagoff's critique provoked Simberloff (2005) to offer a detailed counter-analysis in defense of invasion biology. A key point of Simberloff's response is that Sagoff makes a seemingly arbitrary assumption that increases in productivity and species richness that may be associated with nonnative plant invasions are "desirable" (see also Lodge and Shrader-Frechette 2003). Simberloff specifically rebuts the assumption about the desirability of increased productivity by noting that eutrophication, which is defined as an increased productivity of aquatic ecosystems, is often associated with widespread algal blooms, suppression of economically important fisheries, and other ecological phenomena that are widely regarded as undesirable. Similarly, Simberloff notes Sagoff's default moral position about species richness has strikingly counterintuitive implications, in the sense that an INS could very well increase species richness in an area while otherwise changing the aesthetic character or other properties of ecosystems in ways that most people judge undesirable. To give a hypothetical example, local displacement of four rare native species by five cosmopolitan INS in a specific region would have the effect of increasing gross species richness in that area (by one). According to Sagoff's apparent moral calculus, the increase in species richness would be viewed as a desirable outcome, so long as the rare species were not extirpated globally. Simberloff, by contrast, argues (convincingly, in our view) that very few people are likely to view the replacement of long-established, local ecological associations by INS as a desirable outcome.

Simberloff (2005, p. 595) is, however, considerably less successful with other aspects of his rejoinder to Sagoff. Most notably, Simberloff fails to counter Sagoff's specific claim that nonnative plants pose little extinction risk to native species. Instead, Simberloff reverts to examples of introduced predators that threaten birds (particularly on isolated islands) to support the claim that INS are a major cause of extinction. Because such examples are specifically acknowledged by Sagoff as ones in which the claim of high extinction risk from a particular class of INS is justified by empirical research, the inductive fallacy critique discussed above is left intact. Similarly, Simberloff also seems to fall back into a tautological conception of harm when he stipulates that increases in local species richness are irrelevant as a management consideration, because, in his view, such increases do not correspond with "desired changes in ecosystem function." Ostensibly, this argument can be refuted through citation of specific examples in which INS have been shown to both promote species richness increases and perform ecological functions (e.g., removing contaminants; increasing habitat for native wildlife; promoting soil stability) that are generally regarded as desirable (see Ewel and Putz 2004; Foster and Sandberg 2004).

But moving beyond the merits of specific points, we suggest that the debate between Sagoff and Simberloff ultimately collapses into a caricatured "either-or" that apparently leaves little room for dealing with the moral and empirical ambiguity that actual situations may pose: (1) in the case of Simberloff, identified INS are a priori harmful, with the implication being that there is an a priori duty to control INS whenever encountered; or (2) in the case of Sagoff, INS are rarely if ever harmful, with the implication being that the default (if not quite a priori) moral position is to consider control activities aimed at INS (particularly plants) unjustified. Specifically applying general arguments recently made by Norton (2005), we now turn toward a discussion of adaptive management as a framework that expressly moves beyond irreconcilable debates over a priori judgments by explicitly subjecting all facts and values to the rigors of participatory debate and experimental revision in the context of specific places.

2.2 Adaptive Management

Before getting into more detail about how adaptive management might inform ethics and policy associated with INS, it is important to note that one of the great attractions about adaptive management is that it is already an influential ideal (or, perhaps more correctly, popular buzzword) among ecosystem management professionals and academic researchers. Initially developed as a means of managing forests and fisheries through the use of systems ecology models and iterative scientific monitoring regimes (Holling 1978), the underlying principles and analytic frameworks of adaptive management have been applied over a wide variety of ecological, social, and institutional settings throughout the past two decades (Wescoat and White 2003; Norton 2005). Florida's ecosystem management agencies have specifically cited adaptive management as the guiding resource management philosophy for restoration of artesian springs ecosystems (Pandion Systems 2003) and protection of the state's manatee population (United States Fish and Wildlife Service 2007). In other words, there are clear institutional, not simply abstract academic, justifications for regarding adaptive management as an appropriate framework for evaluating both the historical and contemporary management of the Kings Bay ecosystem.

A summary of key writings (e.g., Holling 1995; Berkes and Folke 1998; Norton 2005) suggests that adaptive management emerges from recognition and integration of the following six concepts: (1) *variability*, in that natural resources always change due to both human management actions and natural variation; (2) *unpredictability*, in that some of these changes will be quite surprising; (3) *uncertainty*, in that new management actions will always have to be initiated in the face of surprises and imperfect information; (4) *experimentation*, in that all management interventions should be treated as provisional experiments from which new observations, hypotheses, and knowledge about the managed resource can be developed; (5) *flexibility*, in that all management policies should be continuously modified to reflect new discoveries about the managed resource; and (6) *participatory*, in the sense that local citizens should be intimately involved as partners with managers and scientists in building basic knowledge and future goals for better managing the resource.

A major rationale for the move toward adaptive management is to correct and/or avoid the traps of what Holling (1995) refers to as management pathology—or the tendency of management institutions to inflexibly entrench particular policies in such a way that they end up undermining the values they were originally set up to protect. Numerous examples of management pathology are found throughout the adaptive management literature, including long-term fire abatement programs creating conditions for "super fires" (Berkes and Folke 1998), spruce budworm control activities that promoted spread of the budworm to much larger spatio-scales (Holling 1978), and collapse of fisheries due to long-term application of inherently flawed sustainable yield models (Finlayson and McCay 1998). To avoid such pathologies, adaptive management calls for use of a systems-type approach that situates the specific scientific findings at one scale of analysis—whether based upon econometrics, population biology, toxicology, or other disciplines—within the context of more general models or frameworks that encompass larger spatio-temporal scales. This "contextualization" of scientific understanding, adaptive management proponents argue, is necessary to avoid what Gunderson (1999) refers to as the trap of "spurious certitude," or the tendency of institutions to justify ongoing policies through scientific findings based upon one (generally reductionistic) scale of analysis. Contextualization in a larger system does not, however, represent a wholesale critique of reductionism, but, rather, is intended to avoid overly general or "universal" (and, thus, usually inappropriate) application of management policies based on one favored disciplinary model or constricted scale of analysis (Gunderson 1999).

An important observation that has emerged from case studies of ecosystem collapse is that local observers and user groups who are in daily contact with an ecosystem often are adept at identifying ecological changes at scales quite different from those monitored by scientists (e.g., Finlayson and McCay 1998). This general observation has led adaptive management proponents to argue for a participatory prescription that calls for widening the scales of analysis through direct involvement of citizen (i.e., non-scientist and non-manager) stakeholders in research development and management decisions. This prescription finds justification in both the epistemological idea that informal "local knowledge" contains key insights gained through day to day observations that are not practical through formal ecological research, as well as a more basic principle of democratic governance that holds that stakeholders should, as a matter of ethical principle, have a direct voice in management decisions that affect their environments and lives (see Fischer 2000; Norton 2005).

Norton's concept of "experimental pluralism" has particular resonance as a means of avoiding the "either-or" dilemma about the harmfulness of INS that emerges from the Sagoff-Simberloff debate. In essence, experimental pluralism expressly seeks to avoid arguments about which scientific claims and moral theories are more correct at a general level, but instead subjects all facts and values to experimental testing and participatory analysis in local contexts—particularly seeking out "input from community members and groups, such as a stakeholder committee or a citizens' advisory committee" (Norton 2005, p. 293) in this discursive process. Under this framework, one can imagine scenarios in which specific INS might be viewed as harmful in some local places and non-harmful or even beneficial in others, while judgments in all cases would be open for radical modification over time in response to changing interpretations about changing conditions.

The most apparent weakness in such an application of experimental pluralism would be the possibility of a newly introduced nonnative species becoming established and spreading to cause irreversible harms before knowledge about the threat becomes widespread. The best answer that we have for this problem is that it seems likely that most stakeholder groups would, in practice, agree to and adopt a precautionary principle that encodes preemptive interventions as a means of avoiding unknown harms from new INS. These precautionary interventions would, like any other management intervention, be subjected to participatory evaluation and modification in response to experience and changing conditions. As such, we conclude that there is no inherent contradiction between precautionary control of INS and adaptive management programs rooted in experimental pluralism.

With that said, we can think of no apparent reason (other than a collapse into an a priori assertion of harm) for rejecting experimental pluralism in cases of long-established INS for which eradication is impossible (thereby making any return to a strictly "native" ecosystem impossible) and where there are well-articulated concerns and debates about whether INS control methods are proving more harmful than the INS being controlled. The Kings Bay case study, to which we now turn, provides an almost tailor-made example in which articulated local knowledge and local values can be integrated with consensual conservation values and scientific knowledge in such a way that alternative management of INS is justified through the principle of experimental pluralism. At the same time, the case also illustrates the powerful hold of reflexive invasion biology-based discourses at the institutional level, and the barriers that such discourses pose to adaptive learning and, more arguably, the technical achievement of more desirable socio-ecological outcomes.

3 Study and Site Methods

Located on the west coast of the Florida peninsula approximately 100 km north of Tampa, Kings Bay is a 250 ha water body formed by at least 30 known (and perhaps many more) artesian springs that have a combined discharge of approximately 2 billion liters per day (Rosenau et al. 1977). The Kings Bay springs complex together forms the headwaters of Crystal River, a tidally-influenced coastal river system that meanders for approximately 7 km before discharging into the Gulf of Mexico. Due to their spring source, the waters of Kings Bay have long been renowned for their remarkable translucence (hence the name Crystal River) and mild year round temperature of approximately 22°C.

Such environmental conditions in the bay and river historically supported dense communities of submersed aquatic plants and a diverse variety of freshwater, estuarine, and marine animals. Most famously, Kings Bay is known as a critical habitat for a significant population of West Indian manatees, an herbivorous marine mammal federally listed as an endangered species. Primary threats to Florida's manatee population include collisions with recreational boats, ingestion of toxins associated with near-shore algal blooms, loss of aquatic plant food sources, and prolonged exposure to water temperatures below the animal's metabolic tolerance (approximately 20°C). Up to 50 manatees reside in or near Kings Bay year round, and more than 300 manatees (approximately 10% of the Florida population) have been recorded in Kings Bay during winter months, when the relatively warm spring waters provide the animals with thermal refuge. The recreational desirability of clear water springs and the opportunity to view large numbers of a charismatic endangered species together serve as the foundation for a significant nature-based tourism economy in the City of Crystal River, a small town (population ~2,000) located on the northern and eastern shores of Kings Bay.

From April 2005 through April 2006, the lead author engaged in a participatory research project in the Crystal River area under the supervision of the two junior authors. The core component of this research project was a series of in-depth interviews with 24 Crystal River residents that catalogued local knowledge about the management history and ecological condition of Kings Bay. Initial interview participants were selected from members of the Kings Bay Water Quality Subcommittee (KBWQS), a citizen council that formally advised the City of Crystal River on water quality issues. Subsequent participants were selected through a modified Delphi Technique in which participants recommended other local citizens perceived to be knowledgeable about the Kings Bay ecosystem. Other aspects of the research project included direct participation in 10 KBWQS meetings, participation in five Kings Bay Working Group meetings (a stakeholder discussion group facilitated by the Southwest Florida Water Management District (SWFWMD) under the auspices of its Surface Water Improvement and Management (SWIM) Plan for Kings Bay), public record e-mail communications with agency managers and research scientists, and a comprehensive review of scientific literature about Kings Bay (see also Evans et al. 2007; Evans 2007).

4 A Changing Ecosystem

Citizen accounts and scientific reports indicate that the modern history of Kings Bay (i.e., post World War II) has been characterized by a series of qualitative changes in ecosystem state associated with different invasive (both nonnative and native) aquatic plant species, management interventions aimed at these invasive species, stochastic natural disturbances (e.g., hurricanes and droughts), and a general increase in water pollution from human activities. Using dominant plant communities as outward marker of general ecosystem state, our research suggests that the following eras can be loosely delineated for Kings Bay over the past five decades: (1) pristine tape grass (*Vallisneria americana*), pre-1950; (2) water hyacinth, circa 1950–1960; (3) hydrilla, circa 1960–1985; and (4) Lyngbya and other algae/cyanobacteria, circa 1985 to present (see Evans 2007 and Evans et al. 2007 for more detailed scientific and historical accounts of these eras).

While we recognize that all ecosystems are in a constant state of flux and that there are major problems with formally defining what is meant by "pristine," there is widespread agreement among local residents, managers, and scientific researchers that modern human impacts to the ecology of Kings Bay were relatively minimal through the end of World War II. Aerial photographs indicate that the early 1950s marked the beginning of major commercial and residential developments that destroyed shoreline vegetation, increased the loading of sediments and other contaminants, and radically altered the hydrology throughout Kings Bay (SWFWMD 2004). These initial disturbances were followed in subsequent decades (circa 1960–1970) by major ditching and canalization projects that directly destroyed wetlands along Kings Bay, and steady population growth and associated land use conversions throughout the watershed (through the present).

Interviews with long-time Crystal River residents suggest that development disturbances in the early 1950s were followed by a rapid expansion of water hyacinth (*Eichhornia crassipes*), a nonnative floating aquatic plant, from shoreline fringe areas into large swaths of open water. Interestingly, the accounts also suggested that water hyacinth was known in Kings Bay well before the plant's population proliferated to nuisance levels,[1] and that local fishermen in particular were known to regard the plant as a reliable habitat for finding bait such as shrimp and crayfish as well as a nursery ground for largemouth bass and other freshwater fish. Expansion of the water hyacinth, one interview participant argued, was "nature's way of dealing with development," an assessment that is generally consistent with scientific literature suggesting that explosive growth of water hyacinth is often a direct result of increased contaminant loading, habitat disturbance, and other human impacts in a water body (see Gopal 1987).

Whatever the ultimate cause, interview participants indicated that the extensive floating mats of water hyacinth did come to be regarded as a navigational nuisance, in much the same way as reported elsewhere in Florida during the first half of the 20th century (see Buker 1982) and throughout many other areas of the subtropics and tropics where water hyacinth has been introduced (see Gopal 1987). Interview accounts also indicated that, similar to other areas of Florida, an herbicide program to suppress water hyacinth apparently was initiated in Kings Bay in the mid to late 1950s.[2]

Although four interview participants with remembrances of this period suggest that aggressive hyacinth suppression initially was welcomed by local fishermen and other local residents frustrated by the impacts of the plant's increasingly prolific growth, local opinions began to shift yet again in the aftermath of the control programs. One long-time resident emotionally recounted the early water hyacinth control program in the following way:

> The crystal water… went to muck when the hyacinths died from the spray, and the fish couldn't be found. As bad as the hyacinth was, what they did to get rid of 'em was worse… The water was always clear with the hyacinths, and the fish was never better—even if we couldn't always get to 'em. It never was the same after they sprayed 'em all down.

On the one hand, such a comment can be plausibly read as a romanticized vision of the water hyacinth's ecological role and, at the same time, an overly critical appraisal (perhaps made more so by years of hindsight and distance from the actual phenomenon) of a management program initiated in response to a clear socio-ecological problem. On the other hand, the basic ecological observations are not implausible due to the fact that water

[1] Historical records indicate that water hyacinth was first introduced into Florida's St. Johns River in the 1880s (Webber 1897) and was present at high levels in the Withlacoochee River, which has reaches that are within 20 km of Crystal River, by the early 1940s. Other than our interview accounts, we do not know of any historical documentation associated with the timeline of water hyacinth's presence in the Kings Bay/Crystal River ecosystem.

[2] We must qualify this timeline by noting that, unlike later periods of aquatic plant control, we were unable to located historical records about the water hyacinth control program in Kings Bay during the early 1950s.

hyacinth is well-known for significant pollutant filtering and water clarifying abilities (e.g., Hu et al. 1998; Kim et al. 2001; Sooknah and Wilkie 2004). Moreover, scientists have observed large algal bloom, loss of fish, and rapid replacement by other INS such as hydrilla following large-scale water hyacinth control in other ecosystem contexts (Clugston 1963; USACE 1973; Bicudo et al. 2007)—findings that are generally consistent with the remembrances of interview participants. In any case, there is widespread perception among Crystal River residents that Kings Bay precipitously declined as a result of hyacinth suppression (even among those who did not directly observe events during that period)—a perception that stands in marked contrast to aquatic plant managers who still regard maintenance of Kings Bay's water hyacinth population at the "lowest feasible level" as a primary management objective (Interagency Working Group 2005).

Beginning in the early 1960s, Kings Bay came to be almost entirely dominated by hydrilla, a submersed plant native to Africa and Southeast Asia that is considered a severe INS problem in many aquatic systems throughout Florida and the southeastern United States. Initial sightings of hydrilla in Kings Bay/Crystal River in approximately 1960 are particularly notable because they mark one of the first records of this species in Florida (Schmitz et al. 1993). Within a few years of first reports, hydrilla was reported to cover much of Kings Bay, growing from the bay bottom until "topped out" at the water surface, shading out native submersed plant species, and severely impeding navigation (Phillipy 1966; Haller et al. 1983).

Overall problems associated with hydrilla were generally perceived as being much more severe and widespread than those associated with water hyacinth, for the simple reason that hydrilla—unlike any historical reports of water hyacinth in Kings Bay—at times would cover almost the entire bay. However, most interview participants did associate at least two positive ecosystem values to hydrilla: (1) a noticeable increase in the amounts of manatees, which presumably were attracted by large amounts of a preferred grazing fodder (see also Kochman et al. 1985) that came to Kings Bay; and (2) an apparent increase in the bay's water clarity due to the filtering capacity of the prolific plants.

Several interview participants provided detailed descriptions of historic hydrilla control efforts in King Bay, making particular note of incidents and techniques documented in published accounts. Hydrilla control experiments in the mid-1960s in which hundreds of thousands of gallons of sulfuric acid were loaded into the water body (Phillipy 1966) were commonly cited as the most notorious example of overzealous aquatic plant control (see also Friedman 1987). However, more long-term controversy was associated with a hydrilla treatment program instituted in the early 1970s that primarily used a combination of copper and diquat herbicides (Haller et al. 1983; Dick 1989). Many citizens apparently believed that these herbicides had adverse effects on fish, birds, and other aquatic life in Kings Bay, while aquatic plant managers cited reports suggesting that the herbicides posed little threat to aquatic organisms in Kings Bay when used appropriately (e.g., Haller et al. 1983). Ultimately, use of copper herbicides in Kings Bay was suspended following documentation of highly elevated copper concentrations in the organs of deceased manatees from the Crystal River area (O'Shea et al. 1984; Facemire 1991).

A fairly discrete end to the hydrilla era and beginning of the Lyngbya era came in September 1985. At that time, a storm surge associated with Hurricane Elena reportedly forced large volumes of salt water into Kings Bay from the Gulf of Mexico, which in turn precipitated a large-scale die-off of salt water-sensitive hydrilla plants (see Mataraza et al. 1996). Within a few days following the storm surge and loss of hydrilla, it is widely reported that Kings Bay then experienced "blooms" of filamentous cyanobacteria such as *Lyngbya wollei* at an ecosystem-scale (see Dick 1989; Cowell and Botts 1994; Mataraza et al. 1996; SWFWMD 2004). Interview participants suggested that while noticeable blooms of filamentous algae in Kings Bay were often associated with an increased intensity in the herbicide program targeting hydrilla during the late 1970s and early 1980s, such blooms were localized and short in duration due to the rapid grow-back of hydrilla (see also Cowell and Botts 1994). Although levels of *L. wollei* coverage in Kings Bay have waxed and waned since the Elena storm surge (e.g., Dick 1989; Cowell and Botts 1994), interview participants and aquatic plant surveys (see SWFWMD 2004) both indicate that *L. wollei* has largely displaced hydrilla as a dominant component of the aquatic ecosystem.

The shift toward *L. wollei* dominance in Kings Bay represented a change in ecosystem state that is, by virtually all accounts, regarded as highly undesirable. Much of the undesirability is a matter of aesthetics, as *L. wollei* is typically described as having an unattractive "slimy" appearance and unpleasant smell—both of which tend to reduce human enjoyment of aquatic systems in which it is found in high quantities (see Gross and Martin 1996; Joyner et al. 2008). *L. wollei* is, however, a source of deeper conservation concern in Kings Bay because—unlike most native and nonnative aquatic plants that have been displaced—it does not provide a suitable food source for manatees (Interagency Working Group 2005) and, even worse, may emit chemicals that are toxic to manatees and other marine mammals (see Bledsoe et al. 2006; Joyner et al. 2008).

However, our stakeholder interviews and participant–observer research both indicate that consensus about the undesirability of outward symptom of ecological decline (i.e., *L. wollei*) has not translated into consensus about how to define, much less approach, the problem in the management context. Instead, discourses among managers, researchers, and local residents are characterized by technical uncertainty about what triggers the ongoing proliferation of *L. wollei*, explicit and implicit disagreements about how *L. wollei* ranks in relation to other potential ecological problems, and stark disagreements about the value, even legitimacy, of past and proposed management interventions. Taken together, the growing pressure to "solve" the problem combined with profound social uncertainty about problem definition, apparent lack of any "right or wrong" answer, and very real possibility that any intervention could create an even worse problem suggest that Kings Bay provides an almost textbook example of a "wicked problem" (see Fischer (2000) and Norton (2005) for more detailed discussion of wicked problems in environmental decision-making).

The lack of a definitive technical explanation about the environmental variables that favor *L. wollei* proliferation is one of the most strikingly wicked aspects of the Kings Bay case study. While most scientists, managers, and citizens originally attributed *L. wollei* to increases in the amount of nitrate-nitrogen discharged from springs as a result of groundwater contamination (e.g., Jones et al. 1998), this explanation has proven increasingly unsatisfactory due to a number of ecological studies that show no apparent correlation between elevated nitrate-nitrogen levels and *L. wollei* coverage in the context of Kings Bay or other Florida spring systems (Cowell and Botts 1994; Mataraza et al. 1996; Stevenson et al. 2004; Joyner et al. 2008). Another prominent institutional hypothesis suggests that *L. wollei* is an INS that was introduced into Kings Bay in the early 1980s (SWFWMD 2004), thereby implying that the spread of *L. wollei* may primarily be a function of its introduction into a new habitat rather than a symptom of declining water quality (see Stevenson et al. 2004). However, historic accounts document *L. wollei* (also known as *Plectonema wollei*) as a conspicuous component of the algal community in early ecological studies of Florida springs (see Whitford 1956), while taxonomic studies generally suggest that *L. wollei* may well be a native cyanobacteria species (or associated species complexes) that mutated and/or became invasive over time due to some, at this point unknown, set of environmental selection factors (e.g., Gross and Martin 1996).

A number of interview participants noted their belief that *L. wollei* was directly related to aquatic plant control activities, and specifically referenced scientific research suggesting that *L. wollei* is unusually resistant to herbicides—including copper, diquat, and endothall compounds (see Dyer et al. 1992; Gross and Martin 1996; Spencer and Lembi 2005)—that have been used in Kings Bay (see also Faulkner 2000). A hypothesis that clearly emerges from such accounts, but one that has not been formally investigated through scientific research in Kings Bay or other Florida springs systems where *L. wollei* is increasingly found at high levels, is that long-term exposure to herbicidal compounds may provide a selective pressure that results in ecosystems dominated by herbicide-resistant strains of *L. wollei* (see also Evans et al. 2007; Evans 2008). Scientific studies indicate that presence of aquatic plants—particularly hydrilla—is negatively correlated with *L. wollei* (Cowell and Botts 1994; Doyle and Smart 1998), suggesting that *L. wollei* is likely to increase as a result of any disturbance (e.g. hurricanes, aquatic plant control, and manatee grazing) that directly reduces aquatic plant coverage.

Various efforts to control *L. wollei* in Kings Bay over recent years have had limited to no measurable success. The most prominent control method has involved the use of several large harvester machines that physically remove algal filaments from the water column, the surface of submersed aquatic plants, and the benthic substrate. Several of our interview participants (and a number of other citizens observed in public meetings) argued that the harvesters actually promote subsequent *L. wollei* blooms by destroying beds of rooted submersed plants, disturbing bottom sediments, and generally increasing turbidity in the aquatic system. While small pilot studies of the harvester method found little evidence of adverse effects on submersed plants, measurements also showed no significant reductions of *L. wollei* (SWFWMD 2004). Reestablishment of native submersed plants and implementation of education and outreach programs for the purpose of reducing nutrient loading into Kings Bay have also been pursued as general restoration and *L. wollei* reduction strategies (SWFWMD 2004). Recent experiments, however, indicated that manatee grazing pressure severely limited the survival of native plants transplanted into Kings Bay through restoration projects (Hauxwell et al. 2004). Furthermore, a variety of studies suggest that *L. wollei* can thrive in very low nutrient conditions, likely making even the most highly effective water quality improvement strategies an ineffective stand-alone approach for *L. wollei* reduction in Kings Bay (e.g., Cowell and Botts 1994; Mataraza et al. 1996; Terrell et al. 1999; Joyner et al. 2008).

5 Invasion Biology and Management Pathology

As evaluated solely from socio-ecological history, the spiraling feedbacks between ecological change and management response are broadly suggestive of Holling's (1995) management pathology archetype in which narrow focus on one goal (in this case, INS control) unwittingly serves as a catalyst for the production of new ecosystem states qualitatively more undesirable than those observed previously. On the surface, it might be argued that the outward adoption of adaptive management by government agencies as a guiding philosophy for conservation efforts in Kings Bay and other Florida springs (e.g., Pandion Systems 2003; United States Fish and Wildlife Service 2007) suggests an explicit recognition of previous institutional pathologies and a concomitant commitment to more flexible, participatory modes of experimental pluralism. However, a highly public debate between aquatic plant managers and local residents about future experiments indicates the presence of what Norton (2005, p. 248) diagnoses as a primary threat to adaptive management: institutional assertion of the idea that "environmental problems are technical problems that should be left to the experts to manage" and, moreover, that "if the majority of the public does not accept the solutions proposed by efforts, then the public must be coerced or 'educated' to accept the expert findings."

In the case of Kings Bay, the proposed solution to the *L. wollei* problem most recently put forward aquatic plant managers is a chemical control program based upon the integrated use of algaecides such as diquat, chelated copper, endothall, and hydrogen peroxide (Bureau of Invasive Plant Management 2006). Not surprisingly, interview accounts and comments observed at public meetings indicate that many Crystal River residents regard such methods as a direct continuation of past chemical control programs that, in their view, contributed to the degraded ecosystem conditions now observed. A primary alternative advocated by a number of citizens—particularly those most critical of chemical control options—is to allow (or even promote) increased levels of water hyacinth in Kings Bay. The apparent hypothesis behind this suggestion is that the nonnative floating plant would reduce *L. wollei* through biological filtration, direct ecological competition (e.g., shading), and, because water hyacinth is known as a preferred manatee fodder (see Lomolino and Ewel 1984), a presumed reduction of manatee grazing pressure on rooted plants (see Evans et al. (2007) and Evans (2008) for more scientific discussion of these hypothesized mechanisms).

Under the terms of experimental pluralism, each of the proposed solutions (and, indeed, any others articulated through open public debate) would be tested through pilot projects, evaluated by the wider stakeholder community, and modified, expanded, or, indeed, abandoned as deemed appropriate through experiential interpretations. By contrast, the following excerpt from an internal agency document clearly shows the cursory dismissal of public suggestions that run counter to agency recommendations:

> An assemblage of local stakeholders has proposed and staunchly supports several non-traditional lyngbya control strategies. Members have been quite critical of any other management efforts as well as proposals to evaluate conditions, management strategies, and research proposals. This is in contrast with agency representatives who support a methodical, scientific approach to documenting and implementing research and safe and effective management initiatives (Bureau of Invasive Plant Management 2006, p. 5).

The document continues by arguing that citizen stakeholders in Crystal River have a lack of "aquatic plant management experience," a tendency to "(p)romote implementing control methods that are ineffective or untested," and concerns that usage of chemicals to control *L. wollei* "will harm manatees, humans, (and) non-target plants." One of the proposed control methods that the agency specifically regards as "ineffective or untested" (and, presumably, dismissible without further study) includes growth of water hyacinth "to shade or remove nutrients to starve lyngbya" (Bureau of Invasive Plant Management 2006, p. 5).

Our direct communications with a wider range of aquatic plant researchers and ecosystem managers (i.e., including agencies other than the Bureau of Invasive Plant Management), with the specific suggestion that increased amounts and selective harvest of water hyacinth could potentially benefit Kings Bay provoked a wide set of reactions. A handful of agency managers expressed a belief that current management policies were not working, while one manager who oversees manatee research went so far as to provide cautious public support for management experiments using water hyacinths for contaminant remediation and manatee protection purposes. Others, however, indicated unequivocal opposition to alternative management of water hyacinth, with citizen proposals described by different managers as "shocking," "environmentally unacceptable," "contrary to science-based knowledge," "a sign of desperation," and "something that no agency or any scientist with an understanding of water hyacinth attributes would support."

These latter responses, taken together with the agency document quoted above, suggest a permutation to Sagoff's (2005) normative critique of invasion biology and Norton's (2005) express worries about the privileging of expert knowledge. In essence, a testable scientific hypothesis that alternative management strategies for water hyacinth would result in decreased growth of *L. wollei* and improvement of manatee habitat is answered through assertion of the idea that water hyacinth, as an INS, is *ipso facto* harmful to the managed ecosystem. Moreover, this normative position is conspicuously framed as settled scientific knowledge, while citizen observations and proposals are framed as non-objective emotionalism that, as such, can be readily dismissed by agency experts. Given Kings Bay's long history of management interventions, surprise shifts in ecosystem state, and critical importance to endangered manatees, such a stance seems remarkably untenable in terms of both the ethics and epistemologies that follow from an adaptive management ideal.

6 Conclusion: Moving Beyond Either-Or

Instead of falling into the trap of either aggressively controlling all INS regardless of the wider socio-ecological context (i.e., the default position of Simberloff and invasion biology-based management) or assuming that most INS control efforts can be abandoned as scientifically unjustified (Sagoff's ultimate position), the adaptive management position suggests that management of INS, like any other management intervention, should be continuously subjected to the value judgments and participatory evaluations of the stakeholder community engaged in experimental pluralism. We suggest that the case of Kings Bay provides a history of ecosystem change and local knowledge that, taken together, directly challenge the assumption that established INS should always be viewed as harmful. Viewed from the most simplistic socio-ecological perspective, INS such as water hyacinth, hydrilla, and Eurasian milfoil (*Myriophyllum spicatum*) provide a source of food for endangered manatees (Campbell and Irvine 1977; Lomolino and Ewel 1984), while *L. wollei*, a presumably native cyanobacterium, has no habitat value for (and may even present a toxicological threat to) manatees. Assuming that protection of manatees is a social good, it is straightforward to argue that ecological science provides plausible support for a move away from rigid invasion biology-based policies that currently prevail over ecosystem management in Kings Bay.

If adaptive management in Kings Bay is to move beyond the realm of trendy buzzword, an obvious first step would be the institution of pluralistic experiments that incorporate local knowledge into the goal-setting, hypothesis development, and evaluative frameworks. A potentially quite promising mechanism for facilitating adaptive management would be the utilization of participatory methods in conjunction with geographic information systems (GIS) technology (see Bojorquez-Tapia et al. 2001) to create a more sophisticated aquatic plant management plan that is clearly integrated with consensually determined goals for ecosystem improvement. For example, a matrix system might be used to create a list of the various benefits and problems—as defined through public conversations among agency and local citizen stakeholders—associated with the aquatic plants currently managed in Kings Bay. Through a similar stakeholder discussion process, maps of Kings Bay could also be used to identify the desired values and uses, as well as the current ecological condition, for different areas of the water body. Existing multi-stakeholder forums, such as the Kings Bay Working Group, could be readily adapted for such dialogic and research processes.

Based upon these aquatic plant and water body value maps, there is the potential for more geographically strategic and openly participatory decisions to be made about aquatic plant management activities that avoid the "either-or" trap about INS control. For example, we think it safe to assume that tape grass or other native plants would be considered the most desirable plant for overall restoration in Kings Bay, but that INS such as hydrilla and Eurasian milfoil presumably would be considered preferable to *L. wollei* in areas designated primarily for manatee grazing. As such, it could be presumed that aggressive control of non-native aquatic plants through chemical and/or mechanical means would not be favored in areas deemed critical for manatee grazing. At the same time, steps could be taken to exclude manatees and restrict growth of hydrilla, Eurasian milfoil, and/or *L. wollei* in areas where restoration of tape grass or other native plants is consensually agreed as a primary goal (see Hauxwell et al. 2004). In areas where navigation is the primary use, chemical and/or mechanical control to maintain plants at low levels might be deemed the most appropriate management strategy. As suggested by several of our interview participants, experimental phytoremediation projects based upon contained growth and harvest of water hyacinth might be first tested in areas impacted most heavily by *L. wollei*.

In a much more philosophical sense, Larson (2005, p. 499) argues that rethinking our relationship with INS helps to dissolve an "illusory separateness from a natural world 'out there'" and forces a direct confrontation with the complex ways in which our modern activities have inexorably changed the planet and its ecosystems. Ultimately, the battle against INS is not, as Florida's aquatic plant managers imply, justified by "settled science," but, rather, is founded squarely upon the shifting sands of human values and uncertain science characteristic of almost all other complex environmental problems. As ecosystems and values change, we should not be surprised to find cases, like Kings Bay, where peace may well be made with yesterday's exotic strangers.

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