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Chapter 9

"SPECIES POLLUTION" IN FLORIDA: A CROSS-SECTION OF INVASIVE VERTEBRATE ISSUES AND MANAGEMENT RESPONSES

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ABSTRACT

The state of Florida has among the two worst invasive species problems in the USA. Besides the sheer numbers of established exotic species in Florida, many present novel difficulties for management, or have other characteristics making effective management extremely challenging. Moreover, initiation of management action requires more than recognition by experts that a potentially harmful species has become established. It also

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requires the political will along with concomitant resources and appropriate personnel to develop effective methods and apply them. We illustrate various aspects of the situation in Florida with examples of invasive vertebrates, the problems they pose(d), and management approaches to the problems.

The problems described include long-established widespread and destructive species requiring intensive localized management (feral swine, feral cats); recently established species with potentially severe repercussions, but no broad operational removal programs yet in place (Nile monitor lizards, Burmese pythons), highly prolific mammals that could rapidly invade wide areas without containment/eradication (Gambian giant pouched rats, black-tailed jackrabbits); recently established, potentially destructive birds that might still be eradicated (purple swamp hens); species where sufficient public outcry resulted in control programs (black spiny-tailed iguanas); and rapidly expanding aggressive species for which no practical management actions are available (northern curlytail lizard). A species subset is used here to exemplify in more detail the array of invasive vertebrate species situations in Florida, including routes of introduction, impacts, surrounding politics, and management actions. These examples not only demonstrate the breadth of the terrestrial invasive vertebrate problems in the state, but they also show the diversity in resolve and response among the many species and the motivating factors.

INTRODUCTION

The negative impacts inflicted by exotic species on native species and ecosystems may only be exceeded by human-caused habitat destruction (Parker et al. 1999; Wilcove et al. 1998). In the USA, exotic species have played a role in the listing of 42% of the species protected by the Endangered Species Act (Stein and Flack 1996). Invasive species can be considered "pathogens of globalization" (Bright 1999) and Florida provides an ideal medium in which such pathogens can incubate. In fact, quantitative indicators for assessing non-native species situations are analogous to epidemiological descriptors of disease status in a population (Meyerson et al. 2008). Florida's subtropical climate, its major ports of entry for many wildlife species to the U.S. (both legal and illegal), its thriving $300 million captive wildlife industry, and its position in an area of destructive hurricanes that can release captive animals make the state especially susceptible to the introduction and establishment of a wide range of species (e.g. Corn et al. 2002, Hardin 2007). Moreover, Florida is isolated from land with similar climates, resulting in the state's native vertebrates typically originating in the southeast U.S. at the southern extremes of their range. Invaders to Florida therefore find relatively fewer native species to contend with than in most tropical/subtropical locations (Hardin 2007). Florida joins Hawaii as the two states with the most severe invasive species problems in the United States (U.S. Congress 1993, Corn et al. 2002). Notably, Florida has more introduced animals than any other region of the U.S. and also ranks high in this respect globally, with breeding populations of new vertebrate species regularly identified (SFWMD 2008).

The impacts from many introductions are unknown or not readily perceived by the public, while others are immediately apparent or have their negative potential revealed over time. Even highly prolific invasive species may fester for a considerable time before exhibiting an explosive expansion of their range (Shigesada and Kawasaki 1997). Management of an exotic species requires more than the recognition of a potential problem, it also requires a governmental/public motivation to address the problem. Invasive species often

present novel control situations for managers, requiring the acquisition of biological knowledge and the development and testing of control technologies and strategies (see, for example, Engeman and Vice 2001).

The situation in Florida is best understood through a variety of examples. Given Florida's climate, it is no coincidence that a large proportion of the species discussed here are reptiles. Overall, the examples not only demonstrate the breadth of the terrestrial invasive vertebrate problems in the state, but they also show the diversity in resolve and response against the many species and the motivating factors.

Feral Swine

Who let the hogs out? In Florida, it originally was the Spanish explorer Hernando de Soto about a half millennium ago in 1539 who introduced feral swine (*Sus scrofa*) to Florida (Towne and Wentworth 1950), and many additional introductions have followed since. This species has the greatest reproductive potential of all free-ranging large mammals in the United States (Wood and Barrett 1979; Hellgren 1999), which combined with a general absence of large predators over much of their range results in continued population increases and range expansions. Swine are well-known for their depredations on crops, livestock and wildlife (e.g., Choquenot 1996; Seward et al. 2004; USDA 2002). In addition, feral swine in Florida have been documented to harbor as many as 45 parasites and infectious diseases (Forrester 1991).

Feral swine are a recreational game animal in Florida, and consequently would not be targeted for eradication (even if that was possible). Furthermore, some claim they are a vital food source for the highly endangered Florida panther (Maehr et al. 1990) (*Felis concolor coryi*). Conversely, feral swine are also a threat to the Florida panther through transmission of pseudorabies virus, as prey-to-panther transmission has been documented to result in the death of the panther (Glass et al. 1994).

The negative environmental impacts of feral swine often require intensive local control. A premium is placed on sanctuaries for protection and preservation of habitats and species in Florida, especially because much of the natural habitat in Florida has been lost to development. There is an ongoing battle in many parts of the state to protect rare habitats from swine damage (e.g., Florida Natural Areas Inventory 1990). Feral swine in Florida have contributed to the decline of at least 22 plant species and 4 species of amphibians listed as rare, threatened, endangered, or of special concern (USDA 2002). Control efforts typically concentrate on conserving special habitats or species, especially in parks and refuges.

Considerable applied research in Florida has been directed towards development of practical in-field methods for implementing, enhancing and evaluating swine removal for resource protection (Engeman et al. 2007b). Methods have been developed for characterizing swine distribution and relative abundance (Engeman et al. 2001, 2007c), and for assessing damage levels in a variety of habitats (Engeman et al. 2003, 2004b, 2007c). An important complement to estimating damage levels was development of credible means to monetarily value their environmental damage (Engeman et al. 2004a). The ability to place monetary values on damage allows the results of management actions to be evaluated in the same metric (dollars) as management expenses. Universally, economic analyses have shown the

benefits for swine removal to be remarkable compared to management costs (Engeman et al. 2003; 2004b; 2007c), and to also supersede habitat conservation benefits derived from hunting (Engeman et al. 2007c).

The ability to value the habitat resource provides an effectual economic management tool for evaluating conservation approaches. Economic analyses can greatly assist managers on how to most efficiently and effectively allocate limited funds towards habitat conservation. Ultimately, many conservation funding decisions are made on a political level by people without high levels of training or expertise in biological sciences. While it is essential to obtain high-quality data to understand the biological impacts of management efforts, placing conservation issues in an economic context can greatly enlighten the political decision making process on swine removal and has been a driving force for expanding conservation efforts through swine removal (Engeman et al. 2007b).

Nile Monitor Lizards

Many exotic arrivals to Florida do not appear in the public conscientiousness. For example, the mainstream public is typically unaware that the number of non-native lizard species breeding in Florida now exceeds the number of native species, with over three times as many exotic species as native in south Florida (Hardin 2007), and many of the exotic lizard species can eat various life stages of other lizards (Meshaka et al. 2004). Nonetheless, problems with several large lizard species recently have received public/media attention, a factor sometimes serving to catalyze action. Notable among these are problems from a very large (up to 2.3 m), visible lizard, the Nile monitor (*Varanus niloticus*), which over the last 15+ years has become firmly established in the Cape Coral area (Enge et al. 2004), and also now appears established in the Homestead area (USDA/Wildlife Services unpublished data). Nile monitors have been commonly sold in the U.S. pet trade (Bayless 1991; Faust 2001), although the size and disposition of the adults makes them ill-suited to captivity (Bennett 1995). This species may be on the cusp of no-return in terms of its potential for eradication from Florida. Its range around Cape Coral is expanding into neighboring wildlands, and it also has become established on nearby Pine Island, and possibly Sanibel Island as well, where it would be a threat to endangered sea turtles and shore birds (Enge et al. 2004; Campbell 2005).

The Nile monitor can rapidly outgrow many, if not most, potential predators (Meshaka 2006), and this large-bodied carnivore is capable of eating a wide variety of vertebrate prey, potentially impacting a number of threatened and endangered species in the process (Meshaka 2006). For example, the burrowing owl (*Athene cunicularia*), a Florida Species of Concern, has already been observed as a prey item (Hardin 2007). This is a prolific species capable of reaching high densities (Western 1974). Based on its native range, this lizard could expand its range and pose severe threats to native fauna throughout Florida, and possibly beyond (Enge et al. 2004).

An intense and prompt eradication effort might still eliminate the Nile monitor from Florida. Accumulation of useful information for the management of the species has begun (Campbell 2005). However, this would be a novel species to subject to control activities. Considerable development of methods and technologies would be needed for the

implementation of a practical, broad-based control or eradication program. Basic information on diet, baits, and trapping technology exists (Campbell 2005). Considerable testing and refinement of additional baits, attractants, and capture methods applicable to large-scale removal are needed. Building on the successful development of acetaminophen as a toxicant for brown tree snakes (Savarie et al. 2001), trials have been initiated and shown promise for this compound to also be effective for Nile monitors (R. Mauldin and P. Savarie, National Wildlife Research Center unpublished data). Despite a reasonably high profile and media attention, funding has not yet materialized for general development of the needed control technologies, nor for initiating a general control or eradication effort. Without prompt action, the likelihood for successful eradication diminishes. It remains to be seen if denial of "de Nile monitor" will take place in time.

BURMESE PYTHONS

The Burmese python (*Python molurus bivittatus*) is another large exotic carnivore entrenched in Florida (Meshaka et al. 2000). The pathway to invasion for this species has been largely attributed to (illegal) pet releases (e.g., Snow et al. 2006). However, the highly destructive impacts from Hurricane Andrew in 1992 included the release of many animals from captive breeding and holding facilities. Recent genetic results showing little differentiation among pythons captured in south Florida are congruent with this possibility for precipitating the population and the resultant numbers currently observed (Collins et al. 2008).

Similar to the Nile Monitor, there is a diminishing probability for successful eradication as time passes without intensive management action. Its range has been expanding, although the total extent of its potential range in the U.S. has been the subject of considerable controversy (Barker and Barker 2008, Pyron et al. 2008). Nevertheless, containment to its current range may not remain realistic without developing and broadly implementing control methodologies. This very large snake (up to 7 m) has been found with increasing frequency in and around Everglades National Park on the southern tip of Florida. The possibility that this snake might replace the American alligator (*Alligator mississippiensis*) as the top-order carnivore in its range cannot be discounted. In addition, this is one of the six largest snakes in the world, and a large python could pose a danger to humans, especially in Everglades National Park which has over a million visitors annually.

Controlling Burmese pythons in everglades habitats of wet sawgrass prairies with interspersed hardwood hammocks will be challenging. The snake appears vulnerable to approaches that take advantage of its reproductive behaviors. Telemetry trials have already demonstrated on a small scale that female snakes during breeding season can be used as lures to locate males, and telemetered males can be used to locate females (Snow et al. 2006). Since it takes three to five years for Burmese pythons to reach sexual maturity, control based on reproductive behaviors would be a multi-year endeavor to capture animals as they reach sexual maturity.

A set of control tools and strategies were successfully developed for another destructive invasive snake, the brown tree snake on Guam (Engeman and Vice 2001). While the Burmese python is a significantly different species than the brown tree snake, the same conceptual

approaches for developing an integrated pest management program can be applied. For example on small scales, multi-capture traps are being designed and research is being conducted on potential attractants within multiple agencies. Similarly, tests also have been initiated into the toxicity to Burmese pythons of acetaminophen, again with promising results (R. Mauldin and P. Savarie, National Wildlife Research Center unpublished data). In Florida, bait placement would need to be specific to Burmese pythons to avoid harming nontarget species. The unique combination of the python's size, dietary potential, and movement ability could be used to make bait delivery specific to the pythons.

The research into control methods and strategies for Burmese pythons has received very limited funding to date, but the technical expertise for developing and implementing control methods is in place should sufficient funding become available for initiating a concerted control effort. Hopefully, the snake's increasingly high profile in the media and in political circles will lead to improved funding in the near future. In the meantime, the range of the snake continues to expand.

Northern Curlytail Lizards

The northern curlytail lizard (*Leiocephalus carinatus armouri*) is endemic to the islands of the Little Bahama Bank, with other subspecies found in the Great Bahama Bank, Cayman Islands, and Cuba (Schwartz and Thomas 1975, Schwartz and Henderson 1991). A small colony established in Palm Beach County through the intentional release of 20 pairs in the 1940s has spread widely (Duellman and Schwartz 1958). Prior to 1968, the range for this population had been expanding north and south along the Atlantic coast at an average rate of 0.98 km/yr, but from 1968 to 2002 it expanded at a much greater average rate of 2.4 km/yr (Smith et al. 2004; Smith and Engeman 2004), and is continuing to expand. Moreover, curlytail lizards are also found in disparate parts of south Florida through human translocations (e.g., Meshaka et al. 2005).

The primary concern with this species' (rapid) range expansion is its depredations on other (small) lizards (Meshaka et al. 2005). Saurophagy is a component of the northern curlytail's ecology (e.g., Smith and Engeman 2004, Dean et al. 2005), and the widely-distributed, also exotic, brown anole (*Anolis segrei*) is a known prey species that could provide expanding populations with a nutritious prey base and a simultaneous reduction in competitors (Meshaka et al. 2005). The northern curlytail is aggressive towards fauna in its size class and was even observed to attack a juvenile northern mockingbird (*Mimus polyglottos*) (Smith and Engeman 2007), the adults of which prey on northern curlytails (Smith et al. 2006). This potential displacer/replacer for the brown anole likely will put the native lizard fauna with which the northern curlytail exists at risk, including state-listed species (Meshaka et al. 2005). The negative impacts would be especially critical in human-disturbed habitat where the northern curlytail lizard is expanding its range and native lizards might already be marginalized.

Although the northern curlytail is unlikely to receive much attention outside herpetological circles, it was described in one newspaper article as "the T-rex of ground critters" (Fleshler 2006). Nevertheless, the northern curlytail lizard, like many of Florida's small-to-medium sized invasive lizards, is unlikely to be targeted for control or eradication.

Its ubiquity within its extended range, small size, and the difficulty in isolating it for control in the presence of native lizard species would make control or eradication difficult, prohibitively expensive, and without the high profile that would engender public support.

Black Spiny-Tailed Iguanas (Ctenosaurs) – "Off to Seize the Lizard"

The black spiny-tailed iguana (*Ctenosaura similis*) on Gasparilla Island is an example of an exotic lizard species (Meshaka et al. 2004) where control was initiated at the behest of affected residents. Also known as ctenosaurs, these large lizards became established on this 11 km-long barrier island along Florida's west coast with an introduction of as few as three individuals around 30 - 35 years ago (Krysko et al. 2003). Since then, the ctenosaur population has saturated the terrestrial habitats on the island in high numbers, including all residential and commercial areas. The boundary line between two counties runs across Gasparilla Island, and the iguanas had become such a nuisance to property owners through damage to landscape plants and homes (especially attics) that residents of both counties voted to self-tax to secure funds for ctenosaur control programs. Moreover, as has been examined for green iguanas (*Iguana iguana*), ctenosaur burrows could undermine public works, such as seawalls and levees, weakening them for withstanding severe storm events (Sementelli et al. 2008).

Ctenosaurs conflict with a variety of ecological interests in addition to the economic interests on the island. While Gasparilla Island is largely developed, it also is the location for Gasparilla Island State Park, 49 ha of mostly natural area on the southern end of the island (FDEP 2002). Also despite the development, Gasparilla Island's beaches are home or potential nesting site for a variety of species federally or state-listed as threatened, endangered or of concern (FDEP 2002). The endemic listed species on Gasparilla Island for which this species may pose a threat include eggs and young of nesting shorebirds, beach mice, hatchling sea turtles and gopher tortoises (*Gopherus polyphemus*) (Krysko et al. 2003). It may also pose a threat to attack snakes on the island (Engeman et al. in press), including some size classes of eastern indigo snakes (*Drymarchon corais couperi*), a threatened species (Moler 1992). Further environmental impacts include a mutualistic association between ctenosaurs and Brazilian pepper (*Schinus terebinthifolius*), the most problematic invasive plant on Gasparilla Island (FDEP 2002, Jackson and Jackson 2007). Populations of both species are enhanced by ctenosaur foraging on Brazilian pepper (Jackson and Jackson 2007). Invasive plant control is time consuming and costly, and the ctenosaur serves to increase the problem and raise potential remediation costs.

Active iguana removal was implemented in both counties to reduce, and ultimately eradicate if possible, their populations, albeit differing approaches have been applied in the two counties. Lee County on the southern portion of the island applied a sole-source bounty system whereby a reward has been paid to a contractor for each lizard removed (by a variety of methods). Charlotte County on the northern portion of the island formed an agreement to remove ctenosaurs with the U.S. Department of Agriculture's Wildlife Services (WS), the federal agency authorized to resolve human-wildlife conflicts. Their multi-faceted approach includes population monitoring, iguana removal (also by a variety of methods), and research

to develop and evaluate control methods (including toxicant screening tests). Over time, the approaches by the two counties will provide an interesting comparison in efficacies and economics. The cost-per-lizard to remove iguanas in Lee County remains constant, whereas the cost-per-lizard decreases with each subsequent iguana removed in Charlotte County. Once the number of ctenosaurs captured in Charlotte County exceeds the amount of the agreement divided by the amount of the Lee County bounty, then the Charlotte County approach becomes more cost-effective.

PURPLE SWAMPHEN

Relatively few non-native bird species have become established in Florida (Hardin 2007), as only about 5% of the roughly 200 non-native species introduced have succeeded at becoming established (Avery 2007). The purple swamphen (*Porphyrio porphyrio*), a recent introduction to Florida, was judged to merit eradication by a consensus of land management agencies based on its increasing population and range expansion, its potential impact to native species, and the potential for an eradication effort to succeed (Ferriter et al. 2008, Hardin 2007). This large rail species is native to Europe, Africa, Asia and Australia. It also is native to American Samoa, a factor potentially complicating its control in Florida if eradication efforts were delayed (Ferriter et al. 2008). Because it is native to American Samoa, the purple swamphen is being considered for inclusion to the Migratory Bird Treaty Act (MTBA). However, the MTBA provides protection for a species throughout all U.S. holdings and historically has not made geographic distinctions within the U.S., which could protect purple swamphens from removal in Florida in the future. This factor increased the urgency to move on the Florida population.

The species was first observed in the wild in urban southeast Florida in 1996, where the population resulted from escapes from a local aviculturist or escaped from the Miami Metrozoo in 1992 as a result of Hurricane Andrew (Avery 2007, Ferriter 2008, Hardin 2007). As the population increased to over 200 birds, it still remained only in developed areas, but by 2006 it had expanded its range to Everglades Conservation Areas and has been reported as far north as Lake Okeechobee (Hardin 2007). Efforts to eliminate the purple swamphen were prompted by its ecological similarity to the native common moorhen (*Gallinula chloropus*) and purple gallinule (*Porphyrula martinica*) and the looming potential for it to be protected by the MTBA (Ferriter 2008, Hardin 2007).

Purple swamphen control was initiated in 2006 in a cooperative effort among biologists with the South Florida Water Management District (SFWMD), the U.S. Fish and Wildlife Service (USFWS), and the Florida Fish and Wildlife Conservation Commission (FWC). Over 800 birds were located and removed during October 2006-August 2007 (Clary 2007). Efforts are scheduled to continue to remove the remainder of the introduced population. At the least, potential impact to native wildlife and vegetation can be minimized, or at the best, the species will be eradicated from Florida (Avery 2007, Hardin 2007).

Feral Cats

The FWC estimates there are between 6.3 and 9.6 million feral cats (*Felis catus*) in Florida (at http://www.floridaconservation.org), which, conservatively, kill millions of small animals in Florida each year (FCIT 2003). Feral cats are generally harmful to native fauna throughout the state, because even cats well-maintained as pets take a high toll of nearby small animals (Churcher and Lawton 1987, Lepcyzk et al. 2003, Woods et al. 2003), especially considering cats continue to hunt and kill when not hungry (Liberg 1984). Globally, feral cats feed heavily on small vertebrates and have led to the extinctions of a number of species (e.g., Burbidge and Manly 2002, Nogales et al. 2003). Feral cats in Florida have been observed to prey on loggerhead (*Caretta caretta*) and green (*Chelonia mydas*) sea turtles, roseate tern (*Sterna dougallii*), least tern (*Sterna antillarum*), American oystercatcher (*Haematopus ullietus*), Florida scrub jay (*Aphelocoma coerulescens*), Choctawhatchee beach mouse (*Peromyscus polionotus allophrys*), Anastasia Island beach mouse (*Peromyscus gossypinus gossypinus*), Key Largo cotton mouse (*Peromyscus gossypinus allapaticola*), Southeastern beach mouse (*Peromyscus polionotus niveiventris*), Perdido Key beach mouse (*Peromyscus polionotus trissyllepsis*), Key Largo woodrat (*Neotoma floridana smalli*), Lower Keys marsh rabbit (*Sylvilagus palustris hefneri*), all federally listed as threatened or endangered (FCIT 2003, Ferriter et al. 2008). Cat removal has been demonstrated to result in immediate rebounds of endangered beach mouse populations (FCIT 2003).

While cats are harmful to wildlife throughout Florida, they are of the particular concern on the islands of the Florida Keys (Ferriter et al. 2008). They have been a factor in the 50% decline in populations of the endangered Lower Keys marsh rabbit (Forys and Humphrey 1999) and cat removal was identified as an integral component in the recovery of Key Largo woodrat (USFWS 1999, 2003). Making matters worse, feral cat colonies can concentrate a large number of instinctive predators in an area and pose significant threats to the smaller fauna in the vicinity. For example, the Ocean Reef Cat Club (ORCAT) at the exclusive Ocean Reef Club residential resort on Key Largo maintains a large feral cat colony adjacent to the federal and state lands supporting the Key Largo woodrat and Key Largo cotton mouse. Despite the protected habitat, the Key Largo woodrat population dropped from 6500 in 1988 to less than 80 animals by the early 2000s (Humphrey 1988, Winter 2004, B. Muiznieks pers. comm.). ORCAT runs an intensive, well-funded trap, neuter and release (TNR) program (Clark and Pacin 2002), but TNR programs are not effective for managing feral cat populations under most circumstances (e.g., Anderson et al. 2004, FCIT 2003, Ferriter et al. 2008, Jessup 2004). The ORCAT colony continues to have around 500 cats neighboring endangered species habitat despite the intensive TNR efforts. Luckily, captive breeding is now helping replenish the Key Largo woodrat population.

Feral and free-ranging cats are notorious for their destruction of avifauna, and this problem is particularly pronounced in Florida where there are large numbers of cats often in the immediate vicinity of small forest remnants and hammocks that migrant birds rely on as migration stopover sites (Winter and Wallace 2006). For example, severe weather in spring 2001 resulted in a massive fallout of migrating warblers in the Keys, where large numbers of the birds were lost to predation by cats (Winter and Wallace 2006). Similarly, the decline of upland bird populations between 1988 and 1998 at Greynolds Park (Miami-Dade County)

was due to a cat colony in the park. The problem was rectified by stricter laws against abandoning or feeding cats, and removal of the existing cats (Winter and Wallace 2006).

Beyond their environmental impacts, feral cats, especially in dense colonies, present human and wildlife disease concerns. While cats can carry a host of diseases and parasites, rabies is the greatest concern. Cats are the most frequently reported domestic animal in the U.S. with rabies (e.g., Barrows 2004). For example, between 1988 and 2003, there were 208 laboratory confirmed diagnoses of cats with rabies in Florida (Barrows 2004). In fact, the Florida Rabies Advisory Committee stated "the concept of managing free-roaming/feral cats is not tenable on public health grounds because of the persistent threat posed to communities from injury and disease" (Barrows 2004, Brooks 1999).

While the threats cats pose to native wildlife, especially endangered species, and the disease concerns are well-documented, removal of feral cats, particularly at cat colonies, is often accompanied by vocal public outcry from cat enthusiasts. The efforts to protect highly endangered species in the Florida Keys from predation by cats are noteworthy examples. These programs did not involve the lethal removal of animals. Rather, feral cat removal involved live trapping and turning cats over to animal shelters. Despite that, opposition to cat removal has been stiff (including sabotage of traps) and has affected management of the endangered species. Thus, feral cats, in particular, can present additional social dimensions creating difficulties for effective population management.

Gambian Giant Pouched Rats

The Gambian giant pouched rat (*Cricetomys gambianus*) in the Florida Keys is an example of how a severe invasive species threat can be managed in a logical, practical and efficient manner, once a threat has been identified. This largest of rat species (up to 2.8 kg; Rosevear 1969) is highly prolific and holds potential for extreme ecological and agricultural negative impacts (Perry et al. 2006, Engeman et al. 2006). Although the species escaped from a captive breeder on Grassy Key around 1999, it was not identified as established in the wild until residents brought it to the attention of the USFWS in 2004. Perry et al. (2006) established the existence of a breeding population and its dispersion potential was subsequently modeled (Peterson et al. 2006). Dispersal of the species to mainland Florida could have resulted in continued spread through much of North America where significant negative ecological and agricultural consequences could ensue (Peterson et al. 2006).

Following verification of the population's existence and confirmation of its invasive and destructive potential, information and methods essential for successful eradication were rapidly developed, including detection and monitoring technologies, population indexing methodologies, population distribution, habitat preferences, trapping methodology, acceptance of bait matrices, efficacy tests of toxicants, and bait stations that exclude native species (Engeman et al. 2006, 2007d). To test and fine-tune the methods prior to implementing full-scale eradication, a pilot eradication project was implemented on Crawl Key, a small key adjoining Grassy Key to which the species expanded its range. Afterwards, surveys found no evidence of Gambian giant pouched rats remaining on Crawl Key, although Hurricane Wilma undoubtedly also contributed to their mortality. The criteria (see Engeman et al. 2006, Parkes and Murphy 2003) were considered obtainable for a successful eradication

to commence on larger Grassy Key, location of the much larger primary population. Surveys following the hurricane on Grassy Key verified the survival of the Gambian giant pouched rat population, and with a greater range than previously thought. Next and a little over two years after the initial report, the full-scale operation to eliminate this population occurred. At least two years of monitoring for Gambian giant pouched rats should be applied to both Grassy and Crawl Keys, as well as other potential sites of occupancy such as refuse transfer sites (including the mainland landfills) and locations of credible reports of sightings should also receive continued monitoring to help insure no propagules from Grassy Key are surviving elsewhere.

Thus, the rapid response eradication effort for Gambian giant pouched rats can be described as a progression of accomplishments:

1. Verify presence
2. Develop detection and population monitoring methods
3. Develop and test potential control tools
4. Test eradication approach (Crawl Key)
5. Apply eradication methods and strategies to Grassy Key
6. Surveillance for survivors or satellite populations

The eradication effort is currently in the surveillance phase. This phase appears to be working well, as the Gambian giant pouched rats that have occasionally been detected on Grassy Key have been successfully targeted for removal. No Gambian giant pouched rats have been detected outside of Grassy Key.

Whereas the logic and flow described here for this eradication effort makes it seem as though the path to Gambian giant pouched rat eradication was a smooth continuum once the problem was identified and verified, it was, in reality, a series of fits and starts (Engeman et al. 2007d). No single block of funding was available to develop the necessary information and implement an eradication effort. Funding and in-kind resources were provided from > 10 federal, state, and local government entities, as well as private concerns. Even Hurricane Wilma may have assisted the eradication effort to some degree, as it struck at a time lessened resources were available for the work. The storm surge overwhelmed a large part of many of the keys, possibly removing small propagule populations.

One potential pitfall that hopefully will not occur is complacency at the apparent success so far. That could undermine availability of necessary resources to see the follow-up monitoring through to its conclusion. Lack of continued vigilance could result in the hard work to date being undone, or worse if survivors or propagules go undetected, eventual Gambian giant pouched rat dispersal to the mainland. On the other hand, successful eradication of this species hopefully would help reduce the general reluctance of managers to attempt eradications of other invasive species in Florida (see, for example the comments by Donlan et al. 2003).

BLACK-TAILED JACKRABBITS

Black-tailed jackrabbits (*Lepus californicus*) are not native to Florida, but by 2003 they had been well-established at Miami International Airport (MIA) for many years. How and when they were introduced to this expansive airport property was unknown. Speculations as to their origins included escapes from a rabbit farm or escapes from transit to dog racing tracks for use in training greyhounds. By 2003, the black-tailed jackrabbit population at MIA was considered to be around 500. They also had been observed in other parts of Florida, but not as breeding populations.

Occupation of the MIA property by a large number of black-tailed jackrabbits posed two serious threats (see Engeman et al. 2007a). First, even though MIA is relatively encapsulated by the Miami metro area, the jackrabbits still posed a significant invasive threat for Florida. The species is highly fecund, and they also are a highly mobile, fast-moving species. Once outside the confines of Miami they could rapidly spread through Florida (and beyond). The other significant problem their population posed was to cause a severe increase in bird airstrike hazards. Black-tailed jackrabbits were often killed by collisions with aircraft and vehicles, or the back-blast from jet engines. Their carcasses proved highly attractive to vultures (*Cathartes aura* and *Coragyps atratus*) for forage. This created a considerable air safety concern, as vultures present significant hazards to aircraft while taking off or landing (e.g., Dolbeer et al 2000). Besides safety concerns, bird strikes also result in lost revenue and very costly aircraft repairs.

Removal of the black-tailed jackrabbit population at MIA was instigated as a response to Federal Aviation Administration (FAA) regulations mandating the problem be solved for safety reasons (From March 2001 to March 2003 at least two dozen vultures were struck by aircraft at MIA). Thus, the human safety issue motivated their removal, rather than their potential for ecological harm should they have dispersed from MIA. Had it not been for their exacerbation of airstrike hazards at MIA, it is unlikely they would have been eradicated and their population would have continued to be a festering threat for eventual dispersal.

The eradication also revealed the political, economical and social complexities involved in carrying a conceptually straight-forward, but highly visible process. The eradication was delayed multiple times to assuage public sentiment towards lethal control by allowing a live-trapping and translocation (to Texas) attempt to proceed first. That endeavor was unsuccessful at removing more than a portion of the population. Finally, a court ruling allowed the eradication effort to go forward for the sake of the flying public's safety. Lethal removal was efficient and effective at eliminating the black-tailed jackrabbit population, and at a significantly lower cost than the live-trapping venture (Engeman et al. 2007a).

The political, economic and management paths to that success may have been convoluted, but because a human safety concern was clearly recognized, the black-tailed jackrabbit apparently became the first well-established invasive vertebrate species intentionally eradicated from Florida.

DISCUSSION

The invasive species situation in Florida is severe, and when one considers the climatic, demographic, and environment situation in Florida, the severity of the problem is even greater than at first glance. The breadth of invasive land animals in Florida that arguably merit eradication, or at least control, is extensive. The list is extremely varied and includes animals ranging from unusual species of distant origins to more recognizable invaders brought in from other states in the U.S., as well as feral domestics. A variety of steps have been taken to reduce the number of introductions, with some apparent success (Hardin 2007). As is often stated (e.g., NISC 2001), prevention is the most efficient and economical means to eliminate exotic species. However, even if no new exotic vertebrates become established in Florida, there is an abundance of established exotic vertebrates that merit management action.

A brief sampling of Florida's invasive species originating from other parts of the globe (besides those detailed already) include species such as the common boa (*Boa constrictor*), Cuban treefrog (*Osteopilus septentrionalis*), green iguana (*Iguana iguana*), black and white tegu (*Tupinambis merianae*), peafowl (*Pavo cristatus*), spectacled caiman (*Caiman crocodilus*), monk parakeet (*Myiopsitta monachus*), rhesus monkey (*Macaca mulatta*), sacred ibis (*Threskiornis aethiopicus*). Species native to the U.S., but exotic in Florida include animals such as coyotes (*Canis latrans*), red fox (*Vulpes vulpes*), black-tailed prairie dogs (*Cynomys ludovicianus*), red-eared slider (*Trachemys scripta elegans*) and armadillos (*Dasypus novemcinctus*), while other feral domestics widespread in Florida besides swine and cats include goats (*Capra hirus*) and dogs (*Canis familiaris*). Many other less noticeable species have become established in Florida, and other species are suspected to be breeding there, but without firm documentation. Not all will be subjected to eradication or control, but some of the invaders could present potentially severe environmental, human health, and/or economic consequences if their populations are not controlled or eradicated.

Species such as Gambian giant pouched rats, Nile monitors, ctenosaurs, Burmese pythons and many of the other exotic species represent novel species to be considered for eradication or control. The Gambian giant pouched rat, purple swamphen and black-tailed jackrabbit are examples of how necessary incentive and resources can be applied to directly design and implement a practical eradication or control program (Engeman et al. 2006, 2007a). Too often, invasive species merely become the subjects of biological and population studies (e.g., Campbell 2007), but there is a limit at some point to the utility in conducting biological studies of introduced species unless the results directly assist in their removal (e.g., Donlan et al. 2003, Simberloff 2003, Campbell 2007). Donlan et al. (2003) concluded that research directly facilitating eradication tools and projects should be of high priority. Developing the information and technologies from which control strategies can be developed and implemented is an essential component to addressing many invasive species situations. Equally important is the development of public and governmental motivation, i.e. funding, to manage invasive species before their populations expand beyond feasible control.

Many of the problematic invasive vertebrates in Florida are predators. Predation not only threatens many rare species (Hecht and Nickerson, 1999), but the deleterious impacts of predation losses is compounded by habitat loss (Reynolds and Tapper, 1996). Predators also increase the risk of catastrophic extinction of prey populations (Schoener et al. 2001). Given the amount of habitat lost to development in Florida and the state's proclivity for catastrophic

hurricanes (two circumstances magnified on the Keys and other islands), a number of species in Florida are at high risk. Since alien predators are more dangerous than native predators to prey populations (Salo et al. 2007), the impacts from invasive predators, whether small like northern curlytail lizards or large like Burmese pythons, could have devastating impacts on Florida's native species, especially the listed rare species.

For a number of well-established species in Florida, such as feral swine, feral cats and green iguanas, there is no practical means to eradicate them from the state. That does not mean they cannot be intensively controlled, managed, or eradicated in situations of greatest priority on a localized scale, especially islands. For example, feral swine are ubiquitous and destructive, but as already discussed, would never be considered for state-wide eradication. However, swine have been successfully targeted in a nearly-completed eradication effort on Cayo Costa and Punta Blanca Islands, with concomitant dramatic improvements in nesting by listed sea turtles and shorebirds. Species like the black-tailed jackrabbit, Gambian giant pouched rat and purple swamphen were identified as feasible, practical, and valuable to eradicate before they become too deeply entrenched across a broad range. To that end, Parkes and Murphy (2003) delineated some "obligate rules" for successful eradication: 1) all individuals of the target species must be at risk of being killed, 2) target species must be removed at a rate greater than the rate they replace their losses, and 3) the risk of immigration must be zero. Given suitable control methods applied in a systematic and sustained integrated pest management program, these criteria could well be met for a number of invasive species in Florida, if their populations are not permitted to fester into an unmanageable situation. The case of the black-tailed jackrabbit demonstrates that, even with many political gyrations, a population of a species with a restricted range can be eradicated without an excessive outlay of resources (Engeman 2007a). To leave such a situation unaddressed is like leaving a slow-burning fuse lit to an ecological bomb.

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INVASIVE SPECIES: DETECTION, IMPACT AND CONTROL

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