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ORIGINAL PAPER

Potential for successful population establishment of the nonindigenous sacred ibis in the Florida Everglades

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Abstract The nonindigenous sacred ibis (*Threskiornis aethiopicus*) was first discovered breeding in the Florida Everglades in 2005 in the Arthur R. Marshall Loxahatchee National Wildlife Refuge. Prior to this, sacred ibises were seen periodically throughout South Florida since the mid 1990s, with occasional confirmed breeding occurrences in Miami-Dade and Palm Beach counties. We used a logistic regression model developed by Allen (Biol Invasions 8:491–500, 2006) to predict the probability of successful establishment of sacred ibis in the Florida Everglades ecosystem. Empirical data collected from several sacred ibis nests and chicks were used to validate those findings. The probability of successful establishment was estimated to be 73%. The physiological condition of nestlings suggested that this species was able to fledge chicks in good condition, thus adding to the potential to increase their breeding population. Exponential population growth rates and expanding distribution of the nonindigenous sacred ibis in France demonstrate this species' potential for becoming invasive in Florida. We suggest that the most prudent and effective management strategy is eradication of the few pioneering individuals that are nesting in the Everglades as well as the urban source population.

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Introduction

Nonindigenous species have become the second greatest threat to global biodiversity after habitat loss (Vitousek et al. 1997; Wilcove et al. 1998; Simberloff et al. 2005) and are a paramount conservation concern in North America (Mack et al. 2000; Duncan et al. 2003; Simberloff et al. 2005). It is becoming increasingly obvious that management agencies will not have the resources to mount a major eradication effort for every new potentially invasive species that appears, so they need tools that can evaluate the potential risk of nonindiginous species becoming established and allow for prioritization of scarce resources. Using such risk assessment tools requires an implicit acknowledgment that some introduced species are not worth eradicating or controlling. This acknowledgment is biologically justified because most introduced species do not establish sustainable populations (Simberloff et al. 2005). There is however a great cost to overlooking those that do become established and invasive because they can threaten biodiversity and compete with native species (Vitousek et al. 1997; Simberloff et al. 2005).

The sacred ibis (*Threskiornis aethiopicus*) was first discovered breeding in the Florida Everglades in 2005 in the Arthur R. Marshall Loxahatchee National Wildlife Refuge (LNWR; Palm Beach County, Florida; Herring et al. 2006). Prior to this, sacred ibises were observed periodically throughout South Florida since the mid 1990s, with occasional breeding confirmed near the Miami Metro Zoo in Miami-Dade County and the Palm Beach Waste Management Facility in Palm Beach County (Herring et al. 2006). The source of the sacred ibis has never been located, but is suspected to be in the vicinity of the Miami Metro Zoo. Since 2005, we documented and monitored sacred ibis sightings and breeding efforts in South Florida with the intent of understanding their potential for becoming established in the Florida Everglades.

The sacred ibis is a colonial wading bird native to wetlands throughout Africa (Hancock et al. 1992). However, they have escaped captivity in 12 European countries and the United States and currently breed in the wild in Belgium, France, Italy, the Canary Islands of Spain (Clergeau et al. 2005), the Netherlands (Ottens 2006) and the United States (Herring et al. 2006). Clergeau and Yésou (2006) reviewed the recent population growth and expansion of the escaped sacred ibises' range in Western Europe, noting that the species' foraging plasticity, human commensalism, and tolerance of wide ranging environmental conditions increase their chance of successful population establishment and growth.

The potential for successful establishment and population growth of nonindigenous sacred ibis is best illustrated by its recent expansion in France. The French nonindigenous sacred ibis population stemmed from less than 75 individuals that escaped in the mid 1980s, and now exhibit an exponential population growth rate (Clergeau and Yésou 2006) with over five thousand individuals (P. Yésou, pers. comm.). Sacred ibis in France have also dispersed hundreds of kilometers from their original site (Clergeau and Yésou 2006) suggesting similar rates of dispersal could occur in Florida if the species becomes established.

Prior successful establishment of large numbers of nonindigenous species in South Florida due to intentional or unintentional release illustrates the potential for Sacred ibis to do so as well. For instance, many avian species that have been released into the wild in South Florida now have established breeding populations and compose from 9 to 21% of the entire avian community (Forys and Allen 1999; Abdelrahman 2000). Often nonindigenous species eventually move from urban areas where they first become established, to natural landscapes like the Florida Everglades (e.g., purple swamphen *Porphyrio porphyrio*; Pranty et al. 2000) where they may compete directly with native species. The decline of many species of wading birds in the Florida Everglades (Crozier and Gawlik 2003) could be further exacerbated by nonindigenous species that exhibit life history traits detrimental to native species, such as depredating eggs and chicks or marauding existing colonies (Williams and Ward 2006).

Statistical models have been developed to evaluate the potential for nonindigenous species to become established in new regions (Kolar and Lodge 2001; Allen 2006). The results of these models can provide quantitative support for developing policy and management strategies.

Our objectives in this study were to (1) assess the potential for successful population establishment of sacred ibis in the Florida Everglades using a modeling approach, and (2) validate those modeling results by examining recent sacred ibis nesting data from across the Everglades. We discuss these results considering recent findings in the literature for European Sacred ibis populations, such as habitat use patterns and human commensalism behavior.

Study area

We collected data on nesting sacred ibis in the Arthur R. Marshall Loxahatchee National Wildlife Refuge and Everglades National Park (ENP; Miami-Dade County, Florida; Fig. 1). Sacred ibis were found nesting in three colonial wading bird colonies in LNWR during 2005–2007, Colony 111 (26°31′ N, 80°16′ W) and New Colonies 3 (26°31′ N, 80°17′W) and 4 (26°31′ N, 80°16.5′ W; Fig. 1). Colonies in LNWR consisted of up to 50 tree islands, 0.04–0.13 ha in size, dominated by cocoplum (*Chrysobalanus icaco*), willow (Salix spp.), dahoon holly (*Ilex cassine*), smilax (*Smilax laurifolia*), red bay (*Persea barbonia*), and wax myrtle (*Myrica cerifer*). Over 90% of the nests in the colonies in LNWR were white ibis (*Eudocimus albus*), with the remainder being, snowy egret (*Egretta thula*), little blue heron (*E. caerulea*), great egret (*Ardea alba*), and black-crowned night-heron (*Nycticorax nycticorax*) respectively.

Research in ENP occurred at the Tamiami West wading bird colony (25°45′ N, 80°32′ W; Fig. 1) during 2007. This colony consisted of one large tree island ∼10 ha in size, dominated by cocoplum, pond-apple (*Annona glabra*) and willow (*Salix* spp.). Over 50% of the nests in the colonies in the Tamiami West colony were white ibis, with the remainder being snowy egret, tricolored heron, little blue heron, great egret, wood stork (*Mycteria americana*), and black-crowned night-heron respectively.

Methods

Modeling probability of successful establishment

We utilized a predictive logistic regression model developed by Allen (2006) to estimate the probability of successful sacred ibis establishment. The model was developed by analyzing potential factors that could contribute to the success of introduced species in South Florida. Allen's (2006) final model included only two variables that were significant predictors of success for nonindigenous species; distance to nearest neighbor and distance to body mass aggregation edge, and took the form: Logit (success) = 1.042 (intercept) + 1.61 (near) − 0.204 (edge).

Allen (2006) defined nearest neighbor distance as the distance in grams to the closest native neighbor in terms of their log(10) body mass and distance to edge as the distance between a species of interest and their nearest native edge aggregation species based on their log(10) mass. The variable distance to nearest neighbor is a test of community level theory of invasion success where species within similar body-mass aggregation recognize and utilize an ecosystem at the same scale (Allen et al. 1999; Allen 2006). Edge species are those with average masses and are found near the edge of an aggregation of species, and are most likely to succeed (Allen et al. 1999). Allen (2006) observed that nonindigenous species were more likely to be successful if they had a body mass further from their nearest neighbor, but closer to the edge of an aggregation.

In our model we used the distance to nearest neighbor and distance to edge for all native species of birds which breed in the Florida Everglades based on the Florida Fish and Wildlife Conservation Commission's (FFWCC) breeding bird atlas (FFWCC 2007). We used nonparametric density estimation to separate all native Everglades species log(10) masses into 10% kernels (JMP 2001). The 10% kernels identified where 10% of all the species masses were located. Species with similar masses were identified by clusters between kernel contour lines. We then identified the cluster that the sacred ibis mass fell into and measured both its nearest neighbor and distance to edge. Body mass values were calculated based on values reported in Dunning (1993) using mean values of combined male and female masses. Distance to nearest neighbor was calculated to be the distance between the log(10) mass of sacred ibis and osprey (*Pandion haliaetus*), and distance to edge species was from sacred ibis to great horned owl (*Bubo virginianus*). We then converted the logit (success) to a probability using the formula: $p/(p-1) = \exp^{\text{logit(succes)}}$ (SAS Institute Inc. 2006).

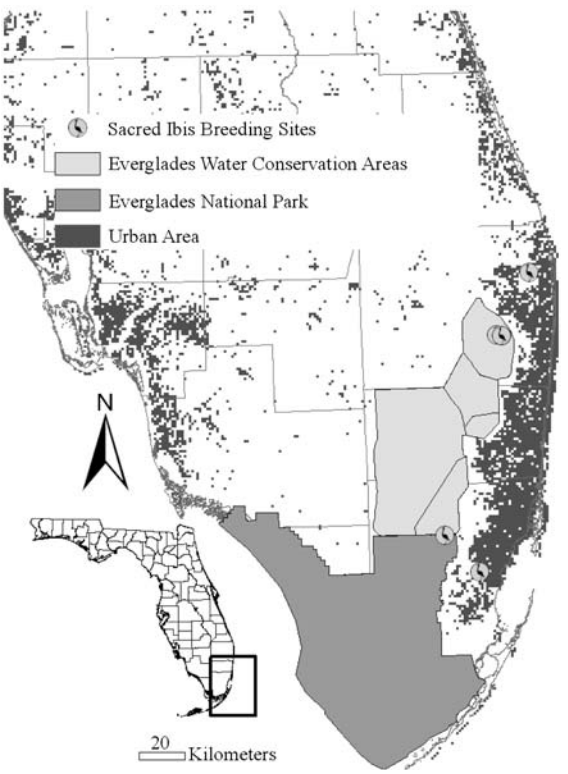

Fig. 1 Location of 12 sacred ibis nests between 2005 and 2007 in South Florida

Sacred ibis chick physiological condition

We located nests opportunistically when in wading bird colonies by watching the flight paths of adults. We palpated the pectoral muscle of sacred ibis chicks to subjectively score pectoral mass (Heath et al. 2003) on a scale of 1–5 (1: prominent keel, 5: muscle greater than keel). Pectoral muscle mass scores were found to be an effective indicator of physiological condition in previous studies (Brown 1996; Heath et al. 2003). We report white ibis chick pectoral muscle mass scores from the same time period across the Everglades for comparison.

Diet

We removed or collected all chicks from sacred ibis nests located during the 2005 and 2007 breeding season in LNWR. Immediately after euthenization, we injected 95% alcohol into the esophagus to prevent post mortem digestion before removing contents. Contents of the esophagus, proventriculus, and gizzard were removed within 1 hr of collection, and preserved in 95% ethanol. While previous studies have only used contents from the esophagus and proventriculus to avoid biasing results (Swanson and Bartonek 1970; Afton et al. 1991) we found no food items in either the esophagus or proventriculus and therefore relied upon gizzard samples to assess diet. Thus we may have missed soft food items that were quickly digested. Diet samples were sorted and identified (most to species or genus). Data were summarized by aggregate wet mass (biomass; Prevett et al. 1979) and presented as % of total diet. Because of small sample size ($n = 3$) we caution against using our estimates for more than a cursory view of what sacred ibis in the Everglades are consuming.

Research was conducted under U.S. Fish and Wildlife Service Research Permit 23354, Florida Fish and Wildlife Conservation Commission, Scientific Research Permit WX04487, United States Department of the Interior National Park Service Scientific Research and Collection Permit 0036, and the Florida Atlantic University, Institutional Animal Care and Use Committee (Protocol A0534).

Results

Probability of successful establishment

Distance to nearest log(10) mass neighbor was 0.0023 log(10) grams and distance to edge was 0.0036 log(10) grams. The Logit (success) was 1.04 and the probability of successful establishment was 73.4%.

Between 2005 and 2007, we documented sacred ibis nesting at 3 wading bird colonies in the Everglades, and at one wading bird colony adjacent to the city of Palm Beach (Palm Beach Waste Management Facility). We located 12 nests in four colonies between 2005 and 2007. Mean number of sacred ibis nests per colony was 2.4 ± 0.5 SE, with a mean number of chicks or eggs per nest of 2.3 ± 0.2 SE. Distances to human development from the three colonies in the Everglades were short, averaging 7.5 km ± 0.9 SE compared to a mean of 14.98 ± 2.4 SE km for all colonies in the Everglades. Total numbers of sacred ibis observed at colonies combined were 23.

Chick physiological condition

Sacred ibis chick pectoral scores averaged 4.0 ± 0.0 SE ($n = 9$), whereas white ibis chicks averaged 2.3 ± 0.7 SE ($n = 178$) out of a possible 5 for muscle mass.

Diet

Sacred ibis chick diet based on aggregate percent mass consisted predominantly of human refuse (e.g., chick bones and meat, cocktail shrimps; 63.2%), with native Everglades prey items accounting for the remainder of their diet; crayfish (*Procamberus* spp. 26.6%), beetles (Coleoptera 3.2%), dragonfly larvae (Odonata 0.8%), and Sabal palm fruit (*Sabal palmetto* 6.2%).

Discussion

The findings of this study suggest that the sacred ibis has a high probability (73%) of successful establishment in the Florida Everglades. As such, wading bird conservation efforts in the Everglades should now include the potential for negative impacts from sacred ibis, particularly given the recent exponential population growth rate and aggressive and destructive colonial behavior of nonindigenous sacred ibis in France (Clergeau and Yésou 2006). Recent research has shown that sacred ibis are effective predators of both eggs and chicks in colonial nesting colonies in their native region (Ward and Williams 2006). Sacred ibis have also been documented destroying sandwich tern (*Sterna sandvicensis*), black tern (*Chlidonias niger*), and whiskered tern (*C. hybridus*) nests in large numbers in areas where they have recently become established (Vaslin 2005; Clergeau and Yésou 2006). We recommend that the highest priority be given to wading bird colonies with both sacred ibis and endangered wood storks.

The extent to which nonindigenous populations of sacred ibis will depredate eggs and chicks of native colonial nesting species has not been determined. However, in their native range sacred ibis were responsible for the predation of 65% of all cape cormorant (*Phalacrocorax capensis*) chick predation mortalities on Penguin Island, Lambert Bay, South Africa (Williams and Ward 2006). Williams and Ward (2006) calculated that the total cape cormorant losses at the Penguin Island colony due to sacred ibis predation were between 10% and 15% of the total annual production. When the same predation rates were applied to a secondary peak for cape cormorant breeding on Penguin Island, total predation by sacred ibis accounted for 43–64% of all nesting efforts during that period (Williams and Ward 2006). Predation by sacred ibis occurred throughout much of the nesting cycle, with ibis targeting eggs and chicks up to five or more weeks old (Williams and Ward 2006).

The diet of the sacred ibis suggests the bird is largely a generalist, with prey items including macro invertebrates, fishes, small rodents, bird eggs and chicks and human garbage (e.g., food scraps; Clark 1979; Kopij et al. 1996; Clergeau and Yésou 2006; Williams and Ward 2006; this study). Sacred ibis are also able to use both wetland and upland habitats during both the breeding and nonbreeding seasons (Clark and Clark 1979; Clergeau and Yésou 2006). Both of these factors support the high probability of successful establishment of the sacred ibis in the Florida Everglades. While most wading birds are limited to breeding during the dry season in the Everglades (e.g., white ibis; Kushlan and Bildstein 1992), in its native habitat the sacred ibis breeds during the rainy season in Africa (Hancock et al. 1992). To date breeding efforts have only been documented during the dry season in Florida but extensive surveys in the wet season are lacking.

One common factor in the establishment of all prior nonindigenous populations of sacred ibis is their close association with humans. Human commensalism has been suggested to be the sacred ibis's strongest trait for becoming successfully established in new regions (Clergeau and Yésou 2006). Those sacred ibis that have been observed breeding in the Florida Everglades averaged only 7.5 km away from human developments, and were located in some of the closest wading bird colonies to developed areas. Also, sacred ibis from the Everglades colonies were observed foraging in highly disturbed sites (e.g., landfill sites). This behavior of feeding in landfill sites or in highly impacted developed sites occurs regularly and likely plays an important role in their success, in both in their native regions (Clark 1979; Kopij et al. 1996), and in areas where they have recently become established (Clergeau and Yésou 2006). The ability to exploit a year-round supply of food in human dominated areas may explain why even in a poor wading bird breeding season in the Everglades (Herring and Gawlik, unpublished data), Sacred ibis chicks were in better physiological condition than their nearest sympatric species, the white ibis. Moreover, the ability to overcome a seasonal or shorter term reduction in available food may allow sacred ibis to circumvent the primary factor thought to limit populations of native wading birds in the Everglades (Gawlik 2002).

The potential for this species to increase its population size could also be a factor of the region where they are released or escaped. Clergeau and Yésou (2006) found that the sacred ibis's reproductive effort (number of eggs) and reproductive success (number of chicks hatched) in France were approximately 16% and 38% higher, respectively, than in the bird's native region. These authors concluded that habitat conditions in France were more conducive to sacred ibis nesting than in their native region. In Florida, the close proximity of nesting to urban areas to date, readily available sources of food in both the Everglades and adjacent urban areas, elevated physiological condition even in a poor nesting year, and temperate climate make it likely that that sacred ibis will have larger clutch sizes and increased fledging success, leading to population growth and range expansion.

Numbers of observed sacred ibis nests located in all wading bird colonies in the Everglades were relatively low during the 2005–2007 periods. However, it is important to note that nest searching for sacred ibis was secondary to our primary objectives when working in these wading bird colonies, which was conducting research on white ibis and great egrets. We suggest that extensive ground or aerial surveys will be needed to assess the true extent of sacred ibis nesting in the Everglades. One behavioral trait that may make such an effort feasible is that sacred ibis nests tended to be clustered with conspecifics, suggesting that if a group of nests is located, it may represent all of the individuals at that colony at that particular time.

Management implications

We suggest that the high potential for the sacred ibis to become established in the Everglades based on our analysis, the documented spread of the species across Europe, and the predation by sacred ibis on other waterbirds, are cumulatively enough evidence to warrant consideration of the sacred ibis as part of the efforts to restore the Everglades (Sklar et al. 2005). Wading birds are being used as indicators of restoration success so interpretation of nesting patterns is dependent on the ability to separate a response from restoration and a response from other factors that affect populations (Gawlik 2006).

The numbers of sacred ibis nests detected in the Everglades is small enough where eradication of each pair from the area is still feasible, if those detected nests do in fact represent all nesting sacred ibis in the area. However, such actions should be taken in conjunction with an exhaustive ground survey effort of all wading bird colonies in South Florida for several years to ensure that all sacred ibis nests are detected. This could be done relatively easily by modifying the existing wading bird nest monitoring that it is being done to support the Everglades restoration.

A qualitative assessment of the source population in urban South Florida suggest that it is still small enough so that eradication there is also feasible, and we believe, critical. Eradication of sacred ibis in the Everglades without addressing the urban source population would likely only postpone a repeated population expansion by the bird. Removal of the urban birds will require coordination among local, state, and federal governments to remove birds as well as to launch a public awareness campaign and the approach used in urban areas may have to be nonlethal. Increasing public awareness of the potential problems of the sacred ibis in the Everglades may be more important than with other less charismatic invasive species because many people will not find the sight of ibis in urban areas to be problematic.

Other successful control efforts of charismatic animals in urban settings, such as white-tailed deer (*Odocoileus virginiaus*; Raik et al. 2006) could serve as a model for management of the sacred ibis in South Florida. Urban wildlife management strategies need to incorporate local-stakeholders, state and federal wildlife agencies, local governments, and local citizens (Raik et al. 2006). The concept of co-management (community-based collaboratives) of nonindigenous species allows for a broader understanding of the issues associated with these species and allows for public participation at some level with monitoring or during the decision making process (Chase et al. 2000).

Regardless of the approach used to control or eradicate sacred ibis, the most critical aspect that will influence the likelihood of success is the time to initiate a response. We advocate a swift approach, where all researchers and the general public working or recreating in the Florida Everglades and surrounding areas should be made aware of the sacred ibis and their potential for successful establishment and negative interactions with native wading bird species. These same individuals can then serve to provide important information on where and when sacred ibis are being detected. Coordinated these details either through a government agency such as the Florida Fish and Wildlife Conservation Commission or U.S. Fish and Wildlife Service would allow for a rapid response, resulting in the removal of adults whenever possible. We also advocate modifying the existing wading bird monitoring that is done as part of the Comprehensive Everglades Restoration Plan to include methods adequate to distinguish nesting sacred ibis from other species of wading birds. After eradication efforts and several years of subsequent extensive surveys without detecting more sacred ibis, it may be appropriate to reduce the frequency of surveys to one in every 3 years, the time it will likely take chicks to be recruited into the breeding population.

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