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ABSTRACT

Predation critically threatens reproductive success of sea turtles and shorebirds at many of Florida's beaches. We examined the biological and bioeconomic results of predator management on two adjacent barrier islands, Cayo Costa and North Captiva, along Florida's west coast. Both islands suffered severe nesting losses due to predation and disturbance due to raccoons, while Cayo Costa also was impacted by a large population of feral swine. In 2006, our initial year of study, neither island received predator management and no least tern production occurred on either island, and sea turtle nest predation was 74% and 60%, respectively, for Cayo Costa and North Captiva. Predators were managed in 2007 on Cayo Costa while North Captiva served as an untreated reference island. North Captiva again had no least tern production and sea turtle nest predation was 84%. In contrast, Cayo Costa produced 31 least terns and sea turtle nest predation plummeted to 16%. Both islands received predator management in 2008 when Cayo Costa and North Captiva respectively produced 20 and 55 least terns and had 15% and 0% sea turtle nest predation. The entire costs for predator management by experts over the course of the study was $USD 39,636, while the returns in additional production of least tern young and hatchling sea turtles was valued over $USD 1.1 million for a resulting benefit–cost ratio of 27.8.
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1. Introduction

Predation critically threatens many rare species (Hecht and Nickerson, 1999), with the deleterious impacts of predation losses compounded by habitat loss (Reynolds and Tapper, 1996). In Florida, nesting beaches have been substantially altered by urbanization and development, leaving few beaches isolated from development, thereby severely reducing the amount of habitat suitable for successful nesting by sea turtles and shorebirds (e.g., Rogers et al., 1996). At the same time, predators abound along many beaches where nesting could otherwise succeed. Nest predation can have severe impacts on reproductive success for sea turtles and shorebirds (e.g., Ellis et al., 2007; Engeman et al., 2003; Engeman and Smith, 2007; Kadlec, 1971; Wilcox and Donlan, 2007). Cayo Costa and North Captiva Islands, along Florida's west coast each offer suitable, and state park-protected, beach habitat for nesting by sea turtles and shorebirds, but each also has had a history of low nest success due to predation.

At many Florida beaches, raccoons (*Procyon lotor*) are an abundant native species that severely impact sea turtle conservation through nest depredation (Engeman et al., 2003; Garmestani and Percival, 2005; Mroziak et al., 2000; Stancyk, 1982; Williams-Walls et al., 1983). Compounding the problem, raccoon populations flourish in association with humans where they often receive artificial support through refuse or direct feeding (Dickman and Doncaster, 1987; Riley et al., 1998; Smith and Engeman, 2002). Raccoons are notorious nest predators (e.g., Engeman et al., 2003; Garmestani and Percival, 2005; Mroziak et al., 2000; NRC, 1990; Rogers et al., 1996; Stancyk, 1982; Williams-Walls et al., 1983), with the pervasiveness and severity of raccoon predation on sea turtle nests in Florida prompting a leading sea turtle conservation organization to identify raccoons as the single greatest source of sea turtle mortality in Florida (Caribbean Conservation Corporation/Sea Turtle Survival League, no date).

Unlike sea turtles, many shorebird nests are on the surface where they are particularly vulnerable to predation (e.g., Parnell et al., 1988). Not only are eggs, chicks, and adults susceptible to predation, but predatory pressures (including by raccoons) can result in abandonment of a nesting colony and localized catastrophic breeding failure (e.g., Ellis et al., 2007; Kadlec, 1971; Rogers et al., 1996).

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Beyond the conservation problems posed by abundant native wildlife, a host of invasive species are significant nest predators at Florida beaches (e.g., Engeman and Smith, 2007). Florida joins Hawaii as one of the two states in the U.S.A. with the most severe invasive species problems (U.S. Congress, 1993). Among the invasive species in Florida that depredate nests on some Florida beaches are feral Swine (*Sus scrofa*). They were one of the first exotic species introduced to Florida, initially released into the wild by DeSoto in the 1500s (Towne and Wentworth, 1950), and today they flourish in Florida and cause widespread damage. The species possesses the highest reproductive potential of any large mammal in North America (Wood and Barrett, 1979, Hellgren, 1999), and the species currently inhabits many areas in such large numbers that it adversely impacts the environment and native fauna and flora.

Here we describe multiyear results on nesting success for sea turtles and shorebirds from predator population management on Cayo Costa and North Captiva Islands, Florida.

2. Methods

2.1. The islands

Cayo Costa and North Captiva Islands are part of a barrier island chain on the western side of the Charlotte Harbor estuarine system along Florida's west coast (FDEP, 2005). Cayo Costa Island is a ca 10 km^2 island that remains largely unchanged since Ponce de Leon viewed it 500 years ago. Although there are approximately two dozen residents on the island, the island is within and protected as Cayo Costa State Park. North Captiva Island is a smaller, 2 km^2 island ca 0.64 km south of Cayo Costa Island. About a third of this island is developed residentially, but with the majority of the island also protected as part of Cayo Costa State Park. Neither island is accessible by automobile, with Cayo Costa Island accessible only by boat, while North Captiva Island also has a small airstrip. Both islands provide beach nesting habitat for sea turtles and shorebirds, including state and federally listed species.

2.2. Nest predators

Raccoons are a highly abundant native species on both islands. Besides the abundant natural resources on the islands, raccoons also have a constant artificial supply of food from human sources. Although there are no human communities on Cayo Costa Island, there is a popular State Parks campground and some homes where raccoons potentially can feed on refuse and pet food. North Captiva offers raccoons the greater benefits of its residential community. Both islands lack larger predators that could maintain raccoon populations at lower levels, and the islands' separation from the mainland deters the introduction of diseases found in mainland raccoon populations, such as rabies, that also could check their populations.

As is the case throughout coastal Florida, raccoons have been the primary turtle nest predator on Cayo Costa Island, furthermore this island had a significant population of feral swine, which also had been documented as nest predators. These large animals additionally hold the potential to be highly disruptive to shorebird nesting. Swine were introduced to Cayo Costa by the 1800s as a food resource for resident Cuban fishermen, and subsequent releases followed until as recently as the 1980s by county park personnel. On this relatively pristine island, feral swine have been highly destructive. In addition to negatively impacting nest success, they have damaged plant communities by foraging on native species and dispersing invasive species, and damaged irreplaceable archeological sites through destruction of artifacts and disturbance of the provenience and stratigraphy of the sites (FDEP, 2005). The biological, ecological and archeological damage inflicted by swine prompted their targeting for removal, and eradication if feasible, from Cayo Costa Island. A requisite for successful swine removal from Cayo Costa Island also required swine removal from Punta Blanca Island, a small satellite sand island (2.3 km in length and averaging ca 0.3 km in width) lying a short distance off Cayo Costa Island. While those animals also had been responsible for habitat damage on Punta Blanca Island, the primary concern was they would likely form a reservoir for repopulating Cayo Costa Island, and were therefore included as part of the Cayo Costa swine management.

2.3. Nest predator management strategy

Cayo Costa was the more naturally pristine of the two islands, but also was a more difficult challenge for protecting shore nesting species due to the presence of the feral swine in addition to raccoons as the depredating species. Reducing a large population of feral swine requires more resources at startup than managing raccoons. In the initial year of predator management (2007) nest predators were only managed on Cayo Costa Island, while nearby North Captiva Island simultaneously provided comparative data in the absence of predator management. In the second year, after considerable swine population reduction for Cayo Costa, nest predators on both islands were simultaneously managed.

A passive tracking methodology that has been an efficient means to monitor feral swine in a wide variety of swine management projects in Florida was applied on Cayo Costa Island (Engeman et al., 2001, 2007a). The tracking plots, coupled with observations of damage and other signs, provided a comprehensive picture of the distribution of swine activity throughout Cayo Costa Island. After identification of the most favorable locations to carry out control activities, baiting with soured corn was initiated to condition the swine to feeding at bait sites. Once swine were consistently feeding at a bait site, control was applied. Swine on Cayo Costa Island were primarily removed by capture in pen traps. The trap itself was a custom-designed collapsible trap for portability, but exhibiting extreme durability, and able to capture groups of swine, including the largest specimens. Swine were also removed by shooting over bait and by snares on swine trails leading to bait. As swine were removed, their distribution was reassessed and the process repeated.

The removal strategies for Punta Blanca Island were substantially simplified considering those swine had been conditioned to being fed by boaters. The narrow strip of land comprising the island also meant swine were accessible from bait sites near any shore. Thus, swine were removed by shooting using a noise-suppressed rifle when they appeared on shore at the arrival of the boat, or they were shot over bait sites to which they were also conditioned to feed.

Raccoons that predate beach nests appear to frequent the beach once nesting begins (e.g., Engeman et al., 2003). Thus, raccoons were trapped in the vicinity of the beaches on Cayo Costa and North Captiva Islands prior to and during shorebird and sea turtle nesting. Raccoons were captured in live traps set overnight and checked in the morning.

Because feral swine were an invasive species targeted for severe population reduction, and possible eradication, descriptive demographic data were recorded for the swine removed in the initial year (2007). These data included gender and age class, where age classes were defined as: adults >45 kg, 14 kg<subadults<45 kg, and juveniles <14 kg.

Nest predator control for both raccoons and swine was carried out by the U.S. Department of Agriculture/Wildlife Services, the Federal agency with responsibility for managing conflicts with wildlife (U.S. Department of Agriculture/Animal and Plant Health Inspection Service et al., 1997), using only approved and humane methods to euthanize animals that conform to the guidelines laid out in the 2000 Report of the American Veterinary Medical Association Panel on Euthanasia (American Veterinary Medical Association, 2001) and set forth as agency policy in USDA/APHIS/WS Directive 2.505.

2.4. Nesting data assessment

The Florida Department of Environmental Protection monitors sea turtle and shorebird nesting across their properties along the Florida coastline, including Cayo Costa and North Captiva Islands. Data on nesting rates and nest success for sea turtles and shorebirds from 2006 (prior to predator management), 2007 (predator management on Cayo Costa Island, but not North Captiva Island), to 2008 (predator management on both islands) were used for assessing impacts of predator management on nesting success.

To monitor sea turtle nesting, beaches were patrolled mornings during turtle nesting season and each new nest deposition and any predator excavations were recorded. At the end of the nesting season nest predation rates were calculated from this information, as nest predation rates have typically been used as the primary criteria for evaluating impacts and remediation efforts of sea turtle nest predation (e.g., Engeman et al., 2003, 2005, 2006). Assessing shorebird nesting success is much more difficult to measure due to the precariousness of nests and the difficulty in determining nest fate. Unlike sea turtles, shorebirds must tend their nests until fledging. Thus, predators (and other disturbances) can greatly affect whether nesting even takes place, the number of nests if it does take place, and of course the success of those nests. Unlike turtle nests buried in the sand, depredation to shorebird nests is not easy to document. Depredation of turtle nests is very visual and the predator species can usually be determined by tracks. Missing shorebird eggs or chicks are much more difficult to observe and to identify the causal agent. Moreover, solitary nesting species require much more effort to locate and monitor, making colonial nesting species most likely to facilitate collection of reliable data. Thus, we focused on colonial species and use them as an indicator of shorebird nesting issues. Because the number of active nests tends to fluctuate during nesting, the Florida Department of Environmental Protection has adopted the peak one-day count as protocol for the most reliable measure (index) of nesting and young production, and the most comparable variable from year to year.

Loggerhead sea turtles (*Caretta caretta*) are by far the predominate turtle species nesting on the islands. Although sea turtle species other than loggerheads potentially could nest on either island, they only occasionally do so, with the most likely other species to nest being the green sea turtle (*Chelonia mydas*). The loggerhead turtle is federally listed as threatened (U.S. Fish and Wildlife Service, 1994), and, while not predicating policy, is classified on the IUCN Red list as endangered (IUCN, 2008), whereas the green sea turtle is federally listed as endangered (U.S. Fish and Wildlife Service, 1994), and also classified on the IUCN Red list as endangered (IUCN, 2008). The shorebirds of most concern with highest potential to nest on the islands included least terns (*Sterna antillarum*), snowy plovers (*Charadrius alexandrinus*), and Wilson's plovers (*Charadrius wilsonia*). Of these, least terns and snowy plovers are Florida state-listed as threatened (Florida Fish and Wildlife Conservation Commission, 2009). The Florida Committee on Rare and Endangered Plants and Animals also considered least terns as threatened, but snowy plovers were considered endangered and Wilson's plovers were considered as species of special concern (Rogers et al., 1996). Least terns, being colonial nesters, were the species most likely to be observed and well-documented, thereby providing the most useful data.

2.5. Data analyses

Sea turtle nest predation rates were compared among years for each island using Fisher's "exact" test. We compared the relative numbers of nests and young produced by shorebirds across years for each island using goodness of fit tests. The swine demographic data and predation rates of sea turtle nests were evaluated using chi-square contingency table tests. The numbers of nests and young observed for each species of shorebird were compared among years using goodness of fit tests.

The maximum one-day observations of shorebird young provided an indexed comparison of minimal numbers of young produced. There was no practical way to conduct similar counts of sea turtle hatchlings, but the number of hatchlings can be effectively estimated (Engeman et al., 2003, 2005). Based on detailed research on loggerhead nesting parameters from other studies on which we have worked in Florida (Engeman et al., 2003, 2005), we assumed the same average clutch sizes (109) and average emergence rates for undamaged nests (0.77) from those two studies would be valid approximations for our current situation. We also assumed nests opened by predators to have 100% loss of eggs. While this may not always be the case (e.g., Caut et al., 2006), experience at other Florida beaches has indicated this to be a fair assumption in the absence of human intervention to restore the remainder of the nest (e.g., Engeman et al., 2003, 2005; R.E. Martin, Ecological Associates, pers. comm.). Moreover, depredated nests in the field were considered as complete losses and not monitored for hatching of the remnants. We estimated the number of hatchlings lost to predation in the presence of predator management, and then we estimated the number that would have been lost assuming the average predation rate from the year(s) prior to predator management. These calculations are well-documented and are summarized in the following equation (e.g., Engeman et al., 2003, 2005):

$$L = N \times C \times E \times P,$$

where L = the number of hatchlings predicted lost to predation, N = the number of nests, C = the average clutch size (C estimated as 109), E = the emergence rate (E estimated as 0.77), and P = the predation rate. If we substitute the predation rate from the year (Cayo Costa Island), or the average of years (North Captiva Island), without predator management into the equation for nesting during the predator management year(s), we then get an estimate of the number of hatchlings that would have been lost in the face of the previous level(s) of predation. The difference between the two estimates is the estimated number of additional hatchlings produced as a result of predator management protecting the nests.

2.6. Benefit–costs of predator management

Given an estimated number (sea turtles) or an observed minimal number (shorebirds) of young produced for each species, we can monetarily value those young. Given differences in productivity between scenarios with and without predator management, we can quantify the value of increased production relative to the cost of predator management.

A variety of methods exist to apply conservative monetary values for rare species (Bodenchuk et al., 2002; Engeman et al., 2002b, 2004). Among the practical and applied means for placing a societal value on a species are statutory penalties, which have been successfully used for valuing a variety of rare species, game species, and other protected species (Bodenchuk et al., 2002; Engeman et al., 2002a, 2004, 2009; Sementelli et al., 2008; Shwiff et al., 2003, 2007; Smith et al., 2003, 2007). This method has a successful history for applying societal economic values for losses of sea turtles and shorebirds in Florida and is the approach of choice here, especially as no other practical options were available or suitable. As in the previously cited economic analyses requiring valuation of sea turtles and shorebirds, we also applied a conservative approach to the present results, whereby the lowest of the statutory values from among multiple enabling statutes was applied. Minimum monetary values (penalties) are clearly specified by statute and administrative code (Florida Statutes 370.021(5) d–f; Florida Administrative Code 39-27.002 and 39-27.011). The statutes specify minimum monetary replacement costs

at $100 apiece, while the administrative code places the value at $500 apiece. Federal law also applies which usually imposes larger values. For example, the Endangered Species Act of 1973 specifies up to $25,000 apiece for civil cases and up to $50,000 for criminal cases, and the U.S. Migratory Bird Treaty Act specifies up to $2000 for "take" of any migratory bird. Both state and federal values typically apply simultaneously. Rather than considering maximal, or even median values we took a conservative approach by using the minimal $100 value specified by Florida Statute. No legislative distinction is made among demographic classes (such as age) within a species. For example, it is possible that an adult breeding female sea turtle might be valued in court higher than a hatchling turtle. However, their minimum legislative values would still be $100, and our intention was to analyze the predator removal approaches in a conservative manner.

The costs for predator management were well-defined by the amount of the Cooperative Service Agreement (CSA) under which the experts operated to carry out all predator management activities. By valuing the losses for each island and year with predator management and also valuing hypothetical losses under the hypothetical scenario of no predator management, we could calculate benefit–cost ratios (BCR) to assess the monetary rewards for the cost of the predator management CSA relative to not having predator management. The general equation for calculating these benefit–cost ratios is:

$$\frac{(\#\ young\ lost\ if\ no\ pred\ mgmt - \#\ young\ lost\ with\ pred\ mgmt) \times \$100}{Cost\ of\ CSA}.$$

3. Results

The nesting success results for loggerhead turtles and least terns were clear-cut and dramatic relative to the impacts of predator management (Tables 1 and 2). As expected, nesting by snowy plovers and Wilson's plovers was not easily observed. Nesting by both species was sporadically documented and when observed, the numbers observed were small, making insightful inferences difficult (across the three years, two islands, and two species, the maximal number of nests observed was 12 and the next most was 6).

Only loggerhead turtle nests were observed during the course of the study. Predator management greatly reduced predation of sea turtle nests on Cayo Costa Island (Table 1). It also appeared to have a beneficial effect on North Captiva Island, but inferences were limited there since only two sea turtle nests were observed during the single year with predator management (Table 1). The predation rates on sea turtle nests on Cayo Costa Island plunged from 74% in the year prior to predator management to 16% and 15% in the two years with predator management (Table 1). The predation rates of sea turtle nests on North Captiva Island were 60% and 84% during the two years prior to initiating predator management. With predator management the predation rate dropped to 0%, but we must keep in mind that only two nests were observed in that year (Table 1). As would be expected from the results for both islands, the differences in rates of predation on sea turtle nests were readily detectable statistically ($\chi^2_2 > 76.7$, $p < 0.0001$, Cayo Costa; Fisher's "exact" test $p = .0058$, North Captiva).

Least tern nests on Cayo Costa Island erupted from 8 in 2006 prior to predator management to 195 and 208 in the two subsequent years with predator management in place (Table 2). More importantly, maximum one-day observation of juveniles went from 0 in 2006 to 31 and 20 in the years with predator management. The results for North Captiva Island were equally impressive (Table 2) going from 1 and 2 nests per year in the two years (2006 and 2007) prior to initiating predator management to 55 in the year with predator management (2008). No young were produced in the two years prior to control, but 62 were produced in the year with predator management. Although statistical analyses are hardly needed to understand these results, differences in nest numbers and production of young were readily found for both islands ($\chi^2_2 > 29$, $p < 0.0001$ in each case).

There were 140 raccoons removed from Cayo Costa Island in 2007 and another 134 in 2008. Also in 2008, there were 125 raccoons removed from North Captiva Island. All animals appeared to be in excellent nutritional condition, which apparently was a reflection of the abundant food resources, both natural and artificial, available on both islands, and insulation from mainland diseases.

In 2007 144 swine were removed from Cayo Costa Island, an average of approximately 14.4 swine/km^2 (Table 3). Of the swine removed 76 were males, with 20 of those were >45 kg (adults), 45 were between 14 and 45 kg (subadults), and 11 were <14 kg (juveniles). Of the 68 females removed, 15 were >45 kg (adults), 45 were between 14 and 45 kg (subadults), and 8 were <14 kg (juveniles). These age distributions were similar between males and females ($\chi^2_2 = 0.75$, $p = 0.69$). In 2008, 22 additional swine were removed from Cayo Costa, after which swine activity on the island was much more difficult to detect. Interestingly, some swine captured had been castrated and tagged, indicating human involvement with the swine population and a consequent concern for future (illegal) reintroductions.

There were 9 swine removed from Punta Blanca Island in 2007, or about 13/km^2, a comparable rate as removed as Cayo Costa Island. Of these, 4 were males, 2 were >45 kg (adults) and 2 were between 14 and 45 kg (subadults). Of the 5 females removed, 3 were >45 kg (adults) and 2 were between 14 and 45 kg (subadults). Following removal of these animals, no further sign of swine activity was detected on Punta Blanca Island. Follow-up surveys would be valuable to ensure in the future that (illegal) reintroductions are detected.

Table 1
Loggerhead sea turtle nesting and nest predation rates on Cayo Costa and North Captiva Islands, Florida for 2006–2008. Predator management was applied to Cayo Costa Island in 2007 and 2008, and only in 2008 for North Captiva Island.

Island	Measure	Year		
		2006	2007	2008
Cayo Costa	# nests	57	76	143
	# predated	42	12	22
	Predation rate (%)	74	16	15
North Captiva	# nests	20	44	2
	# predated	12	37	0
	Predation rate (%)	60	84	0

Table 2
One-day maximum counts of least tern nests on Cayo Costa and North Captiva Islands, Florida from 2006 to 2008. Predator management was applied to Cayo Costa Island in 2007 and 2008, and only in 2008 for North Captiva Island.

Variable	Cayo Costa Island			North Captiva Island		
	2006 (pre-control)	2007 (control)	2008 (control)	2006 (pre-control)	2007 (pre-control)	2008 (control)
# nests	8	195	208	1	2	55
# young	0	31	20	0	0	62

Table 3
Demographic characteristics of the invasive feral swine removed from Cayo Costa Island, Florida in 2007. Age classes were defined as: adults >45 kg, 14 kg<subadults<45 kg, and juveniles <14 kg.

Sex	Age	# removed
Male	Adult	20
	Subadult	45
	Juvenile	11
Female	Adult	15
	Subadult	45
	Juvenile	8
Total		144

The combined benefits from predator management towards production of young loggerhead turtles and least terns on Cayo Costa Island in 2007 were valued at $373,000 (see Table 4 for calculation components). The value of the combined benefits for 2008 was $710,100 for Cayo Costa Island, and $18,300 for North Captiva Island (Table 4). The lower figure for North Captiva Island reflects the low number of loggerhead turtle nests deposited in 2008. In 2007, the single CSA in place covered only the predator management on Cayo Costa Island for $14,582. In 2008, the CSA in place for Cayo Costa Island was for a lesser sum of $10,054, reflecting that swine management had begun a maintenance phase. The amount of the startup CSA for North Captiva Island predator management in 2008 was $15,000. Thus, we calculate BCRs for Cayo Costa Island in 2007 and 2008, and for North Captiva Island only in 2008 (Table 4). In every case the return on predator management was greater than the investment. While the BCRs for Cayo Costa Island were 25.6 and 70.6 for 2007 and 2008, respectively, the BCR for North Captiva Island in 2008 was 1.2, again reflecting the low number of turtle nests. If we consider the 2007 and 2008 CSAs together for both islands, the total returns in additional young turtles and terns produced were valued over $1.1 million for a total expenditure of $39,636, and an overall BCR of 27.8.

4. Discussion

If imperiled sea turtles and shorebirds are to successfully reproduce on Florida beaches, nest predation must be at low levels. There was an immediate and substantial improvement in nesting success by loggerhead turtles and least terns during the first year (2007) of predator management on Cayo Costa Island compared to the previous year, and compared to historical damage levels often near or at 100%. At the same time no predator management was applied to North Captiva Island and the turtles and terns suffered abysmal nesting success there, similar to what occurred the previous year (2006) on both islands without predator management. In 2008 both islands received predator management by experts. Cayo Costa Island continued to exhibit the success it showed in the first year of predator management the year before, and North Captiva Island experienced a dramatic turnaround to successful nesting in its first year of predator management, as was previously observed for Cayo Costa Island's first year. The most recent revision to the U.S. recovery plan for loggerhead turtles in the northwest Atlantic recommends reducing the annual rate of mammalian predation of nests to or below 10% within each recovery unit (National Marine Fisheries Service and U.S. Fish and Wildlife Service, 2008). The contribution to this recommended goal was well-achieved on North Captiva Island, while the 80% reduction in nest predation by dropping from 74% nest predation to 15% nest predation shows great strides towards this goal on Cayo Costa Island. However, we must keep in mind that it has previously been demonstrated that even after multiple years of predator management and minimal nest depredation, removal of predator management on a beach with a history of predation problems may result in a rapid return to high levels of nest destruction (Engeman et al., 2006).

The most recent revision to the U.S. recovery plan for loggerhead turtles in the northwest Atlantic also states “Populations of feral hogs should be eliminated if possible” (National Marine Fisheries Service and U.S. Fish and Wildlife Service, 2008). The most probable places for success in this regard are islands. However, obtaining adequate resources to maintain steady work towards an eradication effort can be challenging (e.g., Engeman et al., 2007b). While it was clear that the swine population on Cayo Costa Island was drastically reduced, there were portions of the island where physical accessibility was extremely difficult, and these areas could harbor remnants of the population during the time frame of control efforts. Continued efforts at removal will be needed to preserve the positive results obtained so far. Otherwise, the high reproductive potential for swine would allow them to rapidly repopulate the island to previous levels. Fortunately, it appears that all swine were removed from Punta Blanca Island. This not only helps protect the environment on that small island, but also removes an opportune situation for swine to naturally reinvade Cayo Costa Island. Eradicating and keeping Cayo Costa Island cleared of swine could serve as a model for motivating further swine eradications to protect other insular habitats and species of concern along Florida's coast.

The success of conservation measures is usually evaluated on the basis of resource improvement, but an economic perspective allows managers and administrators to fiscally assess the rewards for budgetary expenditures on conservation issues. Returns on a predator management investment of $14,582 in 2007 on Cayo Costa Island were $373,000 worth of hatchling turtles and young shorebirds relative to the alternative of no predator control. The returns in 2008 when predator management was applied to both Cayo Costa and North Captiva Islands were even greater at $728,300 for a total investment of $25,054. For the two years combined, returns were in excess of $1.1 million on combined predator management expenditures of $39,636. Therefore, in terms of prioritizing expenditures, especially during lean budget years, maintenance of an active predator management program may well represent among the most economically and biologically rewarding allocations of management resources for conserving rare shore nesting species.

Not only was the predator management highly effective and cost-effective, the management of predators on sea turtle and shorebird nesting beaches likely has more far reaching effects than mitigating just that source of mortality. Research has shown that such coastal-based management to reduce predation to shorebird nests helps

Table 4
Estimates of the additional sea turtle hatchlings and shorebird produced with predator management, their monetary values, the expenditures for predator management, and benefit–cost ratios (BCRs) for Cayo Costa and North Captiva Islands, Florida.

		Island		
		Cayo Costa		N. Captiva
Species	Quantity	2007	2008	2008
Sea turtle	Estimated # hatchlings lost to predation	1021	1800	0
	Estimated # lost if no predator management	4720	8881	121
	Difference	3699	7081	121
	Value	369,900	708,100	12,100
Least tern	Minimum # young produced	31	20	62
	Minimum # young produced with no predator management	0	0	0
	Difference	31	20	62
	Value (US $)	3100	2000	6200
Summary economics	Total value (US $)	373,000	710,100	18,300
	Cost of predator management (US $)	14,582	10,054	15,000
	Benefit–cost ratio	25.6	70.6	1.2

offset losses at sea as fisheries bycatch (Wilcox and Donlan, 2007). Moreover, and more recently, indications are that reducing predation on sea turtle nests also may mitigate losses at sea as fisheries bycatch for those species (Donlan and Wilcox, 2008). The logical extension of this would also imply general mitigation for calamities at sea such as oil spills.

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