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CONSERVATION OF AUDUBON'S SHEARWATER IN THE BAHAMAS: STATUS, THREATS, AND PRACTICAL SOLUTIONS

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ABSTRACT

Populations of Audubon's Shearwater (*Puffinus lherminieri*) are a fraction of previous levels and continue to decline. In this paper, I discuss the status, threats, and solutions to the decline. Measurements of survival of adults in the field range from 79.9% by mark and recapture to 89%-94% using the rate of replacement of mates in breeding pairs. Using estimates of reproductive success of 30%-50%, standard demographic models indicate that adult survival needs to be around 95% to achieve population growth (net reproductive rates (R) > 1). There are 39 islands in the Bahamas where shearwaters have been reported to breed, but 7 are known to have introduced predators and 20 others have not been surveyed. I trapped small mammals at 16 seabird colonies in the Exumas. Rats (*Rattus rattus* and *Rattus Norveigicus*) were detected on 5 cays and mice (*Mus Musculans*) on one. I also measured death rates of shearwaters on the cay that has mice, Allan's Cay, and another without mice, Long Cay. Death rates were 0.008 birds /m^2 on Allan's Cay and 0.004 birds /m^2 on Long Cay. The increased mortality appears to be from Barn Owls that are attracted to the mice. Four practical measures for conservation include surveying and formally protecting the remaining islands, eradicating introduced mammals where possible, immediately controlling introduced mammals by trapping near breeding sites, and constructing additional nest sites at predator-free locations

INTRODUCTION

Populations of Audubon's Shearwater (*Puffinus lherminieri*) have crashed since humans reached the islands of the West Indies in the last 2000 years (Lee, 2000; Steadman et al.1984). These long-lived seabirds lay a single egg per nesting attempt and have protracted juvenile periods of five or more years. Survival in adults of this species and other closely related populations has been estimated at over 90% per season (Mackin, 2004; Lee and Haney, 1996). Shearwaters show high site-fidelity, and formerly large populations have gone extinct or been decimated in the last century. Documented cases include those at Bermuda, Mona Island off Puerto Rico, and Tintamarre island near St. Martin. This species is sensitive to the presence of introduced rats (*Rattus rattus* and *Rattus norveigicus*; Lee 2000) and other mammals.

Traditional methods of building life-tables are difficult for shearwaters. Tracking cohorts throughout life requires decades, and there are no morphological traits (such as annual growth rings) that provide information about age. Thus, each of the life history variables must be estimated individually to approximate the demographic trajectory of a population. Such methods are the only way to determine whether seemingly healthy colonies at protected locations are replacing themselves or slowly dwindling due to external population pressures.

The largest known shearwater colony remaining in the West Indies is at Long Cay, Exuma Cays Land and Sea Park, The Bahamas. Between 800 and 1200 pairs breed there (Mackin, 2004), which represents as much at 40% of the remaining breeding pairs in the West Indies (Lee, 2000) There are at least 10 other sites where shearwaters nest within the Park and the northern Exuma Cays, making it the last known area where this formerly widespread species occurs in abundance.

The second largest known colony in the Bahamas was Allan's Cay, to the north of the Exuma Park. This island is about one-third smaller than Long Cay and had a similar density of birds (1.5-2.5 pairs / 100 m^2) to that on Long Cay as recently as the year 2000. That population, however, has been experiencing mysterious die-offs of birds with hundreds reported dead in some seasons. In May 2003, I saw a house mouse *(Mus musculus)* and found many dead shearwaters with barn owl feathers near the carcasses. While the mice probably do not cause shearwater nests to fail often, they appear to be attracting Barn Owls to the cay.

I have visited approximately half of the remaining shearwater colonies in the Bahamas and searched for undiscovered populations throughout the Exumas. In all cases, the birds have been found in rocky shore habitat where there are abundant, natural cavities in the limestone. Wherever I have found rocky shore with Morning Glory (*Ipomea indica*) and the capertree (*Capparis flexuosa*), I have invariably found shearwaters nesting. This habitat is restricted to the coastal areas of cays, and, consistent with that fact, most of the important shearwater cays are long, thin islands that have large amounts of coastline. If it can be determined that an island is free of introduced mammals, it should be possible to get an estimate of how many shearwater pairs can nest at a colony simply by the amount of coastal habitat that exists there.

In this paper, I analyze 7 years of banding data to estimate the survival and reproduction of Audubon's Shearwater in The Bahamas and estimate survivorship curves and reproductive rates for this population. Using this model and the 39 locations where Shearwaters are reported to breed in The Bahamas, I quantify the remaining habitat, assess the threats posed to the population by introduced mammals and Barn Owls (*Tyto alba*), and explore how eradicating introduced mammals and building artificial nest sites could halt the decline of this species.

METHODS

Estimates of Survival and Reproduction

Birds were banded and nests were marked at Long Cay between 1999 and 2006 (see description in Mackin, 2004). Survivorship of adults was estimated in two ways. First, pairs in which both members were banded were monitored in successive years to see if either member of the pair was replaced. Second, the survival of the overall population was estimated using the Jolly-Seber method (Greenwood, 1996). The model estimates population size and survival by tracking whether individuals were new captures or recaptures and includes information about the last time the individual was captured. One important assumption of the model is that individuals that have been captured do not leave the area or become better at avoiding capture in future occasions.

The reproductive success of active breeding pairs was taken from Mackin (2004), where nests were monitored in May and June and it was assumed that large, healthy chicks left at the end of the field study each year would successfully fledge. Since recent work (Mackin, unpublished data) indicates that Barn Owls take a heavy toll on young shearwaters before fledging, I decreased the estimate by one-half as a best guess of the reproductive success until quantitative estimates can be made.

From these estimates, I built a spreadsheet that modeled the population given the parameters using demographic methods. I found the sum of survival and reproduction at each age class ($\Sigma l_x b_x$) to find the Net Reproductive Rate (R_0) and generation time ($T = \Sigma(x l_x b_x)/R_0$). From this basic table, I substituted different parameters into the model to determine how sensitive the model is to changes in reproduction and survival.

Area and Coastline of Remaining Colonies

To identify the remaining habitat for the species in the Bahamas, I used the West Indies Seabird Geographic Information System (Mackin, 2007) to find all locations where Audubon's Shearwaters have been reported to breed in the modern times. I then used Google Earth software to locate and measure the area and coastline of each cay.

Presence of Rats and Mice

I assessed the presence of introduced mammals on cays in the Exumas by setting sherman style traps (3" x 3.75" x 9" or 4" x 4.5" x 12") baited with peanut butter or rodent bait. Work was assisted by C. Cambell and Z. Ewart from Elon Univesity. Focal cays included Allan's, Long, Warderick Wells, Narrow Water, Tessa Roberts, Radar, and Hog. Traps were placed in randomly aligned transects stratified across the long axis of each cay or the breeding area of larger cays (Warderick Wells). Each transect contained 6 traps spaced at 10 m intervals.

I also trapped other islands with fewer seabirds by quickly placing a single transect with 6 to 8 traps in accessible areas. These islands included Norman's, Shroud, Elbow, Hawksbill, Little Cistern, Hall's Pond, O'Briens, Cambridge, North Rocky Dundas, and South Rocky Dundas Cays.

When mammals were captured, they were killed individually by transferring to a pillow case and administering a quick blow to the head or by drowning within the trap. The tip of the tail was snipped and saved in 95% alcohol for future DNA and isotope analysis.

Barn Owls, Mice, and Shearwaters

To assess the effects of Barn Owls on Shearwater populations, I compared the number of dead shearwaters at Long Cay and Allan's Cay in transects walked in late May and again in August, 2007. Two field assistants, J. Goshen and P. Moore, and I walked the transects on consecutive days in August. We collected each dead bird in a garbage bag and noted where it was found. Birds were in various states of decay. It was impossible to determine the cause of death, but we assumed that the major cause of death was owl predation and that other sources of mortality would be similar. We then compared the number of dead birds at the two colonies.

Since all Procellariiform birds practice flying outside of their nests as juveniles, they might be particularly vulnerable to predation by owls. I collected the carcasses from August and transported them back to Elon University. With the help of C. Campbell and J. Goshen, I inspected them for juvenile characteristics including dark, unworn plumage, wing chords less than 190 mm in length, or remaining down.

Additional Nest Sites

Shearwaters nest in any cavity that is large enough for two adult birds to sit comfortably and protected from heat and rain. New sites were created at 3 small colonies near the Exuma Park Headquarters to see if new populations can be established or enhanced at these protected sites. Nests were constructed by moving rocks to create covered openings with similar properties to shearwater nests at Long Cay. Cement was used to hold rocks in place wherever necessary.

RESULTS

Estimates of Survival and Reproductive Success

In nests that were monitored in multiple years, females in active nests survived at rates of 91% to 92.5% while male survived at 89% to 94.5% (see Mackin, 2004). For all banded adults, mark recapture rates indicate survival of 79.9% ± 1.7 SE in the years when estimates were possible (2000, 2001, and 2002). The data failed the goodness-of-fit test for the Jolly-Seber method ($G=27.8$, $df=3$, $P<0.0001$), which indicates that captured individuals avoid capture in the future and the survivorship estimates are overly low.

Rates of return of birds that were banded as chicks were low. Only 7 of 99 chicks that had been banded from 1999-2002 were recaptured by the end of 2006. Broken down by years, 0 of 14 chicks from 1999 returned, 1 of 22 chicks from 2000 returned, 2 of 21 from 2001 returned, and 4 of 42 from 2002. When averaged over the 4 years, 5.9% ± 2.3% SE of the banded chicks returned to the breeding area within 4 years.

Fledging success of nests was not measured directly because I was not able to visit the colony over the entire breeding season. Mackin (2004) estimated that 48% to 61% of nesting pairs raised a chick to large size each year. Large but as of yet unquantified numbers of chicks are killed by Barn Owls before fledging. Thus, a conservative estimate of fledging success is 24% to 30% per year.

Plugging these parameters into a life-history spreadsheet produces sobering data. With survival at 92% for females and reproductive success at 30% per year with first reproduction in year 5, the net reproductive rate (R) is 0.59, meaning that each female produces 0.59 female offspring over its reproductive lifetime. If reproductive success is increased to 50%, then R increases to 0.98, which is effectively stable. Both of these estimates require the optimistic assumption that survival of chicks to breeding age is being underestimated by a factor of 3. Alternatives that use the data from this study produce even lower estimates of R.

In theory, a population that is not banded or disturbed by researchers might have higher survival of adults. Keeping reproduction at 50% and raising survival of established adults from 92% to 95% does increase R to 1.27, a population that would rapidly increase. Figure 1 graphs the replacement rate versus the average reproductive success if survival is held at 92% or at 95%.

Field data indicate that, at least on Long Cay, most available nest sites are currently being used for nesting. Although I only witnessed one fight over a nest site, I witnessed many occasions of nesting in sub-par nest sites with exposure to extreme temperatures, weather, and, potentially, to predators. Thus, reproduction by the population as a whole could be increased by making more ideal nest sites, where fledging success should be higher than the exposed locations sometimes used at Long Cay.

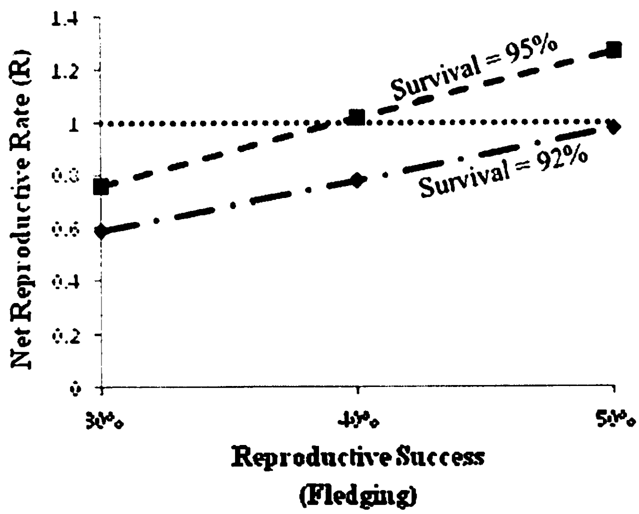

Figure 1: Net Reproductive Rate (R) as a function of Fledging success. When survival is increased from 92% to 95% in the model, the replacement rate where R=1 is more easily achieved.

Area and Coastline of Remaining Colonies

There are 40 cays and islands with historical reports of nesting by Audubon's Shearwater. The largest of these, Eleuthera, last had confirmed nesting shearwaters in 1889 (Lee, 2000). San Salvador is the largest island where shearwaters still nest, but the island has feral cats (*Felis sylvestris*), black rats, and mice and the population is unlikely to be self-sustaining. Of the other nesting cays that have not been visited recently, East Plana Cay is the most exciting. It has large areas of coastal habitat, is difficult for humans to access, and was the last refuge of the Bahamas Hutia (*Geocapromys ingrahami*) before it was reintroduced in the Exumas. Thus, it is possible that East Plana has few or no introduced mammals and might serve as an important source population to sustain the species.

Conception Island and Green Cay (east of Tongue-of-the-Ocean) are the next largest islands, but both are thought to have rats. Three other cays are similar in amount of coastline to Long Cay, remote, and uninhabited. These include South Mira-Por-Vos and two sites on the Cay Sal Bank, the

Island Name	Island Group	Area (ha)	Coastline (m)	Year	Status	Contributor
Eleuthera	Eleuthera	45900	500000	1889	Extirpated*	Lee 2000
East Plana	Plana Cays	601.8	20620	1987	BrS	Buden 1987
Conception	Conception	812	14636	1984	PBrS*	Sprunt 1984
Green	South Andros	182	5702	1884	PBrS*	Lee 2000
South Mira-Por-Vos	Mira-Por-Vos	56.7	3389	1987	BrS	Buden 1987
Double-headed Shots	Cay Sal	2.8	2842	1984	BrS	Sprunt 1984
Long	Exumas	13.7	2827	2000	800-1200	Mackin 2004
Elbow	Cay Sal	2.4	2372	1996	BrS	Hallett 2007
Cay Verde	Ragged Islands	14.7	2227	1998	PBrS	Sprunt 1984
Allan's	Exumas	6.5	2025	2003	100*	Pers. Obs.
Pimlico Rocks	Exumas	4.9	1869	1999	PBrS	Pers. Obs.
Tom Brown's	Walker's Cay	2.8	1761	1946	BrS	Lee 2000
Washerwoman	South Andros	15.7	1722	1984	BrS	Sprunt 1984
Little Cistern	Exumas	11.9	1711	2006	5*	Pers. Obs.
Green	San Salvador	12.8	1617	2003	63	Trimm and Hayes 2005
Pigeon Creek East	San Salvador	6.8	1600	2003	1	Trimm and Hayes 2005
High	San Salvador	12	1584	2000	14	Trimm and Hayes 2005
Channel	Exumas	5.4	1524	2002	100	Pers. Obs.
Atwood	Samana Cay	7.3	1516	1987	BrS	Buden 1987
Pelicans	Abaco	4.3	1508	1984	BrS	Sprunt 1984
Saddle	Exumas	2.8	1381	2006	BrS	Pers. Obs.
Low	San Salvador	6.8	1358	2000	4	Trimm and Hayes 2005
Twins	Exumas	2.4	1282	1994	BrS	Lee 2000
Little Walker's	Walker's Cay	3.3	1268	1999	PBrS	Lee 2000
East Pimlicos	Exumas	2.8	1165	2002	10	Pers. Obs.
Malabars	Exumas	1.4	1138	1994	PBrS	Pers. Obs.
Graham's Harbour	San Salvador	1	1000	2003	6*	Trimm and Hayes 2005
The Gulf Bluffs	San Salvador	0.972	972	2000	24	Trimm and Hayes 2005
South Rocks	Conception	2.5	926	1984	BrS	Sprunt 1984
West Pimlicos	Exumas	1.8	905	2002	BrS	Pers. Obs.
Sandy	Exumas	2.7	865	2005	PBrS	Pers. Obs.
North Point Bluffs	San Salvador	2	854	2000	11*	Trimm and Hayes 2005
Rocky Dundas	Exumas	5.25	798.94	1994	BrS	Lee 2000
Manhead	San Salvador	1.7	798	2000	31	Trimm and Hayes 2005
Goulding	San Salvador	0.1	608	2000	5	Trimm and Hayes 2005
Gaulin	San Salvador	0.97	515	2003	22	Trimm and Hayes 2005
Nancy	San Salvador	1.4	401	2000	4	Trimm and Hayes 2005
Noddy	Exumas	0.08	384	2000	50	Pers. Obs.
Catto	San Salvador	0.7	350	2000	1	Trimm and Hayes 2005
Cut	San Salvador	0.1	100	2003	1	Trimm and Hayes 2005

*Figure 2. Bahamian islands with historical records of breeding by Audubon's Shearwater. Sites are ranked by meters of coastline. Year of last report of breeding and reference of latest survey are given in separate columns.BrS=Breeds in unknown numbers, PBrS=Suspected breeding,*indicates colonies at sites likely or known to have introduced mammals.*

Double-Headed-Shot Cays and Elbow Cay. The area, amount of coastline, and population estimates for the modern colonies are in Figure 2.

Introduced Mammals

Of the 38 remaining locations in The Bahamas, 7 are known or suspected of having rats and other introduced mammals. I placed traps at 16 cays in the Exumas in 2007 and found that only one known shearwater breeding site in the Exuma Park (Little Cistern Cay) had rats and confirmed that Allan's Cay had a large population of house mice (*Mus musculus*). I also discovered nesting of shearwaters at three new sites in the Park, Elbow (near Shroud), Narrow Water, and Cambridge Cays. Rats were also found on Cambridge Cay. These data confirm the prediction of Lee and Clark (1994) that shearwaters are restricted to islands without rats.

Data from trapping of mammals were binary in nature; rats or mice were either captured within two days of trapping or they were not captured in many nights of trapping. The cays in the center of the Park between Little Cistern and Hall's Pond Cay, including Warderick Wells, were found to be rat and mouse free. Foul weather prevented trapping on the rocks in the "Wide Opening" (Saddle Cay, Danger Cay, and others). The lack of rats on more trafficked and larger cays in the Park and the healthy tern colonies of the wide opening indicate that rats are not present, but those cays should be trapped in the future.

Cay	Trap Nights	Mouse	Black Rat	Norway Rat
Allan's	63	6		
Normans	10		3	1
Shroud	71		6	2
Elbow	12			
Hawksbill	44		1	
Little Cistern	32		7	
Long	36			
Narrow Water	24			
Tessa Roberts	12			
Warderick Wells	92			
Radar	12			
Hog	60			
O'Briens	12			
Cambridge	16		4	
North Dundas	8			
South Dundas	6			
Total	510	6	21	3

Figure 3: Results of efforts with small mammal traps at 16 different cays in the Exumas. Cays are listed from north to south. Six of the sixteen cays surveyed had introduced mammals.

Barn Owls, Mice, and Shearwaters

The transect walked on Long Cay consisted of a loop around the northwestern 2/3 of the island. The transect measured 1,193 m in length and 10 m in width. The transect on Allan's Cay was 8,587 m in length and 10 m in width. In May, we found 30 dead shearwaters in various states of decay in the Allan's Cay transect. On Long Cay, we found 55 dead shearwaters. Allan's Cay was cleaned of dead birds in several past instances as scientists tried to identify the cause of the mass mortality. Long Cay was not cleared previously. Carcasses can lie on an island for years and remain recognizable. Thus, it is not possible to interpret the number of dead birds found in the initial clearing.

In August, we found 64 dead shearwaters at Allan's Cay. We found 45 dead shearwaters at Long Cay. On both islands, most birds were found in bunches of 4-8 in low spots where wind is limited and it would be difficult for a shearwater to take off. Owl feathers and pellets occurred near carcasses at both locations. The death rate between May and August was 0.0075 $/m^2$ at Allan's Cay and 0.0037 $/m^2$ at Long Cay. Thus, the death rate at Allan's Cay was twice that at Long Cay, as expected if the mice are attracting more owls or supporting a larger population of owls around Allan's Cay.

Of 45 carcasses collected from Long Cay during August, 6 birds (13.3%) bore juvenile characteristics. Of the 59 carcasses that could be examined conclusively from Allan's Cay, 10 (16.9%) bore juvenile characteristics. These small differences indicate that juveniles are suffering high mortality to owls at both locations.

According to the calculations above, the area surveyed at Long Cay represents between 500 and 800 nesting pairs, 1000-1600 adults, and 250-400 chicks per year, and at least 1000 more unmated individuals. Only six of the birds found dead were chicks, leaving 94 adults killed by owls. This leads to a rough calculation of the death of 3.6%-4.7% per year of the 2000-2600 adults that use the area. If the rate at Allan's Cay is 7.2%-9.4% per year, the population would go extinct in a few decades, which appears to match the speed of the current decline.

Additional Nest Sites

In 2007, 20 nests were constructed at Radar Cay, 18 at Hog Cay, and 7 at Narrow Water Cay. Playbacks of adult mating calls will be used in 2008 to lure more birds to these areas. Nests were easier than expected to construct, taking less than a minute in some cases to turn inhospitable sites into ideal nests.

DISCUSSION

Survival and Reproductive Success

After 8 years of study, the estimates indicate that fledging success and survivorship are not high enough to sustain shearwater populations. Hopefully, the estimates are low, but, in light of the drastic declines experienced by this species, the numbers might be correct. The most realistic models of the life history indicate that the lower estimates of fledging success at 30% are not sustainable in any scenario ($R < 1$ regardless of other parameters) while fledging success of 50% would sustain the population at adult survival estimates as measured in the field (~92%).

Efforts to Restore the Population

I suggest four methods that would increase the reproductive success and survival of Bahamian shearwaters. The first is to protect the remaining sites and survey the 20 colonies where the size of the population is unknown. Priority should be given to the largest sites, but all of these locations are spacious enough that they could be regionally important colonies, since the best estimate of the population for the West Indies is 3000-5000 breeding pairs (Lee 2000). In addition, important colonies that are currently not protected, particularly Allan's Cay, should be brought under official protection from development and poaching.

The second step is to eradicate introduced mammals from infested islands where it is feasible. The link between seabird declines and rat presence on islands is well-known, but the solutions are relatively new. Howald et al. (2007) review the developing field of eradication and recommend routine eradication of rats on islands less than 100 ha.

While efforts to eradicate mice from islands have been more difficult, such actions may be necessary to save the population at Allan's Cay. That population is much smaller than it was in 2000, but it is still at least 100 pairs and will probably recover if the predation can be curtailed. The presence of a small number of endangered iguanas (*Cyclura cyclura*) on the cay complicates the picture for eradication, but those individuals can be captured and moved to islands with appropriate breeding habitat (lacking at Allan's Cay) before the eradication.

A third means of protecting shearwaters involves trapping at colonies where introduced rats or cats are present. On larger islands where shearwaters and other native animals persist, such as San Salvador, island-wide programs that trap and kill invasive mammals near the remaining nest sites can be effective. Rats have relatively small territories and localized trapping efforts have proven successful in many seabird restoration projects. Trapping at smaller islands where eradication is possible can still prove effective as a stop-gap method until eradication proceeds. Such efforts are underway for 2008 in the Exuma Park.

A fourth way to restore populations is to build more nest cavities. We will see how quickly the birds take up the cavities that were constructed in 2007. Playbacks can be used to lure prospecting birds to the areas. This technique is simple and could be done easily at ecotourism sites and on private cays where rats are controlled and individuals would like to enhance the wildlife inhabiting their islands. I see no reason why landowners would not want shearwaters breeding on parts of their islands.

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