PROCEEDINGS

OF THE

TENTH SYMPOSIUM

ON THE

NATURAL HISTORY OF THE BAHAMAS

Edited by
Sandra D. Buckner
and
Thomas A. McGrath

Conference Organizer
Vincent J. Voegeli

Gerace Research Center, Ltd.
San Salvador, Bahamas
2005

Cover photograph – "Little Ricky" - juvenile dolphin, San Salvador, Bahamas (courtesy of Sandra Voegeli, 2003)

Printed in the Bahamas

ISBN 0-935909-76-1

DISTRIBUTION OF NESTING AUDUBON'S SHEARWATERS (*PUFFINUS LHERMINIERI*) ON SAN SALVADOR ISLAND, BAHAMAS

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ABSTRACT

The Audubon's Shearwater (*Puffinus lherminieri*), nearly pantropical in distribution, remains a poorly studied species. The subspecies *P. l. lherminieri* is endemic to the West Indies region. An estimated 5,000 pairs inhabit the Caribbean, but there has been a substantial decline with many colonies becoming extirpated. It is thought that as many as 3,000 pairs (60%) may nest in the Bahamas. In fact, the breeding colony on Long Cay of the Exumas, Bahamas, may be the largest known in the world. Since 2000, we have been studying the behavioral ecology of the Audubon's Shearwaters nesting on San Salvador Island and its satellite cays. This paper focuses on: 1) demography and distribution and 2) the use of radiotelemetry to determine the feeding site locations. We found that a minimum of 187 pairs nest at San Salvador Island, Bahamas. The existence of much suitable habitat suggests that this is a gross underestimate. The information gathered in this study may play a key role in our understanding of the Audubon's Shearwater's biology and aid in developing effective conservation strategies for the protection of this species.

INTRODUCTION

The avian order Procellariiformes is characterized by pelagic, "gull-like" birds that have external nostrils within tubes on the top or sides of the upper mandible (Figure 1). Their nostrils are associated with specialized salt-excreting glands that enable them to maintain an appropriate internal salt concentration. Procellariiforms are represented by about 93 species, consisting of the albatrosses, petrels, diving-petrels, shearwaters, and storm-petrels (Harrison, 1985). The Audubon's Shearwater is the most abundant nesting Procellariiform in the West Indies (W.I.) region (David Lee, pers. comm.).

*Figure 1. Adult Audubon's Shearwater (*Puffinus lherminieri lherminieri*) at San Salvador Island, Bahamas. Photo: W. Hayes*

The Audubon's Shearwater is a relatively small (length 31 cm; wingspan 69 cm) procellarid with dark brown (appearing black) upperparts, white underparts, brownish sides of breast, and brownish undertail-coverts. Sexual dimorphism has not been reported in this species. Other aspects of coloration include a brown tail, black bill, brown iris, and legs/feet that are flesh-colored with the outer sides blackish (Harrison, 1985). The Audubon's Shearwater

could be mistaken for the Little Shearwater, *Puffinus* (*assimilis*) *boydi*, based on plumage color; however, the latter does not occur in the West Indies (W.I.) and is slightly smaller (length 25-30 cm; wingspan 58-67 cm).

Despite its nearly pantropical distribution, this species has been the subject of very few comprehensive studies. The subspecies in the Galapagos Islands (*P. l. sublaris*) has been studied in some detail (Snow, 1965; Harris, 1969). The several subspecies in the Indian Ocean (particularly *Puffinus lherminieri bailloni*) have been the subject of discussion for a few years due to taxonomic complexity (Bretagnolle et al, 2000; Bretagnolle & Attie, 1996). The few publications concerning the Caribbean subspecies are comprised largely of distributional, abundance, and breeding records based on anecdotal observations (Smyth, 1937; Wetmore, 1959; Lawrence, 1889; Collins, 1969; Lee and Clark, 1994). Other shearwater species have been studied more extensively, and can serve as reservoirs from which to draw ideas for studying Audubon's Shearwaters.

During the non-breeding period, Audubon's Shearwaters spend all of their time on the open seas. While breeding, the birds fly to land at dusk where breeding activity occurs during the dark hours (except for in the Galapagos, where breeding is diurnal). The peak activity period is from about 9:00-11:00 pm. At dawn, the birds return to the open seas. During the daylight hours, the birds can be found at sea as solitary individuals or in small foraging flocks, often over *Sargassum*, feeding on fish and other inhabitants of the algal mats. Non-feeding birds may form extensive rafting aggregations on the ocean surface (Murphy, 1936). Except for a few anecdotal observations made in the Galapagos by Harris (1969), our knowledge of this species' feeding habits is very limited. Examination of the stomach contents of 119 Audubon's Shearwaters collected from the Gulf Stream off of North Carolina revealed that the species feeds largely on small fish and squid (David Lee, pers. comm.).

Little is known about the phenology of the Audubon's Shearwater. The available information implies that breeding is initiated earlier in the southern parts of the W.I. (David Lee, pers. comm.). Whereas egg-laying begins in January or February in other Caribbean regions (Murphy, 1936) it probably does not begin in the Bahamas until March and continues through to late May. (Lee and Clark, 1994). Although the birds breed year-round in the Galapagos, they breed annually in the Bahamas, possibly an adaptation to the high occurrence of hurricanes (Lee, 1996). No particular factor has been identified that synchronizes the onset of intracolonial breeding; however, in the Galapagos, intracolonial breeding synchronization has been attributed to populous aerial displays (Snow, 1965). In the Bahamas, prospecting for burrows and courtship appear to begin in late November (David Lee, pers. comm.). Both sexes probably take turns incubating the single-egg clutch, with incubation bouts lasting up to 8-10 days (Palmer, 1962). Lee and Clark (1994) suspect that the mean incubation period is similar to that of the 48.5 days reported by Harris (1969) for the Galapagos population and 51 days for the Bermuda population proposed by Wingate (in Palmer, 1962). The mean fledging period in the Galapagos Islands was 75 days, with a range of 62-100 days (Harris, 1969). Chicks are probably present in the Bahamas from late April thru late July or early August (David Lee, pers. comm.).

For conservation purposes, a clearer picture of what makes habitats suitable for shearwater colonies is needed. Breeding adults usually form nests in burrows, recesses/holes in cliffs, under/among boulders (Snow, 1965), or simply in depressions in dry detritus accumulated between the rocks (Lee and Clark, 1994).

The habitat features that make a cay desirable for an Audubon's Shearwater nesting colony have been the focus of very few

studies. On Reunion Island in the Indian Ocean, Bretagnolle *et al.* (2000) found that Audubon's Shearwaters formed discrete colonies. Most colonies were at intermediate elevations (400-900 m), on cliffs lacking vegetation, and were along the southern part of the island, well inland from the coast. In the Bahamas, Audubon's Shearwaters prefer to nest in rocky habitats, but are not restricted to cliffs (Lee and Clark, 1994). Mackin and Lee (pers. comm.) observed that Audubon's Shearwaters' nests on Long Cay, Bahamas, were most dense (1 nest/28 m^2) on the eastern (seaward) side of the island, and were few or absent from the dense thicket of short palms, gnarled buttonwood trees, and various shrubs on the western side of the island. This subject deserves more examination. Because nesting colonies are difficult to detect except by being present on an island at nighttime, we could more readily locate additional colonies if we could better predict which cays are suitable for nesting. This paper enhances our knowledge in this area by focusing on the data we collected concerning: 1) demography and distribution and 2) the use of radiotelemetry to determine the feeding site locations of the Audubon's Shearwaters of San Salvador island, Bahamas.

MATERIALS & METHODS

Study Site

San Salvador is a relatively small island (156 km^2) found on the eastern edge of the Bahamas. The greatest elevation on the main island is 43 m (Smith, 1993). An extensive system of hypersaline lakes comprises most of the surface area. Temperatures average 31 C during summer and 17 C during the coolest month, December (Smith, 1993). Annual precipitation ranges from 100-180 cm. There is a definite rainy (hurricane) season from August to September, and a lesser rainy season in May and June (Smith, 1993).

There are 11 satellite cays just offshore from the main island (Figure 3), which range in size from 1 ha (Nancy Cay) to 15 ha (High Cay). These cays are the fragments of ancient, lithified eolian sand dunes that formerly supported a dense forest, as is evident from the fossil flora. The plant diversity of these cays is highly variable, ranging from a mere 10 species on Green Cay to more than 40 species on Low and High Cays (Moyroud and Ehrig, 1994). The current vegetation of the offshore cays is similar in varying degrees to the vegetation of the main island (Smith, 1993). Although vegetation of the main island was heavily disturbed by cultivation in the nineteenth century (Olson *et al.*, 1990), the impact of man on the satellite cays is unknown, except that regionally introduced moths (*Cactoblastis cactorum*) have decimated the Prickly-pear Cacti (*Opuntia stricta*) and Black Rats have been documented on Low Cay and High Cay (Hayes *et al.*, 1995).

Methods

Surveys were conducted annually during 2000-2003. We visited 10 satellite cays (all but White Cay), one inland cay (Pigeon Cay), and searched some areas along the rocky coast of the main island. Since the birds are nocturnal at the breeding colony and most readily found at night, camping was required on some cays to determine population sizes. Up to three cays were surveyed on a given night (a minimum of one hour per cay, depending on size). The man-hours for surveys ranged from 3.0 (Catto, Middle Cays) to 10 (Green, Manhead Cays), and were restricted to the period of 2000-0200 hrs. We located shearwater burrows by simply walking around the edge of the island (where possible), listening for the adults' distinct vocalization. Playback (see below) was used to elicit calls from males in some years (since 2002). Flashlights and headlamps were used to illuminate the jagged terrain. If calling was minimal, researchers would walk for about 100 m, then

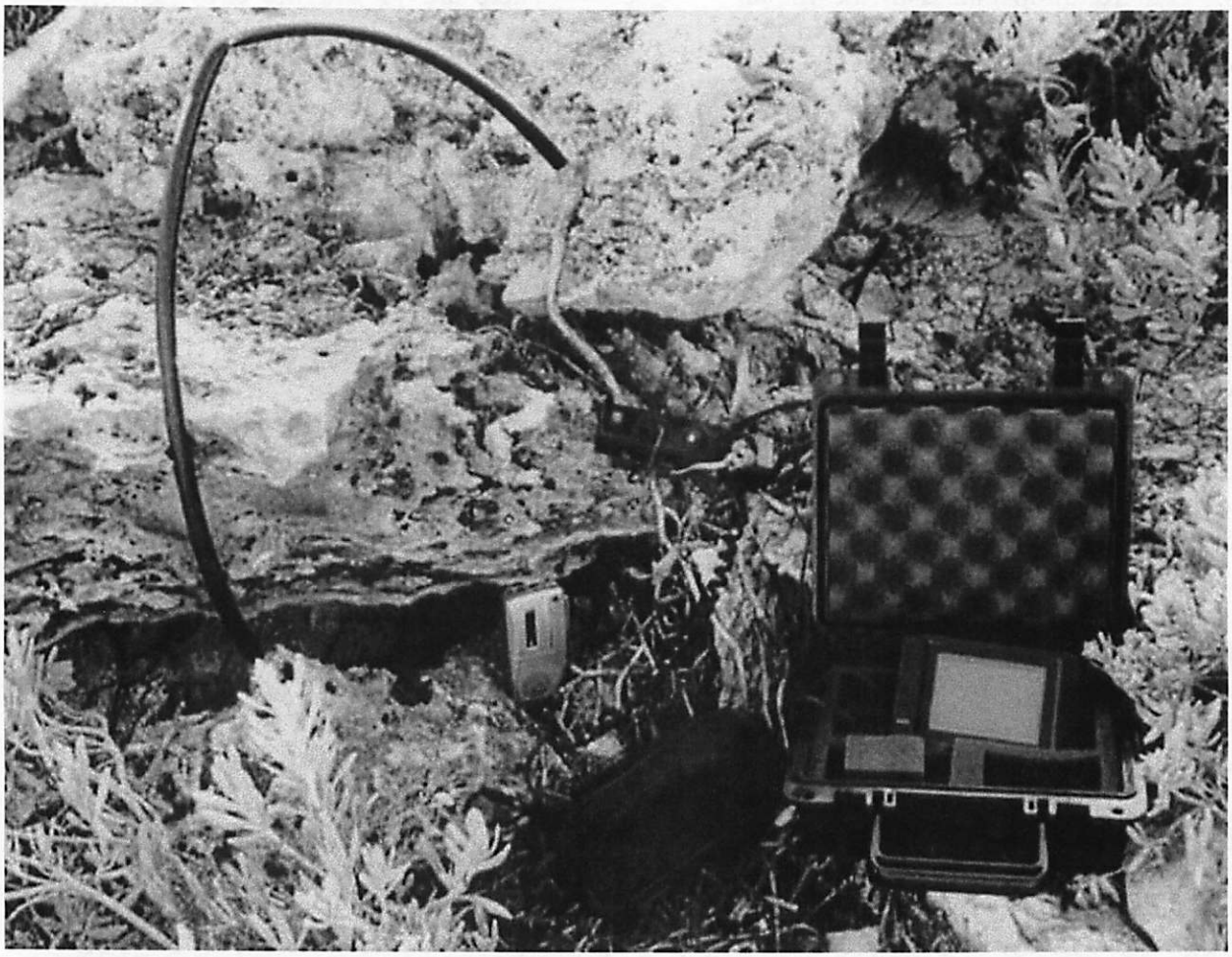

Figure 2. Burrowscope used to examine the interior of subterranean Audubon's Shearwaters' nest.

stop, turn off lights, and listen silently for about 3 minutes before walking on to the next site (about 10-50 m away). Between sites, visual searches were conducted, focusing on areas that seemed like good nesting sites (i.e., rocky with a lot of crevices). If a burrow was initially detected audibly, the researchers used triangulation to locate it precisely. Once a burrow was located visually, the nest contents were determined, the burrow was flagged (for microhabitat evaluation the following day), its GPS coordinates recorded (using a Garmin GPS 12), and data were collected on all birds captured and eggs found at the nest. Coordinates were within 5 m accuracy. Flagging was not done on the main island to keep the burrows inconspicuous. In some cases, more so later in the season, burrows were located by hearing the chirping of shearwater chicks. Birds seen or heard flying were not counted, to avoid double counting.

We conducted the first surveys of Audubon's Shearwaters on San Salvador Island during the week of May 6-14, 2000. The surveys were done on nine offshore cays (all but Nancy and White Cays). From 14 May through 6 June, Trimm camped on Manhead Cay. Initially, Trimm conducted a survey that determined the presence or absence of eggs and chicks in burrows that had been marked during the survey of the previous week. These initial and extended surveys allowed us to calculate a detection rate (i.e., the proportion of a population that is detected in a survey). Rocky habitats on the main island were surveyed at Dump Reef (2.6 man-hours, 28 May), where a colony of White-tailed Tropicbirds nests in the cliffs,

and at North Point adjacent to Cut Cay (4 man-hours, 2 June).

In June 2001, two satellite cays (Cut and Nancy Cays) and one inland cay (Pigeon Cay) were surveyed. On the main island, the bluffs that were surveyed the previous year were resurveyed and two new sites were searched: Pigeon Creek East (PC) and Dim Bay North (DB).

In 2002 (from 5 May to 19 June), surveys were conducted on Manhead Cay, Green Cay and the main island. The main difference in the survey method for these years was the use of playback. Recordings of male and female Audubon's Shearwater vocalizations (and a male-female duet) were obtained from Will Mackin and transferred to cassette tapes. In the field, the male Audubon's Shearwaters respond to male playback, giving away the location of their burrows. The response of females to playback is very limited. Since Green Cay was the main study site for these field seasons, extended surveys there yielded our most precise population data and detection rates for those years. On the main island, the northern coast was resurveyed and nesting pairs were found at The Gulf (TG).

In addition to the island surveys, we took three deep-sea fishing trips to waters north of San Salvador (to "The Hump") to look for seabirds and radiotelemetered Audubon's Shearwaters at sea. Transmitters (model LPB 2350, 8.7g, Wildlife Materials International, Inc., Carbondale, IL) were attached in a backpack style by Teflon chord to seven adults on Green Cay. The locations of feeding flocks were determined using a GPS unit, and the flock composition was determined as best as possible.

In 2003 (from 20 May to 25 June), playback was used to conduct surveys on Green Cay for which a detection rate was determined for that year. On the main island, playback surveys were done along much of the northern coast. Most of the previously surveyed areas were resurveyed. Additionally, Rocky Pt. to Barker's Pt. (RB), Line Hole Settlement bluffs (LH), Northeast Pt. (NE), Hanna Bay bluffs (HB), and most of Riding Rock Pt. (RR) were surveyed. Areas enclosed by the Riding Rock Inn and Club Med properties were not surveyed. Only one deep-sea fishing trip was made.

Burrowscopes were used to look for and examine nests that were deep in burrows or crevices. Each scope was custom-built with a miniaturized black/white CCD camera [the two models used were ProVideo CVC-120R (0.5 lux, 3.6 mm wide angle lens, 7/8" dia X 1-9/16) and ProVideo CVC-130R (0.1 lux; 3.6 mm wide angle lens; 1" dia. X 2-1/4")], five infrared-emitting LED's affixed to the outside of the camera, and a 3-m cable. The unit was powered by a 12V (7 amp-hour) hip-pack battery and the signal was fed to a black-and-white monitor for viewing (Figure 2). The burrowscope was carefully introduced into each burrow entrance and maneuvered around the burrow until we determined whether the burrow was occupied by an adult (or pair), a chick, or an egg.

RESULTS

Estimates for pairs of Audubon's Shearwater nesting on San Salvador Island are shown in Table 1. Figure 3 illustrates the areas that have been surveyed and suitable habitat yet to be surveyed. Nesting pairs have been found on most of the cays and on multiple sites on the main island. None have been found on the inland cays.

To estimate the population, it is necessary to know what proportion of the birds you are actually seeing. A detection rate of nesting birds was determined by comparing the numbers from an initial survey of a particular site to the numbers of an extended survey of the same site. The initial survey would represent a proportion of the birds, while the extended survey will determine exactly how many birds are present. The extended period spent on Manhead Cay in 2000 allowed for the calculation of a detec-

Table 1. Population estimates of Audubon's Shearwaters for San Salvador Island over a three-year period. Estimates are based on a 79% detection rate.

Location	Est. Nesting Pairs	Date
Green Cay	63	June 2002
Catto Cay	1	May 2000
Gaulin Cay	22	May 2000
Cut Cay	1	June 2001
Manhead Cay	31	June 2000
Goulding Cay	5	May 2000
Nancy Cay	4	June 2001
High Cay	14	May 2000
Middle Cay	0	May 2000
Low Cay	4	May 2000
Pigeon Cay	0	June 2001
Riding Rock Point (RR)	0	June 2003
North Point Bluffs (NP)	11	June 2001
Graham's Harbor Bluffs (GH)	6	June 2003
The Gulf Bluffs (TG)	24	June 2003
Rocky Pt. to Barker's Pt. (RB)	0	June 2003
Line Hole Settlement Bluffs (LH)	0	June 2003
Northeast Point Bluffs (NE)	0	June 2003
Pigeon Creek East (PC)	1	May 2002
Dim Bay North (DB)	0	June 2001
Total	***187***	

tion rate for that cay. Because 22 pairs were found during the initial survey there and the extended produced 31 pairs, it means that 71% of the birds were detected during the initial survey on Manhead Cay. Using a similar method, detection rates were calculated for the 2002 and 2003 field seasons on Green Cay (84% and 83% respectively). An average detection rate (over the three years) of 79% was used to determine the final population estimates for all locations (See Table 1). Where multiple surveys were conducted for a single site, the higher values were used. Raw data are presented for Green and Manhead Cays (maximum numbers from extended surveys).

Stepwise linear regression based on nine cays surveyed in 2000 showed that cays

with more available habitat (i.e., proportion of the cay covered by rocky areas) tended to have larger colonies ($F_{1,7} = 6.23$, $P = 0.041$). The coefficient of determination (adjusted r^2) indicated that 39.5% of the variance in shearwater numbers was explained by this variable.

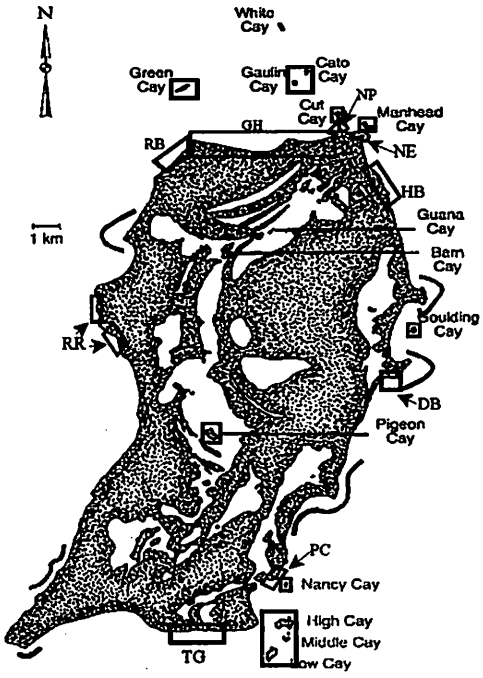

Figure 3. Areas surveyed for Audubon's Shearwaters (in squares) and areas that have potential habitat (curved lines).

DISCUSSION

Results of the population surveys suggest a breeding population of at least 187 pairs on San Salvador Island, with substantial habitat yet to be surveyed. This estimate is twelve times larger than that (15+ pairs) given by Lee and Clark (1994) for San Salvador Island. Our estimate for San Salvador represents 3.7% of the estimated maximum of 5000 pairs nesting in the West Indies (Lee, 2000). West Indian colonies for which shearwater numbers are reported range from less than 10 individuals on a few cays in the British and U.S. Virgin Islands (Lee, 2000), to 3000 on Long Cay, Exumas, Bahamas (Will Mackin, pers. comm.). This colony is probably the largest in the West Indies.

The amount of available habitat was the most important factor predicting the number of nesting shearwaters that occupied the various cays. Cays with a higher proportion of available habitat had higher numbers of nesting shearwaters. Other geophysical factors were unimportant for determining colony size, including size of cay, maximum elevation of cay, distance from the main island, and north-south orientation (Trimm, 2001). Nevertheless, several cays appeared to have considerable habitat but supported only a handful of shearwater pairs (e.g., Goulding Cay) or none at all (Middle Cay). In spite of its small size, Gaulin Cay (1.6 ha) supported the densest colony of shearwaters (15 pairs/ha).

Other factors may affect colony size. One such factor is proximity to the birds' foraging grounds, as the birds may prefer to minimize travel distance. Unfortunately, we do not have a complete picture of where adults forage in relation to their colonies on San Salvador Island. Deep-sea fishing trips and radiotelemetry have only started to yield insights on the foraging locations for shearwaters. Three of seven transmittered Green Cay individuals were relocated on a trip to "The Hump." This rise in the seafloor about 16 km north of San Salvador's northern shore is thought by local fishermen to be a safehaven for fish, hence a major feeding site for seabirds. The most shearwaters I have seen on any single trip made to "The Hump," is an estimated 75 Audubon's Shearwaters. This obviously does not represent the entire shearwater population. In 2003, Hayes observed a huge, offshore flock of seabirds southwest of Low Cay. However, this flock was too far to identify Audubon's Shearwaters. Where adults from other colonies forage is still unknown; they may or may not go to the closest feeding grounds. Further studies involving telemetry would be necessary to better understand where at sea the birds forage. Another fac-

tor that may affect colony size is historical disturbance of the colonies by humans. Activities such as hunting and egging could influence present-day habitat use. Unfortunately, egging remains a common practice with the local residents, though terns are primarily targeted.

There are several reasons why the population estimates in this study are likely to be underestimates of the total population size on San Salvador. First, several cays (White Cay, and a few rocky outcrops off High and Middle Cays) were not sampled, and these may support small colonies. Second, more colonies undoubtedly exist on the main island. Our search of rocky areas on the main island's coast has not been exhaustive. The abundance of suitable habitat on San Salvador's eastern and southern shores suggests that the Audubon's Shearwater population could be more than 500 pairs. These areas need to be surveyed. Finally, the detection rate of 79% can be further refined. Because some cays were sampled during moderate levels of moonlight, detectability (calling) rates might have been reduced, as has been reported for Audubon's Shearwaters in the Indian Ocean (Bretagnolle *et al.*, 2000). The issue of shearwater detection rate as it relates to the effect of ambient light on calling is further complicated when one considers that the prevailing weather affects the relative ambient light availability. Simply increasing search effort and using playback during surveys will increase detection rates.

Population and distribution studies of Audubon's Shearwaters are of prime importance for this declining seabird. Our lack of knowledge concerning this species is partially due to its nocturnal nature and the relative isolation of their colonies. Previously, search efforts have focused on cays. However, our work suggests that we would have a better knowledge of the sizes of Audubon's Shearwaters' colonies and their distribution in the W.I. if we include the rocky coastlines of large islands in our surveys. Devising a model (e.g., habitat suitability index) to predict where the birds are most likely to colonize and forage will help us better concentrate our search efforts on areas of high potential and allow for rapid advances in understanding the behavioral ecology of this secretive species.

ACKNOWLEDGMENTS

We would like to thank the Department of Natural Sciences at Loma Linda University and a Disney Foundation Conservation Grant (for iguana work) for funding this project. The project would not have been possible without the help of the following assistants: Ian Scott, Luke Fisher, Jeremiah Johnson, Naomi Balduff, Bradly Glinton, Shelton Herbert, Pat Barry, and Sarah Wilson. We would also like to thank Dr. Donald T. Gerace, Chief Executive Officer, and Vincent Voegeli, Executive Director of the Gerace Research Center, San Salvador Island, Bahamas, for logistical support.

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