Caribbean Naturalist

No. 70 2019

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Cover Photograph: Adult Red-footed Booby (*Sula sula*) with nestling on a nest in a tree at the Cabo Norte colony in Mona, Puerto Rico. Photograph © Tomás Carlo.

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The ***Caribbean Naturalist*** (ISSN # 2326-7119) is published by the Eagle Hill Institute, PO Box 9, 59 Eagle Hill Road, Steuben, ME 04680-0009. Phone 207-546-2821, FAX 207-546-3042. E-mail: office@eaglehill.us. Webpage: www.eaglehill.us/cana.

Periodical postage paid in Steuben, ME and additional mailing offices. **Special issue proposals are welcome**. On-line secure subscription ordering: rate per year for Caribbean subscribers - $15 regular, $10 students, $75 organizations; for Non-Caribbean subscribers - $20 regular, $15 students, $100 organizations. **Authors**: submission guidelines are available at www.eaglehill.us/cana. **Co-published journals:** The *Northeastern Naturalist* (ISSN 1092-6194 [print], ISSN 1938-5307 [online]), the *Southeastern Naturalist* (ISSN 1528-7092 [print], ISSN 1938-5412 [online]), and the *Urban Naturalist* (ISNN #2328-8965), journals with separate Boards of Editors. The Eagle Hill Institute is a tax exempt 501(c)(3) nonprofit corporation of the State of Maine (Federal ID # 010379899).

Vegetation and Population Survey of the Red-footed Booby (*Sula sula* L.) Colony in Mona Island

Andrew J. Blinn[1] and Tomás A. Carlo[1,*]

Abstract - The *Sula sula* (Red-footed Booby) colony located in the remote Cabo Norte region of Mona island is one of the 3 largest of the West Indies but has been known from only a single informal account from nearly 50 years ago by H. Raffaele. Here we report the first spatially explicit, fully georeferenced survey of birds and nests of this *S. sula* colony. Our goals were to map the location and extent of the colony, to estimate the number of birds and nests, and to assess the structure of the vegetation and how *S. sula* select plant species to build nests in relation to their availability in the environment. We registered 1351 perched birds and 652 nests of *S. sula* on 364 georeferenced trees extending over 19.6 ha. The area is larger than the entire nearby island of Monito, and the population appears to be half of what it was when Raffaele visited, although we only registered perched birds and avoided those flying over. More than 90% of the nests were constructed on *Guapira discolor* (Longleaf Blolly) and *Ficus citrifolia* (Shortleaf Fig). *Guapira discolor* is the most abundant tree in Cabo Norte but a species that is notably absent from the rest of the island, suggesting an important resource for *S. Sula*. Nests were never found on many common tree species such as *Euphorbia petiolaris* (Manchineel Berry) and *Plumeria alba* (West Indian Jasmine or White Frangipani). Results suggest that *S. sula* select nesting sites based on tree attributes such as height and foliage density given that *G. discolor* and *F. citrifolia* have tall dense canopies that provide good structural support to nest platforms, especially *G. discolor*. Our map can guide future surveys in using area-based estimates and robust distance-sampling methods to monitor the population of this important seabird colony.

Introduction

Populations of colonial seabirds have been declining and disappearing worldwide due to the direct and indirect effects of human activities, including the exploitation of birds and guano deposits and the general degradation of marine and terrestrial ecosystems (Paleczny et al. 2015). It is thus critical to document and monitor colonies that remain poorly known. For instance, the Mona Passage that separates Puerto Rico and Hispaniola harbor the islands of Desecheo, Mona, and Monito, which contain some of the largest seabird colonies in the West Indies (Kepler 1978). Still, information on these seabird colonies is rare, with the most recent work dating back at least 4 decades (Barnés 1946, Kepler 1978, Rolle et al. 1964, Raffaele 1973, Wetmore 1918). Here we present the first spatially explicit and fully georeferenced survey of the *Sula sula* L. (Red-footed booby) colony in the northeastern point of Mona Island, Puerto Rico.

For over a century, *Sula sula* has been known from Mona (Bowdish 1902), although it was not until 1973 that H. Raffaele visited a breeding colony and

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Manuscript Editor: Jason Townsend

provided the first and only quantitative assessment of its size (Raffaele 1973). In December 1971, Raffaele visited the Cabo Norte area, a place he described as "probably the most remote and rugged section of Mona" (Raffaele 1973:12). In Cabo Norte, Raffaele (1973) reported 500–700 breeding pairs in December 1971 and 700 nests (in all stages) and 3000 birds in July 1972. These numbers make the Mona site the third largest colony of the entire Caribbean region (Lee and Mackin 2009). Unfortunately, Raffaele did not mention how he reached such numbers in terms of census methods, nor did he describe the extent of the colony, which officially makes this first and only assessment a "guesstimate". In light of this data gap, our goal here is to provide a detailed georeferenced map of the S. *sula* colony in Mona, including an assessment of the vegetation structure used as nesting substrates. We also provide a thorough, spatially explicit census of birds and nests to serve as a foundation to establish a methodologically robust monitoring program for this colony into the future.

Study Site

Mona is a 57-km^2 oceanic island under the jurisdiction of Puerto Rico (Fig. 1). It is a natural reserve administered by the Department of Natural and Environmental Resources of Puerto Rico, and has been a designated US National Natural Landmark since 1975. The *S. sula* colony is located in the northeastern cape of the island locally known as Cabo Norte or "Las Bobas" (18°6'59.11"N, 67°52'11.49"W). According to the classification of Martinuzzi et al. (2008) based on satellite image data, the *S. sula* colony site in Mona contains 2 vegetation types: lowland dry limestone scrubland and lowland dry limestone woodland.

Methods

On March 10–11 of 2008, we visited Cabo Norte and established a 240-m linear transect oriented northeast–southwest (8°) using a compass and tape measure. The transect was located within the central region of the colony (start point = 18° 7'2.21"N, 67°52'13.28"W; end point = 18° 6'54.40"N, 67°52'14.37"W; Fig. 1A). We identified and counted the number of stems at breast height, assigning each to 1 of 4 size categories (<2.5 cm, 2.5–8.0 cm, 8.1–23.0 cm, >23.0 cm) for all the shrubs and trees whose foliage was intersected by the line transect. We measured the diameter at breast height of the 2 largest stems of each sample tree using a DBH tape, and the height and diameter of canopies with a tape measure. We also visited the colony on 4 other occasions (November 2007, February 2009, April 2009, and July 2015) to conduct other research activities (T.A. Carlo, unpubl. data). We conducted the mapping of the entire *S. sula* colony 7–10 March 2016 using a Garmin® eTrex® GPS unit with a high-sensitivity antenna. We started the survey by finding the first trees with perched birds and/or nests at the westernmost side of the colony (Fig. 1A). After georeferencing a tree with birds or nests, we marked the trunk with flagging tape to prevent double counting. We then counted the number of perched adult and juvenile birds ("juvenile" category included first-year birds in any stage after hatching). For

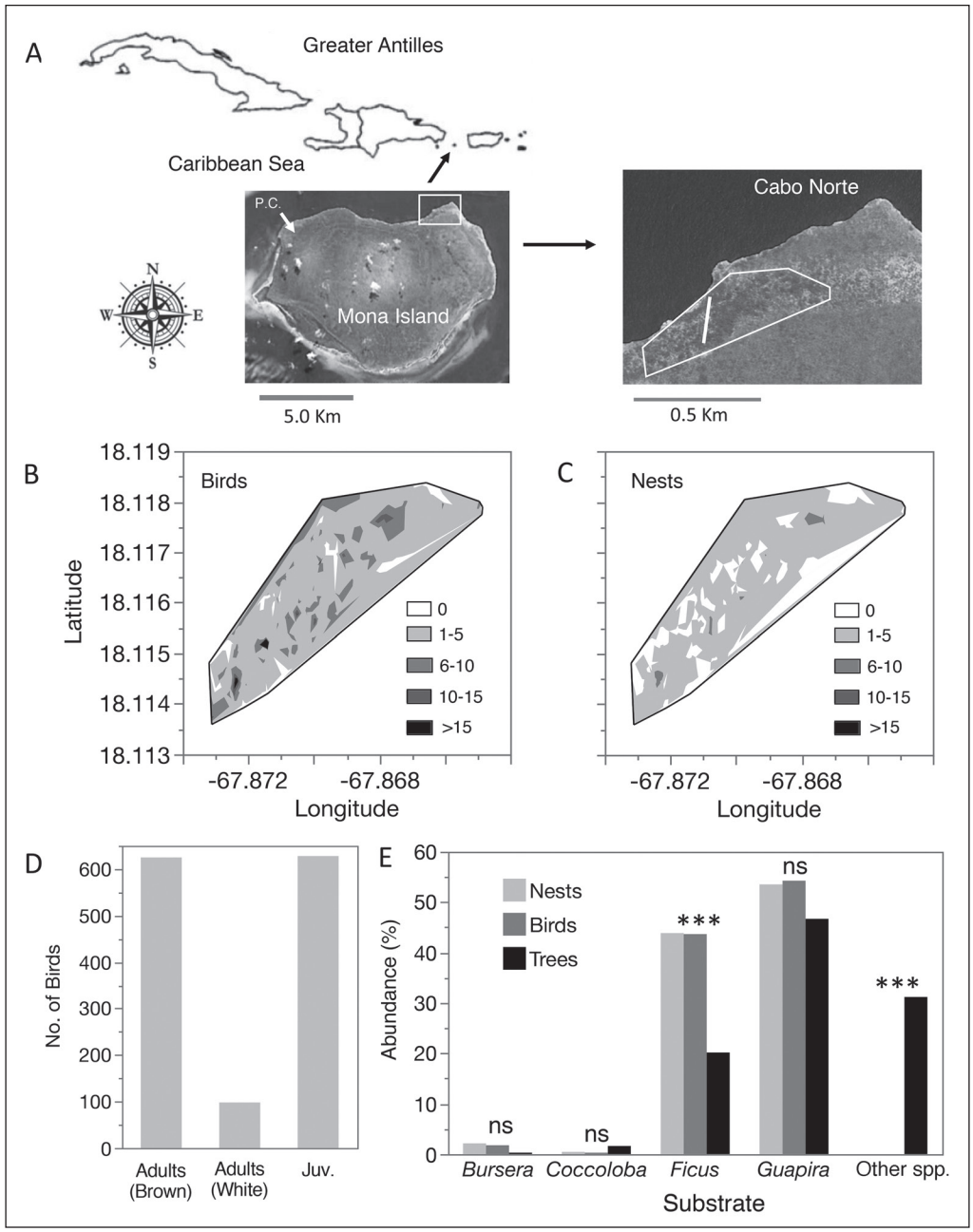

Figure 1. (A) Location of Mona island in the Caribbean and the location of the colony of *Sula sula* in Cabo Norte, including the 240-m linear vegetation transect used to estimate the canopy cover of available tree species in the site. Solid white line shows an area containing nests and birds. P.C. = "Punta Capitán", a site where a historical *S. sula* colony is believed to have existed. Countour maps show the abundance level of (B) perching birds and (C) nests in the colony as extrapolated from the 364 georeferenced locations with birds and nests. (D) Total number of birds by color morph and age class recorded in the March 2016 spatially explicit census of the colony, and (E) the distribution among the available tree species in the site.

adults we also recorded whether they were brown or white color morphs. We systematically walked the entire colony until we could not find additional trees with birds or nests. As is typical in the genus, boobies were very tame and in most instances did not flee as we walked by. During the survey, we observed a flux of birds coming from and going into the sea to forage. The survey was conducted in March to coincide with one of the 2 reproductive peaks previously reported for *S. sula* in the area (Raffaele 1973, Kepler 1978).

To evaluate if *S. sula* had preferences for nesting susbtrates, we used chi-square tests of the observed proportion of nests found in each tree species with the proportion of cover of the tree species in the vegetation transect (Table 1). The expected proportion of nests on trees was the proportion of the cumulative cover of the tree species (excluding shrub species from this calculation because nests were only found on trees). We also compared the density of nests among tree species after controlling for differences in canopy volume among tree species (i.e., dividing the number of nests in a tree by the average canopy volume of the tree species). Last, we used the spatial coordinates of every tree to produce a contour map of the colony

Table 1. Summary of vegetation structural data collected on a 240 m linear transect in the *Sula sula* colony site in Mona island. Averages include the standard error when available.

		Canopy				
Plant species	Form	Cum. cover (%)	Avg. diameter (m)	Avg. height (m)	Number of indiv. (# stems)	Cum. basal stem area (%)
Coccoloba microstachya Willd. (Puckhout)	Tree	1.3	3.6	3.5 ± 1.0	1 (27)	3.3
Corchorus hirtus	Shrub	3.0	1.4 ± 1.1	NA	6	1.5
Croton betulinus Vahl (Beechleaf Croton)	Shrub	0.2	0.5	NA	1	NA
Croton discolor	Shrub	14.3	1.3 ± 0.5	NA	31	NA
Euphorbia petiolaris	Tree	7.4	1.9 ± 0.8	5.4 ± 3.7	11 (60)	6.6
Ficus citrifolia	Tree	16.2	7.9 ± 0.6	4.7 ± 0.3	6 (106)	30.4
Guapira discolor	Tree	37.5	4.5±0.2	3.6 ± 0.1	23 (253)	46.2
Harrisia portoricensis Britton (Higo Chumbo)	Tree	0.3	1.0	1.9 ± 0.7	1 (6)	0.5
Malpighia setosa Spreng. (Bristly Stingingbush)	Tree	1.3	1.3 ± 0.4	2.0	3 (3)	NA
Pilosocereus royenii (L.) Byles & G.D. Rowley (Royen's Tree Cactus)	Tree	1.1	1.7 ± 1.0	0.5 ± 7	2 (2)	0.7
Plumeria alba	Tree	7.0	1.7 ± 0.6	3.7 ± 1.35	12 (44)	9.4
Reynosia uncinata	Tree	7.4	2.3 ± 1.0	0.7 ± 2.7	9 (8)	1.3
Schaefferia frutescens Jacq. (Florida Boxwood)	Tree	0.5	1.2	1.5	1 (1)	0.1
Solanum bahamense L. (= *S. racemosum* Jacq.) (Bahama Nightshade)	Shrub	2.1	1.0 ± 0.5	NA	6	NA
Pentalinon luteum (L.) B.F. Hansen & Wunderlin (= *Urechites lutea* (L.) Britton) (Hammck Viper's-tail)	Shrub	0.3	1.0	NA	1	NA

site with the densities of birds and nests. All analyses were performed in JMP PRO software version 14.0 (SAS Institute Inc., Cary, NC).

Results

In the vegetation transect, we detected 15 plant species, 10 of which were small to large trees and 5 were shrubs (Table 1). The dominant plant in number of stems at breast height, cumulative canopy cover, and number of individuals, was the tree *Guapira discolor* (Spreng.) Little (Nyctaginaceae) (Longleaf Blolly), followed by *Ficus citrifolia* Mill. (Moraceae) (Shortleaf Fig). *Ficus citrifolia* were not quite as abundant as *G. discolor* in numbers but were the tallest and broadest canopy trees of the site (Table 1, Fig. 2). Other small trees such as *Plumeria alba* L. (Apocynaceae) (West Indian Jasmine or White Frangipani), *Euphorbia petiolaris* Sims (Euphorbiaceae) (Manchineel Berry), and *Reynosia uncinata* Urb. (Sloe) were also common but did not contribute much to woody structures above breast height (Table 1). Common shrubs in the site were *Croton discolor* Willd. (Euphorbiaceae) (Lechecillo), *Solanum racemosum* Jacq. (Solanaceae) (Canker Berry), and *Corchorus hirtus* L. (Malvaceae) (Orinoco Jute).

We estimated the area of the colony to have an extent of about 19.6 ha (Fig. 1A). The density within this area varied between 1–5 birds or nests per (Fig. 1B, C), with several high-density patches of 10–15 birds per tree (but sometimes over 50) scattered throughout the colony (Fig. 1B). We counted a total of 1351 perched birds and 652 nests on 364 georeferenced trees (see Supplemental file 1, available online at https:www.eaglehill.us/CANAonline/supple-files/C202-Carlo-s1) that belonged only to 4 species: *G. discolor* (229 trees), *F. citrifolia* (124 trees), *Bursera simaruba* L. (Burseraceae, 6 trees), and *Coccoloba microstachya* Willd. (Polygonaceae, 5 trees). About half of the birds were juveniles (Fig. 1C). The brown morph of *S. sula* was more common with 86.5% of birds (Fig. 1D). Slightly more than half of all *S. sula* birds and nests were recorded on *G. discolor*, while nearly 45% were on *F. citrifolia* (Fig. 1E). Results show that *S. sula* select nesting substrates non-randomly (Fig. 1E). For instance, we did not record any nests or birds perched in some common species such as *Euphorbia petiolaris*, *Reynosia uncinata*, and *Plumeria alba* (included as "other spp." in Fig. 1E), showing that they are significantly avoided (*E. petiolaris*: $\chi^2 = 3.37$, df. = 1, $P < 0.05$; *R. uncinata*: $\chi^2 = 3.40$, df. = 1, $P < 0.05$; *P. alba*: $\chi^2 = 3.07$, df. = 1, $P < 0.05$). In contrast, use of *F. citrifolia* was disproportionally higher than expected by its relative abundance ($\chi^2 = 22.8$, df. = 1, $P < 0.0001$). Use of *G. discolor* was also above its relative abundance (Fig. 1E) but still within the range of expected proportional use ($\chi^2 = 1.7$, df. = 1, $P > 0.05$). Use was also proportional for *B. simaruba* ($\chi^2 = 0.14$, df. = 1, $P > 0.05$) and *C. microstachya* ($\chi^2 = 0.09$, df. = 1, $P > 0.05$) trees (Fig. 1E). It is worth noting that *S. sula* had twice as many nests per tree in *G. discolor* than in *F. citrifolia* trees (Fig. 3A), even though there were more nests per tree in *F. citrifolia* compared to *G. discolor* (Fig. 3B) because *F. citrifolia* trees are about 4 times larger on average than *G. discolor* (Table 1).

Figure 2. *Sula sula* (Red-footed Booby) nest most commonly on (A) *Guapira discolor* in Cabo Norte, Mona. (B) Nests are in part constructed from brances of *G. discolor* (see green leaves) even when nesting in other substrates such as this nest in a *Ficus citrifolia*. The population is dominated by the brown morph, but (C) white adults comprise about 13% of the population. (D) Large *F. citircolia* trees are common in the site, and dozens of birds breed and perch on them. (E) There is a big population of the endangered *Harrisia portoricensis* cactus in the colony, where (F) seedlings and saplings are common. (G) The cliffs (looking west) of Cabo Norte where the colony is located, one of the most remote places in Mona island. Photographs © T.A.Carlo.

Discussion

Our spatially explicit survey revealed that the *S. sula* colony in Cabo Norte encompasses 19.6 ha, which is larger than the island of Monito (15 ha). Our survey of birds and nests shows that the colony is one of the 3 largest of the Caribbean region (Lee and Mackin 2009). All *S. sula* nests we found in Cabo Norte were relatively high on the canopy (2–7 m), which may keep them safe from the browsing perturbations of introduced *Capra hircus* L. (Domestic Goat) and *Sus scrofa* L. (Pig). For nesting, *Sula sula* clearly avoided some abundant (albeit small and feeble) trees such as *P. obtusa* and *E. petiolaris* in favor of the larger tree species with denser foliage and sturdier branches such as *G. discolor*, *F. citrifolia*, *B. simaruba*, and *C. microstachya* (Fig. 1E). In fact, the location of the colony matches quite well a patch of taller arboreal vegetation that contrasts with the lower scrubland around it (Fig. 1A). The use of *G. discolor*, *F. citrifolia*, and *B. simaruba* as nesting substrate has also been reported from Monito and the Cayman Islands (Burton et al. 1999, Kepler 1978), suggesting these trees may be particularly important for *S. sula* in the region.

It is notable that we found more than half of all *S. sula* nests on *G. discolor*, which is the most common tree in the site but rare elsewhere in the island (Brandeis et al. 2012). It is possible that the dense evergreen foliage of *G. discolor* facilitates nest construction and protection (Fig. 2A). We also observed that in Cabo Norte

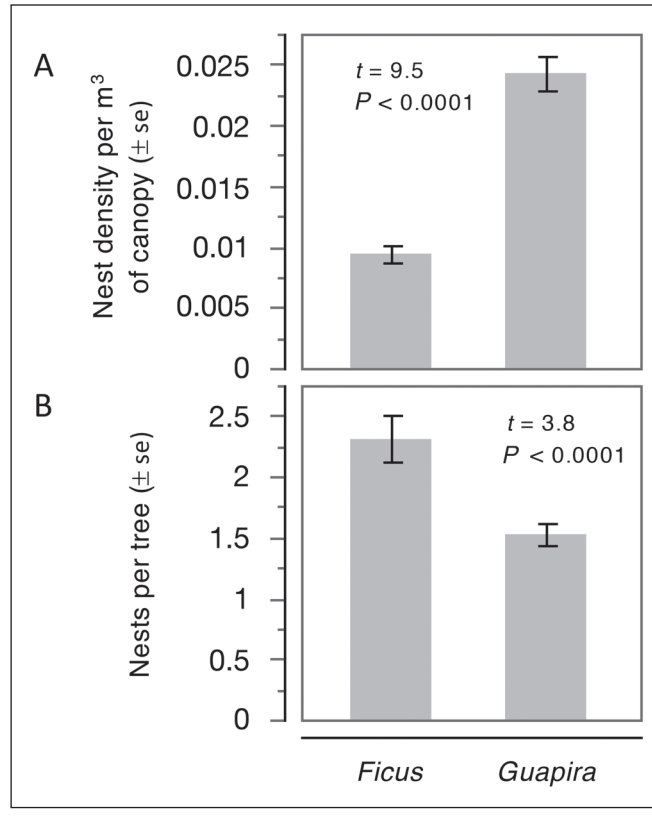

Figure 3. Average number of nests per individual tree in each of the 2 dominant tree species on the site: *Guapira discolor* and *Ficus citrifolia*. Panel A shows the numbers corrected for the average difference in canopy volume of indiviuals trees (*G. discolor* = 63.8 ± 6.2 m^3, *F. citrifolia* = 245.3 ± 50.3 m^3), and B shows the average numbers without correcting for the size differenses of canopies.

S. sula builds and lines their nests with fresh young branches and leaves of *G. discolor*, even when the nest is on another common species like *F. citrifolia* (Fig. 2B). Despite that the number of nests on *G. discolor* was proportional to the relative abundance of *G. discolor* at the scale of the study area, *S. sula* packed nests more densely on *G. discolor* canopies than on the larger and taller canopies of *F. citrifolia* (Table 1, Fig. 3). It is curious that at the scale of the entire island of Mona, *G. discolor* is extremely rare, being only locally common both in Cabo Norte and also at the Punta Capitán area in the northwest point of the island (Fig. 1A). For instance, not a single *G. discolor* was reported from the 26 island-wide grid of forest inventory plots conducted in Mona by the IITF-USDA (Brandeis et al. 2012), nor have we seen individuals of this tree in places other than Cabo Norte and the Punta Capitán area (P.C. in Fig. 1A). Thus, there seems to be a strong association, at least in Mona, between *G. discolor* and *S. sula*, especially if we consider that all other trees on which we found nests (i.e., *F. citrifolia, B. simaruba, C. microstachya*) are common throughout the island (Brandeis et al. 2012). Besides, there are unverified accounts about a former colony of *S. sula* at Punta Capitán that may have disappeared due to hunting and guano extraction operations during the late 19th and early 20th centuries (Miguel A. Nieves, Mona Island's Management Officer, San Juan, PR, USA pers. comm.).

We recorded less than half of the birds reported by Raffaele in 1973. If taken at face value, our numbers would indicate a large population decline since the 1970s. However, it is difficult (if not impossible) to assess the real magnitude of any population change by simply comparing our observations to Raffaele's because of the large methodological differences between the 2 surveys. For instance, Raffaele seems to have used a simple "guesstimate" without a reproducible methodology (Raffaele 1973). It is likely, however, that he was conservative, as most field ornithologists tend to be, in guesstimating 3000 birds in Cabo Norte. Also, Raffaele very likely did not walk through the entire area of the colony like we did. Our 2016 survey was conservative because we only counted birds that were perched on the trees, ignoring the birds that were foraging at sea or flying over, which could be a quite large fraction. For example, in the Shetland Islands (Scottland), *Morus bassana* (= *Sula bassana*) (L.) (Northern Gannett) spends only 39–49% of the time sitting in colonies and the rest foraging and swimming at sea (Garthe et al. 1999). If *S. sula* is like *M. bassana* and more likely to be at sea than at the breeding colony during the day, then we may have easily missed 50–60% of the birds in our census. Correcting for such biases will place the number of *S. sula* in around 3000 birds or more, which will also mean that at the time of Raffaele's visits, the population may have been well over 6000 birds.

Nevertheless, it is important for future studies to move beyond this type of "guesstimate" and start producing reliable population estimates using robust census methods. Our georeferenced map provides a foundation that can be used in combination with fixed-point count stations (or transects) to implement distance-sampling protocols and produce reliable population estimates (Miller et al. 2016, Rivera-Milán et al. 2015). We underscore that *S. sula* has been reported to be strictly diurnal, and unlike other *Sula* species, it always returns to colony sites at

dusk (Weimerskirch et al. 2005). This natural history characteristic could be used to obtain best population estimates if counts are conducted at night instead of during the day when birds are foraging out at sea.

Acknowledgments

We thank Miguel A. (Tony) Nieves, José A. Colón, Oscar Nieves, Aralcy Garrastazú, A. Morales, V. Anadón, and Agnes Farkas for help in conducting fieldwork. Support to A.J. Blinn and T.A. Carlo was provided by the Eberly College of Science undergraduate research program and the Biology Department of Penn State University.

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