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Status of seabirds, habitat, and invasive species in the Cordillera Reef Nature Reserve, Puerto Rico

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Abstract Seabird populations have been decreasing worldwide, and many are threatened or species of special concern. The Cordillera Reef Nature Reserve (CRNR) is located off the northeastern coast of Puerto Rico and is part of the Culebra Important Bird Area. We conducted a seabird population survey in April 2018 consisting of terrestrial point counts and boat surveys on Icacos, Ratones, Lobos, La Blanquilla, and Diablo cays, as well as one unnamed cay. The purpose of the survey was to document and count the various seabird species, describe the available nesting habitat, and document the presence of invasive vertebrates on the different cays of the CRNR. Of the 25 bird species documented throughout the CRNR, five were seabird species. Among these, Red-billed Tropicbirds (*Phaethon aethereus*) and Brown Boobies (*Sula leucogaster*) were the only species nesting within the CRNR, while Magnificent Frigatebirds (*Fregata magnificens*) and Brown Pelicans (*Pelecanus occidentalis*) flew over and roosted on the cays. We also detected a pair of Audubon's Shearwaters (*Puffinus lherminieri*) in Ratones Cay, the first record of this species for the CRNR. Of all the assessed cays, Diablo provided the most suitable nesting habitat for Red-billed Tropicbirds and Brown Boobies. Among the cays, we documented invasive vertebrate species, such as black rats (*Rattus rattus*) and green iguanas (*Iguana iguana*) on Icacos and Ratones, but none on Diablo. This study highlights the significance of the CRNR as an important seabird area, adds new sightings to the available seabird information, documents the occurrence of invasive vertebrates, and reiterates the importance of monitoring seabird colonies for their conservation.

Keywords Audubon's Shearwater, Brown Booby, Caribbean, habitat assessment, invasive species, *Phaethon aethereus*, Puerto Rico, *Puffinus lherminieri*, Red-billed Tropicbird, seabirds, *Sula leucogaster*

Resumen Estado de las aves marinas, el hábitat y las especies invasoras en la Reserva Natural Arrecifes de la Cordillera, Puerto Rico • Las poblaciones de aves marinas han disminuido en todo el mundo y muchas especies están amenazadas o son de especial preocupación. La Reserva Natural Arrecifes de la Cordillera (RNAC) se encuentra en la costa nordeste de Puerto Rico y es parte de Culebra, un Área de Importancia para la Conservación de las Aves. En abril de 2018 se realizó un censo poblacional de aves marinas utilizando puntos de conteo en tierra y censos en bote en los cayos Icacos, Ratones, Lobos, La Blanquilla, Diablo y en un cayo sin nombre. El propósito de este censo fue documentar y cuantificar las especies de aves marinas presentes, describir el hábitat disponible para la nidificación y documentar la presencia de vertebrados invasores en los diferentes cayos de la RNAC. Se documentaron un total de 25 especies de aves en toda la reserva, de las cuales cinco fueron aves marinas. *Phaethon aethereus* y *Sula leucogaster* fueron las únicas especies que se encontraron nidificando, mientras que *Fregata magnificens* y *Pelecanus occidentalis* fueron observadas volando y descansando. Se detectó también la presencia de un par de invidivuos de *Puffinus lherminieri* en cayo Ratones, siendo el primer registro de esta especie para la RNAC. De todos los cayos evaluados, Cayo Diablo presentó el hábitat de nidificación más adecuado para *Phaethon aethereus* y *Sula leucogaster*. Se registraron, además, especies de vertebrados invasores como ratas negras (*Rattus rattus*) e iguanas verdes (*Iguana iguana*) en cayos Icacos y Ratones, pero ninguna en Cayo Diablo. Este estudio destaca la importancia de la RNAC como un área importante para la aves marinas; incluye nuevos avistamientos en la información disponible del grupo, documenta la presencia de vertebrados invasores y reitera la importancia del monitoreo de colonias de aves marinas para su conservación.

Palabras clave aves marinas, Caribe, evaluación de hábitat, *Phaethon aethereus*, Puerto Rico, *Puffinus lherminieri*, *Sula leucogaster*, vertebrados invasores

Résumé Statut des oiseaux marins, des habitats et des espèces envahissantes dans la Reserva Natural Arrecifes de la Cordillera, à Porto Rico • Les populations d'oiseaux marins ont décliné mondialement et beaucoup d'entre elles sont classées comme menacées ou préoccupantes. La Cordillera Reef Nature Reserve (CRNR) est située sur la côte nord-est de Porto Rico et est une Aire Importante pour les Oiseaux et la Biodiversité (*Important Bird and Biodiversity Area*). Un suivi de population d'oiseaux marins a été effectué en avril 2018, constistant à la réalisation de points d'écoute terrestres et de suivis maritimes par bateau sur les cayes d'Icacos, de Ratones, de Lobos, de La Blanquilla,

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de Diablo, et une caye sans nom. L'objectif de cette étude est d'y documenter and compter les différentes espèces d'oiseaux marins, de décrire l'habitat de nidification disponible et de documenter la présence d'espèces de vertébrés invasives dans les différentes cayes de la CRNR. Sur les 25 espèces d'oiseaux recensées dans tout le CRNR, cinq étaient des oiseaux marins. Seuls le Phaéton à bec rouge (*Phaethon aethereus*) et le Fou brun (*Sula leucogaster*) y ont niché alors que le Frégate superbe (*Fregata magnificens*) et le Pélican brun (*Pelecanus occidentalis*) ont été observés en vol et en dortoir dans la réserve. Nous avons aussi détecté la présence d'un couple de Puffin d'Audubon (*Puffinus lherminieri*) sur la caye de Ratones, la première observation de cette espèce pour la CRNR. De toutes les cayes évaluées, Diablo a montré l'habitat de nidification le plus adéquat pour le Phaéton à bec rouge et le Fou brun. La présence d'espèces invasives, comme le Rat noir (*Rattus rattus*) et l'Iguane vert (*Iguana iguana*) a été observée sur Icacos et Ratones, mais aucune n'a été détectée sur Diablo. Cette étude souligne l'importance de la CRNR comme une aire importante pour les oiseaux marins, met à jour les informations disponibles pour ces espèces marines, documente la présence de vertébrés invasifs et rappelle l'importance des suivis de colonies d'oiseaux marins pour leur conservation.

Mots clés Caraïbes, espèces invasives, évaluation de l'habitat, fou brun, oiseaux marins, *Phaethon aethereus*, Phaéton à bec rouge, Porto Rico, Puffin d'Audubon, *Puffinus lherminieri*, *Sula leucogaster*

Monitoring, researching, and understanding threats is necessary to ensure the survival and to improve the status of seabirds worldwide (Croxall *et al.* 2012). Many species are globally threatened and may be vulnerable at their breeding and roosting sites as well as at their marine foraging grounds (Wolf *et al.* 2006). Thus, seabird surveys are essential for evaluating species status and providing conservation recommendations. These surveys are particularly important when baseline information on species counts, their threats, or their habitats is lacking for important seabird areas.

Some of the main threats affecting seabird populations are habitat degradation and invasive species (Croxall *et al.* 2012). Habitat degradation can be caused by the disturbance of coastal zones, which impacts valuable nesting habitats, such as mangroves and shorelines, the preferred nesting habitat for terns, frigatebirds, and pelicans (Zavalanga *et al.* 2009, Croxall *et al.* 2012, Delannoy Juliá 2016). Significant and unregulated recreational activities can also contribute to the degradation of fragile habitat critical to seabirds and their nesting areas. Although seabirds may habituate to visitors, inappropriate intrusions at poorly managed sites may result in adverse effects on breeding individuals (Yorio *et al.* 2001). Furthermore, natural disasters like hurricanes can cause coastal erosion, tree defoliation, and flooding (Schreiber and Burger 2001, Hennicke and Flachsbarth 2009, Huang *et al.* 2017). Hurricanes are one of the most important factors determining the structure of ecosystems on Caribbean islands, and particularly the structure of habitats available for birds (Walker *et al.* 1991).

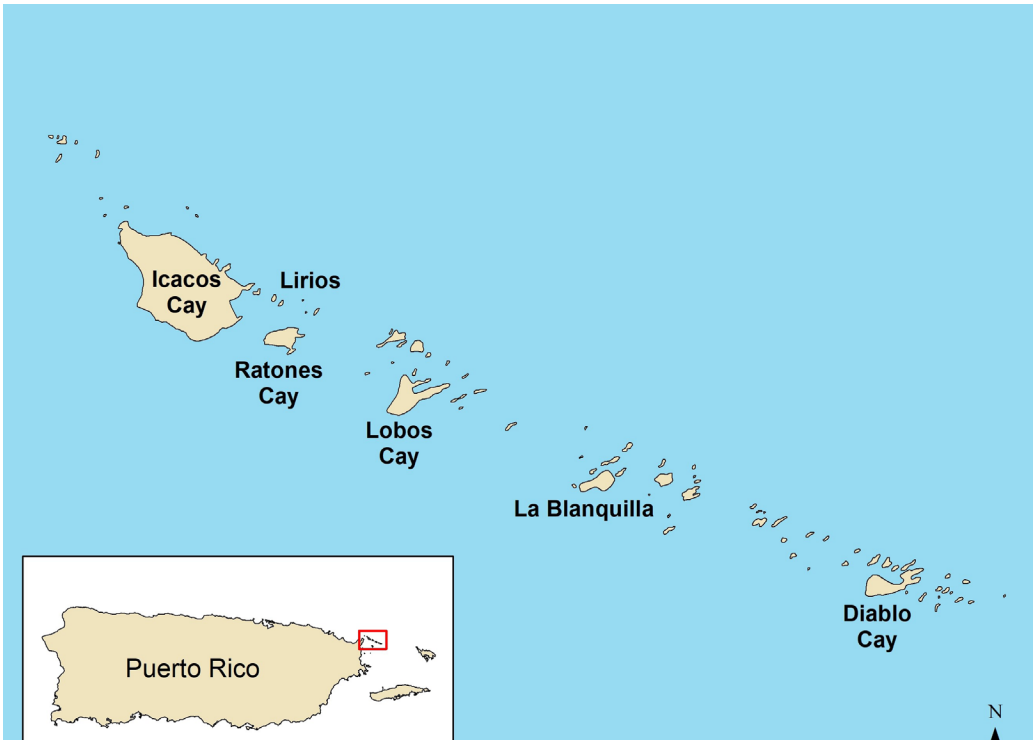

Fig. 1. Study area within the Cordillera Reef Nature Reserve, located to the northeast of mainland Puerto Rico.

Among the most substantial threats to seabird populations are invasive species, which have been identified worldwide as a significant threat to their survival and recovery (Atkinson 1985, Schreiber and Burger 2001). Likewise, invasive species such as rats are known to affect seabird populations (Schreiber and Lee 2000, Schreiber and Burger 2001). Specifically, invasive rodents such as rats (*Rattus rattus*) and house mice (*Mus musculus*) prey on seabird eggs, chicks, and adults, and are likely responsible for numerous seabird extirpations, population declines, and ecosystem changes on islands (Atkinson 1985, Towns *et al.* 2006). There have been several studies in which invasive nest predators, such as rats, have been successfully removed from seabird colonies. After removal, positive changes in the seabird colonies and habitat have been observed and quantified, including higher density of nesting burrows, higher soil nutrient content, and higher plant diversity (Mulder *et al.* 2009, Jones 2010).

The archipelago of Puerto Rico contains at least 15 major sites known to have seabird nesting activity (Delannoy Juliá 2016), some of which are recognized as Important Bird Areas, including the Culebra IBA, which encompasses the Cordillera Reef Nature Reserve (CRNR) (Anadón-Irizarry *et al.* 2009). The CRNR consists of a string of small islands, cays, and coral reefs off the northeastern coast of Puerto Rico (Fig. 1). The reserve is classified as a Critical Wildlife Area by the Puerto Rico Department of Natural and Environmental Resources (DNER) because it supports several seabird breeding colonies, the endangered Virgin Island's tree boa (*Chilabothrus granti*), and the nesting of two endangered sea turtle species (green sea turtle [*Chelonia mydas*] and hawksbill sea turtle [*Eretmochelys imbricata*]) (Ventosa-Febles *et al.* 2005).

Seven seabird species are known to nest within the CRNR: Brown Noddies (*Anous stolidus*), Laughing Gulls (*Leucophaeus atricilla*), Sandwich Terns (*Thalasseus sandvicensis*), Sooty Terns (*Onychoprion fuscatus*), Bridled Terns (*Onychoprion anaethetus*), Red-billed Tropicbirds (*Phaethon aethereus*), and Brown Boobies (*Sula leucogaster*) (Saliva 2009, Castro-Prieto *et al.* 2020). Magnificent Frigatebirds (*Fregata magnificens*) and Brown Pelicans (*Pelecanus occidentalis*) also regularly roost within the CRNR, but neither species has been observed nesting (Saliva 2009). Although this reserve has been classified as an important area for seabirds, few systematic seabird surveys have been conducted in this area. Additionally, there are reports of invasive species, such as rats and green iguanas (*Iguana iguana*; Cardona and Rivera 1988), that could negatively impact seabird species in the CRNR. However, a comprehensive assessment of invasive species has not been conducted within the CRNR.

Given the limited information on seabirds in the CRNR and potential threats they may face, our objectives for this study were to: (1) provide information on the status of seabird species, including assessments of species presence and nesting habitat, and (2) conduct an invasive species assessment focused on, but not limited to, detecting the presence of rats and green iguanas in the CRNR. Documenting the presence of invasive species can be used to inform potential eradication efforts in the future. Our study also provides updated information on seabirds for future comparison during seabird surveys and for implementation of seabird management actions within the CRNR.

Methods

Study Areas

The CRNR is located off the northeastern coast of Puerto Rico (18°22'00N, 65°32'00W), covering nearly 18 nautical miles (~33 km) and an area of 120 ha (Fig. 1). The vegetation in the cays is characteristic of a subtropical dry forest, including trees and shrubs, herbs, grasses, mangroves, and cacti (DNER 2009). Plants present in the cays include *Bursera simaruba*, *Coccoloba uvifera*, *Ficus citrifolia*, *Chrysobalanus icaco*, *Sesuvium portulacastrum*, and *Conocarpus erectus* (DNER 2009). Throughout the cays, seabird habitat includes a mix of crevices along the shores, rocks, and sandy areas and sparse vegetation serving as nesting areas for some species (DNER 2009). We conducted this study between 11–18 April 2018, on the following cays: Icacos (62.72 ha), Ratones (4.40 ha), Lobos (7.68 ha), La Blanquilla (1.61 ha), Diablo (5.66 ha), and an unnamed cay (0.32 ha) (Fig. 1). The unnamed cay surveyed

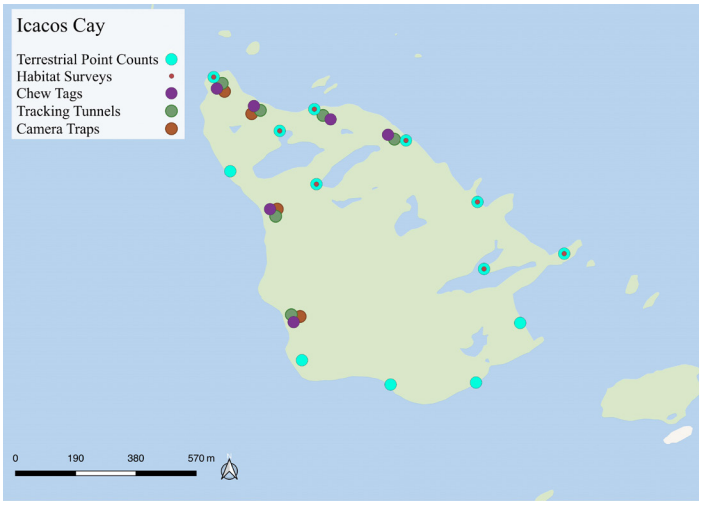

Fig. 2. Location of seabird, habitat, and invasive animal survey points conducted on Icacos Cay, within the Cordillera Reef Nature Reserve, Puerto Rico.

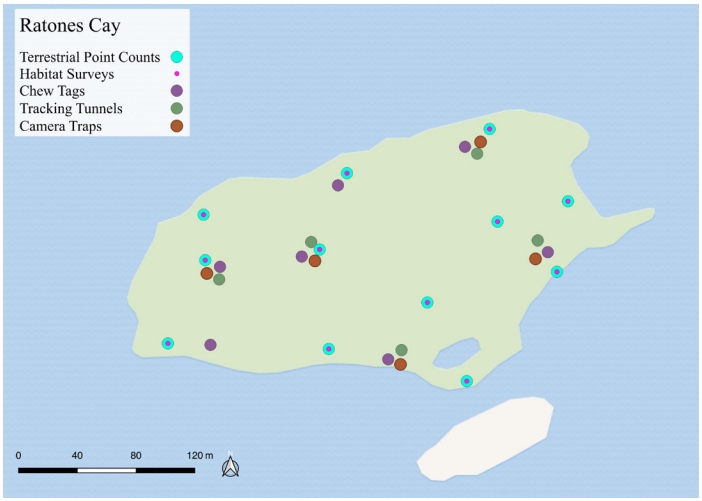

Fig. 3. Location of seabird, habitat, and invasive animal survey points conducted on Ratones Cay, Cordillera Reef Nature Reserve, Puerto Rico.

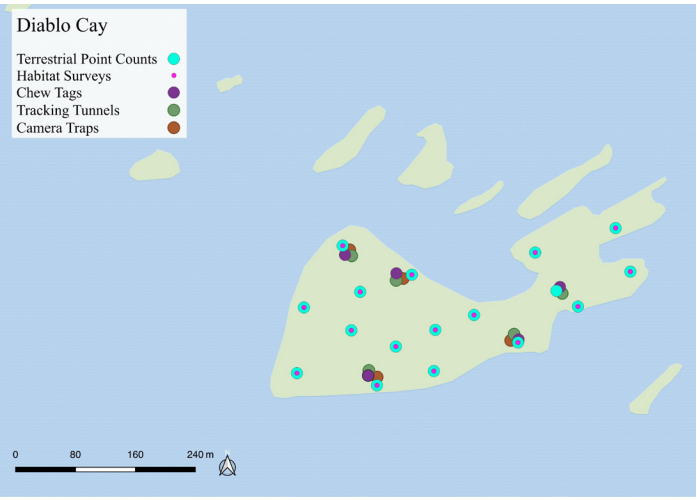

Fig. 4. Location of seabird, habitat, and invasive animal survey points conducted on Diablo Cay, Cordillera Reef Nature Reserve, Puerto Rico.

in this study is located just east of Icacos and north of Ratones cays (Fig. 1). As this cay lacks an official name, we refer to it as "unnamed" throughout this study. Lobos is a private cay that does not belong to the reserve (DNER 2009). Icacos is the only cay assessed in this study with general public access.

Seabird Surveys

We conducted seabird surveys using a combination of terrestrial point counts and boat surveys. These surveys were based on protocols designed by Island Conservation for this assessment (Island Conservation 2018).

Point Counts.— We conducted terrestrial point counts on a set of inland and coastal points randomly selected across each cay. Using these point counts, we identified and counted seabird species and recorded possible nesting activity. In total, two technicians conducted 42 terrestrial point counts, with an effort of 36 person-hours ($\bar{x}$ = 0.86 person-hours per point count), across Icacos (*n* = 14; Fig. 2), Ratones (*n* = 12; Fig. 3), and Diablo (*n* = 16; Fig. 4). Additionally, through opportunistic observations, we recorded all bird species present at each point. At each point we observed a 5-m radius to detect potential burrows or crevices used by some seabirds for nesting. All burrows or crevices larger than 10 cm × 10 cm within the plot were checked for occupancy. A burrow or crevice was considered occupied if there were chicks, eggs, feathers, droppings, odors, eggshells, skeletal remains, or any bird calls present. Using these observations, we tallied burrows and crevices by species of concern, such as Red-billed Tropicbird, White-tailed Tropicbird (*Phaethon lepturus*), and Audubon's Shearwater (*Puffinus lherminieri*). We categorized occupancy using the following criteria: (1) *Breeding*, if eggs or chicks were present; (2) *Well-visited*, if it had signs of having been occupied (e.g., feathers, droppings, eggshells/membranes, skeletal remains, noise, and odor), but no visible egg or chick; or (3) *None*, if there were no signs of it being used or occupied. We documented all evidence of breeding or activity (e.g., chicks, eggs, feathers, droppings, odors, eggshells, skeletal remains, and calls).

Additionally, at each of these terrestrial points, we conducted a surface-nesting search in a circular plot with a 20-m radius for breeding seabirds, such as Brown Noddies, Laughing Gulls, sandwich, sooty and bridled terns, Magnificent Frigatebirds, Brown Boobies, and Brown Pelicans. For this survey, we were interested in ground nests, scrapes, ledge nests, open pits, and nests in trees and shrubs. During these surveys, we counted all active and inactive nests containing eggs or chicks within the circular plot. For each active or inactive nest, we recorded date, time, species, number of adults nesting, adults roosting, and chicks; however, we did not collect data on the quantity of eggs in nests. The entire circular plot was thoroughly searched for nests that may not have been visible from the survey point. When this point occurred within a large seabird colony, we counted from the periphery, taking care to avoid flushing or disturbing birds when possible. It is important to note that although the same point counts were used for both burrow and surface-nesting surveys, the search diameters were different. In complex and dense vegetation, burrow nests are much harder to find and count reliably, thus a smaller area increases the confidence that every burrow has been counted. In contrast, the surface-nesting seabirds were usually relatively visible and easier to count reliably, even with a larger survey plot. Finally, we opportunistically documented all bird species observed while moving between point counts.

Boat Surveys.— The boat surveys consisted of 12 stops over 9 nautical miles (16 km), with an effort of 11 person-hours ($\bar{x}$ = 0.92 person-hours per stop) across Icacos (*n* = 1), Lobos (*n* = 3), La Blanquilla (*n* = 6), and the unnamed cay (*n* = 2). This was done to maximize species detection and survey area, allowing observers to detect seabirds within smaller cays and rocks where landing was not possible. When sea conditions permitted, we circumnavigated the surveyed cays, making short stops as close as possible to the cays and outcrops. We counted each seabird visible from the boat with a minimum of 10 m distance along the shore and 10 m towards the center of the cay. Specifically, we searched for ground nesting seabirds, such as Brown Noddies, Laughing Gulls, Sandwich Terns, Sooty Terns, and Brown Boobies. For each observation, we recorded the number of individual birds by species, time, location, and behaviors on Icacos, Lobos, La Blanquilla, and the unnamed cay, as well as on their adjacent smaller outcrops.

Habitat Assessment

Two technicians conducted 36 habitat assessments with an effort of 36 person-hours ($\bar{x}$ = 1.00 person-hour per point count) across Icacos (*n* = 8; Fig. 2), Ratones (*n* = 12; Fig. 3), and Diablo (*n* = 16; Fig. 4). We utilized the terrestrial point counts to conduct these assessments. At each point, in a 5-m radius, we estimated canopy cover (m), ground cover percentage (e.g., sand, vegetation, rocks, debris, leaf litter, and soil), and vegetation structure percentage (e.g., shrubland, tree, grass, and no vegetation). Because of the dense vegetation on Icacos, which impeded our movements, we only sampled eight locations on the cay.

Invasive Animal Detection Assessment

We used three different detection devices to measure the presence or absence of invasive animal species: chew tags, tracking tunnels, and trail cameras. These devices were randomly placed

near some of the point count locations by two technicians. All three devices were placed on Icacos (Fig. 2), Ratones (Fig. 3), and Diablo (Fig. 4). We recorded and analyzed tracks, markings, and photos two nights after deployment.

Chew Tags.— We used a total of 18 heavy-duty plastic corflute® pieces cut approximately 5.08 cm × 5.08 cm as a primary detection device on Icacos (*n* = 6; Fig. 2), Ratones (*n* = 7; Fig. 3), and Diablo (*n* = 5; Fig. 4). We filled chew tags with a peanut butter attractant and deployed them in randomly selected locations at each study area by nailing each tag to a tree 1–2 m above the ground.

Tracking Tunnels.— We used a total of 16 Commercial Black Trakka® (Black Trakka, Warkworth, New Zeland) tracking tunnels as a second detection device, each randomly placed on Icacos (*n* = 6; Fig. 2), Ratones (*n* = 5; Fig. 3), and Diablo (*n* = 5; Fig. 4). Each unit consisted of a plastic tunnel approximately 10 cm × 10 cm × 50 cm (height × width × length) with an inked footprint card placed inside of the tunnel. We baited each tunnel with a mixture of peanut butter and oats placed in the center of the inked card and attached each card to the plastic tunnel with paper clips. Once prepared, we secured the tracking tunnels to tree trunks about 1–2 m above the ground using plastic tie wraps to reduce interference by lizards, crabs, or invertebrates.

Trail Cameras.— We used a total of 13 Browning Strike Force (Browning, Morgan, UT) and Reconyx PC900 Hyperfire Professional (Reconyx, Holmen, WI) IR motion sensor cameras as a third detection device on Icacos (*n* = 4; Fig. 2), Ratones (*n* = 5; Fig. 3), and Diablo (*n* = 4; Fig. 4). To maximize detection of individuals that possibly missed the other traps, we deployed these cameras at chew tag and tracking tunnel locations. Lastly, we secured the cameras on tree trunks or branches 1–2 m above the ground using plastic tie wraps and faced them towards the chew tags or tracking tunnels.

Results

Seabird Surveys

We documented a total of 25 bird species in our point counts, boat surveys, and opportunistic observations in the CRNR (Appendix 1). The most common seabird species observed were Red-billed Tropicbirds, Brown Boobies, Magnificent Frigatebirds, and Brown Pelicans (Table 1). We also opportunistically heard and observed a pair of Audubon's Shearwaters during one night on Ratones. Among all surveys, we found two nesting seabird species: Red-billed Tropicbirds and Brown Boobies. Throughout the counts, we observed different age classes of Brown Boobies, including chicks, juveniles, and adults. During the terrestrial point counts on Icacos and Ratones, we did not find any active or inactive nests (Table 2). We observed two Brown Boobies roosting on Ratones and Brown Pelicans flying over both Icacos (*n* = 3) and Ratones (*n* = 15). On Diablo, we recorded a total of 15 adult Red-billed Tropicbirds and 112 adult nesting Brown Boobies (Table 2). These coincided with 15 Red-billed Tropicbirds and 120 Brown Boobies active nests as well as one Red-billed Tropicbird and one Brown Booby inactive nest. Additionally, we documented one Red-billed Tropicbird chick and 54 Brown Booby chicks on Diablo (Table 2). During the boat surveys, we recorded Red-billed Tropicbirds flying over Icacos (*n* = 4), Lobos (*n* = 3), La Blanquilla (*n* = 2), and the unnamed cay (*n* = 8), and Brown Bobbies nesting on Lobos (*n* = 342), La Blanquilla (*n* = 291), and the unnamed cay (*n* = 6; Table 1). We also observed adult and juvenile Magnificent Frigatebirds flying over and roosting on Lobos (*n* = 77), La Blanquilla (*n* = 23), and the unnamed cay (*n* = 1; Table 1).

Table 1. Total seabirds observed per survey site during point counts and boat surveys in the CRNR, Puerto Rico.

Survey Site and Species	Type of Survey	Number of Adults	Behavior
Icacos			
Red-billed Tropicbird	Point Count	2	Flyover
	Boat Survey	4	Flyover
Magnificent Frigatebird	Point Count	4	Flyover
Brown Booby	Point Count	6	Flyover
Brown Pelican	Point Count	3	Flyover
Unnamed			
Red-billed Tropicbird	Boat Survey	8	Flyover
Magnificent Frigatebird	Boat Survey	1	Flyover
Brown Booby	Boat Survey	6	Nesting
Ratones			
Red-billed Tropicbird	Point Count	3	Flyover
Magnificent Frigatebird	Point Count	5	Flyover
Brown Booby	Point Count	39	Flyover
Brown Pelican	Point Count	15	Flyover
Lobos			
Red-billed Tropicbird	Boat Survey	3	Flyover
Magnificent Frigatebird	Boat Survey	77	Roosting
Brown Booby	Boat Survey	342	Nesting
La Blanquilla			
Red-billed Tropicbird	Boat Survey	2	Flyover
Magnificent Frigatebird	Boat Survey	23	Roosting
Brown Booby	Boat Survey	291	Nesting
		2	Roosting
Red-billed Tropicbird	Point Count	15	Nesting
		4	Flyover
Magnificent Frigatebird	Point Count	12	Flyover
Brown Booby	Point Count	91	Nesting
		10	Roosting
		17	Flyover

Habitat Assessment

The habitat assessments within our point count plots indicated that the habitat on Icacos, Ratones, and Diablo is primarily composed of sand, rocks, and vegetation (Table 3). Icacos ground cover is composed of an average 38% sand, 20% vegetation, 39% rocks, and 3% soil, with a maximum canopy height of 1.26 m. Icacos has very dense vegetation (shrubland average = 56%) and not many exposed rocks, crevices, and grasses. Ratones ground cover is composed of an average 7% sand, 41% vegetation, 54% rocks, 1% leaf litter, and 2%

Table 2. Seabird nesting recorded per site during terrestrial point counts in the CRNR, Puerto Rico. Adult nesting = any adult seabird found incubating or nest building. Adult roosting = adult seabird perched on a rock or branch. Active nest = all nests found in which an adult was building, incubating, or if eggs or chicks were present in the nest. Inactive nest = no presence of adults, eggs, or chicks in the nest, which includes old nests or unused nests.

Survey Site and Species	Adult Nesting	Adult Roosting	Chicks	Active Nests	Inactive Nests
Icacos					
Red-billed Tropicbird	0	0	0	0	0
Ratones					
Red-billed Tropicbird	0	0	0	0	0
Brown Booby	0	2	0	0	0
Diablo					
Red-billed Tropicbird	15	0	1	15	1
Brown Booby	112	8	54	120	1

Table 3. Percentage ground cover types and vegetation types and mean canopy cover of survey sites on Icacos, Ratones, and Diablo cays in the CRNR, Puerto Rico. Values indicate mean ± standard deviation of the habitat structure in the point count surveys.

	Survey Sites		
	Icacos	Ratones	Diablo
Ground Cover %			
Sand	38 ± 0.52	7 ± 0.18	40 ± 0.43
Vegetation	20 ± 0.26	41 ± 0.34	32 ± 0.33
Rocks	39 ± 0.43	54 ± 0.35	17 ± 0.34
Debris	0 ± 0	0 ± 0	1 ± 0.02
Leaf litter	0 ± 0	1 ± 0.03	10 ± 0.28
Soil	3 ± 0.09	2 ± 0.06	0 ± 0
Vegetation Structure %			
Shrubland	56 ± 0.48	88 ± 0.26	72 ± 0.36
Tree	0 ± 0	0 ± 0	9 ± 0.26
Grass	6 ± 0.11	12 ± 0.26	19 ± 0.32
No Vegetation	38 ± 0.52	0 ± 0	0 ± 0
Canopy Height (m)	1.26 ± 1.74	1.48 ± 0.52	2.13 ± 2.05
Number of Surveys	8	12	16

Table 4. Invasive species detection assessment on Icacos, Ratones, and Diablo cays in the CRNR, Puerto Rico.

Detection Device	Quantity	Number of Trap-nights	Species Detected
Icacos			
Chewing Tags	6	12	black rat
Tracking Tunnels	6	12	black rat, Puerto Rican crested anole, hermit crab
Trail Cameras	4	8	black rat, green iguana
Ratones			
Chewing Tags	7	14	black rat
Tracking Tunnels	5	10	black rat
Trail Cameras	5	10	black rat
Diablo			
Chewing Tags	4	8	None
Tracking Tunnels	5	10	None
Trail Cameras	5	10	None

soil, with a maximum canopy height of 1.48 m. The vegetation structure of Ratones is mainly shrubland (average = 88%), with a large area of rocks with crevices (average = 54%). Diablo ground cover is composed of an average 40% sand, 32% vegetation, 17% rocks, 1% debris, and 10% leaf litter, with a maximum canopy height of 2.13 m (Table 3). The vegetation structure of Diablo is mainly shrubland (average = 72%), with two areas of rocks (average = 17%) and grasses (average = 19%).

Invasive Animal Detections

Invasive species surveys using chew tags, tracking tunnels, and trail cameras found black rats and green iguanas present in all locations except Diablo (Table 4). On Icacos, all tags had chew marks over a total of 12 trap-nights. The inked footprint cards recorded tracks of black rats, Puerto Rican crested anoles (*Anolis cristatellus*), and hermit crabs (*Coenobita clypeatus*) on Icacos over 12 trap-nights. Trail cameras documented the presence of

black rats and green iguanas on Icacos in eight trap-nights. On Ratones, all tags were chewed over a total of 14 trap-nights. Tracking tunnels recorded tracks of black rats over 10 trap-nights and trail cameras recorded black rats in 10 trap-nights. On Ratones, we only detected green iguanas by visual observations. All invasive species documented in this assessment have been reported previously on Icacos and Ratones.

Discussion

The CRNR is an important area for seabirds, but previous systematic surveys in this area are scarce. To our knowledge, the Saliva (2009) survey is the only previous seabird survey conducted on La Blanquilla, La Cucaracha, and an unnamed cay within the CRNR. Saliva (2009) reported five species of seabirds nesting in the CRNR: Brown Noddies, Laughing Gulls, Sandwich Terns, Sooty Terns, and Brown Boobies. Although Saliva (2009) mentions using ground, air, and boat survey methods in general, he did not specify the type of survey he used in the CRNR nor the time of year when he conducted the study, except for the estimates of Brown Booby colonies that were conducted between 2000 and 2004. The estimate of the Brown Booby colony was nearly 600 pairs in 2004 on the unnamed cay, but was not reported for La Blanquilla and La Cucaracha (Saliva 2009). In our study, we estimated a total of 768 pairs of Brown Boobies and counted 730 Brown Booby nests on Lobos, La Blanquilla, Diablo, and the unnamed cay. Saliva (2009) estimated 1,650–1,700 pairs of Brown Boobies nesting in all of Puerto Rico and the adjacent islands.

Additionally, Saliva (2009) only mentions 20–30 pairs of Red-billed Tropicbirds nesting in all of Puerto Rico and the adjacent islands. However, we found 15 Red-billed Tropicbird nests on Diablo in April, just before the peak breeding season. Considering that Red-billed Tropicbird nesting peaks between March and June (Saliva 2009, Castro-Prieto *et al.* 2020), the presence of this number of nests in April suggests that Diablo is an important nesting area for the Red-billed Tropicbird population in Puerto Rico. Saliva (2009) only reported Red-billed Tropicbirds in the Culebra Archipelago and did not report any tropicbirds in the CRNR. This is the first record of this species nesting in the CRNR.

During this study, we detected a pair of Audubon's Shearwaters on Ratones, the first record of this species for the CRNR. The Audubon's Shearwater is a migratory and vulnerable species as recognized by commonwealth law (DNER 2015). This species' nesting areas can be limited and compromised by coastal erosion, damaged by earthquakes, and destroyed by storms (Saliva 2009). Currently, the known breeding sites in Puerto Rico are located in Mona Island and the Culebra Archipelago (Saliva 2009, Castro-Prieto *et al.* 2020). In 2017, the species was rediscovered nesting in Mona Island (CFH unpubl. data), after the last breeding report on that island in 1937 by Smyth (Lee 2000). The population of Audubon's Shearwaters was previously estimated to be 20–25 pairs in the Culebra Archipelago (Saliva 2009) and ~7,500 pairs throughout the Caribbean region (Mackin 2016). Although we did not document nesting in this study, it is possible the observed pair were searching for a place to nest, as we observed them during the nesting season and within proximity to shearwater nesting sites in the Culebra Archipelago. Audubon's Shearwater nesting season begins in early February and ends in July (Saliva 2009, Castro-Prieto *et al.* 2020). Unfortunately, this species has disappeared from several former breeding sites in the Caribbean, mainly due to predation by invasive species such as rats (Lee 2000). Considering this, the species has been classified as Near Threatened (Lee 2000), making Audubon's Shearwater a conservation priority for the region. Population trends for this species are decreasing (Birdlife International 2020); therefore, records such as this one are vital and should be considered when implementing local and regional conservation and management strategies.

Lobos, La Blanquilla, and Diablo had the highest overall nest counts for Brown Boobies, suggesting that these cays have adequate habitat for the species. Brown Boobies generally nest in flat areas with grass in open sun (Schreiber and Norton 2020), while tropicbirds (Bright *et al.* 2014, Orta *et al.* 2020) and shearwaters (Kirwan *et al.* 2020) generally nest on rocks with herbaceous vegetation. Diablo contains two large rocks with grasses that provide space for a large Brown Booby nesting colony. Additionally, these rocks have many crevices and burrows along their edges that are ideal for nesting tropicbirds and shearwaters. Importantly, Diablo is also isolated, has no landing area, and is challenging to access. This cay is the farthest from the main island of Puerto Rico of all the cays in the CRNR, and human visitation is not allowed. There are anecdotal reports of fishermen disembarking on the cay, but illegal visitation seems minimal, and we did not observe any signs of significant human disturbance or human impacts on the habitat.

Similarly, the inaccessibility of La Blanquilla restricts human access and limits anthropogenic disturbance. La Blanquilla has neither a landing area nor a beach, so we could not conduct a complete assessment of this cay. Nonetheless, we were able to get close enough by boat and observed an abundance of rocks and crevices that seabirds were utilizing as nesting and roosting areas.

Lobos Cay has two smaller cays adjacent to it, which are part of the cay but are not connected to it by land. In this cay, we documented high numbers of Brown Boobies nesting. Lobos is private, limited in visitation, and the current owner seems to be aware of the nesting seabird colony, which benefits from a rat-control program implemented by the cay administrators.

Icacos and Ratones had the lowest overall seabird nest counts. Icacos seems to have less potential nesting areas for seabirds due to very dense vegetation that covers most of the cay and fewer exposed rocks and grasses. The average percent ground cover on Icacos is not truly representative of the whole cay because we were only able to sample the north portion of Icacos. Icacos is frequently visited by tourists and fishermen and contains invasive species, unlike Diablo.

We recorded the presence of invasive species, such as black rats and green iguanas, in both Icacos and Ratones. Although a previous black rat eradication program was conducted in Ratones (Tolson *et al.* 2008), it is unknown if the current rat presence is due to an eradication failure or a re-invasion from a different source. Ideally, genetic samples of rats should have been taken during the eradication to enable comparisons with the genetics of the current rat population on Ratones to determine their origin. It is well documented that rats have detrimental impacts on seabird colonies on islands, including predation of eggs, chicks, and adults, and cause both vegetation

and habitat disturbance (Jones *et al.* 2008). Rats are the invasive species with the largest impacts on seabird populations and are responsible for several seabird extirpations and population declines (Atkinson 1985). Rats are successful invaders because of their generalist foraging strategy and high adaptability to novel environments, which allows them to opportunistically prey on seabirds (Fleet 1972, Major *et al.* 2007). The presence of black rats and green iguanas on Ratones is a concern for the survival of the Red-billed Tropicbird population and the possible Audubon's Shearwater breeding pair present on the cay.

Invasive green iguanas are primarily herbivorous and could be affecting the local vegetation (Govender *et al.* 2012). Although one account suggests that green iguanas feed on bird eggs and chicks, the behavior is considered extremely rare (Schwartz and Henderson 1991). Other studies show that green iguanas are strictly herbivores and do not consume eggs or chicks (Lara-López and González-Romero 2002, Arce-Nazario and Carlo 2012). Another study found that green iguanas, egrets, and rats visited bird nests, but only rats were associated with egg predation (Carlo and García-Quijano 2008). Additionally, in situations where the population density of green iguanas is high in coastal cliff habitats, iguanas could cause indirect damage by disturbing nests and damaging eggs or chicks (C.A. Rodríguez Gomez, pers. comm.).

Diablo was the only cay with no invasive species detected, which, coupled with low human activity, results in fewer threats to the ground-nesting seabirds. Diablo is also the farthest cay in the CRNR from the main island of Puerto Rico, which minimizes accidental transport of rats to the cay. Studies have shown that natural stressors such as invasive species (Atkinson 1985, Schreiber and Burger 2001), habitat modification (Saliva 2009), and hurricanes (Schreiber and Burger 2001, Jones *et al.* 2008, Hennicke and Flachsbarth 2009, Wolfaardt *et al.* 2012, PRCCC 2013, Huang *et al.* 2017) can negatively affect seabird populations. Ground-nesting birds, including those that nest in crevices or burrows, such as Brown Boobies, Red-billed Tropicbirds, and Audubon's Shearwaters, tend to recover slowly from natural disturbances because they have only one slow-growing chick per year and, therefore, have a low reproductive output (Schreiber and Lee 2000, Schreiber and Burger 2001, PRCCC 2013).

This study was conducted eight months after Hurricanes Irma and María. Some areas surveyed within the CRNR still had noticeable signs of hurricane impact such as broken trunks, fallen branches, and coastal erosion. We observed considerable coastal erosion in Lobos Cay, which possibly reduced breeding areas for the Brown Boobies and other ground-nesting seabirds. Few seabird surveys have been conducted in the CRNR, and there are no studies documenting the effects of hurricanes on breeding seabird populations in Puerto Rico. Disturbances such as hurricanes cause changes in the physical environment and the availability of resources, affecting bird populations and communities (Wiley and Wunderle 1993, Perdomo-Velázquez *et al.* 2017). More long-term monitoring of seabird populations, both before and after hurricanes, is required to accurately assess the health of breeding seabird populations and the ability of seabird populations to recover after natural disasters.

This study can serve as a reference for future habitat assessments emphasizing seabird nesting. Future studies should focus on conducting surveys and monitoring seabird populations during their breeding season, comparing the amount and suitability of nesting areas, and establishing a long-term seabird monitoring program. Lastly, a well-planned management strategy should be developed within the Reserve Management Plan to specifically mitigate the effects of invasive species, including eradication efforts followed by the implementation of permanent biosecurity measures to prevent re-invasion, such as the establishment of bait stations, motion-sensing cameras, and baited traps. This study highlights the significance of the CRNR as an important seabird area, updates the available seabird information with new sightings, documents invasive species occurrence, and reiterates the need for regular seabird surveys for their conservation and management.

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Title Page Illustration

Brown Booby (*Sula leucogaster*) with chick on Diablos Cay, Cordillera Reef Nature Reserve, Puerto Rico on 11 April 2018. Photograph by Luis A. Ramos-Vázquez.

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Appendix 1. Total counts for each bird species observed per site during fieldwork in the Cordillera Reef Nature Reserve, Puerto Rico.

Scientific Name	Common Name	Quantity
Icacos		
Anas bahamensis	White-cheeked Pintail	6
Rallus crepitans	Clapper Rail	2
Himantopus mexicanus	Black-necked Stilt	2
Haematopus palliatus	American Oystercatcher	2
Charadrius wilsonia	Wilson's Plover	5
Charadrius semipalmatus	Semipalmated Plover	3
Arenaria interpres	Ruddy Turnstone	11
Calidris alba	Sanderling	40
Calidris minutilla	Least Sandpiper	12
Limnodromus griseus	Short-billed Dowitcher	2
Tringa melanoleuca	Greater Yellowlegs	4
Tringa flavipes	Lesser Yellowlegs	12
Phaethon aethereus	Red-billed Tropicbird	2
Fregata magnificens	Magnificent Frigatebird	4
Sula leucogaster	Brown Booby	6
Pelecanus occidentalis	Brown Pelican	3
Tyrannus dominicensis	Gray Kingbird	1
Margarops fuscatus	Pearly-eyed Thrasher	1
Setophaga petechia	Yellow Warbler	3
Coereba flaveola	Bananaquit	3
Unnamed		
Phaethon aethereus	Red-billed Tropicbird	8
Fregata magnificens	Magnificent Frigatebird	1
Sula leucogaster	Brown Booby	6
Ratones		
Crotophaga ani	Smooth-billed Ani	4
Phaethon aethereus	Red-billed Tropicbird	3
Puffinus lherminieri	Audubon's Shearwater	2
Fregata magnificens	Magnificent Frigatebird	4
Sula leucogaster	Brown Booby	6
Pelecanus occidentalis	Brown Pelican	8
Nyctanassa violacea	Yellow-crowned Night-Heron	2
Falco peregrinus	Peregrine Falcon	1
Setophaga petechia	Yellow Warbler	1
La Blanquilla		
Arenaria interpres	Ruddy Turnstone	1
Phaethon aethereus	Red-billed Tropicbird	2
Fregata magnificens	Magnificent Frigatebird	23
Sula leucogaster	Brown Booby	293
Lobos		
Haematopus palliatus	American Oystercatcher	2
Phaethon aethereus	Red-billed Tropicbird	3
Fregata magnificens	Magnificent Frigatebird	77
Sula leucogaster	Brown Booby	342
Diablo		
Zenaida aurita	Zenaida Dove	1
Haematopus palliatus	American Oystercatcher	2
Phaethon aethereus	Red-billed Tropicbird	31
Fregata magnificens	Magnificent Frigatebird	12
Sula leucogaster	Brown Booby	287
Nyctanassa violacea	Yellow-crowned Night-Heron	1
Falco peregrinus	Peregrine Falcon	1