SPECIES RICHNESS AND DENSITY OF SEABIRDS IN ISLA DEL COCO BAYS, COSTA RICA, RELATED TO THE OCCURRENCE OF BREEDING COLONIES

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SUMMARY

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Isla del Coco is one of the five oceanic islands situated on the eastern tropical Pacific Ocean and represents an important nesting and roosting site for seabirds. Despite several factors that can potentially impact its seabird fauna, knowledge about species density and distribution as well as of the size of its breeding colony is limited, currently consisting of bird checklists only. The objective of this study is to compare seabird species richness and density at four bays at Isla del Coco as a function of proximity to breeding colonies. In terms of richness, no pattern was identified. However, we found that the two sites situated near main breeding colonies had higher seabird densities (> 5 individuals ha^{-1}) than the two sites without major breeding colonies. The difference in the densities could be explained by food availability and the presence of nesting habitat. It is possible that the seabirds are foraging near the colonies rather than venturing into long offshore trips.

Key words: eastern tropical Pacific, roosting site, seabirds, foraging ground, oceanic island

INTRODUCTION

Seabirds are an ecologically diverse group that inhabits all seas and oceans (Parsons *et al.* 2008). In a recent global assessment, Croxall *et al.* (2012) reported ~350 seabird species, of which 28% are threatened globally, 5% are critically endangered and 10% are near threatened, thus rendering seabirds among the groups of birds most threatened. Oceanic islands, which provide roosting and breeding sites for many endemic and migrant seabird species, are particularly vulnerable to anthropogenic impacts (Coulson 2001). In addition, waters around these islands are often important feeding grounds for resident and visiting populations, e.g. Hawaii (Harrison *et al.* 1983) and Galápagos (Mills 1998). Therefore, oceanic islands contribute greatly to global biodiversity and require special attention in terms of conservation (Lara-Lara *et al.* 2008).

Isla del Coco is one of the five oceanic islands of the eastern tropical Pacific and has a remarkable biodiversity (Cortés 2012). Its shores are dominated by steep rocky cliffs up to 180 m high and by a dozen rocky islets (Montoya 2008, Lizano 2012) surrounded by a productive ocean (Ballance *et al.* 1997). These topographic characteristics make Isla del Coco an important nesting and roosting site for seabirds (Slud 1967, Stiles & Skutch 1989, Montoya 2008). As a result, it was declared a Costa Rican National Park in 1978, a UNESCO World Heritage site in 1997 and an important international wetland for aquatic birds (Ramsar Convention) in 1998 (Cortés 2008). Nevertheless, its marine avifauna is threatened by invasive species, such as rats and cats, by ocean and noise pollution, and by fishing activities (Gómez 2007, Montoya 2008, Orias 2012). Despite its importance as a rare habitat for seabirds in the eastern tropical Pacific and its vulnerability to impacts, there is limited knowledge about the density and distribution of its species, as well as about the size of its breeding colonies, consisting only of occasional bird lists (reviewed in Montoya 2008). Increasing such knowledge would be useful for conservation efforts. Recent assessments have been limited to species checklists, which tally 38 seabird species on Isla del Coco and nearby waters (Garrigues & Dean 2014, Garrigues *et al.* 2015, Sandoval & Sánchez 2016), classified into three categories: reproductive (n = 8; colonies present), resident non-reproductive (n = 9; regular use of the island or close waters for roosting and feeding during non-breeding period) and vagrant (n = 21; species recorded accidentally on the island or adjacent waters) (Montoya 2008, Garrigues *et al.* 2015, Sandoval & Sánchez 2016).

The objective of this paper is to compare the seabird community, in terms of species richness (number of species) and density (individuals ha^{-1}), at four bays around Isla del Coco, and to relate these parameters to the proximity to major breeding colonies in order to determine the relative importance of different areas of the island. We expected to find a lower density of seabirds in bays without breeding colonies, because seabirds would forage further in the waters nearby (Shealer 2001). On the other hand, we expected that those same bays would have higher species richness because the probability of finding more species is higher in sites not dominated by a few species.

METHODS

Study area

Isla del Coco (5°31′N, 87°02′W), Costa Rica, is the only emerged point of the Coco Cordillera in the eastern tropical Pacific Ocean, and is located ~494 km southwest of Cabo Blanco, Nicoya Península, Costa Rica (Fig. 1) (Cortés 2008). Isla del Coco National Park includes a main island of 24 km^2, several islets and a protected marine area of nearly 2000 km^2 (22 km radius around the island) (Montoya 2007, Lizano 2012). The surrounding waters are affected by the seasonal movement of the Inter-Tropical Convergence Zone (ITCZ; Broenkow 1965, Alfaro 2008), El Niño Southern Oscillation (ENSO; Fiedler & Talley 2006) and seasonal upwelling in the Gulf of Papagayo (Lizano 2008). Those phenomena have considerable impact on the distribution and abundance of most of the marine species of the region. In addition, given that Isla del Coco is located within the ITCZ, the island experiences very high levels of precipitation (Alfaro & Hidalgo 2016). As a consequence, its steep topography is covered by a dense rainforest and by a cloud forest on the west highland side of the island, providing a high diversity of habitats for seabirds and other fauna (Trusty *et al.* 2006, Acosta-Vargas 2016).

Data collection

We conducted the study from 30 September to 3 November 2015. Using a boat (7 m in length), we surveyed four different sites on the northern side of Isla del Coco: Weston Bay, Chatham Bay, Wafer Bay and Punta María (Figure 1). We classified each bay into one of two categories: having major breeding colonies (Weston and Chatham) and not having major breeding colonies (Punta María and Wafer). We carried out a total of 10 surveys: Weston Bay (n = 3), Chatham Bay (n = 3), Wafer Bay (n = 2) and Punta María (n = 2). In Weston and Chatham bays, the third survey was conducted around the headland that supports the main breeding colony. All surveys were replicated three times during the study period. While the vessel was moving, we recorded the number of birds per species over the sea area within the surveying track (~1 km long, parallel to the coastline) and the coastline. To prevent multiple counts of the same individual, we did not record birds flying from behind the surveying track; in addition, during each survey we noted down the maximum number of individuals per species at any given moment. Vessel-following birds were recorded at the first encounter and ignored thereafter. The censuses were done during peak seabird activity—sunrise (05h30–06h30) or sunset

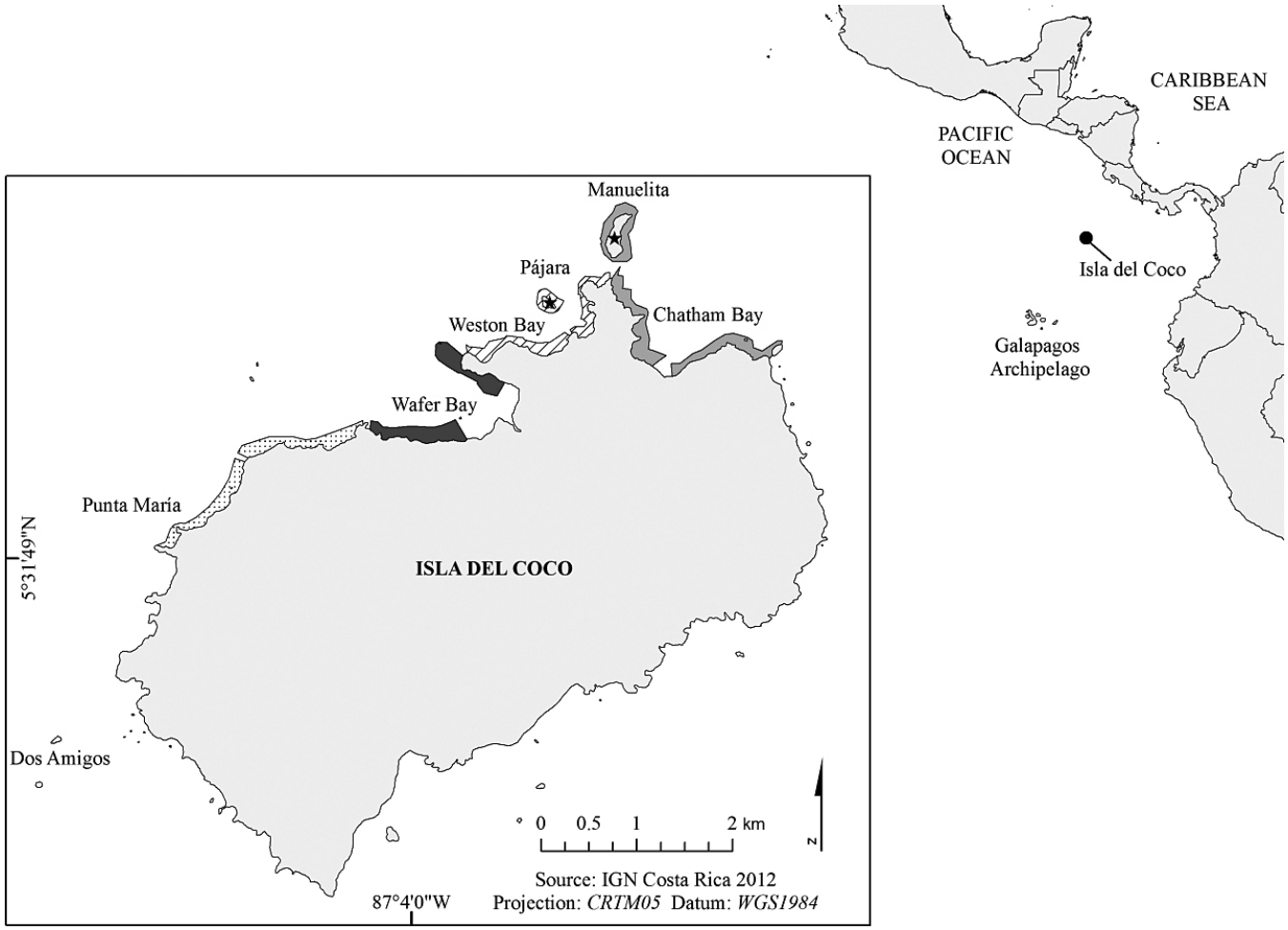

Fig. 1. Location of Isla del Coco in the eastern tropical Pacific. The striped, dotted and colored areas represent the surveyed areas. The stars represent the main seabird breeding colonies.

hours (16h30–17h30). The start and end points of the surveying tracks, as well as several intermediate points, were recorded with a GPS (Garmin GPSMAP 60Cx) to determine distances. Then polygons were drawn, and the surveyed areas were calculated using ArcGIS 10 (Fig. 1).

Statistical analysis

We used JMP 7.0 (SAS) to prepare two generalized linear models (GLM) with a Poisson probability distribution to compare how the density of individuals (response variable) varied among bays (four levels: Chatham, Weston, Punta María and Wafer) and between bays with and without major breeding colonies (two levels). We performed two analyses of similarity to compare bays based on species density (using a Euclidean similarity distance method) and species richness (using the Jaccard similarity index), and paired groups to construct cluster-trees using the software PAST 3.09 (Hammer *et al.* 2001). Using two non-parametric tests, we tested whether species richness varied among bays. First, we used a Kruskal-Wallis (KS) test to compare whether the richness varied regardless of species identity. Second, we carried out a one-way analysis of similarity (ANOSIM) using the Jaccard similarity index, performing 9 999 permutations to determine whether richness varied among bays considering species identity. In both analyses, the response variable was the number of species found in each sample of the surveys, and the independent variables were the bays (four levels).

RESULTS

Of the five families recorded, Sulidae dominated, representing 94.33% of the total abundance (number of individuals), followed by Fregatidae, with 5.13% and by Laridae, with 0.47% (Table 1). Regarding the species, the Red-footed Booby *Sula sula* was the most abundant (72.9% of the individuals registered); the Brown Booby *S. leucogaster* was the second most abundant species (21.4%), while the Great Frigatebird *Fregata minor* was the third (5.1%). Less abundant species were the Western Osprey *Pandion haliaetus*, Audubon's Shearwater *Puffinus lherminieri*, Magnificent Frigatebird *F. magnificens*, Masked Booby *S. dactylatra*, Franklin's Gull *Leucophaeus pipixcan*, Black Noddy *Anous minutus* and White Tern *Gygis alba*, which represented less than 4% of the total relative abundance (Table 1).

The two sites with major breeding colonies had a higher density of individuals than the two sites that did not have major colonies (GLM: $\chi^2 = 69.60$, df = 1, $P < 0.001$; Fig. 2). When bays were analyzed separately, Weston and Chatham showed similar seabird densities, which were higher than the densities at Punta María and Wafer ($\chi^2 = 80.56$, df = 3, $P < 0.001$; Fig. 2). Based on species abundance (number of individual per species), we found that the two sites that had the major breeding colonies were very similar and were grouped together in the Euclidean similarity analysis. They differed from the two sites that did not have major breeding colonies, which were grouped apart in the analysis (Fig. 3A). Finally, when considering species richness (presence only), Wafer and Weston bays showed the higher similarity, followed by Punta María. Chatham was the most diverse bay in terms of species richness (Fig. 3B). However, species richness was similar among bays (KS = 2.98, $P = 0.35$; ANOSIM: R = 0.20, $P = 0.14$).

DISCUSSION

The seabird assemblage found in the vicinity of Isla del Coco is typical of the eastern tropical Pacific, dominated by Red-footed Boobies and associated Magnificent and Great Frigatebirds (Smith & Hyrenbach 2003). The Masked Booby was recorded only in Punta María, the sampling area nearest the islet known as Dos Amigos Grande, the only reported breeding colony of this species in Isla del Coco (Montoya 2008). The presence of Masked Boobies and Western Ospreys in Punta María explain the dissimilarity—in terms of richness—of this location compared to Wafer and Weston bays (Fig. 3B). In Chatham, species richness was much higher than in the other three sites. Consequently, the similarity analysis produced a different group (Fig. 3B). As a result, contrary to what we expected, we did not observe any pattern in species richness among the four locations. Nine of the 10 species recorded were present in Chatham and three occurred only in this bay (Audubon's Shearwater, Magnificent Frigatebird and Franklin's Gull). This could be explained by the topography of the site: within the surveyed area, the coastline shows a higher diversity of habitats such as beaches, cliffs, plant-covered slopes and tropical forests.

TABLE 1
List of species and their relative abundance during observations of seabirds at Isla del Coco, in the eastern tropical Pacific

Order	Family	Scientific name	English common name	% Birds	Population trend
Accipitriformes	Pandionidae	*Pandion haliaetus*	Western Osprey	0.05	Increasing
Procellariiformes	Procellariidae	*Puffinus lherminieri*	Audubon's Shearwater	0.02	Decreasing
Pelecaniformes	Fregatidae	*Fregata magnificens*	Magnificent Frigatebird	0.02	Increasing
		Fregata minor	Great Frigatebird	5.11	Decreasing
	Sulidae	*Sula dactylatra*	Masked Booby	0.05	Decreasing
		Sula leucogaster	Brown Booby	21.37	Decreasing
		Sula sula	Red-footed Booby	72.91	Decreasing
Charadriiformes	Laridae	*Leucophaeus pipixcan*	Franklin's Gull	0.02	Increasing
		Anous minutus	Black Noddy	0.34	Stable
		Gygis alba	White Tern	0.11	Stable

The distinct types of vegetation of these environments could provide a greater variety of niches to support a higher number of species (Hamer *et al.* 2001).

The present study validated our hypothesis that the bays with the major breeding colonies would exhibit higher seabird density. The bays of Chatham and Weston contained densities between 5.26 individuals ha^{-1} and 6.68 individuals ha^{-1}, while in Punta María and Wafer the density was lower, down to 3 individuals ha^{-1} (Fig. 2B). On the one hand, this difference could be explained by the resources available. Isla del Coco supports a very high fish biomass, one of the highest recorded in the tropics (Friedlander *et al.* 2012, Alvarado *et al.* 2016). This high availability of food in nearshore waters could sustain the large seabird densities observed in the four sites studied. In particular, the fish biomass at Chatham and Weston is higher than in Wafer and Punta María (J.J. Alvarado, unpublished data). Furthermore, Chatham's high fish biomass is associated with the presence of Manuelita headland inside the bay, which has one of the highest fish biomass and density of Isla del Coco. Fish represents an important component of the seabird diet (Shealer 2001). Diet and foraging behavior of seabirds usually varies from site to site (Mellink *et al.* 2011) and according to oceanographic conditions, which influence the occurrence of preys (e.g. changes in fish-depth distribution during El Niño; Ballance *et al.* 2006, Mellink *et al.* 2011). Therefore, in order to further our understanding of the ecological role of seabirds at Isla del Coco, additional surveys, including samplings in deeper waters, are needed to assess the foraging grounds, foraging behaviors and diet of seabirds during breeding and non-breeding seasons as well as during El Niño and La Niña conditions.

On the other hand, the higher densities found in bays that have major breeding colonies can be explained by the fact that they represent nesting habitats (Montoya 2008). The Red-footed and Brown Boobies are probably foraging in waters surrounding the breeding colony, taking local foraging trips rather than flying to distant deeper waters (Shealer 2001, Sommerfeld *et al.* 2015). It has been hypothesized that the foraging behavior of seabirds breeding in large aggregations may deplete food supplies around the colony (Storer 1952, Ashmole 1963, Oppel *et al.* 2015). However, during the study we did not see any active nests. We could only observe that most of the seabirds were building nests, carrying branches from the mainland to the headland. Therefore, the resources available at the bay are probably sufficient for adults feeding themselves only, not their chicks.

Isla del Coco has been recognized as an important seabird breeding site (Slud 1967, Montoya 2008), and its surrounding

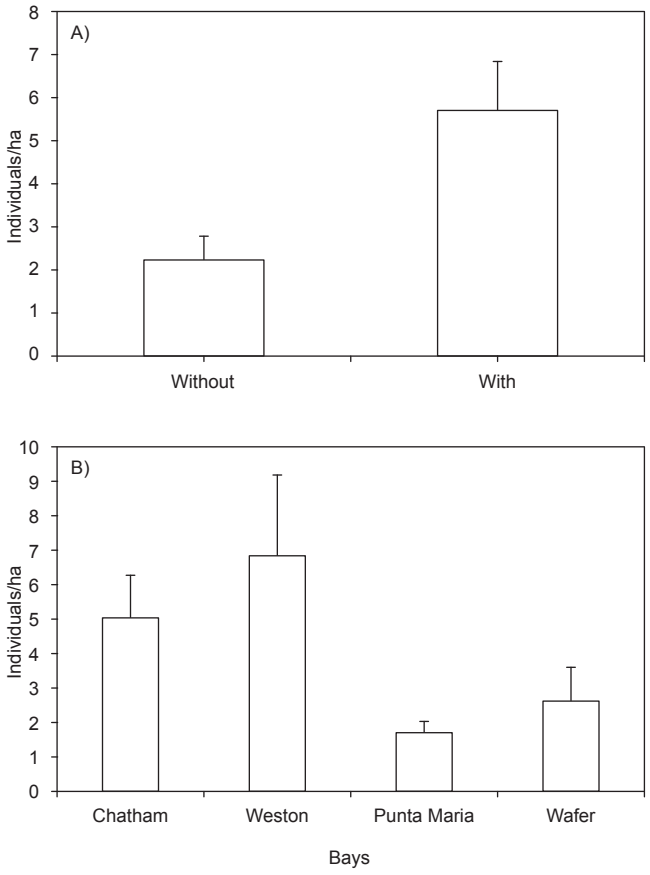

Fig. 2. Average density (whiskers represent standard error) of seabird species in (A) bays with and without headlands, and (B) each bay separately, at Isla del Coco, Costa Rica.

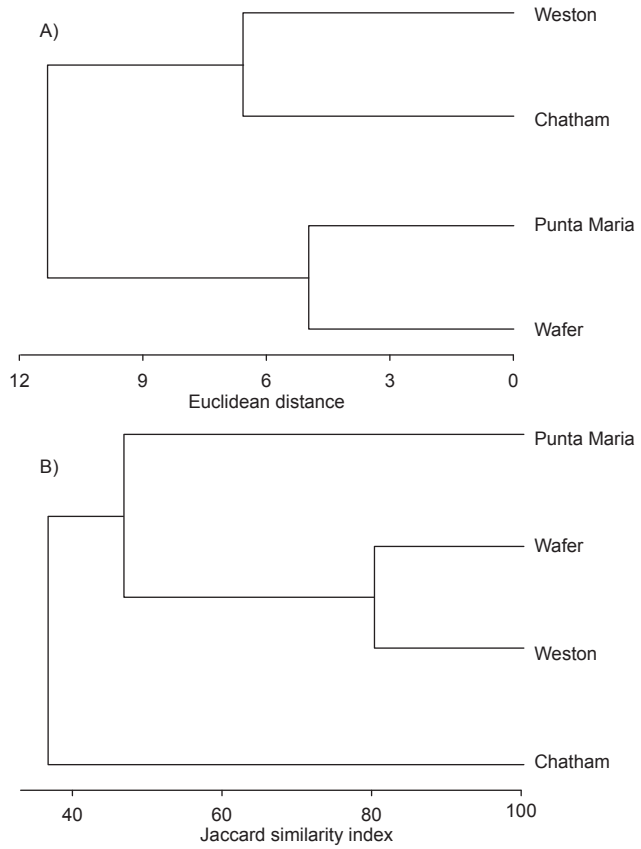

Fig. 3. Similarities between four bays at Isla del Coco, Costa Rica, based on (A) density of each seabird species (where lower values mean higher similarity), and (B) species richness in each bay (where values closer to 100 mean greater similarity).

waters are used as foraging grounds (present study). Moreover, the populations of most of the surveyed species are decreasing at a global level (Table 1). Consequently, to preserve its seabird populations, which are a key part of the ecosystem, it is important to continue to implement conservation measures at Isla del Coco, as controlling invasive alien species and illegal fisheries.

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