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Foraging movements of Abbott's Boobies during early chick-rearing and implications for a marine Important Bird Area in Christmas Island waters

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Abstract. Abbott's Booby *Papasula abbotti* is a relictual species now endemic to Christmas Island, Indian Ocean, and one of the world's most threatened seabird species. While actual and potential threats to the species on Christmas Island are being managed, no conservation measures concerning the marine habitat of the birds, such as the delineation of marine Important Bird Areas (IBA), are currently being implemented as knowledge on the foraging areas of Abbott's Booby has been scarce. Using GPS-loggers to track Abbott's Boobies during their foraging trips, the present study provides detailed information about the foraging movements of the species during early chick-rearing. The birds foraged relatively close to the island with a median range of 56.8 km (range = 3.6–56.7 km). They chose trip directions according to their nesting sites in the north and south of the island and foraged preferably in north-westerly and south-easterly directions of Christmas Island, respectively. Applying the protocol of BirdLife International, the tracking data were used to identify a potential IBA for Abbott's Booby during early chick-rearing. According to the small foraging distances and the limited range of trip bearings, the delimited IBA was relatively small, encompassing only a narrow corridor of about 4,500 km^2 to the north-west and south-east of Christmas Island. Given the small size and low economic relevance of this area, the delineation of this IBA appears feasible and would be an important first step to protect Abbott's Boobies at sea as well as the species' foraging habitat.

Key words. Abbott's Booby, *Papasula abbotti*, foraging movements, Important Bird Area, conservation, Christmas Island

INTRODUCTION

Abbott's Booby *Papasula abbotti* is one of the most threatened seabirds in the world. It is a relictual species now endemic to Christmas Island (hereafter CI), a small oceanic island in the tropical eastern Indian Ocean. The species once was abundant in the western Indian Ocean where it was extirpated due to harvest and habitat destruction around the 1920s (Bourne, 1976; Nelson, 1978; potentially a subspecies existed in the western Pacific, Steadman et al., 1988). Its remaining population on CI is small, about 5000–8000 individuals, and assumed to be declining but information on population trend as well as reasons for the potential decline are scarce (Garnett et al., 2011). At present, Abbott's Booby is listed as Endangered by IUCN criteria (IUCN, 2013) and under the *Environment Protection and Biodiversity Conservation (EPBC) Act* 1999.

In the past, a major impact on Abbott's Booby on CI has been the destruction of its breeding habitat by mining. The birds nest in the canopy of primary rainforest, which up until 1985 was being progressively cleared for phosphate mining (Nelson, 1978; Reville et al., 1990). In the 1980s, Christmas Island National Park was created to protect the species by prohibiting further mining within the park's boundaries. Today, the park encompasses most breeding areas, and a rainforest rehabilitation programme was initiated to reduce wind turbulence caused by previous forest clearing potentially affecting breeding birds negatively (Director of National Parks, 2002). In addition, a programme to control the Yellow Crazy Ant (*Anoplolepis gracilipes*), an invasive species thought to affect the reproductive success of Abbott's Booby (Garnett & Crowley, 2000), was commenced in 2000 (Director of National Parks, 2002).

While those conservation measures target threats on CI, no protection measurements are currently implemented or developed concerning the marine habitat of the species. However, the booby is thought to be potentially threatened in its marine habitat by disruption of its feeding ecology caused by heavy tuna fishing in the Indian Ocean over the last 50 years and by entanglement in fishing gear (Garnett et al., 2011). In addition, it has been found that Abbott's Boobies may be exposed to off island harvest (Hennicke, 2012).

Marine Important Bird Areas (hereafter IBA) have been shown successfully to be management tools that can

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contribute positively to the protection of threatened seabirds (e.g., Fishpool & Evans, 2001; BirdLife International, 2010). As such, they might also be useful conservation measures for Abbott's Booby and its foraging habitat. However, knowledge on the habitat utilisation of Abbott's Booby has been scarce and insufficient for identifying marine areas relevant to the species (DEH, 2004; Garnett et al., 2011). The only recorded foraging area of Abbott's Booby is off the southern coast of Java (Becking, 1976), but it is assumed that the birds use a much larger marine foraging area (e.g., Hirons et al., 1976; Nelson, 1978; van Balen, 1996; DEH, 2004). Thus, improved knowledge on where the birds forage is crucial to protect Abbott's Boobies at sea as well as their foraging habitat.

This study aimed to collect detailed data on foraging movements of Abbott's Boobies during early chick-rearing, a breeding stage generally considered to being crucial to the reproductive success of seabirds (Schreiber & Burger, 2002), and to use this information to identify marine areas which are important to the species during this stage and might therefore qualify as IBA.

MATERIAL AND METHODS

Study animals and field sites. The study was carried out on Christmas Island, Indian Ocean (10°25'S, 105°40'E) from 2004–2010. Every year, fieldwork took place from late August till early October, when Abbott's Boobies rear young chicks. Study nests of Abbott's Boobies were located in the canopy of the primary rainforest by systematic ground searches in two areas of CI about 5 km apart where nest densities were high: in the north-west of the island (North-West-Point, NWP; 2004–2010) and in the south-west (Eastern Circuit Track, ECT; 2005–2010). Study nests were at heights of 12–40 m and were accessed by tree-climbing: A thin line was shot into the top of the nest tree with a catapult and used to pull up a 10.5 mm static climbing rope. This rope was then used to climb the tree with jumars. From searching a nest to retrieving a logger took on average about 10 days per deployment, thus allowing only relatively small numbers of deployments during each breeding season. In addition to tree climbing, in 2004 nests alongside roads were accessed using a 45 m mobile crane fitted with a two-person cage that was carefully directed by a crane rigger towards nests.

Birds were caught on their nest by hand or using a ca. 1 m noose pole. Upon capture, birds were brought down to the ground in a bag for logger attachment/retrieval. Birds were marked with colour paint on the lower abdomen for identification from the ground.

After handling, birds were taken back up into the tree in a bag and released on their nest where they immediately resumed breeding duties. Logger attachment/removal took approx. 10–15 min; total time from catch to release was about 30 min.

All study birds had chicks between 1–8 weeks of age which were guarded by one adult at all times.

Foraging movements. In all years, birds were equipped with different types of GPS loggers to record foraging movements. Between years, logger models varied slightly. The logger mass was never higher than 5% of the adult mass, the limit for which loggers may have adverse effects on bird behaviour (Phillips et al., 2003).

GPS loggers were protected from water by an epoxy housing or by sealing them into a condom and a plastic bag. Devices were attached to tail or back feathers using Tesa Tape (Beiersdorf, Germany). In total, 54 birds (49 different individuals as some birds were equipped in several years) were equipped with GPS loggers from 2004–2010 and data on 141 foraging trips were recorded. This yielded 1313.4 h of data on foraging movements with 128,619 location fixes.

The GPS loggers recorded the positions of birds with a precision of ±5 m. The sampling interval was 10 s or 3 min for all but three individuals in 2004 and three in 2010 for which the sampling interval was 15 min.

Before, during and after logger deployment, nests were monitored regularly from the ground to check for absence and presence of study birds and their partners on the nests.

Foraging range was defined as the maximum distance of a bird from Christmas Island during a foraging trip and was calculated using spherical trigonometry (arc distance formula, Robinson et al., 1978).

The bearing of a trip was defined as the direction (angle) from the nest to the furthest location from nest. For easier visualisation, angles were categorised in groups of 45° (N, NE, E, SE, etc., see Fig. 2), while analyses were performed with actual values (angular degrees/radians).

Wind direction. Data on wind direction was obtained from the Australian Bureau of Meteorology collected at the weather station at the CI airport at 0900 hours every day. Median values for September were calculated for every study year.

Statistical analyses. Statistical analyses were performed with SPSS 11.5 (SPSS Inc., Chicago, USA), and R Studio (Version 0.94.92, RStudio, Inc) using the R version 2.13.0 (The R Foundation, R Development Core Team, 2010).

For the analysis of angular data circular statistics (R package "circular") were used (Batschelet, 1981; Zar, 2010). Bearings of foraging trips were examined on the trip level as average bearings for birds do not necessarily reflect the actual orientation of the animals' trips (cf. Zar, 2010 and Zavalaga et al., 2008).

A 95% fixed Kernel Density Estimation was used to determine the total foraging area. Kernel Density Estimations were conducted with the R package "adehabitatHR" using positional long/lat data transformed in UTM (Zone 48) and *ad hoc* h-values for kernel smoothing (Seaman & Powell, 1996; Wood et al., 2000). Trajectories of the 15 min sampling intervals were interpolated to locations every 3 min assuming

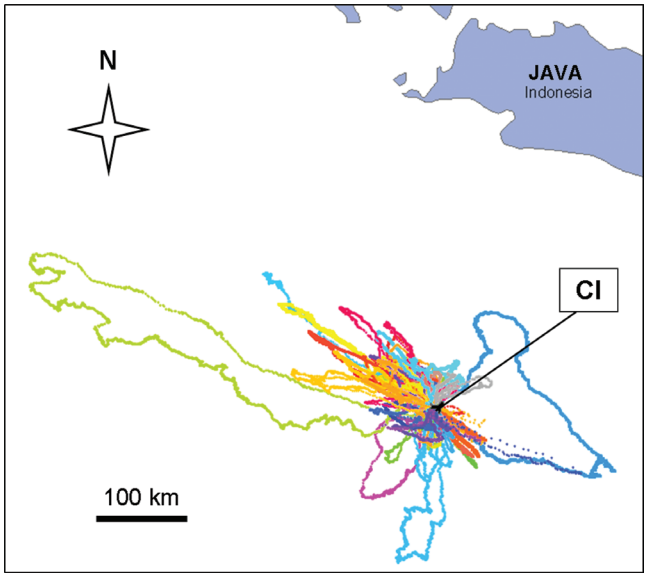

Fig. 1. Foraging movements of Abbott's Boobies during early chick-rearing recorded with GPS-loggers from 2004–2010. Each colour represents a different individual.

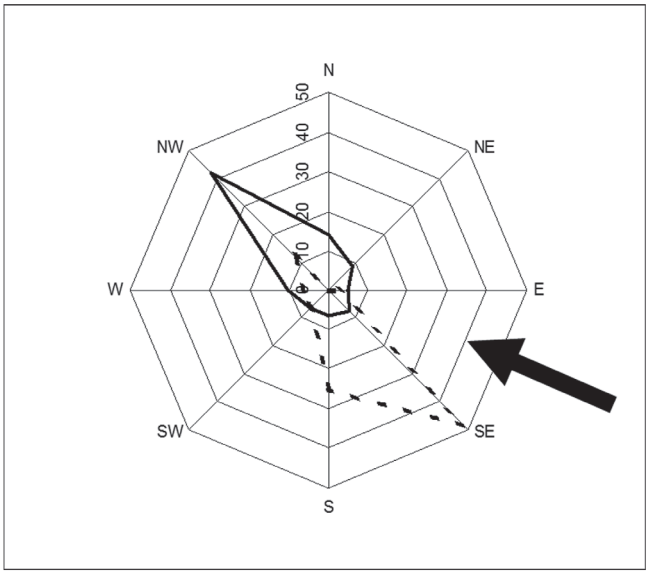

Fig. 2. Directions of foraging trips of Abbott's Boobies from the two sub-colonies (ECT = dotted line; NWP = solid line) during early chick-rearing from 2004–2010. The arrow indicates the main wind direction during the study period, numbers show relative frequencies (%).

a constant flight speed and direct flight path between fixes while every 18th location fix was taken into account from loggers with 10 s sampling intervals, i.e., all trips were divided into 3 min intervals to make them comparable.

For all statistical tests, the threshold for significance was $p < 0.05$ and all tests were 2-tailed.

Marine Important Bird Area. To identify important marine areas within the foraging habitat of Abbott's Boobies, the protocol of the marine IBA toolkit from BirdLife International was used (BirdLife International, 2010, http://www.BirdLife.org/datazone/info/marmethods). This method was specifically developed as a standardised, scientifically sound and widely applicable protocol to delimit marine IBA for seabirds.

The protocol uses First-Passage-Time analysis (Pinaud & Weimerskirch, 2005) to determine the scale at which each tracked individual is interacting with the environment (i.e., foraging, travelling). Kernel Density Estimation (see above) is then applied to each trip to determine 'core use areas' using the scale determined by First-Passage-Time analysis. Final IBA boundaries are determined by merging all overlapping 'core use areas' so that the resultant area is the largest site necessary to adequately cover the foraging movements of the individual birds triggering the area. As some individuals contributed several trips to the database, variance tests comparing the site fidelity to specific marine areas within and between individuals were used to avoid pseudo-replication, and bootstrapping was used to assure representativeness of the available data on individual birds for the population.

RESULTS

Abbott's Boobies used a large area around CI as foraging habitat (Fig. 1), covering in total 108,503 km² (95% Kernel Estimation of all location fixes).

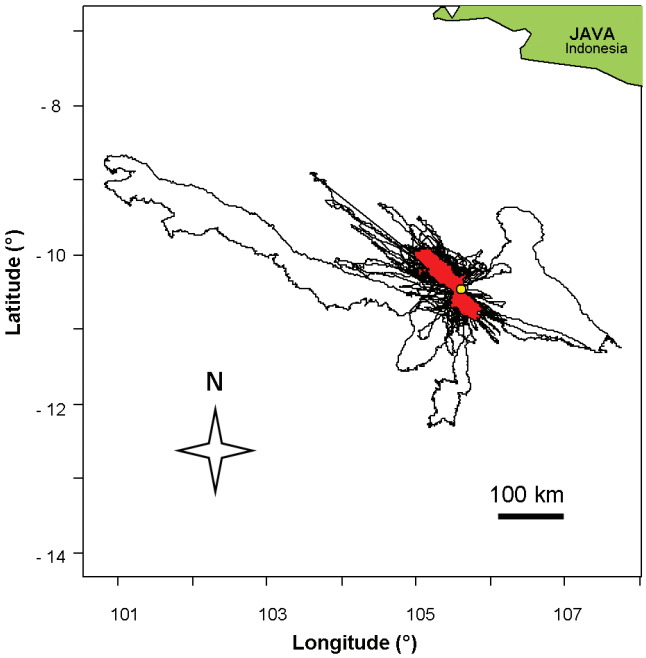

Fig. 3. Marine Important Bird Area (red) for Abbott's Boobies during early chick-rearing according to the methodology of BirdLife International. Paths of foraging trips are shown as black lines (see also Fig. 1), CI is depicted as yellow dot.

The median foraging range (= max. distances from nest) was 56.8 km, ranging from 3.6–556.7 km (n = 127).

The bearings of the foraging trips were not distributed uniformly but trips were mainly directed towards north-westerly and south-easterly directions. There were significant differences in trip bearings between NWP and ECT colonies (Watson's U^2 test, $U^2 = 1.049$, $p < 0.001$). Birds breeding in the north-west of the island (NWP) headed mainly for north-westerly directions (41.8% of trips; median bearing of

all trips= 315.7°), whereas birds breeding on the south-west of the island (ECT) preferred south-easterly directions (47.9% of trips; median bearing of all trips = 158.4°) (Watson's one-sample U^2 tests against Uniform distribution, $U^2 = 1.078$, $n = 79$ and $U^2 = 1.084$, $n = 48$ respectively, $p < 0.01$ for both colonies; Fig. 2).

Over the study years, wind direction was relatively constant with a mean of 112.5° (±13.0) (Fig. 2).

The area that was identified as marine Important Bird Area was a corridor of about 30 km width and 160 km length, encompassing about 4,500 km² and being orientated in a south-east–north-west axis with CI in its middle (Fig. 3).

DISCUSSION

The present study provides detailed information about the foraging movements of the Endangered Abbott's Boobies during early chick-rearing.

Although the total foraging area of Abbott's Booby was large, covering over 100,000 km², and the furthest foraging location was over 550 km away from the island, the birds foraged on average relatively close to CI, with an average foraging range of less than 60 km. In addition, the birds did not fly to the Java Trench up-welling area or the Banda Sea where they have been observed before (Becking, 1976; Hirons et al., 1976; Nelson, 1978; van Balen, 1996). Thus, as Christmas Island has neither a shelf nor a considerable sublittoral zone but the seafloor drops off to about 2000 m close to the coastline (Gray, 1995), the Abbott's Boobies' foraging habitat during early chick-rearing represents a truly oceanic tropical environment. Those waters are generally considered to have a relatively low, unpredictable abundance but, at the same time, homogenous distribution of prey (Longhurst & Pauly, 1987). Apparently, prey availability close to CI was sufficient to find enough food to allow the adults sustaining themselves as well as their chicks and it was not necessary for them to forage in highly productive areas such as the Java Trench up-welling.

Abbott's Boobies headed out to marine areas in all directions off Christmas Island but the majority of trips was made to north-westerly and south-easterly directions. Those two directional preferences arose from birds of the two colonies heading out to different directions and having a narrow range of trip directions. Although study colonies were only about 5 km apart, animals nesting in the north foraged mainly in north-westerly directions whereas birds nesting in the south preferred to head out towards south-easterly directions. Consequently, the birds utilised different foraging areas. This spatial segregation between the colonies might reduce intra-specific competition and should therefore enhance foraging success under the oligotroph marine conditions of their marine habitat.

Potentially, the relatively narrow range of trip bearings of both colonies and their foraging zones lying in opposite directions of CI can be linked to wind. Seabirds often use wind to reduce energy expenditure during flight (Furness & Bryant, 1996; Spear & Ainley, 1997; Weimerskirch et al., 2000) and Abbott's Boobies having evolved a wing morphology for a dynamic soaring/gliding flight suggests a strong interconnection of their foraging behaviour with wind (Nelson, 1978). During the study years, winds blew constantly from south-southeast resulting from CI being usually under the influence of south-east trade winds during the study periods (Gray, 1995). As such, wind direction was relatively predictable and could have been taken into account by the boobies for foraging decisions. Being exposed to a marine environment with relatively homogenous prey distribution, foraging on the opposite side of CI would not necessarily have increased the prey availability for birds of either colony. Therefore, the choice of the trip bearing could reflect a behavioural adaptation of Abbott's Booby to reduce energy expenditure, i.e., flying to the other side of CI, under the prevailing conditions of predictable winds and unpredictable but relatively homogenous prey distribution.

According to the narrow range of trip bearings of both colonies and their opposite trip directions, the important foraging areas of Abbott's Boobies encompassed only a narrow, south-east–north-west oriented corridor of about 160 km length with CI in its middle. Given its relatively small size of only about 4,500 km²and its directional orientation, this IBA lies completely within the Exclusive Economic Zone of Australia around CI. Moreover, the marine areas around CI are not used intensively for industrial fisheries, like tuna fisheries (IOTC, 2006), and hence their economic importance is rather small. As the present study was limited to the period of early chick-rearing, further investigations are necessary to include foraging movements and habitat utilisation also during other stages of the Abbott's Booby's reproductive cycle into the considerations of delimiting IBAs, like incubation, post-fledging care and post-breeding. In addition, other seabirds breeding on CI should also be taken into account, particularly the Critically Endangered CI Frigatebird *Fregata andrewsi*. However, using the identified IBA as a spatial nucleus for the creation of a marine protected area for chick-rearing Abbott's Boobies would be a significant first step to expand the protection of this endangered species to its marine habitat.

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