AN ISLAND-WIDE SURVEY OF ABBOTT'S BOOBY *PAPASULA ABBOTTI* OCCUPANCY ON CHRISTMAS ISLAND, INDIAN OCEAN

CHRISTOPHER R. J. BOLAND[1,2], MICHAEL J. SMITH[2], DION MAPLE[2], BRENDAN TIERNAN[2] & FIONNUALA NAPIER[2]

[1]*Research School of Biology, Australian National University, Canberra 0200 Australia (chris.boland@anu.edu.au)*
[2]*Christmas Island National Park, Christmas Island, Western Australia 6798 Australia*

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SUMMARY

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Decades of phosphate mining on Christmas Island in Abbott's Booby *Papasula abbotti* nesting habitat has created a conservation threat to this rare endemic seabird. The status of Abbott's Boobies could be further jeopardised by other processes, such as the impact of Yellow Crazy Ants *Anoplolepis gracilipes* and other invasive species. Here we report on the current distribution of Abbott's Booby on Christmas Island based upon occupancy data collected during an island-wide survey in 2009. We used a combination of sightings and the characteristic vocalisations of the species to establish presence/absence within the area of each survey point. A subset of the survey points was repeat-surveyed, allowing us to estimate detection probabilities. Average detectability using our approach was 0.65 (SE 0.04). We related occupancy by Abbott's Booby to several environmental covariates using site-occupancy species distribution modelling techniques. We did not find any evidence of a significant relationship between occupancy by Abbott's Booby and distance to the nearest road or to high-density Yellow Crazy Ant colonies. However, we did find that occupancy by Abbott's Booby was significantly and positively related to both elevation and distance to the nearest disturbed area. Abbott's Booby nesting habitat is restricted to the central plateau on Christmas Island and has diminished because of major disturbances. There is evidence that the species now inhabits previously unoccupied areas but still does not re-occupy habitat that immediately surrounds areas cleared for phosphate mining several decades ago.

Key words: Abbott's Booby, phosphate mining, Yellow Crazy Ant, Christmas Island, occupancy modelling

INTRODUCTION

Abbott's Booby *Papasula abbotti* is the rarest and largest of the sulids. The species formerly nested on islands in the central and western Indian Ocean, but was lost from these localities because of habitat degradation (Nelson and Powell 1986). Now the only breeding colony is on Christmas Island, an Australian external territory in the eastern Indian Ocean where the most recent Abbott's Booby population estimate was 2 500 pairs in 1991 (Yorkston & Green 1996). Accordingly, the species is listed as endangered under the Australian Government's *Environment Protection and Biodiversity Conservation Act 1999*. The low rate of recruitment of this large, long-lived seabird inhibits its capacity to recover quickly from a population decline. Breeding is biennial, parents raise a single young, and juveniles suffer high mortality. As a result, pairs successfully replace themselves only once every 24 years on average (Nelson & Powell 1986, Reville *et al*. 1990).

On Christmas Island, the population has been threatened by habitat loss due to phosphate mining (Reville *et al*. 1990). From 1968 until 1987, when clearing primary forest for phosphate mining ceased, one-third of the species' remaining nesting habitat was cleared, and the breeding population experienced a concomitant decline (Nelson 1971, Nelson & Powell 1986, Reville *et al*. 1990, Yorkston & Green 1996). Furthermore, Abbott's Boobies build nests on thin lateral branches high in the canopy of rainforest trees. Wind tunnel experiments demonstrated that clearing forest increases turbulence in the canopy (Brett 1989), lowering breeding success and site fidelity, and increasing adult mortality of Abbott's Booby nesting in surrounding areas (Reville *et al*. 1990). Although forest clearing for phosphate mining stopped in 1987, the resulting clearings remained, probably constraining the rate of recovery of the Abbott's Booby population (Yorkston & Green 1996). This may explain why the population was still found to be in decline in 1989 (Reville *et al*. 1990). In 1996, Yorkston and Green reported that the population on Christmas Island was stable, but still expressed concern for the species should significant habitat disturbance continue.

Unfortunately, significant habitat disturbance has continued in the form of a biological invasion by Yellow Crazy Ants *Anoplolepis gracilipes*. In the late 1990s, vast, high-density Crazy Ant colonies began to be recorded (O'Dowd *et al*. 2003). By 2002, more than 2 500 ha (or about 25% of the island's forest) were invaded by high-density Crazy Ant colonies, now considered to be one of the major environmental threats to Christmas Island (O'Dowd *et al*. 2003). The ants potentially further degrade Abbott's Booby habitat (Department of Environment and Heritage 2004) by extirpating the terrestrial Christmas Island Red Crabs *Gecarcoidea natalis* from the area. Because the Red Crabs are a dominant primary forest floor consumer of leaf, shoot, and seed material, their removal from an area typically results in a denser, more diverse and different forest understorey (O'Dowd *et al*. 2003), which may ultimately degrade Abbott's Booby nesting habitat. Also, they forage for honeydew secreted by introduced scale insects high up in the canopy, swarming over nesting birds, which can cause the birds to abandon their nesting attempt (Davis *et al.* 2008, 2010). However, there are few data on the threat that Yellow Crazy Ants (or their control) might pose to Abbott's Booby, so claims of an impact relating to Crazy Ants are largely speculative. As the major environmental management authority on the island, Christmas Island National Park attempted to control the spread of high-density colonies by baiting with Presto (active ingredient: fipronil) in 2002 and 2009 (Boland *et al*. 2011).

Since 2001, Christmas Island National Park has been conducting a biennial, island-wide survey for Yellow Crazy Ants and Christmas Island Red Crabs. In 2009, this survey was extended to include an estimate of presence/absence of Abbott's Booby, which allowed the bird's current distribution to be mapped and the relationship between occupancy and several environmental variables to be assessed. As a baseline dataset, this information will allow future monitoring of changes in distribution.

METHODS

Study area

Christmas Island (10°25'S, 105°40'E) is a 135 km^2 limestone and basalt oceanic island located 360 km south of Java, Indonesia. The island has a central plateau that rises steeply to 361 m above sea level and is fringed by a coastal terrace. The climate is monsoonal with the wet season generally between November and May. Mean annual rainfall is 2 068 mm, mean maximum temperature is 27.3 °C and mean minimum temperature is 22.8 °C (Australian Bureau of Meteorology). About 74% of the island is covered with natural vegetation, mostly structurally simple, broad-leaved rainforest (Claussen 2005). Christmas Island National Park covers 63% of the island (Christmas Island National Park 2002).

Field surveys

Since 2001, Christmas Island National Park has carried out annual ant-baiting programs and biennial island-wide surveys (see Boland *et al*. 2011 for more detail). In 2009, the 889 near evenly spaced survey points (≈ 366 m apart) were sampled once, and a subset of randomly chosen blocks of sites were surveyed on two (n = 223) or three (n = 14) occasions (Fig. 1). Sites for repeat surveying were grouped in randomly chosen blocks that encompassed an area around 2.25 km^2. This approach was required because of the logistical difficulties associated with traversing the island. Once the effort was made to travel to a particular area, it was important to repeat-survey as many sites in that area as possible. The number of sites repeat surveyed in a block on any occasion varied depending on the difficulties associated with moving between sites in a given area, the weather, and the number of surveyors available on a particular day. Each site was surveyed by two or three individuals from a team of 14. At any time, each team always included one of the five most experienced surveyors and all individuals were trained in the survey protocol before commencement of the program.

At each survey point, we counted Abbott's Booby by watching and listening for birds for a minimum of 10 minutes. The species is very vocal and aural assessment of their occupancy was particularly important. High-density Yellow Crazy Ant colonies were identified and mapped after each island-wide survey following the procedures outlined in Boland *et al*. (2011). Surveys were conducted between May and August 2009.

Breeding biology

Abbott's Boobies build their nests near the top of rainforest trees (about 10–40 m above the ground). The breeding cycles last 15–18 months. Successful pairs can nest once every 2 years, but often take rest years between attempts to raise a chick. Most pairs breed only once every 3 years. Mating usually takes place in April. Each pair lays a single egg between April and July, which is incubated for about 56 days. Chicks hatch from June to November; they fledge about 170 days later and become independent after an additional 200 days (Marchant & Higgins 1990).

Statistical approach

We classified survey sites by their linear distance in kilometres to the nearest high-density Yellow Crazy Ant colony, as mapped in

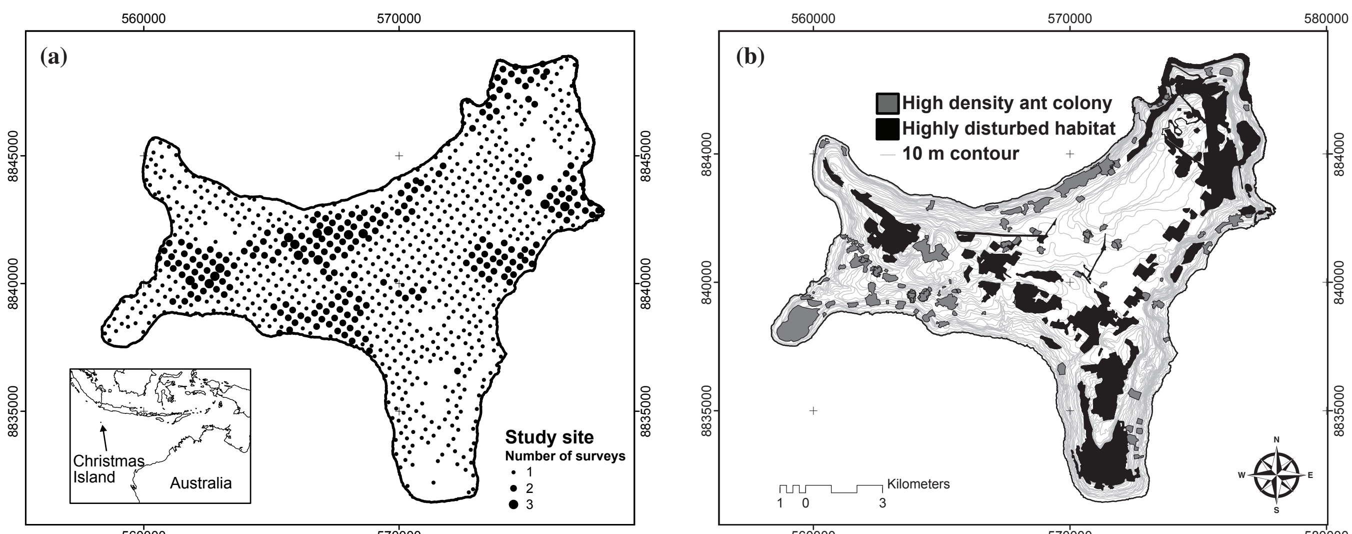

Fig. 1. Christmas Island and the island-wide survey points (a). The size of the point symbol depicts the number of times we surveyed the site. Highly disturbed areas, roads, contours, and high-density Yellow Crazy Ant colonies as of 2009 (b). Projection is in UTM (WGS84, Zone 48 S).

2009 (Fig. 1), and used this value as a covariate in the model. Sites were also classified by their elevation and distance to the nearest road. A habitat disturbance map from the Christmas Island GIS (Commonwealth of Australia 1987–2011) was used to classify sites by their distance in kilometres to the nearest significantly disturbed area. Because most of the disturbed habitat on Christmas Island is in the central part of the island (Fig. 1) and Abbott's Booby does not breed in low elevation coastal habitats, we suspected *a priori* that a quadratic term may better represent occupancy by Abbott's Booby, as occupancy would be more likely with increasing distance from a disturbed area, but less likely with proximity to the coast. If so, we would expect a positive relationship between occupancy and distance from disturbance and a negative quadratic term.

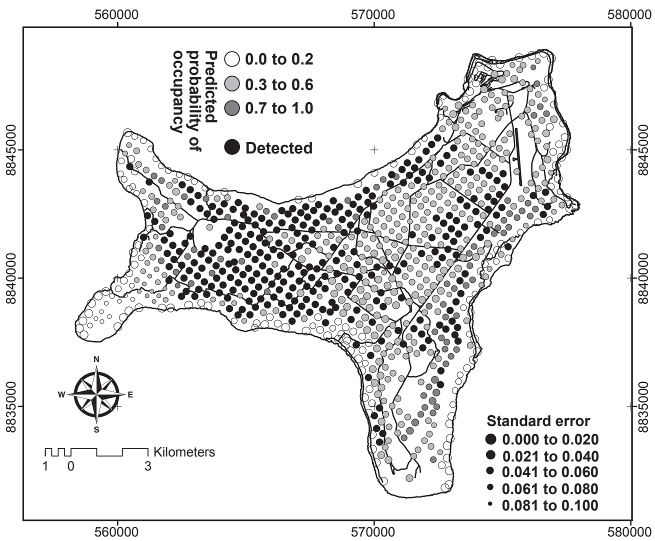

Fig. 2. Sites at which Abbott's Booby was detected (solid black circle), model averaged probability of occupancy (shading of circles) and associated standard error (size of circles) at non-detection sites. Projection is in UTM (WGS84, Zone 48 S).

Because detection of a particular species occupying a site is not guaranteed during a brief visual and aural survey, we used site-occupancy species distribution modelling that explicitly accounted for imperfect detection as part of model-fitting (Royle & Dorazio 2008, Kéry 2010). Each site was categorized as occupied (where on each visit the species can be detected with an unknown probability) or unoccupied (where the probability of detection is zero; Royle & Dorazio 2008, Kéry 2010). Because data were collected from a subset of sites that were repeat surveyed, we could infer the probabilities of detection of Abbott's Booby (cf. Royle & Dorazio 2008, Kéry 2010). By using this approach, we could reduce bias in our inferences about occupancy and better examine relationships between the probability of occupancy by Abbott's Booby and potential indicators of the impacts associated with high-density Yellow Crazy Ant colonies and habitat disturbance.

Accordingly, the probability of occurrence (Ψ_i) of the Abbott's Booby at the *ith* site was modelled as a logistic function of distance to nearest high-density Yellow Crazy Ant colony (YCA_C_i), highly disturbed area (D_i) and road (Rd_i), in addition to site elevation (Ele_i) and a quadratic distance to disturbed area term ($D2_i$), using the logistic regression equation:

$$\log\left(\frac{\Psi_i}{1 - \Psi_i}\right) = \beta + \beta.YCA\_C_i + \beta.D_i + \beta.Rd_i + \beta.Ele_i + \beta.D2_i$$

The β parameters represent the intercept and slopes of the relationships between the log-odds of occupancy by Abbott's Booby and the various predictor variables.

The probability of detection was modelled as constant because the detection of Abbott's Booby at each site was predominantly associated with their aural signals and was unlikely to be affected by any of the covariates we could use. Models were run in the "unmarked" package (version 0.8-7) in R software (R Development Core Team 2007). In particular, we used the "occu" function

TABLE 1
Parameter estimates from the models that accounted for 95% of the accumulative AIC weights

Model	AIC	ΔAIC	AIC weight	Detection	Occupancy					
				Intercept	Intercept	Elevation	Distance to nearest road	Distance to nearest disturbed area	Quadratic term (distance to nearest disturbed area)	Distance to nearest high-density Crazy Ant colony
1	1213.05	0.00	0.58	0.61	0.40	1.27		1.17	-0.70	
2	1214.93	1.88	0.23	0.61	0.40	1.27	0.04	1.15	-0.70	
3	1215.30	2.25	0.19	0.63	0.38	1.25	0.04	1.06	-0.69	-0.15
Model-averaged estimate				0.61	0.40	1.27	0.04	1.14	-0.70	-0.15
2.5 CI[a]				0.29	-0.04	0.93	-0.19	0.78	-0.99	-0.39
97.5 CI				0.93	0.83	1.61	0.27	1.51	-0.41	0.09

[a]CI = confidence interval

(e.g. model_1<-occu(~1~Rd, Data)). All possible covariate combinations were compared with AIC (Burnham and Anderson 2002). Models that accounted for 95% of the cumulative AIC weights were considered to be equally well supported. Model-averaged estimates of the most supported models were calculated within the AICcmodavg R package (e.g. modavg(cand.set = cand. models, modnames = modnames, parm = "Elevation", parm.type = "psi") Mazerolle 2012). All covariates were log-transformed and standardised. We checked model fit by examining simulated datasets from each fitted model using the parametric bootstrapping technique of Fiske and Chandler (2010). Specifically, we used a chi-square statistic to compare observed and expected values generated from simulated datasets.

RESULTS

Abbott's Booby was detected at 287 survey sites across the island (32% of sites), mostly on the island's central plateau (Fig. 2). The model-averaged probability of detection for Abbott's Booby using our survey protocol was 0.61 (95% CI 0.29 to 0.93). Three models accounted for over 95% of the AIC accumulative weight and, collectively, these models included all covariates (Table 1). Examination of the goodness-of-fit for the three models indicated adequate model fit.

Despite their inclusion in some of the supported models, the model-averaged 95% confidence intervals for relationship of occupancy to the distance to nearest high-density Yellow Crazy Ant colony and to the distance to nearest road included zero, and consequently, were judged not to be important (Table 1). We did find significant evidence for positive relationships between occupancy and both distance to nearest disturbance and elevation (95% CI did not include zero; Table 1). Additionally, a negative quadratic term was also important (95% CI did not include zero). Collectively, these relationships indicate that Abbott's Booby was more likely to occupy higher elevation sites with increasing distance from disturbance (Fig. 2 and Fig. 3).

DISCUSSION

Before human settlement, Christmas Island had thick vegetation, with an unbroken forest canopy reaching heights of 30–45 m. Abbott's Booby nested principally in the centre and west of the island (Gibson-Hill 1947, Nelson 1971) in the tops of certain species of emergent trees on the central plateau (Nelson and Powell 1986). Our data demonstrate that this preference of Abbott's Booby for nesting on the central plateau has remained. The birds continue to avoid the more exposed fringing coastal terrace and the eastern edge of the island, which is subject to prevailing southeast wind.

Between 1968 and 1987, approximately one-third of the rainforest nesting habitat of the Abbott's booby was felled for phosphate mining (Yorkston & Green 1996). Much of the bird's preferred habitat in the western and central portions of the plateau was cleared (Fig. 1). This land clearing induced a significant edge effect: birds nesting within 300 m of the mined area suffered lower breeding success and increased mortality because of greater wind turbulence (Brett 1989, Reville *et al*. 1990). By comparing rates of recruitment and mortality, Reville *et al*. (1990) concluded that the population was still in decline in 1989, two years after forest clearing had ceased. Our data indicate that this land clearing is still affecting the Abbott's Booby – more than 20 years after clearing ceased – as these birds are less likely to occupy habitat within or near a disturbed area, because such sites lack emergent, high-canopy trees suitable for nesting.

One impact of edge-induced canopy turbulence is that adult Abbott's Booby abandon traditional nest sites and seek new ones (Brett 1989, Reville *et al*. 1990). Our island-wide survey data indicate that Abbott's Booby have begun occupying areas that traditionally have been avoided, such as the eastern third of the island and the western edge of South Point (compare Fig. 2 with Nelson 1971, Nelson & Powell 1986, Yorkston & Green 1996). Whether these habitats have improved or the birds are now using suboptimal habitat remains unknown but should be the focus of future research. In addition, our results showing increasing likelihood of occupancy with increasing distance from disturbance

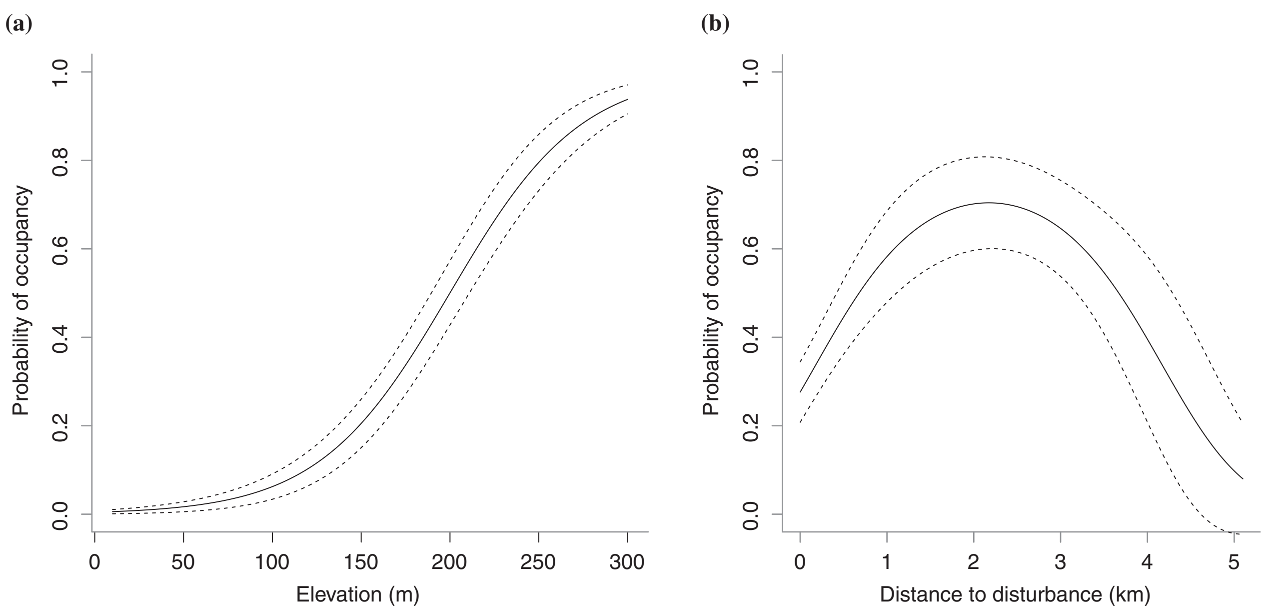

Fig. 3. Predicted relationship between occupancy by Abbott's Booby and elevation (a) and distance to the nearest disturbed area (b), mean model-averaged estimate and 95% CI (dashed lines).

suggest that areas surrounding disturbed habitats continue to represent suboptimal habitat for Abbott's Booby.

In 2000, Christmas Island National Park embarked on a program to control the spread of high-density Yellow Crazy Ant colonies by baiting with Presto (active ingredient: fipronil). Nonetheless, by 2002, more than 2 500 ha (or about 25%) of the island's forest was invaded by high-density Crazy Ant colonies, which were treated by a large-scale heli-baiting campaign in September 2002. Over the ensuing seven years, Crazy Ant infestations began to gradually reappear, requiring a second heli-baiting campaign across 784 ha in September 2009 (Boland *et al*. 2011). Our data do not support the idea that the presence of these high-density Crazy Ant infestations has negatively affected the distribution of Abbott's Booby on Christmas Island. Indeed, if anything, Abbott's Booby was more likely to occupy sites near Crazy Ant infestations (negative but non-significant relationship between occupancy and distance to nearest high-density Crazy Ant colony). However, our results are based upon presence/absence data, and detailed population studies may identify a negative impact yet to be detected by our survey protocol. Lag effects associated with high-density Crazy Ant infestation and control (i.e. changes in vegetation communities) may be detected in future surveys.

Our results suggest that the approach taken here provides reliable mapping of Abbott's Booby nesting habitat on Christmas Island. If data are collected regularly (e.g. during the biennial island-wide survey), they should provide natural resource organisations on the island with timely indications of significant change. However, this survey approach is not a substitute for detailed study of the species' demography and breeding behaviour; rather, in combination with other information, the survey approach will allow managers to detect and better understand broad changes in distribution over time. The attraction of this approach is that it provides sound census information at a low cost, adding value to an existing program.

However, our approach has limitations. Abbott's Booby forage at sea and, accordingly, may be detected simply moving through an area and, conversely, may be missed when individuals are away from their nests. Both of these factors would reduce detection probabilities (our estimate was 0.65) and could lead to some degree of overestimation of occupancy. With continued surveying, our understanding of the species' distribution and its variability should improve. Such surveys will help to determine the need for management action in the future.

Should major changes in the distribution of Abbott's Booby be detected, management actions would be justified. What degree of decline should trigger a management response, and what that management response should be, are yet to be determined by the appropriate natural resource management agencies. However, it is clear from this and previous work that any new disturbance will further restrict a limited and reduced habitat resource upon which the species depends.

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