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Short communication

The use of Google Earth™ satellite imagery to detect the nests of masked boobies *Sula dactylatra*

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Masked boobies *Sula dactylatra*, like many other species of Sulidae, do not construct elaborate nests. However, their nest sites produce a characteristic 'nest signature'. We found that these nest signatures could apparently be seen in freely available satellite images (Google Earth™) of the main island of Ascension in the south Atlantic. We verified that this was the case by comparing nest signatures detected on these satellite images with field reports of occupied nests. We found that the locations of these nest signatures determined from satellite images agreed closely with the coordinates of actual nests on the ground. We used this information to determine the position and size of a previously unreported masked booby colony on the island. Thus, we show that the presence and abundance of some species can be estimated using freely available satellite imagery if a suitable signature in the satellite image can be found. Regularly updated satellite imagery of target sites could also be used for population monitoring. While this would be expensive, initial evaluation of the technique for particular species or populations can be achieved using freely available images. We encourage wildlife managers to view their study sites on Google Earth™ for evidence of their target species.

Key words: Army Ornithological Society, Ascension Island, censusing, masked booby, population estimation, satellite imagery, seabirds, Sula dactylatra, United Kingdom Overseas Territories

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Censusing breeding seabird populations, especially on remote and rugged coastal sites, presents problems (Bibby et al. 2000). The standard bird population census methods of point counts, territory mapping and line transects are usually inappropriate and look-see counts can be prone to detection probability bias and unsystematic errors (Thompson 2002).

Photographic images of penguins Spheniscidae against a contrasting background provide an efficient census technique that has been used increasingly in recent years (e.g. king penguin *Aptenodytes patagonicus*; Guinet et al. 1995, Adélie penguin *Pygoscelis adeliae*; Schwaller et al. 2003 and emperor penguin *A. forsteri*; Fretwell & Trathan 2009). Satellite imagery has also been used to identify seabird nesting habitat (Williams & Dowdeswell 2007), but such an approach is not taken lightly because it involves considerable expenditure and high levels of interpretative expertise in remote sensing and geographical analyses. A less costly satellite imagery technique has been used recently by Begall et al. (2008) to analyse the magnetic alignment of grazing herbivores. They used satellite images that are freely available from Google Earth™. Such imagery typically reveals structures or animals as small as 2 m or sometimes less (Google Earth™ 2010), and this should enable the nests of larger birds to be detected. We applied such imagery to a remote location, Ascension Island in the south Atlantic (07°57'S, 14°24'W; 9,700 ha), which is an important breeding site for pelagic seabirds (Sand-

ers 2006, Hughes et al. 2008). We show that analysis of Google Earth™ images showing 'nest signatures' of masked boobies *Sula dactylatra* on Ascension is corroborated by contemporary field surveys. Most population studies of seabirds have been concerned with numbers found in a defined area at a specific time. The general applicability of our findings depends partly on reliable estimates of a species' range (Newton 1998) and nest signatures can provide a guide to breeding range. Before mammals were introduced, Ascension Island hosted several million seabirds including two large colonies of masked booby at North and South Gannet Hills (Ashmole et al.1994). Masked boobies have suffered a dramatic population decline (Ashmole et al.1994) and breeding sites were largely restricted to offshore islets. Feral domestic cats *Felis silvestris* were eradicated in 2004 and a recovery programme is now in place (Ratcliffe et al. 2009). We suggest that analysis of Google Earth™ images for nest signatures can provide a convenient and accurate means of censusing masked boobies on Ascension.

Methods

Study site

Our study site was the Letterbox Peninsula (hereafter referred to as 'Letterbox') on the eastern side of Ascension Island. The study site is 120 ha and is bounded by sea cliffs on three sides and the neck joining to the mainland is 1,000 m wide. Letterbox is probably the most inaccessible site to humans of anywhere on Ascension Island (Fig. 1). The site has been seldom visited due to the lack of vehicle access; the route is particularly arduous, the return trip from the road head to Letterbox takes 4-5 hours and is not recommended for inexperienced walkers (Anon. 1992). The whole site is usually devoid of vegetation although a mass flush of soft feather pappus grass *Enneapogon cenchroides* can occur following rainfall after long periods of drought. A footpath divides the study site into two sectors: a flat northern sector and a larger more rugged southern sector (see Fig. 1).

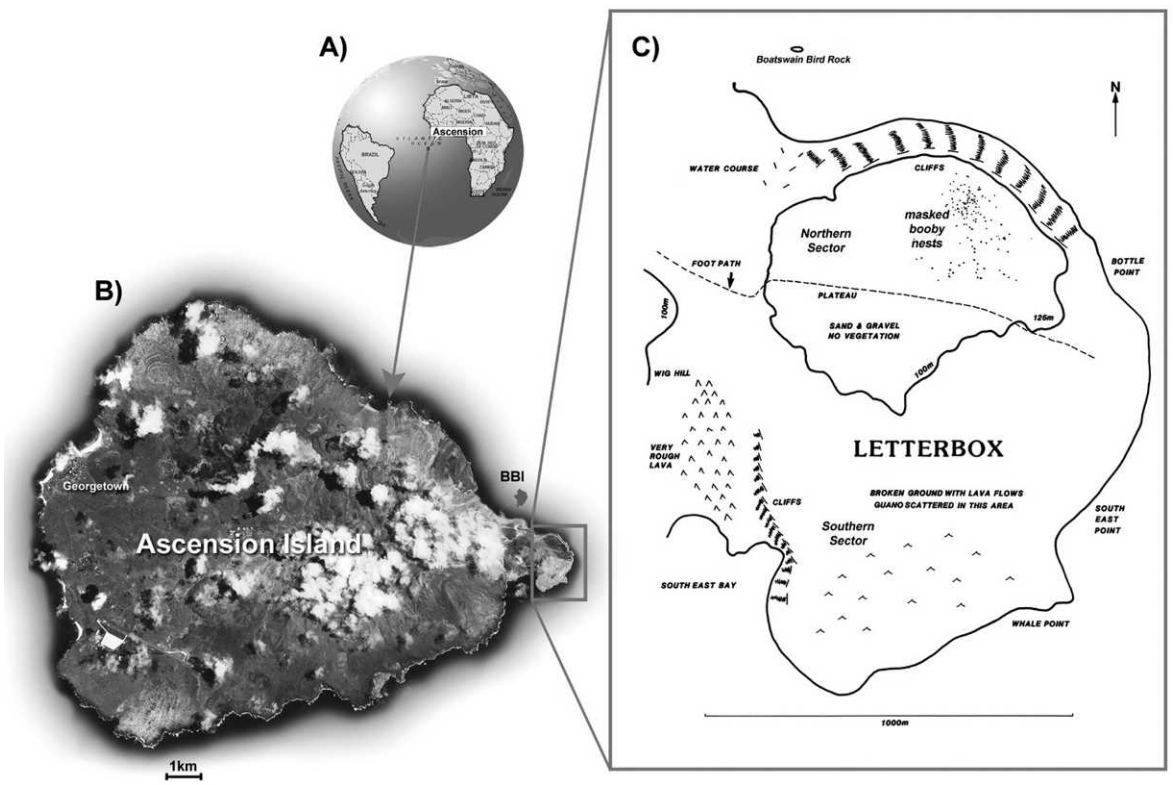

Figure 1. Location of Ascension Island in the south Atlantic (A), the entire island (B) and the Letterbox Peninsula, the study area (C), which shows the northern and southern sectors, the footpath, which divides them, and the locations of the masked booby nests in the former.

Breeding biology of masked boobies

Breeding of masked boobies takes place in small colonies with each pair producing a single slow-growing chick (egg laying-fledging ca 160 days; del Hoyo et al. 1992). Peak laying by masked boobies in the Atlantic occurs between February and August (Nelson 1978). On Ascension, Dorward (1962) identified that the peak of breeding occurred between May and August but our fieldwork suggested an extended breeding period until October (B.J. Hughes, unpubl. data).

Identification of nests

Masked boobies do not construct a nest, but eggs are laid directly on the ground. The bird clears debris and the darker surface layer from the area that can be reached while sitting at the centre of the nest site. This action exposes a lighter coloured substrate. The nest may also be surrounded by accumulated excreta ejected from the centre of the nest site by the adult and juvenile birds (Fig. 2). Together these produce a conspicuous circular patch of cleared ground $\approx$ 2 m in diameter (Nelson 1978). We refer to this patch of cleared ground as the nest signature.

Nest counts - fieldwork

Apparently occupied nests (AONs) were defined as nests containing eggs or chicks with an adult in attendance (see Fig. 2) and were monitored on Letterbox by survey teams from the Army Ornithological Society (AOS). The AOS mounted 17 expeditions to Ascension Island from 1990 to 2009 (Hughes et al. 2008), and on 10 occasions counts of masked bobby nests were made. Nest attempts were monitored by rapid look-see counts and were conducted both inside and outside the species' peak laying period. Counts were conducted on foot by 2-5 observers starting mid-morning for a period of 2-4 hours. The search of the study site consisted of walking around the perimeter of the peninsula for a distance of ca 3.5 km and scanning for AONs from vantage points. From 2004 onwards, the World Geodetic System (WGS84) coordinates of AONs were recorded using calibrated Garmin 12 XL Global Positioning System (GPS) instruments.

Google Earth imagery

In 2007, Google Earth™ updated the image of Ascension Island with an image taken on 24 January 2006. The nests of masked boobies can be seen on this image by entering the geographical coordinates -07.94536, -14.29904 (degrees and decimals of a degree) into the 'Fly to' location box in Google Earth™ and zooming in to an altitude of 500 m.

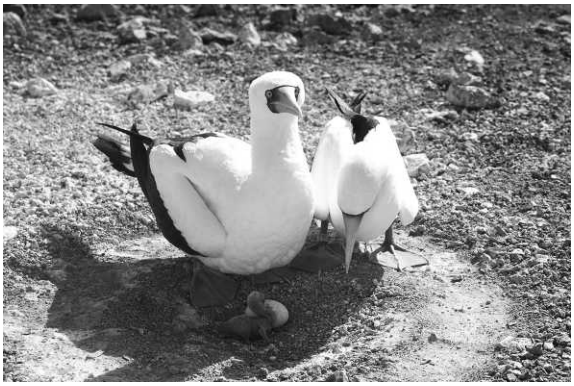

Figure 2. A pair of masked boobies with a 1-day old chick and an egg. The nest site is formed by birds clearing an area of surface debris some 2 m in diameter to reveal a lighter coloured substrate. The photograph was taken on Letterbox, Ascension Island on 22 May 2007 (Photo: Roger Dickey).

Nest counts - satellite imagery

We determined the number of nest signatures from Google Earth™ satellite images taken on 24 January 2006 (Fig. 3) viewed from an altitude of 500 m. We identified the nest signatures on the image (as described earlier). To confirm whether they were masked booby nests, the GPS coordinates of known nests (detected during fieldwork) were inputted to the 'Fly to' box of Google Earth™. We checked the image to confirm that a nest signature appeared under the cursor located by the GPS coordinates, thereby confirming that the two locations were identical.

Results

Nest counts - ground surveys

We recorded no nest attempts by masked boobies during five of the 10 surveys carried out by the AOS (Table 1). We recorded the GPS coordinates of 26 masked booby AONs during ground surveys and most were found in the more rugged and less accessible southern sector of the study site (see Fig. 1). The mean annual number of AONs between 1990 and 2005 was 5.6 $\pm$ 2.7 (SE; N = 10). The first count post-dating the satellite image was on 10 February 2006 (i.e. 17 days after the satellite image was taken), and five AONs were recorded (see Table 1).

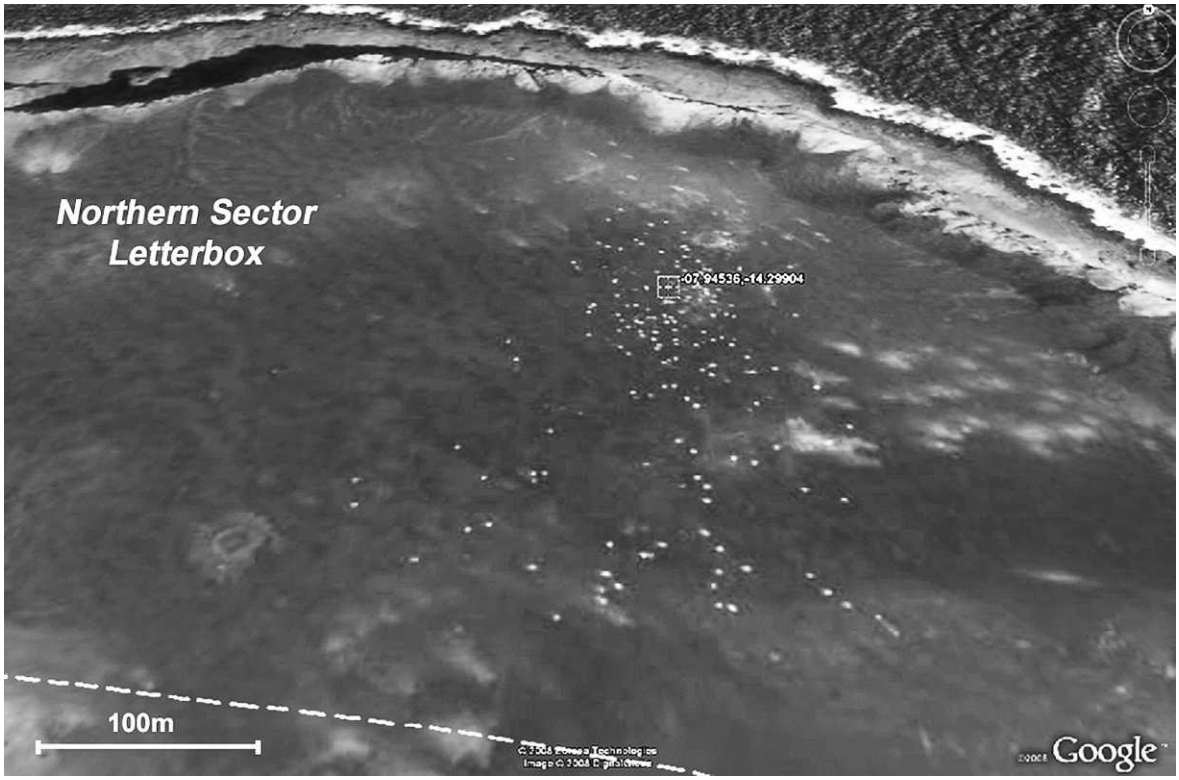

Figure 3. Google Earth™ satellite imagery taken on 24 January 2006 of masked booby nests close to the coastal cliffs on the northern sector of Letterbox on Ascension Island. Nests show up as white spots on the image. Readers are encouraged to view the actual image on Google Earth™ by entering the geographical coordinates -07.94536, -14.29904 (degrees and decimals of a degree) into the 'Fly to' location box and zooming to an eye altitude of 500 m or less.

Table 1. Month and year of nest counts and numbers of nests of masked boobies that were incubating or chick rearing at Letterbox on Ascension Island in the south Atlantic during 1990-2006. Nests were monitored in the northern (N) and the southern (S) sectors of the study site approximately every two years (see Fig. 1 for details) and either inside (In) or outside (Out) the peak of the breeding season (see text for details).

Month/year	Number of nests	Sector	Season
March 1990	4	S	Out
July 1992	0	S	In
April 1994	0	S	Out
October 1996	24	S	In
June 1998	4	S	In
November 2000	0	S	Out
June 2002	0	S	In
February 2004*	0	S	Out
November 2004*	6	S	Out
October 2005	18	N	In
February 2006	5	S	Out

* Two counts occurred in 2004 with AOS expeditions to Ascension timed to coincide with the subannual breeding season of the sooty tern *Onychoprion fuscata*, another seabird species at the focus of ongoing research efforts.

Nest site signature counts - satellite imagery

We entered the GPS coordinates of masked booby AONs recorded during ground surveys into the 'Fly to' box in Google Earth™. A white dot was apparent on the satellite image under or close to these GPS coordinates confirming that it represented a booby nest. The mean distance of the cursor from the nearest white dot was 6.3 m ± 1.4 (SE; N = 25). In total, we counted 153 white dots (i.e. nest signatures) on the satellite image. A dense area of nest signatures was visible in the satellite image of 24 January 2006 in the more open northern sector (see Fig. 3). This previously unreported site (ca 15 ha in area) lies east of the 14°18' meridian and its satellite image contained 117 nest sites (see Fig. 3). In the southern sector there were 36 nest signatures clearly visible on the satellite image but only five had been identified as occupied by masked boobies during the ground survey conducted 17 days after the satellite image had been taken. A nest signature appears on the satellite image under the GPS coordinates of six AONs found during ground surveys in November

2004 (i.e. a survey conducted 14 months before the satellite image had been taken).

Discussion

The close agreement between coordinates of nests reported from ground surveys and those from images of nest signatures confirms that nest sites of masked boobies can be detected using satellite images that are freely available on Google Earth™. We have also confirmed that nest signatures remain detectable for at least 14 months following nest occupation and we have shown that satellite imagery can identify an unreported colony in an inaccessible uncensused area (in this case a site containing 117 nest signatures in the northern sector of Letterbox; see Fig. 1C). A second unreported colony, outside our study site, on the south coast of Ascension (see Fig. 1B) at the geographical coordinates -07.98012, -14.34510 (degrees and decimals of a degree) is visible on the satellite image. We have also shown that there is not a one-to-one relationship between nest signatures and active nests, with only ca 14% of signatures corresponding to occupied nests in the southern colony on Letterbox during one particular season when field surveys and satellite image acquisition were approximately contemporaneous (17 days apart). The ratio of nest signatures to AONs may vary from this as it depends upon the longevity of nest signatures under the prevailing conditions, especially under heavy rain conditions that can either wash away the nest site completely if torrential or obscure it with the emergence of vegetation (Fig. 4).

Census of masked boobies on Letterbox

Masked boobies regularly nested in the southern sector of Letterbox during the breeding seasons from 1990 to 2006 (see Table 1). In the southern sector, 36 nest signatures were identified on satellite imagery and a maximum of 24 AONs were recorded in a single season during ground surveys (see Table 1). In the northern sector, 117 nests were constructed between 1995 and 2002 as was evident from the persistence of nest signatures from satellite image that suggested past rather than current breeding. As ground surveys were conducted in alternate years between 1995 and 2002, it is likely that nests were occupied during seasons when there was no ground survey. Growth in the breeding population of masked booby on Letterbox, following the eradication of feral domestic cats in 2004, can be measured against this baseline.

Figure 4. A masked booby surrounded by a mass flush of soft feather pappus grass obscuring the bird's nest site. The photograph was taken on Letterbox, Ascension Island in October 2009 (Photo: Dave Thomas).

The fact that nests in the northern sector were not detected during the ground surveys, and the fact that on 50% of the ground surveys no AONs (see Table 1) were seen in either the northern or the southern sectors, highlight the ineffectiveness of occasional ground surveys using look-see counts to census the masked booby population on Ascension. Part of the reason for the inaccuracy of these look-see counts is explained by the time of day of surveys, even if they are conducted at the peak of breeding seasons. During the middle of the day many birds were likely to be absent, away from the nest sites on foraging trips (Dorward 1962), making detection difficult. Using satellite imagery mitigates the problems posed by the absence of adults from nest sites since the nest signatures are readily seen regardless of the presence of birds on those sites. However, as discussed below, this decreased the probability of underestimating the population and could be offset by the problem of overestimating the number of occupied nests due to nest signature persistence.

Persistence of nest signatures

The time required to lose the nest signature following its departure or abandonment by breeding birds is not well established and nest signature counts from satellite imagery would tend to overestimate nest attempts in any one season. A nest of a masked booby on Fort Thornton, 12 km

west of Letterbox on the outskirts of Georgetown (see Fig. 1B), was occupied in November 1996 (B.J. Hughes, pers. obs.) by a juvenile that was nearly ready to fledge and it has not been occupied since (B.J. Hughes, unpubl. data). The nest signature is faintly distinguishable to the trained eye on the satellite image taken in January 2006. However, Letterbox is exposed to constant southeasterly trade winds that blow across this desert landscape at a speed of 15-35 km/hour and nest signatures are likely to be lost through dust coverage more quickly than on Fort Thornton. We, therefore, suggest that nest signatures of old nests on Letterbox may last 2-8 years. However, torrential rainfall may accelerate the process of nest signature loss. Seeds of dormant soft feather pappus grass found on Letterbox germinate rapidly in response to heavy rain (see Fig. 4). A mass flush occurred in 2009 and this made the detection of abandoned masked booby nests difficult for observers on the ground. A mass flush also occurred in 1995 in response to 349.2 mm of rain during the year, which is three times the annual average. It is, therefore, likely that all nest signatures visible on the satellite image are nests constructed some time after this mass flush in February 1995. Letterbox was monitored by the Ascension Island Conservation Office between 2002 and 2006 (Radcliffe et al. 2009), but no AONs corresponding to the 117 nest signatures detected on the satellite image were reported. This suggests that nests in the previously unreported colony were constructed some time between 1995 and 2002, in years when no ground surveys were conducted. Further research is needed to determine the persistence of abandoned nests in different habitat types to provide estimates of the potential error in population studies based on satellite images.

The method which we have employed to census breeding masked boobies is simple, non-invasive and low cost. We suggest that use of Google Earth™ to count nests that were previously unreported overcomes some logistical problems of censusing birds on the ground and can certainly reveal unknown colonies that are worthy of further investigation. Google Earth™ imagery is available for most locations on the earth. Searches in the office using nest signatures of a target species can identify the geographical range of nest sites. It may be worthwhile for other wildlife scientists to check whether satellite imagery available on Google Earth™ can be used to detect suitable signatures of other target species and to use these for estimates of wildlife abundance or to reveal populations in inaccessible terrain. Potential nest signatures are visible on Google Earth™ images of St Helena, Gough and other remote islands and await analysis. The average period between updates of Google Earth™ imagery is three years and updates could be used for population monitoring. Commercially available satellite imagery of target sites could also be used for monitoring. While the latter would be expensive, initial on the ground evaluation of the technique for particular species or populations can be achieved using freely available images.

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