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Status and phenology of breeding seabirds and a review of Important Bird and Biodiversity Areas in the British Indian Ocean Territory

PETER CARR^{1,2,3*} , STEPHEN VOTIER^{2,3}, HEATHER KOLDEWEY³,
BRENDAN GODLEY³, HANNAH WOOD¹ and MALCOLM A. C. NICOLL¹

¹*Institute of Zoology, Zoological Society of London, Regent's Park, London NW1 4RY, UK.*

²*Environment & Sustainability Institute, University of Exeter, Penryn Campus, Cornwall TR10 9EZ, UK.*

³*Centre for Ecology & Conservation, University of Exeter, Penryn Campus, Cornwall TR10 9EZ, UK.*

* Author for correspondence; e-mail: peter.carr@ioz.ac.uk

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Summary

Seabirds are one of the most threatened avian taxa and are hence a high conservation priority. Managing seabirds is challenging, requiring conservation actions at sea (e.g. Marine Protected Areas - MPAs) and on land (e.g. protection of breeding sites). Important Bird and Biodiversity Areas (IBAs) have been successfully used to identify sites of global importance for the conservation of bird populations, including breeding seabirds. The challenge of identifying suitable IBAs for tropical seabirds is exacerbated by high levels of dispersal, aseasonal and asynchronous breeding. The western Indian Ocean supports ~19 million breeding seabirds of 30 species, making it one of the most significant tropical seabird assemblages in the world. Within this is the British Indian Ocean Territory (BIOT), encompassing 55 islands of the Chagos Archipelago, which supports 18 species of breeding seabird and one of the world's largest no-take MPAs. Between January and March in 1975 and 1996, eight and 45 islands respectively were surveyed for seabirds and the data used to designate 10 islands as IBAs. A further two were proposed following an expedition to 26 islands in February/March 2006. Due to the historic and restricted temporal and spatial nature of these surveys, the current IBA recommendations may not accurately represent the archipelago's present seabird status and distribution. To update estimates of the BIOT breeding seabird assemblage and reassess the current IBA recommendations, we used seabird census data collected in every month except September from every island, gathered during 2008–2018. The maximum number of breeding seabirds for a nominal year was 281,596 pairs of 18 species, with three species making up 96%: Sooty Tern *Onychoprion fuscatus* - 70%, Lesser Noddy *Anous tenuirostris* - 18% and Red-footed Booby *Sula sula* - 8%. Phenology was a complex species-specific mix of synchronous and asynchronous breeding, as well as seasonal and aseasonal breeding. Nine of the 10 designated IBAs and the two proposed IBAs qualified for IBA status based on breeding seabirds. However, not every IBA qualified each year because Sooty Terns periodically abandoned breeding islands and Tropical Shearwater *Puffinus bailloni* breeding numbers dropped below IBA qualifying criteria in

some years. Further, one survey per year does not always capture the periodic breeding of some tropical seabirds. We propose therefore, that IBAs in BIOT are better designated at the island cluster level rather than by specific island and require two surveys six months apart per year. This work highlights the merits of long-term, systematic, versus incidental surveys for breeding tropical seabirds and the subsequent associated designation of IBAs.

Keywords: British Indian Ocean Territory (BIOT), Chagos, Important Bird and Biodiversity Areas (IBAs), Review, tropical seabird phenology, status, distribution.

Introduction

The global health of the oceans is under severe pressure from anthropogenic intervention (Jackson 2008, Game *et al.* 2009), with profoundly negative consequences for marine biodiversity. Marine megafauna has been particularly negatively impacted (McCauley *et al.* 2015) and of these seabirds (Phaethontiformes, Sphenisciformes, Procellariiformes, Suliformes, Laridae, Stercorariidae and Alcidae) are more threatened than other comparable groups of birds (Croxall *et al.* 2012). At sea, the greatest threat is from bycatch (Dias *et al.* 2019), as well as competition with fisheries (Sherley *et al.* 2018) and pollution (Votier *et al.* 2005). On land, the principle threat is from alien invasive predators (Hilton and Cuthbert 2010, Dawson *et al.* 2015, Dias *et al.* 2019), as well as habitat degradation (Croxall *et al.* 2012), hunting and trapping (Dias *et al.* 2019) and disturbance (Burger and Gochfeld 1994, Carney and Sydeman 1999, Dias *et al.* 2019).

Internationally significant breeding sites for seabirds have been identified globally through terrestrial Important Bird and Biodiversity Areas (IBAs; Donald *et al.* 2019). At sea, Marine Protected Area (MPAs) are part of a suite of tools available to combat the rapid depletion of seabirds and other marine megafauna (McCauley *et al.* 2015), especially if they are “no-take” reserves (Koldewey *et al.* 2010). In the Tropics, 13 very large MPAs > 100,000 km² have been designated (<http://www.mpatlas.org> accessed 20 March 2018) and these surround 60 terrestrial IBAs that have at least one breeding seabird as their qualifying species (data from <http://www.datazone.birdlife.org> accessed 20 March 2018). Although none of the 13 very large MPAs were designated specifically for seabirds, where MPAs are no-take and the seabird breeding sites in them are in protected IBAs, they provide a very powerful conservation tool.

Despite tropical MPAs being an important seabird conservation tool, there has been little published on seabird status and distribution within them. This is likely due to a combination of their recent creation (of the 13 very large tropical MPAs designated to date, only two, the Great Barrier Reef Marine Park and the Galapagos Marine Reserve were designated in the 20th century) and therefore a lack of data from long-term studies (Maxwell *et al.* 2014), remoteness (VanderWerf and Young 2018), immense size (Maxwell and Morgan 2012) and the logistical challenges of monitoring them (Wilhelm *et al.* 2014). In addition, tropical seabirds can present unique challenges to census work (VanderWerf and Young 2017) due to aseasonal and asynchronous breeding (Lack 1954, Nelson 1978), secretive and/or nocturnal breeding (Newman *et al.* 2009), inaccessible breeding areas (VanderWerf and Young 2018), extensive potential breeding sites and in some cases small, mobile breeding populations. This has resulted in at least some of the very large tropical MPAs having the terrestrial IBAs situated within them designated based upon *ad hoc* data (e.g. Brooke 2006, Carr 2006) rather than comprehensive multi-year datasets. However, designation of terrestrial IBAs based upon spatially and temporally limited data may be necessary as a pragmatic, but limited, solution to initiate the identification of hitherto unrecognised priority sites (BirdLife International 2004).

In 2010 the British Indian Ocean Territory (BIOT) was designated, at that time, as the world's largest no-take MPA (Figure 1 - <https://biot.gov.io/environment/marine-protected-area/> accessed 6 March 2019). BIOT includes the 55 islands of the Chagos Archipelago, 10 of which are designated as terrestrial IBAs (BirdLife International 2004, Carr 2006) and a further two have been proposed (McGowan *et al.* 2008) (Table 1; Figure 1 - Nelson's Island, Figures 2 and 3 - all other IBAs). The

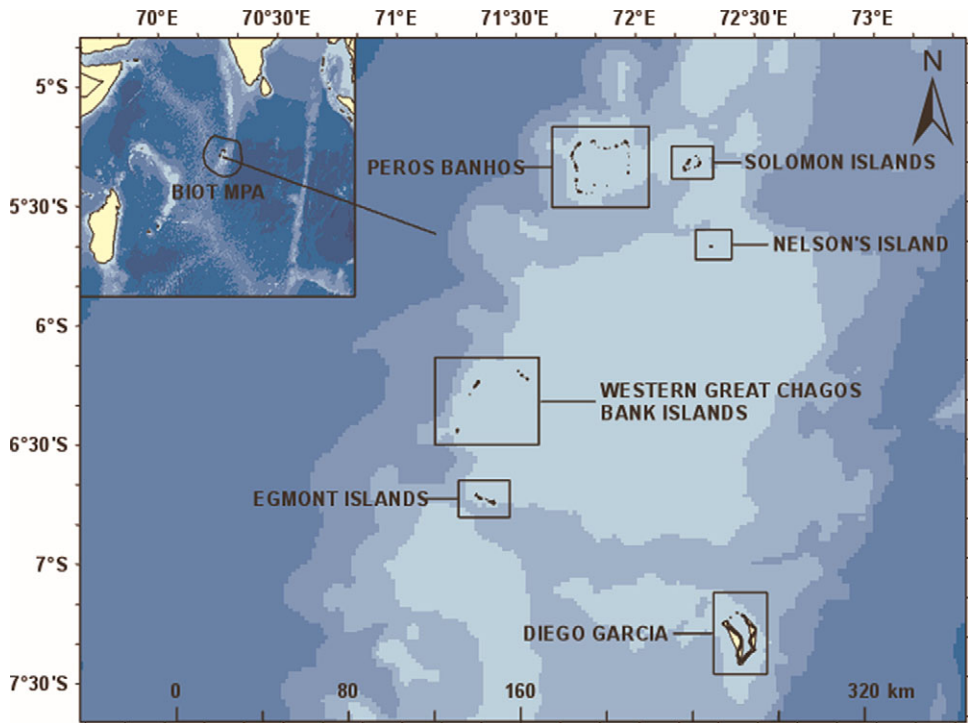


Figure 1. The British Indian Ocean Territory Marine Protected Area in an Indian Ocean context and the major land masses of the Territory.

initial designation of 10 IBAs was based on two spatially and temporally limited breeding seabird censuses from eight islands in January/March 1975 (Baldwin 1975) and 45 islands in February/March 1996 (Symens 1999), with revisions to these designations proposed following a census of 26 islands in March 2006 (McGowan *et al.* 2008). Due to the time elapsed and the limited spatial and temporal nature of the censuses, they may not have captured the true, present day status and distribution of breeding seabirds in BIOT.

Since 2008, breeding seabirds in BIOT have been monitored annually, including intra-annual repeat surveys and during this period every island has been surveyed at least once. Eighteen species of seabird breed (Carr 2011), all of which are 'Least Concern' on the IUCN Red List (<https://www.iucnredlist.org/> accessed 16 March 2018). The long-term nature of these surveys has enabled us to overcome previous sampling limitations. Here we update the status and distribution of breeding seabirds in BIOT, describe their breeding phenology and then assess whether the present designation and delimitation of terrestrial IBAs effectively captures the conservation requirement.

Methods

Study site

The British Indian Ocean Territory is a United Kingdom Overseas Territory situated in the central Indian Ocean. It totals $\approx 644,000$ km² of which ≈ 60 km² is permanently above the high-water mark (Sheppard *et al.* 1999). Declared in 2010, the BIOT MPA encompasses the entire Territory and is an IUCN category 1a, strict no-take marine reserve. Except for a UK/US Naval Support Facility on Diego Garcia, BIOT has been uninhabited since 1974 (Edis 2004, Wenban-Smith and Carter 2017). Historically, native forests were cleared (Bourne 1971) and invasive alien predators

Table 1. Designated and proposed terrestrial Important Bird and Biodiversity Areas of the British Indian Ocean Territory as at 2018.

IBA	Criteria of designated status (from BirdLife International 2004, Carr 2006)	Criteria of proposed status (from McGowan <i>et al.</i> 2008)
IO001 Barton Point Nature Reserve, Diego Garcia	A4ii Red-footed Booby (16,067); A4iii > 10,000 pairs of seabirds	A4ii Red-footed Booby (4,061) retain A4iii
IO002 Danger Island	A4i Brown Noddy (11,100); A4ii Red-footed Booby (3,470); A4iii > 20,000 waterbirds	Not surveyed in 2006, retain until next survey
IO003 Sea Cow	A4i Brown Noddy (11,500); A4iii > 20,000 waterbirds	Failed to requalify; retain until annual monitoring implemented
IO004 North Brother	A4ii Tropical (Audubon's) Shearwater (420); A4iii > 10,000 pairs of seabirds	A4ii Tropical (Audubon's) Shearwater (183); retain A4iii
IO005 Middle Brother	A4i Sooty Tern (12,500); A4iii > 20,000 waterbirds	Failed to requalify; retain until annual monitoring implemented
IO006 South Brother	A4i Lesser Noddy (7,300); A4i Brown Noddy (6,100); A4iii > 20,000 waterbirds	Failed to requalify; retain until annual monitoring implemented
IO007 Nelson's Island	A4i Lesser Noddy (13,700); A4i Brown Noddy (8,300); A4iii > 20,000 waterbirds	Not surveyed in 2006, retain until next survey
IO008 Petite Bois Mangue	A4i Lesser Noddy (12,000); A4iii > 20,000 waterbirds	A4i Sooty Tern (9,186); A4iii > 20,000 waterbirds
IO009 Parasol	A4i Sooty Tern (14,000); A4iii > 20,000 waterbirds	A4i Sooty Tern (9,186); A4iii > 20,000 waterbirds
IO010 Longue	A4i Sooty Tern (32,000); A4iii > 20,000 waterbirds	Failed to requalify; retain until annual monitoring implemented
Proposed, Petite Coquillage		A4i Sooty Tern (34,669); A4iii > 20,000 waterbirds
Proposed, Grande Coquillage		A4i Sooty Tern (15,429); A4iii > 20,000 waterbirds

introduced (Symens 1999, Wenban-Smith and Carter 2017). Of those remaining, the black rat *Rattus rattus* is the most pervasive being present on 26 islands totalling 91.4% of the BIOT landmass (Carr and Harper 2015, Harper *et al.* 2019). The archipelago is made up of five atolls, Diego Garcia, Egmont Islands, Great Chagos Bank, Peros Banhos and the Salomon Islands (Figure 1). The rat-free islands of the Great Chagos Bank and north-eastern Peros Banhos (Figures 2 and 3) are of the greatest importance to breeding seabirds. The rat-infested, deforested atolls of the Egmonts and Solomons (except the island of Mapou) and the islands of western Peros Banhos are ecologically devastated and will not support large colonies of breeding seabirds in their present environmental condition. The rat-infested island of Diego Garcia is an anomaly, as it supports an extensive colony of Red-footed Booby in its remaining oceanic island rainforest (this study).

Breeding seabird status and distribution

Between November 2008 and November 2010, every island of BIOT was censused at least once for breeding seabirds. This period was used to validate the 10 designated and two proposed IBAs,

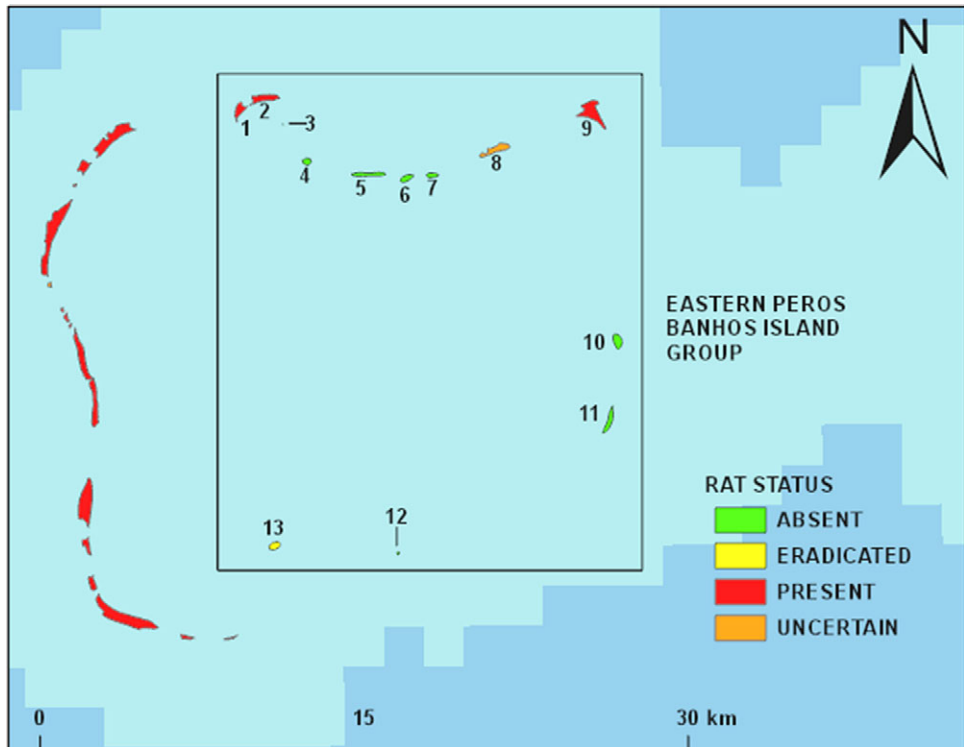


Figure 2. Proposed Eastern Peros Banhos island group terrestrial Important Bird and Biodiversity Area. 1 = Passe, 2 = Moresby, 3 = Saint Brandon, 4 = Parasol, 5 = Longue, 6 = Grand Bois Mangué, 7 = Petite Bois Mangué, 8 = Manoel, 9 = Yeye, 10 = Petite Coquillage, 11 = Grand Coquillage, 12 = Coin du Mire and 13 = Vache Marine.

identify hitherto unknown islands that were important for breeding seabirds and identify islands that were unlikely to ever support numbers of breeding seabirds in their present ecological condition. Thereafter (2011–2018), efforts were concentrated on monitoring the 12 IBA islands and, when possible, as many other islands as feasible within the constraints of the visit. Counts were made between 08h00 and 17h00 and lasted for 1–4 hours. Breeding seabird populations were estimated for all islands using Apparently Occupied Nests (AONs) following Bibby *et al.* (2012). The same survey methods as previously used in BIOT by Symens (1999) and McGowan *et al.* (2008) were employed, refined as outlined below:

Shearwaters (Procellariidae): Wedge-tailed *Ardenna pacifica* and Tropical Shearwater breed in BIOT. In the two largest colonies on North and South Brother (Figure 3) the species breed sympatrically. On all breeding islands burrows are generally dug into sandy substrates and are extremely susceptible to collapsing. Burrows are often hidden under dense vegetation. These factors make accurate counts of the two species problematic. On islands where few nests have been detected (Diego Garcia, Danger, Sea Cow, Resurgent, Nelson, Coin du Mire, Petite Coquillage; Figures 2 and 3) all burrows were inspected for occupancy. Burrows were deemed occupied (= 1 AON / one breeding pair / two adult individuals) when adults or chicks were present, feathers, fresh faeces or scratch marks were noted or the smell of preen oil was strong in the burrow. On islands with many nests, notably South and North Brother, breeding numbers were estimated by obtaining the mean number of AONs from a minimum of ten 100-m² plots (sum of AONs for each

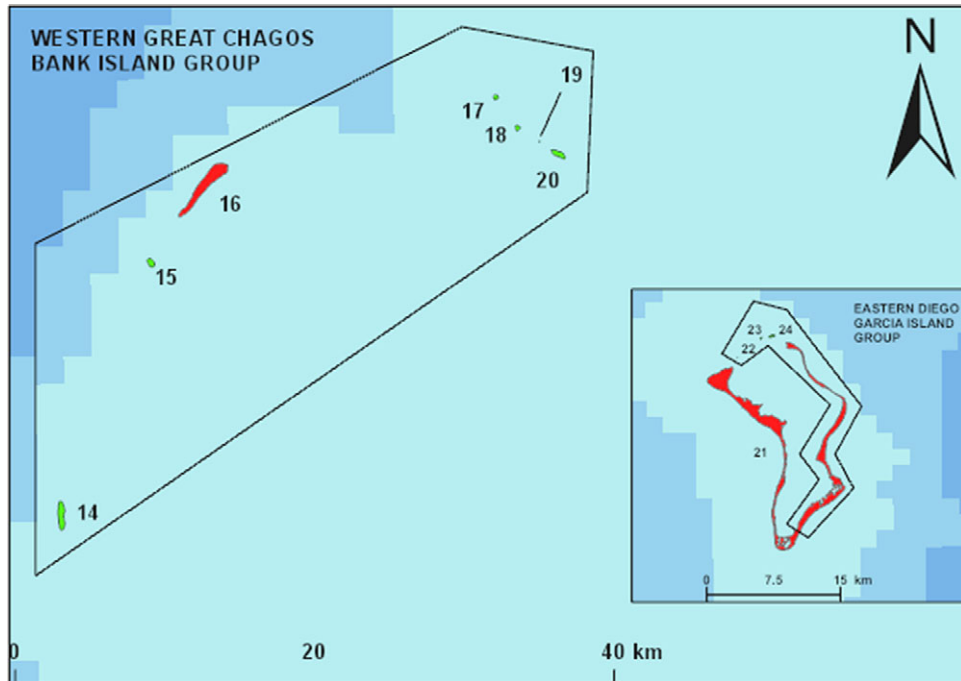


Figure 3. Proposed Western Great Chagos Bank island group terrestrial Important Bird and Biodiversity Area. 14 = Danger, 15 = Sea Cow, 16 = Eagle, 17 = North Brother, 18 = Middle Brother, 19 = Resurgent, 20 = South Brother. Inset: Eastern Diego Garcia island group revised terrestrial Important Bird and Biodiversity Area. 21 = Diego Garcia, 22 = West Island, 23 = Middle Island and 24 = East Island

plot divided by the number of plots), dividing this number by 100 to produce a mean number of AONs per m² and then multiplying this figure by the colony surface area in m² (Walsh *et al.* 1995). Plots were not randomly selected due to the potential of burrow damage but were distributed throughout both colonies. Colony surface area was calculated by mapping the colony circumference using the Area Calculation function on a handheld Global Positioning System on South Brother and was the whole island area on North Brother.

Tropicbirds (Phaethontidae): White-tailed *Phaethon lepturus* and Red-tailed Tropicbird *P. rubricauda* breed in BIOT. The former breeds on all atolls and has been recorded nesting in holes in trees (Bourne 1971) and epiphytic *Asplenium nidus* boles (this study). The latter breed on the ground near human habitation on rat-infested Diego Garcia (Carr 2011). Counts of Red-tailed Tropicbird were made by locating calling birds above the colonies and then searching the area underneath where AONs were directly counted. White-tailed Tropicbird was the hardest species to accurately count of all the seabirds due to its very low density and preference for nesting in dense forest; to date only two nests have ever actually been located (Bourne 1971, P. Carr pers. obs.). AONs were estimated from the number of individual birds recorded in the interior of forests nest prospecting or counting pairs conducting aerial courtship displays above islands.

Boobies (Sulidae): Red-footed, Brown *Sula leucogaster* and Masked Booby *S. dactylatra* breed in loose colonies throughout the year in BIOT. The latter two are terrestrial nesters and restricted to rat-free islands, the former is an arboreal breeder and widely distributed including on rat-infested islands (Carr 2011). Masked Booby breeds on Coin du Mire and Resurgent (Figures 2 and 3) and

AONs either counted directly or from the sea when landing was not possible. Brown Booby breed on seven islands and AONs were counted directly on each. Red-footed Booby breed on 38 islands. AONs were counted directly while walking the circumference of an island. Islands with obvious open areas in the interior sometimes held breeding birds and required checking (all IBAs plus Moresby and Grand Bois Mangué; Figure 2). Two islands, Danger and Nelson's had birds breeding throughout the interior as well as on the coast. During visits when high numbers were breeding on these islands, direct counts of AONs was not possible. On these occasions, random 100-m² plot counts throughout the colonies were made and the same calculations used for shearwaters were followed. The colony on Diego Garcia extends ~40 km around the coast and AONs was counted directly with some birds (< 0.1%) breeding in the interior that were located by calling nestlings and visually from a maintained dirt road.

Frigatebirds (Fregatidae): Greater *Fregata minor* and Lesser Frigatebird *F. ariel* breed in loose colonies throughout the year in BIOT. Both nest on the rat-free islands of Nelson's, North Brother and Grand Coquillage and Greater only occasionally on Middle Brother (Figure 3). Nests are sited on low vegetation on all islands except North Brother where they are positioned above 10-m in *Pisonia grandis* trees. AONs were counted directly, care was taken with species identification on high or distant, partially concealed nests. When time was short or identification not possible, both species were lumped together and recorded as frigatebird sp.

Terns (Sterninae): Nine species of tern breed in BIOT. Colonies of all terrestrial nesting terns (Table 3) were censused by direct counts except Sooty Tern. This species' breeding numbers were estimated when possible during incubation and birds were less easily flushed. A minimum of ten 100-m² plots were censused from throughout the colonies and the same calculations followed as for shearwaters. To prevent unnecessary disturbance plots were counted from the perimeter of the colony.

Three species of tern nested in trees or shrubs, Common White Tern *Gygis alba*, Brown *Anous stolidus* and Lesser Noddy. Where Lesser Noddy was breeding in colonies too large for direct counts of AONs (South Brother, Nelson's and Petite Bois Mangué; Figure 2) the AONs in a minimum of ten 100-m² random plots were counted within the colony area and the same calculations as for shearwaters were followed. AONs of lone pairs of Common White Tern and Brown Noddy were made by direct counts or from breeding behaviour displays of courtship, copulation, nest defence, food carrying or calling nestlings. When counting mass breeding events of Sooty Tern and Lesser Noddy and time prohibited the methods above, the breeding population was estimated by comparing the size of the colony and density of nests with known-size colonies.

For each island in the archipelago the maximum number of breeding pairs of any species recorded between 2008 and 2018 was taken as the estimate of the breeding population. (An average number of breeding pairs over the survey period could not be accurately calculated due to the complicated breeding phenology of tropical seabirds not facilitating a non-skewed distribution of data, i.e. an over-abundance of zero counts).

Breeding phenology

Breeding phenology data were collected for all species focusing upon seasonality and synchronicity of breeding in relation to conspecifics. If the total population bred at the same time annually it was termed seasonal. If the total population bred at the same time but not annually it was termed periodic. If the species bred throughout the year with defined spikes in laying it was termed episodic. If there was no set breeding period, it was termed aseasonal. When breeding, if the total population laid eggs within a 14-day period it was termed synchronised. If there was some coordination between laying dates, for example, within a Red-footed Booby colony "sub-colonies" lay in a synchronised manner it was termed partially synchronised. If there was no coordination in egg-laying it was termed asynchronised. Assessments of seasonality and synchronicity were made at the archipelago, atoll and island level.

Table 2. Important Bird and Biodiversity Area selection criteria (precised from Sanders 2006)

	Category	Criterion
A1	Species of global conservation concern	The site regularly holds significant numbers of a Globally Threatened species or other species of global conservation concern.
A2	Assemblage or restricted range species	The site is known or thought to hold a significant component of the restricted-range species whose breeding distributions define an Endemic Bird Area (EBA) or Secondary Area (SA).
A3	Assemblage of biome-restricted species	The site is known or thought to hold a significant component of the group of species whose distributions are largely or wholly confined to one biome.
A4i	Congregations	The site is known or thought to hold, on a regular basis >1% of a biogeographic population of a congregatory waterbird species.
A4ii		The site is known or thought to hold, on a regular basis >1% of the global population of a congregatory seabird or terrestrial species.
A4iii		The site is known or thought to hold, on a regular basis, >20,000 waterbirds or >10,000 pairs of seabirds of one or more species.
A4iv		The site is known or thought to exceed thresholds set for migratory species at bottleneck sites.

Terrestrial Important Bird and Biodiversity Area criteria

IBA-qualifying criteria followed BirdLife International (2004) and Sanders (2006) (Table 2). Biogeographically BIOT is classified as part of South Asia (BirdLife International 2004), hence regional and global population figures used for IBA qualification are from BirdLife International (2004). IBA criteria were assessed at island, atoll and the archipelago scale (Table S1 in the online supplementary material).

Results

Breeding Seabird Status and Distribution

Excluding zero counts, the surveys produced 1,547 records of 18 species breeding on 55 islands over 10 years (one record = the total number of one species breeding on a given island during a single census visit). Using maximum counts from all islands of all species from the survey period (Table S1) BIOT holds 281,596 pairs of breeding seabirds of which \approx 96% is made up of three species, Sooty Tern (70%), Lesser Noddy (18%) and Red-footed Booby (8%).

Every island in BIOT had at least one seabird recorded breeding and North Brother, with 12 breeding species, was the most diverse. Longue (Figure 2) held the greatest number of breeding seabirds with 48,000 pairs of Sooty Tern recorded in 2012, the embryonic island of Saint Brandon (Figure 2) held the least over the decade with a single pair of Black-naped Tern *Sterna sumatrana* in 2016. Eight species nested exclusively on rat-free islands, of these, six are ground-nesting. The 11 rat-free islands that are currently designated/proposed IBAs (Table 1; Figures 1–3) accounted for \approx 94% of the total number of breeding birds - over half a million individual adult birds (Table S1).

BIOT holds breeding seabird populations of significance at the regional and global scale for six species: Tropical Shearwater - 5.44% of the global population; Red-footed Booby - 7.62% of the global population; Greater Crested Tern *Thalasseus bergii* - 2.82% of the regional population; Black-naped Tern - 2.77% of the regional population; Sooty Tern - 19.75% of the regional population and Lesser Noddy - 10.16% of the regional population.

Breeding phenology

Of the 18-breeding species, eight were synchronised, three were partially synchronised and five were asynchronous. Brown Noddy adopts two strategies: lone pairs nesting arboreally throughout the year, including on rat-infested islands (aseasonal and asynchronous); and synchronised in dense terrestrial colonies exclusively on rat-free islands at unknown periods (periodic). Two species were seasonal, seven were periodic, three were episodic and five were aseasonal. Three species, White-tailed Tropicbird, Little *Sternula albifrons* and Roseate Tern *Sterna dougallii* had too few data to accurately determine their synchronicity and seasonality (Table 3).

Terrestrial Important Bird and Biodiversity Area qualification

Surveys of the designated and proposed IBAs were conducted an average of 13.7 times (range 11–19, $n = 12$) during 2008–2018 (Table S2). None of the 18 species of breeding seabird in BIOT are globally threatened, endemic, restricted-range species or largely confined to one biome (del Hoyo *et al.* 1992), therefore no site qualifies for IBA status under criteria A1, A2 or A3 (BirdLife International 2004). All islands that qualified were under criterion A4 (congregations). Using decadal data (Table 4), of the 10 currently designated IBAs, nine qualified under either A4i, ii or iii or combinations thereof. One IBA never qualified at all. Both proposed IBAs qualified under A4i and iii. However, when assessed on an annual timescale (Table 4), only a single IBA, Petite Bois Mangue (Figure 2), qualified every time it was surveyed. Every other island failed to qualify at least twice (range 2–6) during the 10 years.

Between 2008 and 2018 (Table 4), of the five original qualifying species, Brown Noddy never met IBA qualifying numbers. On the two islands designated due to Red-footed Booby, this species made IBA criteria five times during 13 censuses. It met IBA criteria for the first time in 2012 on Nelson's Island when 3,300 breeding pairs were present. On the three islands that qualified through breeding numbers of Lesser Noddy, IBA criteria were met 14 times out of 25 visits. One island originally qualified for IBA status via Tropical Shearwater. On this island (North Brother) it met IBA status once in the decade, in 2015, though qualified for the first time on South Brother in 2014 and again in 2015. Six islands qualified for IBA status through the presence of Sooty Tern colonies 14 times during 46 visits over 10 years.

At the atoll level (Table S1), five species qualify three atolls as IBAs; Diego Garcia - Red-footed Booby (A4ii); Great Chagos Bank - Tropical Shearwater (A4ii), Red-footed Booby (A4ii); Greater Crested Tern (A4i), Sooty Tern (A4i) and Lesser Noddy (A4i); Peros Banhos - Sooty Tern (A4i) and Lesser Noddy (A4i). These three atolls would all qualify for A4iii. The qualifying criteria for Black-naped Tern is 150 individual birds, and while the Egmont Islands atoll only held 70 breeding pairs (140 individuals), if chicks and non-breeding birds are counted this atoll would qualify with this species under A4i.

At the archipelago level (Table S1), six species have IBA qualifying populations - Tropical Shearwater (A4ii); Red-footed Booby (A4ii); Greater Crested Tern (A4i); Black-naped Tern (A4i); Sooty Tern (A4i) and Lesser Noddy (A4i). The archipelago would further qualify under A4iii criteria for holding > 20,000 waterbirds or > 10,000 pairs of seabirds.

Discussion

Prior to 2008 there had only been three spatially and temporally limited breeding seabird censuses in BIOT (Baldwin 1975, Symens 1999, McGowan *et al.* 2008). The surveys reported here during 2008–2018 instead provide a more detailed annual picture of breeding seabirds on the archipelago and reveal in a nominal year 281,596 pairs of breeding seabirds of 18 species. The counts also demonstrate that the present system of delimiting IBAs in BIOT at an island scale does not

Table 3. Seabird breeding phenology in BIOT 2008–2018

SPECIES	Partially							Comments	
	Synchronised	synchronised	Asynchronised	Seasonal	Periodic	Episodic	Aseasonal		Unknown
Wedge-tailed Shearwater <i>Ardenna pacifica</i>	■			■					Terrestrial breeding species. Breeds October – April. Exceptional breeding of > 5 pairs was recorded on Diego Garcia in July and August 2009 and June 2018
Tropical Shearwater <i>Puffinus bailloni</i>	■			■					Terrestrial breeding species. Breeds October – April
Red-tailed Tropicbird <i>Phaethon rubricauda</i>		■			■				Terrestrial breeding species. Has been recorded breeding semi-colonially from February through to July. When breeding the spread of laying dates is > 21 days
White-tailed Tropicbird <i>Phaethon lepturus</i>								■	Arboreal breeding species
Masked Booby <i>Sula dactylatra</i>			■				■		Terrestrial breeding species. Limited data, continuous breeder possibly with laying spikes like Red-footed Booby
Red-footed Booby <i>Sula sula</i>		■				■			Arboreal breeding species. Egg laying spikes occur in December/January and June/July
Brown Booby <i>Sula leucogaster</i>		■				■			Terrestrial breeding species. Limited data, continuous breeder possibly with laying spikes. Laying spikes differ by island
Greater Frigatebird <i>Fregata minor</i>			■				■		Arboreal breeding species. Breeds continuously throughout year with no noticeable spikes
Lesser Frigatebird <i>Fregata ariel</i>			■				■		Arboreal breeding species. Breeds continuously throughout year with no noticeable spikes
Greater Crested Tern <i>Thalasseus bergii</i>	■				■				Terrestrial breeding species. Nomadic breeder, colonies are synchronised though periodic. Colonies on the same island may not be synchronised with each other
Roseate Tern <i>Sterna dougallii</i>								■	Terrestrial breeding species
Black-naped Tern <i>Sterna sumatrana</i>	■				■				Terrestrial breeding species. Nomadic breeder, colonies are synchronised though periodic. Has nested on man-made structures such as floating platforms and roofs on Diego Garcia
Little Tern <i>Sternula albifrons</i>								■	Terrestrial breeding species
Bridled Tern <i>Onychoprion anaethetus</i>	■				■				Terrestrial breeding species. Synchronised breeding occurs on individual islands throughout the year. Possible egg laying spikes like Red-footed Booby
Sooty Tern <i>Onychoprion fuscatus</i>	■				■				Terrestrial breeding species. Synchronised breeding occurs at unknown intervals. Has been recorded breeding sub-annually in BIOT MPA

Table 3. (Continued)

SPECIES	Partially							Comments
	Synchronised	synchronised	Asynchronised	Seasonal	Periodic	Episodic	Aseasonal	
Brown Noddy <i>Anous stolidus</i>								Terrestrial and arboreal breeding species. When terrestrial it is colonial, synchronised and periodic at an unknown interval. Lone pairs breed arboreally, aseasonally and asynchronised
Lesser Noddy <i>Anous tenuirostris</i>								Arboreal breeding species. Individual colonies are synchronised. Breeds at unknown intervals and colonies on different islands can have very different breeding dates
Common White Tern <i>Gygis alba</i>								Arboreal breeding species. Lone pairs breed aseasonally

Table 4. Counts of species that originally qualified the ten designated and two proposed Important Bird Areas (IBAs) in the British Indian Ocean Territory, censused between 2008–2018. Records of newly qualifying species are in *italics*. **Bold text** denotes a species' count met IBA qualifying criteria A4i, A4ii or A4iii. NC = IBA was not censused in that year.

IBA	ORIGINAL QUALIFYING SPECIES (BIOT QUALIFYING COUNT OF BREEDING PAIRS) NEW QUALIFYING SPECIES	YEAR COUNT OF IBA QUALIFYING SPECIES (IBA QUALIFYING CRITERIA – IF APPLICABLE)										
		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
DIEGO GARCIA	RED-FOOTED BOOBY (16,067)	NC	2,880	4,625 (A4ii)	3,530 (A4ii)	2,932	NC	3,663 (A4ii)	NC	NC	NC	9,969 (A4ii)
DANGER ISLAND	RED-FOOTED BOOBY (3,470)	NC	700	3,500 (A4ii)	NC	63	1,145	400	45	45	NC	NC
	BROWN NODDY (11,100)		35	40		40	24	45	12	12		
SEA COW	BROWN NODDY (11,100)	NC	130	140	NC	30	42	52	22	NC	NC	NC
SOUTH BROTHER	BROWN NODDY (6,100)	NC	60	50	0	30	40	41	7	6	NC	NC
	LESSER NODDY (7,300)		10,000	0	0	0	57	9,800	11,500	30		
	SOOTY TERN (10,000)		(A4i/A4iii)	0	800	800	0	(A4i/A4iii)	(A4i/A4iii)	5,000		
	TROPICAL SHEARWATER (400)		10,000	0	0	0	2	0	0	0		
			(A4i/A4iii)					400	345			
								(A4ii)	(A4ii)			
MIDDLE BROTHER	SOOTY TERN (12,500)	NC	10,000	10,500	400	32,000	10	2,200	5,000	NC	NC	NC
			(A4i/A4iii)	(A4i/A4iii)		(A4i/A4iii)						

Table 4. (Continued)

IBA	ORIGINAL QUALIFYING SPECIES (BIOT QUALIFYING COUNT OF BREEDING PAIRS) NEW QUALIFYING SPECIES	YEAR COUNT OF IBA QUALIFYING SPECIES (IBA QUALIFYING CRITERIA – IF APPLICABLE)										
NORTH BROTHER	TROPICAL SHEARWATER	200	120	166	NC	0	0	120	1,200 (A4ii)	NC	NC	NC
	(420)	0	10,000 (A4i/A4iii)	0		0	0	0	0			
NELSON'S ISLAND	SOOTY TERN											
	(10,000)											
	BROWN NODDY	14	70	80	20	650	64	41	14	12	NC	350
	(8,300)	50	10,000 (A4i/A4iii)	1,400	0	11,000 (A4i/A4iii)	820	12,000 (A4i/A4iii)	50	10,000 (A4i/A4iii)		6,500 (A4i/A4iii)
PARASOL	LESSER NODDY	490	600	500	300	3,300 (A4ii)	996	(A4i/A4iii)	310	(A4i/A4iii)		(A4i/A4iii)
	(13,700)									12		683
	RED-FOOTED BOOBY (3,300)											
PARASOL	SOOTY TERN	NC	15,000 (A4i/A4iii)	31,250 (A4i/A4iii)	NC	37,500 (A4i/A4iii)	0	10,000 (A4i/A4iii)	0	5,000	0	NC
LONGUE	SOOTY TERN	NC	20,000 (A4i/A4iii)	0	NC	48,000 (A4i/A4iii)	0	0	0	11,000 (A4i/A4iii)	0	NC
	(32,000)											
PETITE BOIS MANGUE	SOOTY TERN	NC	0	0	NC	0	0	0	0	0	NC	NC
	(20,424)		10,000 (A4i/A4iii)	10,000 (A4i/A4iii)		10,000 (A4i/A4iii)	11,500 (A4i/A4iii)	14,000 (A4i/A4iii)	11,000 (A4i/A4iii)	12,500 (A4i/A4iii)		
	LESSER NODDY											
PETITE COQUILLAGE	SOOTY TERN	300	20,000 (A4i/A4iii)	10,000 (A4i/A4iii)	NC	0	NC	0	0	8,000	NC	NC
	(34,669)											
GRAND COQUILLAGE	SOOTY TERN	10,000 (A4i/A4iii)	NC	0	NC	38,000 (A4i/A4iii)	0	1,000	0	0	0	2,304
	(15,429)											

capture the present status and distribution of its qualifying breeding seabird species. It has further exposed the limitations of using temporally and spatially limited censuses due to the complex nature of tropical seabird breeding phenology.

Terrestrial Important Bird and Biodiversity Area species' monitoring in BIOT

Appropriate census methods for tropical seabirds requires an understanding of their breeding phenology (VanderWerf and Young 2017, 2018). Our long-term survey data have revealed much of the breeding phenology of BIOT seabirds, though the periodicity of breeding Lesser Noddy and Sooty Tern is not yet understood (Table 3). When assessed at an island level, BIOT now has four seabird species breeding in IBA qualifying numbers: Tropical Shearwater, Red-footed Booby, Sooty Tern and Lesser Noddy (Table 4, Table S1). We discuss the status and monitoring of these species in turn.

Globally, Tropical Shearwater is synchronised and both a seasonal and aseasonal breeding species, with the season dependent upon location and the length of cycle variable with locality. Generally, it breeds in summer at higher latitudes, e.g. Reunion, July–October, but year-round close to the equator, e.g. on Seychelles (del Hoyo *et al.* 1992). In BIOT it is seasonal (October–March) and synchronised with a breeding population of 1,000–2,000 pairs. The largest colonies are found on the rat-free islands of North and South Brother (Table 3, Table S1) where it nests in amongst the more abundant Wedge-tailed Shearwater. The colony on South Brother was discovered in 2014 and another, unsurveyed, large colony may exist on Nelson's Island (Carr *et al.* 2018). Nocturnal burrow-nesting seabirds are difficult and/or labour intensive to accurately census (e.g. Dyer and Hill 1991, Bonnet-Lebrun *et al.* 2016), therefore interannual variation in counts may relate to a lack of sampling precision. Tropical Shearwater is the only IBA qualifying species where a single annual survey of the archipelago conducted between November and March would capture the entire breeding population.

Globally, Red-footed Booby is aseasonal, episodic, asynchronised (Carboneras *et al.* 2019) and a partially synchronised breeder (Nelson 1978). In BIOT it is a partially synchronised, episodic breeder with a total annual breeding population that could reach $\approx 21,000$ pairs in years when peak breeding across the archipelago was synchronised (Table 3, Table S1). There are two breeding spikes: one in January when the prevailing winds are north-west and a second larger event in June/July when the stronger Southeast Trades blow. This species is not difficult to census accurately when breeding but due to the two spikes in egg laying some six months apart, it requires two surveys *per annum* to capture the entire breeding population (as in 2018 on Diego Garcia – Table 4, Table S1). The original IBA qualifying count of 16,067 breeding pairs (BirdLife International 2004) is erroneous as it was assumed at that time that birds bred throughout the forested interior of the eastern arm of Diego Garcia – see Carr (2005) for further information.

Globally, Sooty Tern breeds year-round in some places and is seasonal in others (Gochfeld *et al.* 2019d). It can breed sub-annually and the breeding cycle takes 9.5 months, both at population and individual levels (Hughes 2014). It breeds in the western Indian Ocean at many locations from 04°S (Seychelles) to 26°S (southern Madagascar) and the breeding season is related to latitudinal variations in food availability (Gochfeld *et al.* 2019d). In BIOT it is the most numerous bird species with a maximum breeding population of $\approx 200,000$ pairs (Table 4, Table S1) and is highly synchronised within colonies and, all colonies throughout the Archipelago nest at the same time. However, it breeds at unknown intervals and like on Ascension Island (Chapin 1954) it has bred subannually. In BIOT it is not island philopatric, having interannual variation in breeding island selection (this study). Feare (1976) and Feare and Feare (1984) found periodic desertion of breeding colonies in the western Indian Ocean due to tick infestation, and this is the likely cause in BIOT (Carr *et al.* 2013, Carr 2014). Periodic desertions of breeding islands make IBA designation at the island level in BIOT challenging.

In the western Indian Ocean, Lesser Noddy of the race *tenuirostris* on Seychelles laid eggs between late May and late June in most years during 1995–2002 (Gochfeld *et al.* 2019b). Elsewhere race *melanops* on Houtman Abrolhos Island (off Western Australia) laid August–early December.

Some colonies are stable but others shift location from year to year (Gochfeld *et al.* 2019b). In BIOT, we estimated $\approx 50,000$ breeding pairs (Table 4, Table S1) where it is a highly synchronised breeder and strongly philopatric. However, it is asynchronous between colonies and breeds at unknown intervals. There are three epicentres of breeding in BIOT holding $\approx 10,000$ pairs in peak years – on rat-free Petite Bois Mangue, Nelson’s Island and South Brother. In 2009, when repeat surveys of islands were undertaken, the former held peak breeding numbers in February, the latter two islands peaked in July. A single, temporally limited count of the archipelago may not necessarily account for the year’s entire breeding population. Previous predictions of a population decline seem unfounded (McGowan *et al.* 2008).

Brown Noddy formerly qualified four islands for IBA status but no longer breeds in sufficient numbers with a current estimate of $\approx 3,000$ breeding pairs (Table 4, Table S1). This species is ‘Least Concern’ (BirdLife International 2018), with a globally stable population and no known large-scale threats or declines (Gochfeld *et al.* 2018). Some small populations are believed to be vulnerable to introduced predators (Gochfeld *et al.* 2018) though this cannot be the cause of decline in BIOT because the large breeding colonies ($< 7,500$ individual birds) recorded by Baldwin (1975) and Symens (1999) were on predator free islands – that have remained predator-free (Harper *et al.* 2019). McGowan *et al.* (2008) first noted the decline of this species; why it declined so rapidly from 1996 to its present-day stable population remains a mystery.

Greater Crested Tern and Black-naped Tern had confirmed or potential IBA qualifying breeding populations at the atoll level (Table S1). The former nests in large dense colonies in Australia and elsewhere in very small colonies and the breeding season varies with location, with April–June recorded in the Indian Ocean. In Aldabra and south-west Australia it has two annual breeding peaks but individual birds only nest once a year (Gochfeld *et al.* 2019c). The latter breeds September–November elsewhere in the Indian Ocean. It usually breeds in small colonies of 5–20 pairs but sometimes up to 200 (Gochfeld *et al.* 2019a). In BIOT both species breed in colonies of up to 50 pairs at unknown intervals throughout the year. Occasionally, two colonies of the same species are sited on the same beach on an island but will be at different breeding stages. Both species are not philopatric and locating colonies requires extensive searching of all islands including those that are rat-infested.

To conclude, an accurate estimate of BIOT breeding seabirds requires biannual censuses during January/February and July/August. These censuses should occur at least every four years to meet IBA monitoring guidelines and IUCN Red List review periodicity (BirdLife International 2006).

Terrestrial Important Bird and Biodiversity Area designation in BIOT

As part of the ongoing IBA monitoring process, IBAs should meet the criteria they were listed for and boundaries identified and mapped (BirdLife International 2006). This review demonstrates that the present site boundaries of the BIOT IBAs do not reflect the current status and distribution of breeding seabirds, thus requiring a revision.

IBA site boundaries are usually determined based on environmental, administrative, and practical factors (Fishpool and Evans 2001 in Harris *et al.* 2011) and the larger the area included, the more likely the population thresholds for IBA site designation will be reached (Harris *et al.* 2011). Options for larger spatial scale IBAs in BIOT are to designate at the archipelago, atoll or parts of atoll (island cluster) level, all of which have been incorporated in other UK Overseas Territories (UKOTs; Sanders 2006).

In BIOT, the lack of granularity when recording species at the archipelago level is thought to preclude this option. Consisting of five atolls up to 200 km apart (Diego Garcia – Peros Banhos; Fig. 1) that have differing climatic conditions north to south (Stoddart 1971), monitoring at the archipelago scale may not capture finer scale shifts in population dynamics. Hence, this scale of IBA may not detect population dynamics of seabirds and therefore cannot be used to assess the efficacy of the MPA. Further, conservation management requires a finer scale than archipelago to identify specific islands in need of environmental rehabilitation, i.e. rat eradication and/or reforestation.

Atoll scale IBA designation and monitoring would be a better option. At this level, fine-scale changes can be identified, and atolls are unique, readily defined units. However, the access to visiting yachts, military presence, protection status and ecological quality of islands in Peros Banhos and Diego Garcia may preclude this option. Peros Banhos is an atoll of two distinct halves (Carr 2011). One half, all islands west of Vache Marine and Passe (Figure 2), are ecologically impoverished with invasive rats and the clearance of native forest for coconut. The eastern half holds five IBAs and is a Strict Nature Reserve (Figure 2; Carr 2011, Carr *et al.* 2013, Harper *et al.* 2019). Similarly, on Diego Garcia, the eastern arm is a RAMSAR site, Strict Nature Reserve and IBA, the western arm a sophisticated military facility with very little native habitat left (Carr *et al.* 2013). Therefore, designating these entire atolls as IBAs would not reflect the true status and distribution of seabirds.

The final option is to designate parts of atolls, e.g. clusters of islands as IBAs. Clusters of islands have been made IBAs elsewhere in the UKOTs, e.g. Beaver Island Group, Falklands (Sanders 2006) and elsewhere in the western Indian Ocean, e.g. Farquhar–South Island and islets IBA in the Seychelles (BirdLife International 2019). Globally, no “cluster of islands” IBAs have been created to cater for shifting populations of breeding seabirds. In BIOT, this grouping would capture the periodic desertion of breeding islands by Sooty Tern. It is also a defined unit that can be readily censused, does not misrepresent or over-inflate the importance of the breeding seabirds due to spatial scale and is manageable in terms of size, protection and conservation measures if needed.

Removing invasive predators aids the recovery of seabird populations (e.g. Hilton and Cuthbert 2010, Bedolla-Guzmán *et al.* 2019, Holmes *et al.* 2019), with rat eradication a priority not only for seabirds, but also for surrounding reef ecosystems (Graham *et al.* 2018, Savage 2019). For conservation practitioners, including ecologically impoverished islands into a discrete cluster of IBA islands would give a focus to environmental rehabilitation projects. Adopting the island cluster strategy would align well with proposed management recommendations relating to the control of invasives. For example, having the islands of eastern Peros Banhos (Figure 2) designated would focus rat eradication efforts on the three islands where they are still present (Passe, Moresby and Yéyé; Figure 2). Similarly, the western islands of the Great Chagos Bank should include Eagle Island (Figure 3).

Using Important Bird and Biodiversity Areas to monitor the efficacy of Marine Protected Areas (MPAs)

Seabirds are used to identify and delineate MPAs (e.g. Thaxter *et al.* 2012, Ronconi *et al.* 2012). Monitoring the efficacy of the BIOT MPA could be achieved through seabird tracking to establish their use of the no-take zone for foraging and non-breeding. Further, demographic monitoring of terrestrial IBAs within MPAs could quantify the level of protection afforded, both at sea and on land. Monitoring breeding seabirds within the BIOT MPA is also a method for globally testing the validity and effectiveness of an extremely large tropical, strict no-take MPA for the conservation and protection of top predators, a subject of which the requirement and efficacy is still debated (e.g. Game *et al.* 2009, De Santo *et al.* 2011, De Santo 2013, McCauley *et al.* 2015, Hilborn 2017, O’Leary *et al.* 2018).

Recommendations

To address the shortcomings in seabird data collection, BIOT requires a standardised, systematic breeding seabird monitoring programme. To accurately reflect the present status and distribution of breeding seabirds in BIOT, it is recommended that the boundaries of the terrestrial IBAs are redrawn. The data collected in 2008–2018 presented in this study will facilitate an effective monitoring programme and redrawing of terrestrial IBA boundaries. It also provides the opportunity, with baseline figures provided, to initiate credible assessments of the role of the BIOT MPA

Table 5. Recommendations for the revision of terrestrial Important Bird and Biodiversity Areas in the British Indian Ocean Territory.

IBA name	Qualifying criteria (breeding pairs)	Comments
Eastern Diego Garcia island group	A4ii Red-footed Booby (9,969)	Site includes West, Middle and East Islands. On Diego Garcia island, IBA includes all land from the Plantation Gate ($-7.411^{\circ}\text{S } 72.453^{\circ}\text{E}$) to Barton Point ($-7.234^{\circ}\text{S } 72.434^{\circ}\text{E}$)
Western Great Chagos Bank island group	A4i Sooty Tern (52,000), Lesser Noddy (15,735) A4ii Red-footed Booby (5,469), Tropical Shearwater (1,615) A4iii site holds at least 20,000 waterbirds	IBA includes Danger Island, Sea Cow, Eagle Island, the Three Brothers and Resurgent
Nelson's Island	A4i Lesser Noddy (12,000) A4ii Red-footed Booby (3,300) A4iii site holds at least 20,000 waterbirds	
Eastern Peros Banhos island group	A4i Sooty Tern (145,000), Lesser Noddy (20,850) A4iii site holds at least 20,000 waterbirds	IBA includes all islands from Ile du Passe to Vache Marine inclusive

in seabird conservation using a suite of seabirds from different foraging guilds. Taking into consideration the complicated breeding phenology of tropical seabirds, the shifting nature of breeding Sooty Tern and the challenges of monitoring a vast area/MPA, we make four recommendations:

1. Terrestrial IBAs are delimited and refined as follows (Table 5, Figures 2 and 3):
2. Every four years, two breeding seabird censuses of all islands should be undertaken six months apart, one in January/February and the other in July/August.
3. The revised designation of IBAs is used to inform and prioritise the rehabilitation of ecologically impoverished islands in BIOT, with a focus upon islands of currently low ornithological importance within the revised IBAs.
4. The results of IBA monitoring is used as a tool to assess the efficacy of the BIOT MPA for the conservation of seabirds.

Supplementary Material

To view supplementary material for this article, please visit <http://dx.doi.org/10.1017/S0959270920000295>.

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