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The protection of the marine birds and sea turtles of St Brandon's Rock, Indian Ocean, requires the conservation of the entire atoll as an ecosystem

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Abstract

A survey of seabirds and turtles at St Brandon's Rock, 400 km north of Mauritius, was undertaken in 2010. We estimated that 1.1 million seabirds of seven breeding species were present at the archipelago, and counted 279 turtle tracks and nesting pits of green turtles. Hawksbill turtles were also present. The number of species of seabird and overall number of seabirds breeding at the atoll have decreased. An analyses of 30 different islets that make up the atoll shows that the seabird species mostly partition their use of islets based upon islet size, with four species preferring larger islets and two species preferring smaller islets. Alien species introduced historically are still present, and other threats such as shipwrecks remain. We propose conservation and other measures that should adequately protect the birds, turtles and coral reef by treating the atoll as a system.

Keywords: Mauritius, Cargados Carajos, IBA, invasive species, marine debris

Online supplementary material: Tabulated supplemental and historic data is available online in Supplementary Appendix S1 at

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Introduction

Many seabirds breed on a large number of islands distributed throughout the tropical oceans and feed over the surrounding seas, lagoons, and coral reefs (e.g. Feare 1984, Harrison 1985). This makes changes in their population sizes difficult to determine (BirdLife International 2014a). Examples of threats to seabirds, turtles, and coral reef island ecosystems are guano collecting, over-fishing, poaching of birds, turtles and their eggs, chemical pollution, marine debris, solid waste, ships running aground, oil spills, and introduced species such as mammalian predators (Camphuysen et al. 2005; Post et al. 1998). In addition, hypoxia, as well as ocean temperature increase and acidification due to climate change, are global-scale threats that will most likely have impacts on seabird numbers and distribution (Doney et al. 2012; Inchausti et al. 2003). Therefore, in order to conserve and manage coral reef island ecosystems, it is necessary to know which and how many seabirds occupy which of these island ecosystems identify the threats, and propose appropriate conservation measures.

St Brandon's Rock (SBR, 16° 23' S, 59° 27' E), also known as Saint Brandon's, St Brandon's island, St Brandon's Atoll and Cargados Carajos, is a coral-reef atoll that is situated approximately 400 km north of Mauritius and belongs to the Republic of Mauritius (Post et al. 1998). It consists of 15 prominent sandbars and 24 vegetated islets in a coral reef and lagoon system that is 56 km long (north to south) and 22 km wide (Fig. 1; Government of Mauritius 1986, Post et al. 1998). The only economic activity is fishing and occasional tourism. There are no freshwater bodies on any of the islets.

Seabirds previously recorded breeding on SBR are sooty tern (*Sterna fuscata*), roseate tern (*S. dougallii*), lesser noddy (*Anous tenuirostris*), brown noddy (*A. stolidus*), fairy tern (*Gygis alba*, also known as white tern), red-footed booby (*Sula sula*), brown booby (*S. leucogaster*), masked booby (*S. dactylatra*), greater frigatebird (*Fregata minor*), lesser frigatebird (*F. ariel*), and wedge-tailed shearwater (*Puffinus pacificus*; Newton 1956, Staub and Gueho 1968, Newlands 1975, Williams and Rowlands 1980, Feare 1984). However, by 1997 it appeared as if the red-footed booby, brown booby, and the wedge-tailed shearwater were no longer breeding on SBR (Post et al. 1998). SBR was recognised as an Important Bird Area (MU016) in 2001, based on an estimate of 100 000 to 500 000 birds occurring there (BirdLife International 2014b).

The Endangered green turtle (*Chelonia mydas*) and Critically Endangered hawksbill turtle (*Eretmochelys imbricata*) (IUCN 2014) have a circum-tropical distribution and breed on SBR's beaches (Post et al. 1998). The green turtle's range extends more into temperate seas to the north and south of the tropics than that of the hawksbill turtle (Carr et al. 1966, van Dam and Diez 1996). Both species have been recorded migrating long distances between their nesting beaches and foraging areas (Carr et al. 1978, Miller et al. 1998).

A management plan suggested for SBR recommended that regular monitoring of seabird and turtle populations be undertaken (Post et al. 1998). Knowledge of trends in populations of the seabirds and turtles would identify any problems that may arise and inform conservation management. The present study was undertaken to: 1) count the number of birds and turtles using SBR, 2) assess if there were any changes in numbers compared to previous estimates of abundance, 3) characterise the atoll's constituent islets for their bird and turtle diversity, 4) identify the threats to SBR, and 5) suggest recommendations for its future protection.

Methods

A dedicated survey of the birds and turtle nesting activity on 30 of SBR's islets was undertaken from 25–30 October 2010. Transport to and from SBR was with the fishing vessel *La Derive* (Raphaël Fishing Co Ltd). Due to rough seas, it was not possible to land on North Island, one of the larger, more important, seabird islands in the atoll. Due to time constraints three small sandbar islets were not surveyed: Îles Tec Tec, Île Fou and Mapou. Supporting information on birds and turtles was obtained on an expedition to SBR in October 2014.

In 2010, counts were made of all birds, turtle tracks and turtle nesting pits on Baleine, Chaloupe, Île Cocos, Île Longue, Loup Garou, Petit Capitaine, Digier, Roseate Island, *La Derive*, Avocaire, Bouquet, Île Tortue, Petit Raphael South, Petit Raphael North, Île Raphael and Poulailier, where landings were effected (Fig. 1). Counts of birds and turtle tracks at Petit Dagorne, Grand Dagorne, Grand Dagorne South, Île Longue North, Verronge, Courson, Perle and Frégate were made from the boat. All surveys were during daytime and finished before dusk.

Transect counts were made to estimate numbers of birds at Grand Capitaine ($n = 9$), Île du Sud ($n = 9$), Île Paul ($n = 11$), Albatross ($n = 9$), Sirène ($n = 6$) and Puits à Eau ($n = 2$). The transects provided densities of birds and maps of colonies, which were used to determine their areas. All adult birds, eggs, nestlings, deformed and dead birds within 5 m of transects were counted on both sides. Using the coordinates of the start and end of each transect with GPS (Garmin 76S or Garmin Gecko), we determined the length of each transect in MapSource v 6.14 and hence the area covered by transects and the densities of birds. We scanned the 1:60 000 map of SBR (Government of Mauritius 1986) and imported it into OziExplorer version 3.95.4p using four-point calibration. We then traced an outline and calculated the surface area of each islet. We plotted transects on the map to demarcate and estimate the extents of bird colonies of each island.

We report numbers of individuals observed or estimated from extrapolation rather than pairs due to overlapping breeding windows and the presence of non-breeding adults or juvenile birds. More detail on breeding periods is provided Williams and Rowlands (1980) and in the Supplemental Materials.

All turtle tracks emerging from or re-entering the sea were counted and divided by two to determine individual nesting attempts on each islet. Tracks were identified to species based upon their width and the pattern of gait, with green turtle tracks being symmetrical and 100 to 130 cm wide, compared to hawksbill turtle tracks that are asymmetrical and 70 to 85 cm wide (Pritchard and Mortimer 1999). The numbers of nesting pits were also counted on each islet, although we did not determine whether a nest was successful or aborted. Nests were identified to species based upon the track leading to it.

On each islet we noted the presence of introduced species such as mice, rats, chickens, rabbits, domestic cats, and geckos. In addition, we conducted a survey of the marine debris that had washed up onto the shores of each islet although only the presence or absence of marine debris per islet is noted here.

To compare the biodiversity of the islets, we did a cluster analysis of each islet's bird and turtle composition (Tables 1 & 3), with Sørensen as distance measure and nearest neighbour as linkage method. For North Island, we used the latest available data (Post *et al.* 1998). Next, the bird and turtle data in Table 3 were ordinated together using non-metric multidimensional scaling (NMS), using the clusters identified as grouping variable. The surface area of each islet was used as an environmental variable. The data were relativized per islet (not per species) to accommodate the

large differences in numbers between islets. The starting configuration was set at random. Six axes and 500 iterations were allowed, with 250 runs with real data, and 250 runs with randomised data for Monte Carlo tests of significance of each dimensionality to test the probability of stress having been derived by chance. The final ordination was stress-tested. We used MjM Software PC-ORD version 6.07 (www.pcord.com).

Results and Discussion

Data are presented in Tables 1-4 and Figs. 1-3, with additional tables (S1-S3) and information in the online Supplementary Appendix S1.

Seabird populations and distribution

The number of adult birds of the 21 species estimated to be at SBR in October 2014 was 598 144 (total of Tables 1 & 2). Of these, the vast majority, 594 817 (99%), were of the seven species that breed on the islets, as evident from the presence of nests, eggs and nestlings (Table 3). The four most numerous bird species in descending order were sooty tern (450 493), lesser noddy (81 2008), brown noddy (45 503) and fairy tern (17 570) (Table 1). In addition, there were small breeding populations of roseate tern, lesser frigatebird and red-footed booby. We also estimated about 158 572 chicks on nests (Table S1). Assuming a 1-to-2 ratio for egg and two parents, that there were additional non-breeding adult birds, and taking into account that we did not count North Island, the entire population of adult birds could exceed 1.2 million.

In more detail, with reference to Fig. 1 and Table 1: Albatross Island had the largest breeding colonies of sooty tern (405 000), lesser noddy (49 500) and brown noddy (18 600), and the second largest breeding population of fairy tern (3 840). With an egg to parent ratio of 0.99 for sooty tern (Table S2), the number of breeding adults for this species on this islet alone may exceed 800 000. Île Paul had the largest breeding populations of fairy tern (6 000) and red-footed booby (69), the second largest colony of lesser noddy (8500), and the fourth largest colonies of sooty tern (320). Puits à Eau had the second largest breeding colony of sooty terns (41 300). Sirène had the second largest breeding colony of brown noddy (9 920) and the third largest populations of sooty tern (3 860) and fairy tern (3 540). Île du Sud had the third largest breeding colony of lesser noddy (8 130). Grand Capitaine had the largest breeding colony of lesser frigatebird (65) and the fourth largest breeding colonies of lesser noddy (7 200) and fairy tern (1 830). Île Cocos had the largest breeding colony of roseate tern (241); the second largest colony (21) was on Chaloupe. We could not land on North Island during this visit, but it was an important breeding ground for red-footed boobies and lesser frigatebirds in 1997 (Post et al. 1998). No wedge-tailed shearwaters were seen in 2010 or 2014 but fishermen told us that they were some on North Island. Our surveys were during daytime and finished before dusk – therefore wedge-tailed shearwaters may have been missed if they were present. North Island may be the last hold-out for the wedge-tailed shearwater, last seen in the mid-1950s (Staub and Guheo 1968). Although not actively searched for (our surveys were during daytime), we did not see any nesting burrows. North-Island is probably the least well-known of the atoll and requires a further visit.

The remaining <3 000 birds of 13 species were Palaearctic migrants visiting SBR during the northern winter (Tables 1 & 2) (del Hoyo et al. 1996). Various waders were observed including ruddy turnstone (*Arenaria interpres*), whimbrel (*Numenius phaeopus*), and curlew sandpiper (*Calidris ferrunginea*). These were seen as singletons or in loose aggregations on many of the islets. The

remoteness of SBR from other island groups in the Indian Ocean may make it an important stop-over or final destination for small numbers of migratory or vagrant birds. Projected climate change and sea level changes may alter the importance of SBR in this regard (Courchamp et al. 2014). However, the predominantly sandbar islets are dynamically increasing in height and size with various storms, but they should be closely monitored.

The cluster analysis identified seven clusters at 40% information remaining. The percent chaining was 31.3%. These seven clusters were used as grouping variable for the NMS ordination. The NMS ordination derived three axes, of which only one and two are shown (Fig. 2). Axis 1 explained 40.1% of the variation, axis 2, 25.5%, and axis 3, 19.2%. The final stress was 11.9, and the final instability was 0.00962. Kruskal indicates that a final stress of between 10 and 20 provides a usable picture (McCune and Grace 2002).

Sooty tern, red-footed booby, lesser noddy and lesser frigatebird had a strong association with the larger northern islets (groups 1, 3 and 7) in the same direction as the surface area vector such as Albatross, North Island, and Puit à Eau, but also île Cocos in the south (Fig. 2). With opposing vectors, brown noddy and roseate tern associated with most of the smaller southern islets. Interestingly, fairy tern ordinated opposite to brown noddy, but occurred on most islets, large and small. Perpendicular to the surface area vector, the green turtle and the major non-breeding migratory birds were less selective or influenced by the size of the islets.

Seabird populations and trends

There have been previous surveys of birds on SBR (Newton 1956, Staub and Gueho 1968, Newlands 1975, Williams and Rowlands 1980, Post et al. 1998, Tataya and Khadun 2002), the data of which are summarised in Table S1. Post et al. (1998) may have underestimated the number of seabirds on SBR in 1996 and 1997 (Table S5) or there may have been poor breeding in those years. For this reason, data from Post et al. (1998) were not used in the assessment of seabird abundance changes per islet. Assuming comparable survey methods, we deduced the following trends from Tables 1 and S1:

- Newlands (1975) surveyed Sirène, île Raphael, Poullailier and Puit à Eau and recorded 125 000 sooty terns and 58 fairy terns. For the same four islets, the present study recorded 45 160 sooty terns and 3565 fairy terns. Prolonged presence of rats at Puit à Eau was most likely the reason for the discrepancy.
- The breeding colony of sooty terns on Poullailier has decreased by the largest amount, from 40 000 birds in the 1970s (Newlands 1975) to locally extinct by 2010. In the mid-1960s, Poullailier was home to more than 6500 sooty terns (Table S1) (Staub and Gueho 1968).
- The breeding colony of sooty terns on Sirène declined from 80 000 birds in the 1970s (Newlands 1975) to only 3 860 birds in 2010. However, in the mid-1960s there were only about 1 000 sooty terns on Sirène (Table 6) (Staub and Guheo 1968).
- Fairy terns on île Raphael decreased from 58 in the 1970s to 25 in 2010. The 2010 survey recorded 3540 fairy terns on Sirène, whereas Newlands (1975) did not record any.
- Newlands (1975) and the 2010 study did not record any fairy terns on Poullailier or Puit à Eau.

With the little comparable data available, it seems that the overall numbers and number of breeding species for SBR have decreased over time. Differences in breeding windows on the different islets and possible occasional local relocation of breeding colonies probably obscure any definite trends, so that regular and standardised surveys should be conducted. With an estimated 1.2 million birds in 2010, one can assume that enough of a buffer remains, at least for the smaller species, while

concern should be expressed about the lesser frigatebird and red-footed booby. Feare (1984) also expressed serious concerns about the boobies in the Indian Ocean.

Due to a lack of comparable data, we could not assess trends in non-breeding sea- and shorebirds. However, because of the isolated nature of SBR (400 km away from the next nearest land, Mauritius, with Rodrigues, Agalega, and Cosmoledo Atoll in the Seychelles further away, Rocamora et al. 2003), the importance of SBR as a stopover or final non-breeding ground needs further investigation.

Timing of bird breeding throughout SBR

The time of year and number of adult birds per egg or nestling counted (Table 2), suggest that the sooty terns on Albatross and Sirène were near the peak of the on-going round of breeding, but may have already passed it on Puit à Eau (see Supplemental Materials for considerations and Table S1). Sooty terns breed synchronously on an island but asynchronously between islands. For lesser noddy, only the colony on Île Tortue was near the peak of breeding, but past it on the remaining nine islets (Table 2). Brown noddy was past the peak of breeding on all 13 islets at which they were breeding, but especially on Bouquet and Île Tortue. Fairy terns on Île Longue, Bouquet, Île Tortue, Île Paul and Albatross were all near the peak of breeding, but past it on the other six islets where they were breeding. Roseate terns on Digier and Roseate Island were near the peak of breeding, but past it on Chaloupe and Île Cocos. Lesser frigatebird and red-footed booby were recorded breeding on Île Paul where they both were past the peak of breeding (Tables S1).

We can therefore assume that breeding is not always synchronous between different islets and species at SBR, a condition that may be advantageous, but should be protected and managed as such (see Rocamora et al. 2003, Feare et al. 2007, Jaquemet et al. 2007, Jaquemet et al. 2008, and Catry et al. 2009 for more on the breeding phenology of seabirds in the western Indian Ocean). Visits to some of the islets by tourists or for other reasons could be restricted to certain periods of the year, but this would require regular monitoring.

Turtle populations and distribution

We observed 276 green turtle tracks on 15 islets, and 539 green turtle nesting pits on 11 islets (Table 4). We recorded no hawksbill turtle tracks in 2010, although we observed a single adult at sea near to Ile Tortue. In 2014 however, we observed four hawksbill turtles close to Ile Tortue, and 13 near Grand Dagonne in a disturbed area overgrown by algae.

Based on the number of tracks on beaches, the five most important islets for green turtles in descending order of importance (based on numbers alone) were Île Cocos, Puit à Eau, Albatross, Sirène, and Grand Dagonne South (Table 4). The order of importance is similar considering the number of nests, with Frigate replacing Grand Dagonne South and the addition of Île Tortue as the only changes (Table 4). The remaining islets contained 0–6 tracks or nests. Previously, North Island was, based on the number of tracks, the most important for green turtles (Post et al. 1998). In addition, local fishermen informed us that hawksbill turtles laid eggs on Île Tortue in November 2013.

Threats and their trends

The number of islets infested with rats (*Rattus rattus*), mice (*Mus musculus*), chickens (*Gallus gallus domesticus*), and geckos (*Hemidactylus frenatus* and *Lepidodactylus lugubris*) has increased from the 1970s and 1990s to 2010 (Table S2). From the 1970s and 1990s to 2010, the number of

islets infested with rabbits (*Oryctolagus cuniculus*) has remained the same. Despite Île du Sud being inhabited by people, rats have never been recorded (Table S2). Rats, mice, rabbits, chickens and geckos (the latter three are no threat to birds or turtles, but included here for completeness) were recorded on islets from which guano was extracted in the past (Tables S2 & S3). The exception is rats on Poulailier, which has never been occupied by people and has never seen guano extraction (Tables S2 & S3). At low tide however, it is sometimes possible to pass from Île Raphael, the nearest islet to Poulailier. Île Raphael has both human inhabitants and rats, and the nearest distance between them is approximately 900 m (Fig. 1), well within swimming distance for rats. There is a similar distance between Poulailier and Puit à Eau on which rats were also recorded (Table S2 & Fig. 1) (Newlands 1975, Post et al. 1998). Further, it is occasionally possible to pass between these three islets at seasonally low tides. There have been efforts from the Raphaël Fishing Co Ltd to eradicate rats from Île Rafael, without success.

Guano extraction ended in the 1960s (Post et al. 1998). Seabird and turtle poaching incidents appear to have decreased over time on SBR (Table S3), probably due to education of the rotating personnel by the Raphaël Fishing Company. However, additional fishing permits were recently granted which allows small temporary human settlements on islets such as Îles Tec Tec (occupied since 2012). This may increase poaching. Fish processing (four islets) and human habitation (eight islets) has decreased to only three islets by 2010 (Table S3) and four by 2014.

Sooty terns entangled in marine debris were found on Poulailier and Albatross in 2010 (Table S3). In 2014, we encountered five dead noddies on Courson; three were trapped in discarded fish traps, one was entangled in rope from one of the traps, while the cause of death of the fifth could not be determined. Solid waste from past and current inhabitants is evident on the four inhabited islets with marine debris washed up on all shores (Table S3).

Burning of vegetation to control ticks occurred on Courson and Île du Sud (Table S3) (Post et al. 1998). During the 2010 survey, there were no signs of vegetation burning on any of the islets surveyed, but there were signs of a burning of waste on Courson in 2014.

Human occupation on the different islets of SBR varies slightly between years. In 2010, there were 48 people consisting of fishermen and staff of the National Coast Guard and Mauritius Meteorological Services on three islets, and in 2014 there were 41 people on four islets, all on a rotational basis. The numbers of pleasure craft visiting SBR were low until 2010 (less than five per year), but has been increasing yearly to 15-20 by 2014 (J. Mervin pers. obs.). Access to SBR is restricted and requires special permits, except for Mauritian vessels. Increased unsupervised private visits to SBR might constitute a future threat to sensitive nesting birds and turtles from direct disturbance, inappropriate waste management, and the introduction of invasive alien species.

Shipwrecks, mainly of fishing vessels, occur on SBR about once every two years. The frequent storms and cyclones move the wreckage across the reef through the shallow lagoons until they eventually disappear into deeper waters. In September 2012, a recently refurbished and repaired fishing vessel ran aground near Grand Dagorne. Soon after, the wreck broke up in storms, a green filamentous alga started to spread from near the wreckage covering a huge area. This alga does not dominate any other part of the reef. Presumably, freshly applied anti-foulant was released from the hull due both to its freshness and to abrasion of the hull. The large area affected by the algae may reduce the foraging area for birds, affect the spawning grounds for reef fish, and affect the turtles that may feed on the algae. A yacht participating in the Volvo Ocean Race also ran aground in November 2014; shipwrecks are a potential source of additional invasive alien species reaching the atoll.

Conservation of St Brandon's Rock

Of the species found on SBR in 2010, only the Eurasian curlew is considered to be globally Near-threatened; all the other species are of Least Concern (Tables 1 and 2; IUCN 2014; BirdLife International 2014a). However, SBR has been recognised as a marine IBA (Barnes 1998, Fishpool and Evans 2001). The archipelago on a regular basis holds $\geq 1\%$ of the global population of four congregatory seabirds (Tables 1 & 2). The maximum global population estimates for sooty tern, lesser noddy, brown noddy and fairy tern are 22 million, 1.2 million, 1.1 million, and 1.1 million birds (the last figure is from a 2009 estimate of "poor quality"), respectively (BirdLife International 2014a). Using these maximum global population estimates and the results of the present study (using counted birds only) SBR holds 2.0%, 6.8%, 4.1%, and 1.6% of the global populations of sooty tern, lesser noddy, brown noddy, and fairy tern, respectively. Albatross Island alone holds 1.8%, 4.1%, and 1.7% respectively, of the maximum estimated global populations of sooty tern, lesser noddy, and brown noddy. Île Paul holds 1.0% of the global population of fairy terns. If the numbers of adults are doubled due to birds being away from nests and non-breeding adults foraging away from the islets, then the percentages of the birds at SBR above would double. An inventory of sooty terns in the western Indian Ocean estimated 6 200 000 pairs, with 20 000 pairs (0.3% of the total) for SBR (Feare et al. 2007). Assuming 400 000 pairs on SBR revealed by this study, SBR hosts 6.5% of the western Indian Ocean population, indicating the regional importance of SBR.

In essence, small and large islets are important to different breeding bird species (NMS ordination in Fig. 2.). Therefore, both sizes of islets need protection; large islets house large colonies of abundant species and small islets harbour less numerous breeding species. The small islets seem to allow brown noddy and roseate tern to maintain their presence away from the large colonies of Sooty Tern. Non-breeding migratory bird species and green turtle seem less dependent on islet size.

Island biogeography (MacArthur and Wilson 1967) predicts an increase in species richness with an increase in surface area. Santos *et al.* (2010) analysed biodiversity datasets of 97 archipelagos and concluded that archipelagos can in most cases be seen as distinct entities. They found that smaller constituent islets have lower species richness than the larger ones, but only in few cases does the species richness on the largest islet equal the total species richness for the archipelago. There are therefore species that occur only on smaller islets. Concurrently, species richness also increases with an increase in habitat diversity (Hortal et al. 2009). The combination of small and large islets in SBR thus offers a variety of habitats that are differentiated by species preferences for either breeding synchronously in large colonies on large islets (sooty tern), as small colonies on small islets (roseate tern), as loose aggregations (synchronous or asynchronous) on both small and large islets (brown noddy and lesser noddy), and the ability of some species to breed as single pairs seasonally but with less synchrony on small islets (fairy tern). Although there is an obvious dynamic in breeding between islets (e.g. the sooty tern), this allows some buffer for breeding failures, especially for large colonies.

Conservation of poorly studied taxa on islands also benefit from protection of better-known bird and mammal diversity (Aslan et al. 2014). As mentioned before, SBR remains less well known for taxa other than birds. Island biogeography theory therefore supports the notion of managing and conserving isolated atolls such as SBR in its entirety.

St Brandon's Rock as an Important Sea Turtle Area

Since the early 19th Century, marine turtle populations within the Republic of Mauritius (Mauritius,

Rodrigues, Agalega, and SBR) have declined considerably due to demand for meat, eggs and shells (Mangar and Chapman 1996). Rarely now do turtles nest on mainland Mauritius and Rodrigues because of high levels of disturbance and coastal development on favourable nesting beaches. Turtles still nest on Agalega, but from a recent survey, nesting activity appears to be much lower than we observed on SBR (Webster and Cadinouche 2013). Furthermore, the harvesting of turtles and eggs on Agalega is ongoing (Griffiths and Tatayah 2007, Webster and Cadinouche 2013) and more prevalent than detected on SBR (Table S3). Our observations demonstrate that SBR is the most important nesting ground for green turtles and possibly for hawksbill turtles within the Republic of Mauritius. The conservation of SBR would support the protection of turtle nesting grounds and support regional efforts to conserve these threatened species.

Recommendations

Additional government conservation measures should be afforded to SBR beyond its recognition as a Marine Important Bird Area which was based on a previous estimate of 100 000 to 500 000 birds occurring there (BirdLife International 2014b). We also propose a boundary for such a conserved area as in Fig. 3 (70X100 km). With better information on shoals and undersea mountains, the boundary can be adapted later. The total area of the proposed St Brandon's conserved area is 6 300 km² that includes approximately 260 km² of coral reef, lagoon, and shallow water and approximately 5 km² of land and tidal flats (Fig. 3). This additional protection of the atoll is warranted on ecological and biodiversity grounds and can be enforced if wardened. The development of a conservation management plan is needed for the entire atoll rather than piecemeal efforts. Relevant eradication programmes for rats and other invasive species should be established to allow recolonization of islets now lacking nesting birds. The removal of rats, mice and rabbits from the archipelago is achievable, but suitable biosecurity protocols would need to be in place to prevent reinvasion from Mauritius or elsewhere. Special measures should be considered to reduce disturbance during the breeding season, particularly on islands with sensitive species. Roseate terns, e.g., are very skittish breeders, and their chicks tend to run into the sea when disturbed and more often than not die, not being able to make it back to shore.

Marine debris should be removed on a regular basis, but the logistical implications are enormous. Since the high amounts of marine debris is not of local origin (based on unpublished surveys done in 2010) preventative international measures should be improved. An extended biodiversity assessment of both the terrestrial and marine ecosystems is needed. From our cursory inspections, the reefs of SBR house many fish and coral species. Post (1997) already lists many of these. From experience based on two research expeditions (2010 and 2014), the establishment of a facility from which to base biodiversity research and conservation operations would be highly supportive in reaching conservation targets and may reduce poaching merely by its presence and outreach. Such a facility will also allow obtaining long-term and more defined data on all aspects of the biodiversity of SBR and can therefore serve a representative station to research and monitor the effects of changes in climate, ocean pH, and pollution on biodiversity.

Conclusions

In the vast Indian Ocean, the few relatively predator free oceanic islands that can maintain large and viable colonies of breeding birds and breeding beaches for turtles are rare. Especially with the global changes now affecting all small island and coral reefs in the tropics, the mostly unspoilt nature of much of SBR presents an important conservation opportunity. The Indian Ocean is the world's third

largest, yet is relatively unknown from many natural history respects. This ocean will play an increasing role in the future due to trade, development, natural resource exploitation, and conflict. The data presented here offers convincing evidence for identifying opportune and timely conservation, monitoring and scientific actions. SBR is one such opportunity that is achievable with concerted effort. We have shown that the planning of conservation efforts must be based on the atoll as a system.

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Supplementary materials

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Protection of marine birds and turtles at St Brandon's Rock, Indian Ocean requires conservation of the entire atoll

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Considerations for the breeding cycle of marine birds on SBR

Sooty tern (Conover 1984), lesser noddy (Surman and Wooller 1995), brown noddy (Conover 1984; Morris and Chardine 1992), lesser frigatebird (del Hoyo et al. 1992), fairy tern (del Hoyo et al. 1996) and red-footed booby (del Hoyo et al. 1992) produce single egg clutches. Roseate terns sometimes produce one, but mostly two-egg clutches (Ramos 2001; Tree 2005). The number of adult birds per egg or nestling (EN) for the time of year provides a measure of where in the breeding cycle the seven breeding species on SBR were. For birds that produce single- or two-egg clutches, there should be two or one adult birds for every EN and consequently a ratio of between 1 and 2; this means that the species are near to the peak of the breeding season. We did not distinguish between viable and addled eggs during the survey. This might exaggerate the number of viable eggs, which could result in an overestimation of EN. Historical data of seabird populations on SBR are not available for all of the islets. Consequently, we could only compare changes in seabird populations for the subset of islets surveyed during the current study with one or more of the previous surveys.

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Table S1: Summary of all information available for counts of individuals of breeding seabirds for St Brandon’s Rock.

	Year	Month	Albatross Island	Avocaire	Baleine	Bouquet	Grand Capitaine	Petit Capitaine	Chaloupe	Courson	Digier	Grand Dagonne	Grand Dargorne South	Petit Dargorne	Frégate	Île Cocos	Île du Sud	Île Longue	Île Paul	Île Raphael	Petit Raphael	Petit Raphael South	Île Tortue	Loupe Garou	North Island	Perle	Poulailler	Puits a Eau	Roseate	Sirène	Verronge	REF	
Sooty tern	1955	January																								P	P					Newton 1956	
	1963-65	Nov-Dec	> 2 500																						> 500	> 6 500	>500		> 1 000			Staub and Gueho 1968	
	1970s																									40 000	5 000		80 000			Newlands 1975	
	1971	Jul-Aug	B																	P				P		B	B					Williams and Rowlands 1980	
	1996	Oct-Nov																														Post et al. 1998	
	1997	May	>50 000																					10 000		10 000	30 000					Post et al. 1998	
	2002	May																		P												Tatayah and Khadun 2002	
	2010	Oct	405 000				P		1					8					320			4						41 300		3 860			This study
Lesser noddy	1955	January					P								P	P	P	P	P	P				P	P	P	P	P	P			Newton 1956	
	1963-65	Nov-Dec	P	P			P			P					P	P	P		P	P			P		P	P	P	P	P			Staub and Gueho 1968	
	1970s																																Newlands 1975
	1971	Jul-Aug	B				B									B	B		B	B			B		B					B			Williams and Rowlands 1980
	1996	Oct-Nov								>200																							Post et al. 1998
	1997	May	1 000	1 000	40		1 000			100						1 000	2 000	>2	2 000	100	100				1 000					2 000	40		Post et al. 1998
	2002	May															P															Tatayah and Khadun 2002	
	2010	Oct	49 500	564		2	7 200		6				3	1	2	2 210	8 130	19	8 500	215			124								4 730		
Brown Noddy	1955	January					P									P	P	P	P	P				P	P	P	P	P	P			Newton 1956	
	1963-65	Nov-Dec	P	P			P			P					P	P	P		P	P			P		P	P	P	P	P			Staub and Gueho 1968	
	1970s																																Newlands 1975
	1971	Jul-Aug	B				B			B		B*		B*			B		B		B		B		B					B			Williams and Rowlands 1980
	1996	Oct-Nov																															Post et al. 1998
	1997	May	1000	1000	40		90			100						1 000	2 000	>2	2 000		>2									2 000	40		Post et al. 1998
	2002	May					P										P															Tatayah and Khadun 2002	
	2010	Oct	18 600	3	84	335	7 990	63	29	35	58	119	8	18		279	1 300	20		6 220			287	27				2	2	9 920	2		This study
Fairy Tern	1955	January					P*	P*								P	P	P	100*						P	P	P	P	P			Newton 1956	
	1963-65	Nov-Dec	P	P			P*	P*		P					P	P	P		P	P			P		P	P	P	P	P			Staub and Gueho 1968	
	1970s																			58													Newlands 1975
	1971	Jul-Aug	B	B		B	B	B		B		B*	B*	B*		B	B		B	B	B		B		B					B			Williams and Rowlands 1980
	1996	Oct-Nov								>200							P																Post et al. 1998
	1997	May	>200	1000	40		90*	90*		100						1 000	2 000	>2	2 000	100	>2				1 000			40					Post et al. 1998
	2002	May					P																									Tatayah and Khadun 2002	
	2010	Oct	3840	138	9	91	1 830	4	1	18	2	4	6		30	607	1 380	5	6 000	25	9		28							3 540	1		This study
Roseate Tern	1955	January					24*	24*								>2				7	1											Newton 1956	
	1963-65	Nov-Dec	P	P			P*	P*		P					P	P	P		P	P			P		P	P	P	P		P		Staub and Gueho 1968	
	1970s																																Newlands 1975
	1971**	Jul-Aug				P											P	P					P										Williams and Rowlands 1980
	1996	Oct-Nov																															Post et al. 1998
	1997	May					30*	30*																									Post et al. 1998
	2002	May					P*										P															Tatayah and Khadun 2002	
2010	Oct			4			14	21		6					241		7			1									18			This study	

Greater Frigate Bird	1955	January		>200*	>200*			>20			Newton 1956
	1963-65	Nov-Dec	P	P*	P*		P	P			Staub and Gueho 1968
	1970s										Newlands 1975
	1971**	Jul-Aug	B	G			B	B P			Williams and Rowlands 1980
	1996	Oct-Nov									Post et al. 1998
	1997	May									Post et al. 1998
	2002	May									Tatayah and Khadun 2002
	2010	Oct									This study
Lesser Frigate Bird	1955	January	>10	P*	P*		>10		1		Newton 1956
	1963-65	Nov-Dec	1 000	500*	500*		500	P			Staub and Gueho 1968
	1970s										Newlands 1975
	1971**	Jul-Aug	B	B			B	B	B		Williams and Rowlands 1980
	1996	Oct-Nov		14*	14*			300			Post et al. 1998
	1997	May			50 0						Post et al. 1998
	2002	May					P				Tatayah and Khadun 2002
	2010	Oct		65			2	30			This study
Wedge-tailed Shearwater	1955	January							6	>2	Newton 1956
	1963-65	Nov-Dec							50		Staub and Gueho 1968
	1970s										Newlands 1975
	1971**	Jul-Aug									Williams and Rowlands 1980
	1996	Oct-Nov									Post et al. 1998
	1997	May									Post et al. 1998
	2002	May									Tatayah and Khadun 2002
	2010	Oct									This study
Masked Booby	1955	January		P?*	P?*		P? P?	P? P?	400 P?	P? P?	Newton 1956
	1963-65	Nov-Dec							400		Staub and Gueho 1968
	1970s										Newlands 1975
	1971**	Jul-Aug							B		Williams and Rowlands 1980
	1996	Oct-Nov									Post et al. 1998
	1997	May									Post et al. 1998
	2002	May									Tatayah and Khadun 2002
	2010	Oct									This study
Red-footed Booby	1955	January									Newton 1956
	1963-65	Nov-Dec									Staub and Gueho 1968
	1970s										Newlands 1975
	1971**	Jul-Aug									Williams and Rowlands 1980
	1996	Oct-Nov									Post et al. 1998
	1997	May							200		Post et al. 1998
	2002	May									Tatayah and Khadun 2002
	2010	Oct						69			This study

* Combined count for the two islands

** Also present on Zo Zo Posé (Unknown to us)

Sea-birds and turtles of St Brandon's Rock

Table S2: The presence (P) at different islets of introduced species on St Brandon's Rock in November 1963 and 1964 and December 1965 (Staub and Gueho 1968), the 1970s (Newlands 1975), January–February 1996 (Mauritius Wildlife Foundation 1996), May 1997 (Post et al. 1998), 2005 (O. Maurel, Raphael Fishing Co. Ltd., pers. obs.) and October 2010, our 2010 expedition

Islet	Rat				Cat			Mouse				Rabbit			Chicken				Indian Grey Partridge	Gecko		
	1970s	1996	1997	2010	1963–1965	1996	2005	1970s	1996	1997	2010	1970s	1996	2010	1970s	1996	1997	2010	1963–1965	1996	1997	2010
Baleine																						
Île Cocos						P	P		P		P					P				P		P
Île Longue																						
Loup Garou																						
Grand & Petit Capitaine																						
Avocaire										P	P	P					P	P			P	
Île Tortue																						
Petit Raphael South				P																		
Petit Raphael North																						P
Île Raphael		P	P	P		P?			P?	P			P?	P		P				P	P	P
Poulailler	P	P	P	P																		
Île du Sud								P			P			P			P	P				P
Île Paul																	P	P				
Albatross Island	P				P	P?	P		P	P	P	P	P?	P	P	P?		P	P	P	P	P
Sirene	P		P?	P																		
Puits a Eau	P	P	P	P																		
Grand Dagorne																						
Courson (1997)																						
Perle			P?																			
Frégate			P																			
North Island																						
No. of islands	4	3	4 + 2?	5	1	1 + 2?	2	1	2 + 1?	3	4	2	2?	2	1	2 + 1?	3	4	1	3	3	5

Sea-birds and turtles of St Brandon's Rock

Table S3: Evidence of threats to the birds and turtles of St. Brandon's Rock in November 1963 and 1964 or December 1965 (Staub & Gueho 1968), May 1997 (Post *et al.* 1998), October 2010 and October 2014, our expeditions

	Bird poaching			Turtle poaching			Guano digging		Marine debris		Entangled birds		Solid waste*			Human Habitation		Fish Processing	Vegetation burning	
Islands	1963–1965	1997	2010	1997	2010	2014	1963–1965	1997	1997	2010	2010	2014	1997	2010	2014	2010	2014	2010	1997	2010
Baleine									yes	yes										
Île Cocos									yes	yes				yes	yes**	past	yes	past		
Île Longue									yes	yes										
Grand & Petit Capitaine	yes	past							yes	yes										
Avocaire									yes	yes			yes	yes		yes		yes		
Île Tortue									yes	yes										
Petit Raphael									yes	yes										
Île Raphael		past		past		yes			yes	yes			yes	yes	yes	yes	yes	yes		
Poulailler		yes			yes				yes	yes	yes									
Île du Sud	yes		yes		yes				yes	yes			yes	yes		yes	yes	yes	yes	
Île Paul	yes	yes							yes	yes										
Albatross Island	yes	yes		yes			??	1960s	yes	yes	yes					past				
Sirene							yes	1960s	yes	yes										
Puits a Eau		yes		yes					yes	yes						past				
Grand Dagorne									yes	yes					wreck					
Îles Tec Tec															Yes		yes	yes		
Courson		yes							yes	yes		yes			yes				yes	
Perle								1960s	yes	yes						past				
Frégate		1960s						1960s	yes	yes						past				
North Island		yes					??	No	yes	yes										
No. of islands		9		3	2			4	19	18			3	3		8		4	2	0

* Excludes marine debris

** Solid waste being removed