Status and trends of White-tailed Tropicbirds *Phaethon lepturus* in the Seychelles.

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**Abstract**

The successful design and implementation of monitoring programmes is an important tool in the effective management of biodiversity, especially in developing nations where resources are scarce and threats are high. Here we use the monitoring programmes of White-tailed Tropicbirds (Phaethon lepturus; a key Indian Ocean breeding seabird )in the Seychelles as a case study to review the effectiveness of these programmes, particularly with regards to determining the national conservation status of P. lepturus. We combined monitoring efforts from five of the region’s most vital nesting sites and present the first regional summary on the level and trends of breeding success at each of the sites. At Aldabra atoll on average 15.2% of nests were successful compared with 33% on Cousin Island, 40.2% on Aride Island, 51.6% on Cousine Island and 55% on Denis Island. In addition, at Aldabra there was a significant negative temporal trend in breeding success observed. The Aride Island population showed a continuous negative trend in nest density, whereas the Cousine island nest density increased. The strengths and weaknesses of the current programmes are discussed and recommendations are made to improve the effectiveness of these conservation efforts and streamline the monitoring programmes for *P. lepturus* across the Seychelles.

Keywords: Seychelles, Tropicbirds, Management, Ecology, Breeding

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**Introduction**

Effective biodiversity monitoring programmes are integral to the conservation of biodiversity, providing managers with science-based evidence to make effective management plans. However, poorly designed monitoring programmes or lack of institutional capacity often result in data piling up. Without rigorous and regular analysis, programmes are unable to fulfil their original aims—delivering information on trends in key aspects of biodiversity, providing early warning of problems, generating evidence of conservation success or failure and highlighting ways to make management more effective (Lindenmayer et al. 2012). Often monitoring programmes within a region are carried out at multiple sites but with little management connectivity in aims, methods and results. Coordinating biodiversity monitoring programmes between sites can potentially increase the effectiveness of the results obtained, reduce costs of protecting biodiversity and improve the efficient allocation of limited conservation resources (Punt *et al.*, 2012; Mazor, Possingham and Kark, 2013; Montesino Pouzols *et al.*, 2014; Dallimer and Strange, 2015). But large-scale comparisons of monitoring programmes are scarce, making it difficult to define regional conservation status for important species and determine the effectiveness of national efforts and produce good recommendations. Here we use the monitoring programmes of White-tailed Tropicbirds (*Phaethon lepturus;* a key Indian Ocean breeding seabird)in the Seychelles as a case study to review the effectiveness of these programmes, particularly with regards to determining the national conservation status of P. lepturus.

The Western Indian Ocean has recently been identified as a key area to prioritize for the conservation of global marine biodiversity in the face of climate change (Ramírez et al. 2017). With 115 islands stretching across an exclusive economic zone of 3.2 million km2,the Seychelles is a challenging location for articulated monitoring efforts. Biodiversity monitoring programmes are widespread across the Seychelles islands and if successfully designed and implemented they have potential to form an integral role in informing conservation management. The Seychelles supports the greatest abundance of tropical seabirds in the Indian Ocean, estimated to be ca 3.4 million pairs (le Corre et al. 2012). It is the main breeding ground for White-tailed Tropicbirds (*Phaethon lepturus)*, with anestimated 56% of the Western Indian Ocean breeding population (le Corre et al. 2012). As a pelagic species with large home ranges, monitoring of a single location is often not enough to assess regional trends. Fortunately, monitoring of *P. lepturus* breeding success has been conducted on a number of Seychelles islands. *P.lepturus* has been the focus of monitoring efforts, firstly because of convenience; it is one of the most ubiquitous seabird species and one of the most easily accessible to monitor due to its being a ground nester (Burger and Lawrence 2000); and secondly because it is considered to be an important indicator species, whose status reflects or predicts the condition(s) of the broader environment.

Seabirds, as long-lived top marine predators, possess several attributes that make them useful as environmental indicators (Einoder, 2009), as they provide both a measure of health of the species as well as an indication of overall state of the surrounding ecosystem (Parsons et al. 2008; Piatt et al. 2007). *P. lepturus* is a pelagic seabird that undertakes long foraging trips and feeds mainly on surface-dwelling prey, such as flying fish and squid (Schreiber & Clapp 1987; Catry et al. 2009). This specificity of their foraging strategy limits their rate of provisioning when these particular food sources are scarce (Schaffner, 1990) and therefore directly relates to chick rearing success (breeding success). Additionally, *P. lepturus* is ground nesting (Burger and Lawrence 2000) and therefore nesting success is highly susceptible to habitat integrity and environmental perturbations such as climatic variations (Ancona et al. 2011) and invasive alien species (Russel and Le Corre, 2009).Determining trends in this indicator species at a regional scale is an essential first step for effective management of this species as well as for providing an early warning system of broader scale environmental changes.

Although *P. lepturus* is listed as ‘Least Concern’ on the IUCN red list, the species is suspected to be in decline owing to predation by invasive species at nesting sites (IUCN Red List). However, despite the monitoring programmes in place across the Seychelles, the national conservation status of *P. lepturus* is unknown. Neither is it clear whether the monitoring programmes in place are adequate to answer the questions of population and breeding status or broader environmental change. Here, for the first time, we compile national multi-island monitoring data of *P. lepturus* in the Seychelles to: (1) identify trends in breeding success across sites; (2) assess trends in nesting density across sites, where possible; (3) identify trends in breeding seasonality across sites, where possible. Lastly, we aim to use these results to determine the national conservation status of *P. lepturus* in the Seychelles and make recommendations to improve effectiveness of monitoring efforts.

**Material and methods**

**Study Sites**

We analysed data available from five islands in the Seychelles: Aldabra Atoll, Aride Island, Cousin Island, Cousine Island, and Denis Island (Figure 1). These sites cover the main breeding sites in Seychelles for *P.lepturus* where monitoring occurs (Aldabra, Cousin, Cousine & Aride) as well as Denis island, of which little is known about the *P.lepturus* population. The sites vary in size, geomorphology, elevation, protected status, management types, predator threats and estimated *P. lepturus* population size (Table 1). Although other islands also have *P. lepturus* breeding populations, most are not monitored.

All the monitoring programmes were developed separately, and despite being based on the guidelines developed by a local NGO, Nature Seychelles, in the “Seabird monitoring handbook for Seychelles” (ref, date), guidelines are limited to a description of the methods to obtain breeding success data, and not specifically how to set up a long-term monitoring programme. The studies varied in area covered, monitoring duration, frequency, methods and monitoring area habitat type (Table 2).

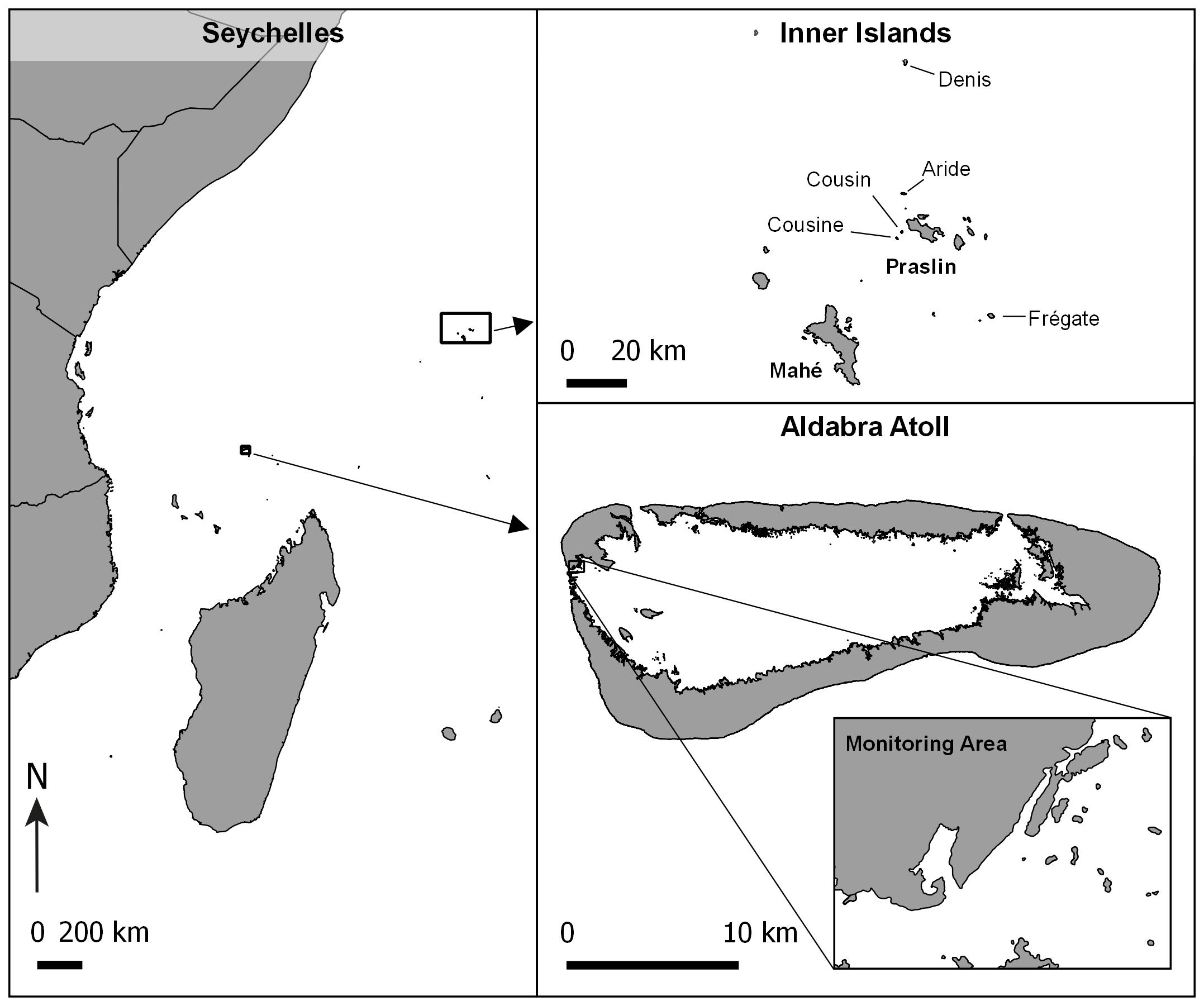


Figure 1: Map showing the location of the Seychelles within the South-West Indian Ocean region and the five monitoring site locations (Aldabra, Cousin, Aride, Cousine and Denis) within the Seychelles from which data was used for the study of *P. lepturus* breeding success.

Table 1: Details of the five study locations in the Seychelles where data was collected for the study of *P.lepturus* breeding success.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Island** | **Protection status** | **Land area (ha)** | **Geomor-phology** | **Location** | **Max height asl (m)** | **Management** | **Population estimates** | **Nest predators** | **Other Disruptive\* species** |
| Aldabra Atoll | UNESCO World Heritage site (1982); Special Reserve (1975) | 15,254 | Coralline | 9.2255**°**S,  46.1310**°**E | 8 | Public Trust | 2000 pairs 1 | Black rat*,* grey heron, Aldabra drongo4  Coconut crab1 | Red-tailed tropicbirds4 |
| Aride | Special Reserve (1975) | 74 | Granitic | 4.2000**°**S, 55.6667**°**E | 134 | NGO | 1,446 pairs 2 | Seychelles skink, wright’s skink and Seychelles fody5 | *Pisonia grandis* 4 (bird-catcher tree), big headed ants4 (until 2016), ticks. |
| Cousin | IUCN class 1A Special Reserve (1975) | 27 | Granitic | 4.3314**°**S, 55.6631**°**E | 69 | NGO | 2110 pairs 3 | Seychelles skink, wright’s skink and Seychelles fody, ghost crabs6 | *Pisonia grandis*4 |
| Cousine | Privately owned | 26 | Granitic | 4.3500**°**S, 55.6333**°**E | 72 | Private | 450–850 pairs8 | Seychelles skink, wright’s skink and Seychelles fody, ghost crabs 7, Seychelles magpie-robin5. | *Pisonia grandis*4,giant tortoise5*,* big- headed ants4. |
| Denis | Privately owned | 140 | Sand cay | 3.8000**°**S, 55.6667**°**E | <4 | Private | ca. 40 pairs (this study) | None perceived, cats removed in 2000, rats removed in 2002. |  |
| 1Diamond 1971, 2Burger and Lawrence 2000, 3Bowler et al. 2002, 4Recorded but unpublished, 5Observed but unpublished, 6Phillips 1987,  7Malan et al. 2010, 8Skerrett et al. 2001, \*Observed to or thought to hinder breeding success by increasing nest desertion or causing parent mortality. | | | | | | | | | |

**Monitoring nesting success**

For all five islands, nesting *P. lepturus* were defined as an adult with an egg or a chick on a nest. Nests were checked (and new nests searched for) every 2–14 days, depending on the island (see Table 2). To determine nest outcome, the stage at which the nest was last observed active was recorded. If a nest was observed to have been occupied by an egg or a young (partially feathered) chick and it was subsequently observed empty or with signs of predation/death on the succeeding visit, it was assumed that the nest had failed. If a nest was observed to be occupied by a fully feathered chick and then found empty in the subsequent visit without signs of predation/death, it was assumed that fledging had occurred and therefore that the nest was successful (hereafter breeding success). For those sites that monitored all nests within a specific area (Aride, Aldabra, Cousine) the number of nests is hereafter referred to as nesting density and is used as a proxy for breeding population size. New nesting attempts were only included in the dataset when the attempt was at the egg incubation stage to avoid data bias introduced by including nesting attempts that had already succeeded in reaching chick stage. However, all sites were searched thoroughly for nests on each visit so discovering late stage nesting attempts was rare. Each nesting attempt was characterised by the date of the first record, and whether the attempt resulted in a successful fledged chick or not. If the nest was unsuccessful we also recorded whether failure occurred at the egg or at the chick stage.

Table 2. Details of the five *P*.*lepturus* monitoring programmes in the Seychelles, including the last assessment conducted of breeding success.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Island** | **Area monitored (ha)** | **Dates of data collection** | **Frequency of monitoring** | **Methods** | **Nest Distribution** | **Nest Habitat Type** | **Last assessment** |
| Aldabra Atoll | ?? | Feb 2009– Nov 2016 | Continuous year-round monitoring, every 2 weeks | The entire monitoring area was searched and all new nests recorded and tagged. These nests were visited on subsequent surveys until nest outcome was determined. | Only on lime stone islets or coastal outcrops. Only monitored on 13 lagoon islets and an outcrop of Picard Island. | Lime stone cavities or cavities in dense vegetation on small islets and coastal outcrops. | Prys-Jones et al. 1980 |
| Cousin Island | 20 | 2005–2007, 2009–2016 | Once/twice a year beginning in Feb and/or July, nests visited every 3–4 days. | The survey effort was defined by a set number of nests rather than a specific area. Approximately 100 nests at incubation stage were tagged. These nests were visited on subsequent surveys until nest outcome was determined. | Ubiquitous though predominantly monitored on the plateau both along the coast and inland. | Bare scratched patches inside rock or log cavities or against tree roots or boulders. | Phillips, 1987 |
| Aride Island | 5 | Jan 2011– Dec 2016 | Continuous year-round weekly monitoring | The entire monitoring area was searched and all new nests recorded and tagged. These nests were visited on subsequent surveys until nest outcome was determined. | Ubiquitous though only monitored on coastal plateau along coastal and inland areas of forest. | Bare scratched patches inside rock or log cavities or against tree roots or boulders. | Ramos et al. 2005 |
| Cousine Island | James?? | Jan 2007– Dec 2011 | Continuous year-round weekly monitoring | 90 nest sites were monitored continuously. Each new nest was tagged and visited on subsequent surveys until nest outcome was determined. | Ubiquitous though only monitored on accessible eastern side. | Bare scratched patches inside rock or log cavities or against tree roots or boulders. | Malan et al, 2010 (data from 2003–2005) |
| Denis Island | Ca 65 | Nov 2015–Sept 2016 | Continuous year-round monitoring, every 2 weeks | The entire monitoring area was searched and all new nests recorded and tagged. These nests were visited on subsequent surveys until nest outcome was determined. | Ubiquitous though more abundant in forest. Monitored in all areas except the coconut plantation. | Mostly in trees cavities or on forked branches/trunks as well as on ground amongst tree roots or boulders. | NA |

**Statistics**

We analysed overall breeding success, and temporal trends in breeding success and nesting density wherever possible. However, due to differences in data collection methods, duration, and age of the monitoring programmes, we were unable to compare breeding success directly between monitoring sites.

We explored temporal trends for Aldabra, Aride, and Cousine, where monitoring is continuous throughout the year and spans 4­­–10 years. To do that, we employed a set of Generalised Additive Models (GAM) in each location with nest density or breeding success as a response variable. Nest density was defined as the number of nests recorded within the monitoring area per month while breeding success was fitted as a binomial variable (nest fledged = 1; nest failed = 0). We employed a normal and binomial error structure for the density and success models respectively. We included two independent continuous variables as smooth terms, ‘date’ (time since first survey) and ‘month’ in order to assess long term trends while accounting for the possible seasonality in the response variables. Survey effort was constant over the year in all these tree locations, and as we are not performing comparisons across sites it was not necessary to account for potential sources of variation among the areas surveyed. Models were fitted using the MGCV package in R 3.2.

Data for Cousin and Denis Islands were insufficient to perform this analysis and therefore only annual average breeding success was included for these sites. Cousin data was collected using a selection of nests chosen at one point in the year and this selection was followed until all outcomes were accounted for, no additional nests were added. Also, at Cousin, the number of nests monitored was not constrained by survey area; simply a sample of nests were chosen.

The Denis Island monitoring programme was in-place for just under one full year. Whilst not comprehensive, the data obtained from these sites was sufficient to obtain a general indication of breeding success. In any case, evaluating the differences in methods is also a key aim of this study and we therefore take this up in the discussion.

**Results**

We observed variation in breeding success (% of successful nests) between monitoring sites. Success was highest at Denis Island followed closely by Cousine Island and was lowest at Aldabra Atoll (Table 3). The relative proportion of nests that fail at the egg or chick stage, however, did not vary greatly between sites. Breeding success remained constant over the years in which monitoring was carried out on all islands except Aldabra, where a significant decreasing trend was observed (df=1, x2=7.61, p=<0.05; Fig 2A; Table 4).

Table 3. Number of *P. lepturus* nests monitored in study period, overall nesting success (% successful nests, i.e. fledglings) and the proportion of nests that failed at egg or chick stage at each site (%).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Island** | **Total nests monitored** | **Annual mean # nests monitored** | **Annual mean # nests successful (fledged)** | **(%) of failed nests failed at egg/chick stage** | **Annual mean nesting success (± SE)** |
| Aldabra Atoll | 333 | 42 | 6.4 | 66 / 34 | 15.2% (± 2.29) |
| Aride | 1033 | 172 | 69 | 62/38 | 40.2% (± 3.8) |
| Cousin | 854 | 93 | 37 | 64/36 | 33% (± 4.04) |
| Cousine | 537 | 107 | 52.2 | 72/28 | 51.6% (± 2.9) |
| Denis | 39 | 39 | 55 | 61/39 | 55%\* (± 9.3) |
| \* Mean monthly success | | | | | |

In Aldabra, there was no significant temporal variation in nesting density (the number of new nesting attempts recorded per year). However, we observed a significant decline in nesting density in Aride (the smoothing term had df=1.6, x2=35.2, p=<0.001 Fig 2B; Table 4) and an increase in Cousine (df=1.9, x2=29.2, p=<0.05; Fig 2A; Table 4). On Aride nesting density showed a seasonal pattern(df= 3.8, x2=49.1, p=<0.001; Fig 3; Table 4) with a peak in nesting attempts during September and October, a secondary peak between April and June and a low in December and January. Seasonality in nest density is present though weaker on Cousine (df= 3.1, x2=12.7, p=0.003; Fig 3; Table 4) and virtually nonexistent on Aldabra.

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***Figure 2:*** *Long-term trends in (A) Nesting density of new P. lepturus and (B) probability of breeding success on five islands in Seychelles. Grey bands indicate the corresponding standard error of the model predictions. Vertical bars indicate standard deviation for Denis island.*



***Figure 3:*** *Seasonality in nesting density of P. lepturus at Aldabra, Aride and Cousine Islands. Shaded areas indicate the standard error of the model predictions.*

***Table 4:*** *Generalised additive model output for nesting density and breeding success. Trend refers to temporal change and season refers to changes observed on an annual cycle (seasonality).*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Model** | **Island** | **Term** | **e.d.f.** | **χ2** | ***p*** |
| success | Aldabra | trend | 1.00 | 7.61 | 0.006 |
| Aride | trend | 1.00 | 0.14 | 0.706 |
| Cousine | trend | 1.00 | 0.06 | 0.802 |
| nests | Aldabra | season | 0.64 | 1.17 | 0.151 |
| trend | 2.11 | 5.68 | 0.090 |
| Aride | season | 3.78 | 49.1 | <0.001 |
| trend | 1.60 | 35.2 | <0.001 |
| Cousine | season | 3.09 | 12.7 | 0.003 |
| trend | 1.99 | 9.25 | 0.014 |

**Discussion**

**Status & Trends**

This study provides the first evidence to support a national conservation status for *P. lepturus* within the Seychelles. The results show an overall stable trend in breeding success in the granitic Seychelles (Aride, Cousine and Cousin) but a decline in the breeding success at Aldabra. Trends in nesting density at all three sites, monitored for multiple years, differed. At Aride, the nesting density was in decline, at Aldabra it was stable and at Cousine it was increasing. The differences in trends across sites coupled with the variation in monitoring programme methods and longevity, does not allow us to infer a national or regional population status. Improved monitoring across Seychelles and the inclusion of other important breeding sites across the Western Indian Ocean (Europa Island, Mauritius, Reunion, Rodriguez, Comores and Madagascar (Le Corre et al, 2008) is necessary for such an enterprise. Within the Western Indian Ocean and outside of the Seychelles, there is currently only data published on the Europa Island *P. lepturus* population. There, breeding success has been recorded at 6.9% (Ringler, et al., 2015), and is thought to be impacted by rat predation, though no trend data is currently available.

Our study therefore represents just one piece of the puzzle, albeit a significant one. We acknowledge and wish to highlight the issues which prevented a more robust conclusion and discuss the extent to which the current methods are suitable for the effective management of *P. lepturus*.

**Current Methods**

The five monitoring programmes for P. lepturus used in this study demonstrate the high level of commitment and resources allocated to this species within the Seychelles. We have demonstrated that the individual monitoring programmes, with monitoring over multiple years, fulfil the aim of establishing temporal trends in breeding success despite differences in methods and effort. The continuous year-round monitoring carried out at Aride, Aldabra and Cousine provided information on the breeding seasonality as well as a continuous measure of nesting density over time, within the surveyed area. The benefit of which, is that in essence you can ‘kill two birds with one stone’ establishing the status of the breeding population and measuring the breeding success of that population within one survey effort. On Aride for example, we were able to establish that the breeding population is in decline, but as breeding success remained stable the decline was likely not linked directly with factors influencing chick rearing. To avoid bias, the samples must be representative of the whole population (Sutherland, 2006). As population size varies between sites, as does nesting habitat, the choice of sample area must be site specific.

The frequency in which nesting attempts were monitored also varied between sites; on Cousin nests were monitored every 3–4 days, on Aride and Cousine weekly and on Aldabra and Denis every two weeks. The benefits of more frequent nest monitoring are that it increases the likelihood of determining the cause of nest failure and obtaining a more accurate record of the stage at which the nesting attempt failed. Additionally, the more often the area is visited and searched, the less likely it is that nesting attempts that fail at an early stage, will be missed. However, this may also be costly in terms of resources (time and personnel) and could have negative effects on the breeding success of the birds due to the excessive disturbance. The negative effect of investigator disturbance on breeding success has been reported for other long-lived seabirds (Blackmer et al. 2004); where weekly and daily handling of parents reduced hatching success by 50 and 56% compared to the control group. Nest monitoring frequency therefore must be a compromise between obtaining quality data and causing least impact. Although in the case of *P.lepturus*, monitoring does not require the handling of birds; to establish if the adult is sitting on an egg, a stick is used to gently lift the adult’s chest up enough to identify an egg. As no data has been recorded on how frequently this practice results in nest desertion (or at least displacement of adult) under each of the monitoring regimes, it is not possible to make assertions. Based on the breeding stage timings of P. lepturus, the egg incubation stage is 40 days followed by an average 76 days until fledging, with 30 days after hatching generally being the point when flight feathers begin to emerge (Phillips, 2008). The 2-week monitoring regime is therefore adequate to record each of these stages.

Sharing data from multiple sites has allowed us to make better sense of the findings; we found that the decline of nesting density on Aride is not mirrored on Cousin and Cousin. Cousin maintains a stable population trend (1987 to 2014, unpublished census data) and Cousine island shows an increasing population trend (this study and 2003 to 2017 unpublished census data). For these islands that are within close geographical proximity, it is reasonable to expect *P. lepturus* to be under similar influence of external factors (climatic variations and food availability) thus indicating that the factor/s driving the decline in nest density on Aride are island specific. As we see from table 1, all islands, despite their proximity, vary greatly in predation pressure or nest site availability (e.g. competition for nest sites with other species). The continuous negative trend in nesting density on Aride was previously reported by Bowler et al. (2002), where the nesting population of *P. lepturus* suffered an apparent decline of 60% between 1989 and 1998. Additional work by Catry et al (2009) determined that annual adult survival could not be linked to inter-annual variability in oceanographic conditions but may be more influenced by *Pisonia grandis* fruiting events, which accounted for 23.2% of the adult mortality. *P.grandis* is a native tree and thrives in acidic guano enriched soils, It produces sticky seeds which can trap and kill seabirds and is common across Aride, Cousin and Cousine.

This highlights an important consideration when using a species as an indicator of broader environmental changes, that it is important to be able to disentangle the effects of local impacts on breeding success and nesting density and those external factors such as climatic changes impacting prey availability. This can be achieved by having a measure of local impacts such as predation levels and habitat changes.

This study has provided us with information that can feed directly back into management decisions on where to focus research efforts and conservation resources. It is clear that the we now need to investigate the causes of decline in breeding population of P. lepturus at Aride and the decline in breeding success at Aldabra.

***Monitoring Programmes Recommendations***

In order to build upon current knowledge and efforts and improve the value of data for *P.lepturus* throughout the Seychelles werecommend that anationwide monitoring plan should be implemented with consideration for the spectrum of resources available at each site. The major characteristics of effective monitoring programs typically include carefully posed questions and objectives and a conceptual model of the ecosystem or population (Lindenmayer & Likens, 2010). We make the following recommendations for the Seychelles *P. lepturus* monitoring programmes:

1. To enable national level monitoring of *P. lepturus* and enable new monitoring programmes to be established, a standardised protocol should be developed and ideally followed at all sites, coupled with a standard database format to ensure data management enables and leads to frequent analysis. The protocol should outline the conceptual model and the specific aim and objectives of the monitoring programme (Reynolds et al, 2017).
2. For optimal results we propose a year-round continuous long-term monitoring of a designated area (with consideration for accessibility for regular monitoring and representative of typical nesting habitat and breeding population). For those sites with more limited resources, an annual survey of breeding success should be conducted at the same time each year in the same designated survey area to also allow for a long-term measure of nesting density.
3. Additional parameters may be included that do not increase time or personnel required though will be greatly beneficial in future analysis to eliminate or highlight certain factors, should a decline be observed. These may include a measure of nest site choice; for tropical seabird species nest microhabitats and behavioural thermoregulation, are important factors during egg brooding and early chick development (Hart et al, 2017). Nest site choice can be recorded in terms of habitat type (e.g vegetation/rock crevice/tree limb etc) and site exposure (e.g level of shade, peripheral cover from weather and accessibility to predators). Secondly the monitoring can include recording evidence or observation of predator interaction. Another, easy addition is to include whether the observer causes any disturbance to the nest, such as the adult flying off or moving away from the egg.
4. Any additional programmes that monitor the ecosystem that *P. lepturus* individuals interact with (identified in the conceptual model) are beneficial. This more integrated ecosystem approach will not only assess changes but may also deliver evidence of underlying reasons for observed changes (Kupschus et al. 2016). For example, monitoring trends in natural or invasive predators, vegetation phenology and climate variables.
5. Should a declining trend be observed then further actions may be taken to determine cause, these may include the use of camera traps on nests to observe factors such as predation, chick feeding frequency and nest desertion by adult (Rendall et al, 2014). If there is no obvious cause then further investigation of external factors such as climate and food availability may be investigated via satellite data coupled with geo-tagging birds (Campos et al, 2017; Le Corre et al, 2012).

*Conclusions*

The Western Indian Ocean has recently been identified as a key area to prioritize for the conservation of global marine biodiversity in the face of climate change (Ramírez et al. 2017). The Seychelles Archipelago supports the greatest abundance of seabirds in the tropical Indian Ocean (Le Corre et al, 2012). Regional seabird population success and trend data is not readily available despite data being collected for many years at several locations. A greater effort must be made to streamline regional data and utilise the results to steer management practices and channel research resources towards the most critical areas. This study highlights a decline in nesting success at Aldabra atoll and a decline in nest abundance at Aride, both require further understanding and therefore management should focus research efforts and conservation resources at establishing likely causes of these declines. This will be most effective by establishing an ecosystem approach to monitoring and implementing adaptive management across the region.

**References**

Ancona, S., Sanchez-Colon, S., Rodriguez, C., Drummond, H., 2011. El Nino in the warm tropics: local sea temperature predicts breeding parameters and growth of blue-footed boobies. J. Anim. Ecol. 80, 799–808.

Au, D.W.K., Pitman, R.L., 1986. Seabird interactions with dolphins and tuna in the eastern

tropical Pacific. Condor 88, 304–317.

Ashmole N.P., 1971 Seabird ecology and the marine environ- ment. In: Farner DS, King JR, Parkes KC (eds) Avian bio- logy. Academic Press, New York, p 223–286

Ashmole N.P, Ashmole MJ (1967) Comparative feeding eco- logy of seabirds of a tropical oceanic island. Peabody Mus Nat Hist Yale Univ Bull 24:1–131

BirdLife International. 2017. *Phaethon lepturus* (amended version of 2016 assessment). The IUCN Red List of Threatened Species 2017: e.T22696645A111235714. <http://dx.doi.org/10.2305/IUCN.UK.2017-1.RLTS.T22696645A111235714.en>.

Bost C. A., le Maho Y.. Seabirds as bio-indicators of changing marine ecosystems: new perspectives, Acta Oecologia , 1993, vol. 14 (pg. 463-470)

Bowler, J., M. Betts, I. Bullock and J. A. Ramos. 2002. Trends in Seabird numbers on Aride Island Nature Reserve, Seychelles 1988-2000. Waterbirds 25: 26-38.

Bailey, R S. 1968. The pelagic distribution of sea-birds in the western Indian Ocean. *Ibis* 110 (4): 493–519. doi:[10.1111/j.1474-919X.1968.tb00060.x](https://doi.org/10.1111/j.1474-919X.1968.tb00060.x).

Blackmer, A.L., Ackerman, J.T. and Nevitt, G.A., 2004. Effects of investigator disturbance on hatching success and nest-site fidelity in a long-lived seabird, Leach's storm-petrel. Biological Conservation, 116(1), pp.141-148

Burger, J., & Gochfeld, M. (1991). Nest-Site Selection by the Herald Petrel and White-Tailed Tropicbird on Round Island, Indian Ocean. *The Wilson Bulletin,* *103*(1), 126-130. Retrieved from http://www.jstor.org/stable/4162981

Burger AE, Lawrence AD (2000) Seabird monitoring handbook for Seychelles: suggested methods for censusing seabirds and monitoring their breeding performance. Birdlife Seychelles, Mahé´, Seychelles.

Burger, A. E. and Betts, M. (2001) Monitoring populations of Red-footed boobies Sula sula and frigatebirds Fregata spp. breeding on Aldabra Atoll, Indian Ocean. B. Brit. Ornithol. Club 121: 236–246.

Bristol, R., 2007. Seabirds of the granitic Seychelles: a review of status, threats, uses and conservation. Ostrich 78, 453-453.

Campos, L.F.A.S., Andrade, A.B., Bertrand, S. and Efe, M.A., 2017. Foraging behavior and at-sea distribution of White-Tailed Tropicbirds in tropical ocean. *Brazilian Journal of Biology*, (AHEAD), pp.0-0.

Catry, T., Ramos, J.A., Monticelli, D. et al. J Ornithol (2009). Demography and conservation of the White-tailed Tropicbird Phaethon lepturus on Aride Island, Western Indian Ocean 150: 661. <https://doi.org/10.1007/s10336-009-0389-z>

Catry, T., Ramos JA, Jaquemet S, Faulquier L, Berlincourt M, Hauselmann A, … Le Corre M. (2009). Comparative foraging ecology of a tropical seabird community of the Seychelles, western Indian Ocean. *Marine Ecology Progress Series*, *374*, 259–272.

COULSON, J.C., 2001. Colonial breeding in seabirds. In: E.A. SCHREIBER and J. BURGER, eds. *Biology of marine birds*. Boca Raton: CRC Press. p. 87-113.

Le Corre, M., Jouventin, P., 1997. Ecological significance and conservation priorities of Europa Island (western Indian Ocean), with special reference to seabirds. Revue d’Ecologie 52, 205–220.

DEARBORN, D.C., ANDERS, A.D. and FLINT, E.N., 2001. Trends in reproductive success of Hawaiian seabirds: is guild membership a good criterion for choosing indicator species? *Biological Conservation*, vol. 101, no. 1, pp. 97-103. http://dx.doi. org/10.1016/S0006-3207(01)00030-1.

DOBSON, A.F. and MADEIROS, J., 2010. Threats facing Bermuda’s breeding seabirds: measures to assist future breeding success. *Proceedings of the Fourth International Partners in Flight Conference: Tundra to Tropics*, pp. 223-226.

Diamond, A W. 1971. The Ecology of the Sea Birds of Aldabra. Phil.Trans.R.Soc.Lond. 260 (836): 561–71.

Diamond, A.W., 1975. The biology of tropicbirds at Aldabra Atoll, Indian Ocean. *The Auk*, vol. 92, no. 1, pp. 16-39. http:// dx.doi.org/10.2307/4084415.

Einoder, L. D. 2009. A review of the use of seabirds as indicators in fisheries and ecosystem management. Fisheries Research, 95(1), 6–13.

Garnett S. T. and Crowley G. M. (2000) *The action plan for Australian birds 2000*. Canberra: Environment Australia.

Grant, G.S., 1982. Avian incubation: egg temperature, nest humidity, and behavioral thermoregulation in a hot environment. Ornithol. Monogr. 30, 1–70.

HAMER, K.C., MONAGHAN, P., UTTLEY, J.D., WALTON, P. and BURNS, M.D., 1993. The influence of food supply on the breeding ecology of kittiwakes Rissa tridactyla in Shetland. *Ibis*, vol. 13, pp. 255-263.

Harrison CS, Hida TS, Seki MP (1983) Hawaiian seabird feeding ecology. Wildl Monogr 85:1–71

Hart, Lorinda A., Colleen T. Downs, and M. Brown. 2016a. “Hot footing eggs: thermal imaging reveals foot mediated incubation in White-tailed Tropicbirds, Phaethon lepturus.” *Journal of Ornithology* 157 (2). Springer Berlin Heidelberg: 635–40. doi:[10.1007/s10336-015-1323-1](https://doi.org/10.1007/s10336-015-1323-1).

Hart, Lorinda A., Colleen T. Downs, and Mark Brown. 2016b. “Sitting in the sun: nest microhabitat affects incubation temperatures in seabirds.” *Journal of Thermal Biology* 60. Elsevier: 149–54. doi:[10.1016/j.jtherbio.2016.07.001](https://doi.org/10.1016/j.jtherbio.2016.07.001).

Lorinda A. Hart, Colleen T. Downs, Mark Brown. (2017) Keeping it regular: Development of thermoregulation in four tropical seabird species. *Journal of Thermal Biology* **64**, 19-25.

Haverkamp, P. J., Shekeine, J., de Jong, R., Schaepman, M., Turnbull, L. A., Baxter, R., … Schaepman-Strub, G. (2017). Giant tortoise habitats under increasing drought conditions on Aldabra Atoll—Ecological indicators to monitor rainfall anomalies and related vegetation activity. *Ecological Indicators*, *80*(Supplement C), 354–362. <https://doi.org/https://doi.org/10.1016/j.ecolind.2017.05.029>

Kupschus, S., Schratzberger, M., and Righton, D. (2016). Practical implementation of ecosystem monitoring for the ecosystem approach to management. *J. Appl. Ecol*. 53, 1236–1247. doi: 10.1111/1365-2664.12648

Leal, G. R., Serafini, P. P., Simão-Neto, I., Ladle, R. J., & Efe, M. A.. (2016). Breeding of White-tailed Tropicbirds (Phaethon lepturus) in the western South Atlantic. *Brazilian Journal of Biology*, *76*(3), 559-567. Epub April 19, 2016.<https://dx.doi.org/10.1590/1519-6984.16514>

Le Corre, M. & Jouventin, P. (1997). Ecological signi®cance and conservation priorities of Europa Island (western Indian Ocean) with special references to seabirds. Rev. Ecol. Terre Vie 52: 205±220.

Le Corre, M., Jaeger, A., Pinet, P., Kappes, M.A., Weimerskirch, H., Catry, T., Ramos, J.A., Russell, J.C., Shah, N. and Jaquemet, S., 2012. Tracking seabirds to identify potential Marine Protected Areas in the tropical western Indian Ocean. *Biological Conservation*, *156*, pp.83-93.

Leverington, F., Costa, K. L., Pavese, H., Lisle, A., & Hockings, M. (2010). A global analysis of protected area management effectiveness. *Environmental Management*, *46*(5), 685–698. https://doi.org/10.1007/s00267-010-9564-5

**Lindenmayer DB**, **Likens GE**. **2010**. The science and application of ecological monitoring. *Biol. Conserv.* 143: 1317–28

Lindenmayer, D. B., Zammit, C., Attwood, S. J., Burns, E., Shepherd, C. L., Kay, G., & Wood, J. (2012). A Novel and Cost-Effective Monitoring Approach for Outcomes in an Australian Biodiversity Conservation Incentive Program. *PLoS ONE*, *7*(12). https://doi.org/10.1371/journal.pone.0050872

Madeiros, J.L. 2008. Breeding Success survey of White-tailed Tropicbirds Phaethon lectures catsbyii on the islands of Bermuda– 2006 to 2008 Nesting Seasons. Bermuda Government Report.

Malan, G., D. Hagens, and Q. Hagens. 2010. Nesting success of White Terns and White-tailed Tropicbirds on Cousine Island, Seychelles. *Ostrich* 80 (2): 81–84. doi:[10.2989/OSTRICH.2009.80.2.3.830](https://doi.org/10.2989/OSTRICH.2009.80.2.3.830).

Matt Parsons, Ian Mitchell, Adam Butler, Norman Ratcliffe, Morten Frederiksen, Simon Foster, James B. Reid; Seabirds as indicators of the marine environment, *ICES Journal of Marine Science*, Volume 65, Issue 8, 1 November 2008, Pages 1520–1526, <https://doi.org/10.1093/icesjms/fsn155>

Phillips, Nj. 1987. The breeding biology of White-tailed Tropicbirds *Phaethon lepturus* at Cousin Island, Seychelles. *Ibis* 129 (January 1983): 10–24. doi:[10.1111/j.1474- 919X.1987.tb03156.x](https://doi.org/10.1111/j.1474-919X.1987.tb03156.x).

Piatt, J., Harding, A., Shultz, M., Speckman, S., Van Pelt, T., Drew, G., & Kettle, A. (2007). Seabirds as indicators of marine food supplies: Cairns revisited. *Marine Ecology Progress Series,352*, 221-234. Retrieved from http://www.jstor.org/stable/24872147

Prys-Jones, R. P., and C. Peet. 1980. Breeding periodicity, nesting success and nest site selection among red-tailed tropicbirds Phaethon rubricauda and white-tailed tropicbirds P. lepturus on Aldabra Atoll. *Ibis* 122 (1): 76–81. doi:[10.1111/j.1474-919X.1980.tb00873.x](https://doi.org/10.1111/j.1474-919X.1980.tb00873.x).

Olson, C.R., Vleck, C.M., Vleck, D., 2006. Periodic cooling of bird eggs reduces embryonic growth efficiency. Physiol. Biochem. Zool. 79, 927–936.

Ramos, Jaime A., and Carlos Pacheco. 2003. “Chick growth and provisioning of surviving and nonsurviving white-tailed tropicbirds (Phaethon lepturus).” *The Wilson Bulletin* 115 (4): 414–22. doi:[10.1676/03-052](https://doi.org/10.1676/03-052).

Ramos JA, Bowler J, Betts M, Pacheco C, Agombar J, Bullock I, Monticelli D. 2005. Productivity of White-tailed Tropicbird on Aride Island, Seychelles. Waterbirds 28: 405– 542.

F. Ramírez, I. Afán, L. S. Davis, A. Chiaradia, Climate impacts on global hot spots of marine biodiversity. Sci. Adv. 3, e1601198 (2017).

Rendall, A. R., D. R. Sutherland, R. Cooke, and J. White. 2014. Camera trapping: a contemporary approach to monitoring invasive rodents in high conservation priority ecosystems. *PLoS ONE* **9**, e86592.

Regan, H. M., Hierl, L. A., Franklin, J., Deutschman, D. H., Schmalbach, H. L., Winchell, C. S., & Johnson, B. S. (2008). Species prioritization for monitoring and management in regional multiple species conservation plans. *Diversity and Distributions*, *14*(3), 462–471. <https://doi.org/10.1111/j.1472-4642.2007.00447.x>

Reynolds, J. H., Knutson, M. G., Newman, K. B., Silverman, E. D., & Thompson, W. L. (2016) A Road Map for designing and implementing a biological monitoring program. *Environmental Monitoring and Assessment* (July) **188**:399–424.

Ringler, David, James C. Russell, and Matthieu Le Corre. 2015. “Trophic roles of black rats and seabird impacts on tropical islands: Mesopredator release or hyperpredation?” *Biological Conservation* 185. Elsevier Ltd: 75–84. doi:[10.1016/j.biocon.2014.12.014](https://doi.org/10.1016/j.biocon.2014.12.014).

Rocamora, G., Feare, C., Skerrett, A., Athanase, M., & Greig, E. (2003). The breeding avifauna of Cosmoledo Atoll (Seychelles) with special reference to seabirds: Conservation status and international importance. *Bird Conservation International,* *13*(2), 151-174. doi:10.1017/S0959270903003137

RODRIGUES, A.S., T.M. BROOKS, S.H. BUTCHART, J. CHANSON, N. COX, M. HOFFMAN & S.N. STUART. 2014. Spatially explicit trends in the global conservation status of vertebrates. PloS ONE 9: e113934.

RUSSELL, J.C. and LE CORRE, M., 2009. Introduced mammal impacts on seabirds in the Îles Éparses, Western Indian Ocean. *Marine Ornithology*, vol. 37, pp. 121-129.

Safford R. and Hawkins F. 2013. The birds of Africa: Vollume III: The Malagasy region, 1st edition. Bloomsbury Publishing Plc, London, UK.

SARMENTO, R., BRITO, D., LADLE, R.J., LEAL, G.R. and EFE, M.A., 2014. Invasive house (*Rattus rattus*) and brown rats (*Rattus norvegicus*) threaten the viability of red-billed tropicbird (*Phaethon aethereus*) in Abrolhos National Park, Brazil. *Tropical Conservation Science*, vol. 7, pp. 614-627.

SCHAFFNER, F.C., 1991. Nest-site selection and nesting success of white-tailed tropicbirds (*Phaethon lepturus*) at Cayo Luis Pena, Puerto Rico. *The Auk*, vol. 108, pp. 911-922.

Schaffner, F. C. (1990), Food Provisioning by White-Tailed Tropicbirds: Effects on the Developmental Pattern of Chicks. Ecology, 71: 375–390. doi:10.2307/1940275

Schreiber RW, Clapp RB (1987) Pelecaniform feeding ecology. In: Croxall JP (ed) Seabirds: feeding ecology and role in marine ecosystems. Cambridge University Press, Cam- bridge, p 173–188

Skerrett, A., Bullock, I. and Disley, A. (2001) *Birds of Seychelles*. London, UK: Helm Books.

ŠÚR, M., BUNBURY, N., & VAN DE CROMMENACKER, J. (2013). Frigatebirds on Aldabra Atoll: Population census, recommended monitoring protocol and sustainable tourism guidelines. *Bird Conservation International,* *23*(2), 214-220. doi:10.1017/S0959270913000087

Sutherland, W.J. ed., 2006. Ecological census techniques: a handbook. Cambridge University Press.

Stonehouse, Bernard. 1962. “The Tropic Birds (Genusphaethon) Of Ascension Island.” *Ibis* 103B (2): 124–61. doi:[10.1111/j.1474-919X.1962.tb07242.x](https://doi.org/10.1111/j.1474-919X.1962.tb07242.x).

**Supplementary Material**

Additional Island Information

*Aldabra Atoll*

Aldabra Atoll is a raised coral atoll, approximately 1150km southwest of the main Seychelles island of Mahé (Figure 1), and consists of four main islands totalling 155 km2 area around a central 195.9 km2 lagoon. *P. lepturus* nest predominantly on islets within the lagoon. The habitat of the islets (area between 41 and 570 m² (mean 249 m²) consists of pitted limestone crevices and salt tolerant vegetation with varying degrees of coverage.

*Aride Island*

Aride is the northernmost granitic island of the Seychelles Archipelago and is situated 15 km away from Cousin Island and 50 km from the main island of Mahé (Figure 1). Aride’s 74 ha consist of 5 ha of flat plateau and 69 ha of mountainous terrain. The island has been restored from a degraded coconut plantation. A colony of *P. lepturus* nests across the island but monitoring is consistently conducted on the plateau along coastal and inland areas of forest.

*Cousin Island*

Cousin is 2 km from Cousine Island and 35km from the main island of Mahé (Figure 1). Cousin’s 27 ha consist of 21.6 ha of flat plateau and 5.4 ha of mountainous terrain. The island has been restored from a degraded coconut plantation. A colony of *P. lepturus* nests throughout this habitat but are predominantly monitored on the plateau both along the coast and inland.

*Cousine Island*

Cousine Island, 2 km west of Cousin and 32 km NE of the main island of Mahé (Figure 1). The island is close in proximity, size and habitat to Cousin Island and likewise has been restored from a degraded coconut plantation. A colony of *P. lepturus* breeds across the island but monitoring has concentrated throughout the accessible plateau on the eastern side.

*Denis Island*

Denis Island is ca. 43 km north of Aride Island and 80 km north-east of the main island of Mahé (Figure 1). Denis holds a small population of *P. lepturus* which nest across the island.