A REGIONALLY SIGNIFICANT POPULATION OF WHITE-TAILED TROPICBIRDS *PHAETHON LEPTURUS* ON KUREHDHOO (LHAVIYANI ATOLL), REPUBLIC OF THE MALDIVES

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Received 27 February 2024, accepted 05 April 2024

ABSTRACT

RUSSELL, J.C., STEIBL, S. & STEVENS, G.M.W. 2024. A regionally significant population of White-tailed Tropicbirds *Phaethon lepturus* on Kurehdhoo (Lhaviyani Atoll), Republic of the Maldives. *Marine Ornithology* 52: 191–196. http://doi.org/10.5038/2074-1235.52.2.1581

Coral atoll islands are important breeding sites for tropical seabird species, but on many of these islands, disturbances from humans and introduced mammals have extirpated breeding colonies. In the Republic of the Maldives (Indian Ocean), little published information exists on the location and extent of seabird breeding colonies. Here, we document what appears to be a regionally significant breeding site for White-tailed Tropicbirds *Phaethon lepturus* on Kurehdhoo, the northern-most inhabited island of Lhaviyani Atoll in the central Maldives. We systematically surveyed the entire island on two separate occasions, six months apart, to count the number of White-tailed Tropicbird nests, their breeding stage, and habitat. We counted 128 and 202 nests at all breeding stages, indicating year-round breeding and an estimated population size of about 800 adults. This population is most likely the outcome of 14 y of sustained rat control across the entire island in the presence of native atoll vegetation. The effort has allowed White-tailed Tropicbirds to rapidly increase in number and a small population of Tropical Shearwaters *Puffinus bailloni* to establish on the island. These discoveries demonstrate that land-based seabird conservation opportunities exist in association with island resort land use in the Republic of the Maldives.

Key words: eradication, Indian Ocean, island, rat, seabird

INTRODUCTION

Coral atoll islands around the world provide important nesting grounds for tropical seabird species (Berr *et al*. 2023). However, even among island types, coral atoll islands are small and have been disproportionately impacted by humans (Steibl *et al*. 2024). Seabirds on atoll islands have been harvested by humans for food (Mondreti *et al*. 2018) and extirpated throughout large areas of their range by the loss of habitat and introduction of predatory mammals, particularly Black Rats *Rattus rattus* and Pacific Rats *R. exulans* (Russell & Holmes 2015). However, rats can also be eradicated from islands (Spatz *et al*. 2022), and this can lead to spectacular recoveries in seabirds (Le Corre *et al*. 2015).

The Maldives have been inhabited by people for approximately two and a half millennia (Knoll 2018), but the natural history of these islands has never been well documented. Most reliable natural history observations only date back to the early 19th century, and these records make little mention of seabirds, although earlier references note some islands with abundant nesting seabirds (e.g., La Harpe 1780). There is no reason to assume the coral atoll islands of the Maldives were not originally densely populated with seabirds as was, and still is, the case for other atoll islands in the Indian Ocean (including Chagos Archipelago to the south of the Maldives and Lakshadweep Archipelago to the north; Bourne 1971, Carr 2015, Pande *et al*. 2007). It is likely that seabirds were largely extirpated from most islands in the Maldives over its long history of human occupation before the modern natural history patterns were established and documented. However, nesting and roosting colonies of seabirds, although poorly documented, are still found on some islands scattered throughout the Maldives (Anderson & Shimal 2020); seabird presence likely coincides with low human disturbance, native vegetation, and the absence of introduced mammalian predators. Given the number of islands in the Maldives and the potential number of seabirds they could support, identification of seabird breeding colonies, threats to these colonies, and the outcomes of management interventions would greatly benefit seabird conservation in this region (Anderson 1996).

The White-tailed Tropicbird *Phaethon lepturus*, also known as the bosun bird among mariners, or dhandifulhu dhooni in Dhivehi, is a widespread tropical seabird species found on both volcanic and coral atoll islands. The global population is estimated at 400 000 individuals and is classified as Least Concern by the International Union for Conservation of Nature (IUCN), but the species is not well studied and is likely in decline globally (BirdLife International 2023). The main threat to White-tailed Tropicbirds is depredation by introduced mammalian predators (Saunier *et al*. 2022). The Maldives lies at the northern range limit for the species in the Indian Ocean, and although it has never been genetically tested, it is likely the nominal sub-species *P. l. lepturus* (Humeau *et al*. 2020). White-tailed Tropicbirds are recorded as a widespread breeding resident in the Maldives, but as is the case globally, they are also noted as likely in decline locally (Anderson & Shimal 2020). We visited Kurehdhoo (Lhaviyani Atoll, Maldives) in July 2023 where we discovered a large breeding colony of White-tailed Tropicbirds that, to date, had not been recognized. We surveyed the entire island colony in July 2023 and again in January 2024.

METHODS

Kurehdhoo (styled as Kuredu in English; 5°32′58″N, 73°27′51″E; Fig. 1) is a 43.23-ha (0.4323 km^2) island lying on the northern reef edge of Faadhippolhu (administratively also known as Lhaviyani) Atoll, in the central Maldives (http://www.onemap.mv). The island is home to one of the first resorts in the Maldives, operating since December 1988; today it has a large footprint on the island (389 rooms). Despite the resort development, important fringing vegetation primarily composed of beach cabbage *Scaevola taccada* remains around the coast, and pockets of screwpine *Pandanus tectorius* and hibiscus *Hibiscus* sp. forest remain throughout the island, interspersed by large specimens of banyan *Ficus benghalensis* (Steibl *et al*. 2021).

Black Rats are controlled as a public nuisance and have presumably long been present on the island given that they share a genetic mitochondrial lineage closest to India (M. Moseley unpubl. data; Varudkar & Ramakrishnan 2015). Prior to 2010, rat control was achieved by twice-monthly visits by pest control contractors distributing poison. Since 2010, rats have been systematically controlled by resort staff using an island-wide permanent grid of about 160 live-traps that are checked daily. A small number of rats are caught each week.

On 22 July 2023 (JCR & SS, 8 h) and again from 10 to 15 January 2024 (JCR, 19.5 h), we systematically surveyed the entirety of Kurehdhoo by walking a transect of search tracks, recording every White-tailed Tropicbird nest found on the ground (their predominant nesting location). Transect search width was adapted to the line-of-sight provided by immediate vegetation and topography from a few up to 10 m. For every nest found, we recorded whether an adult was present and the breeding stage (prospecting, egg, or chick). Chicks were classified as age class 1 to 3 depending on the plumage (entirely down, intermediate, entirely feathered plumage). We also recorded the plant habitat where the nest was located. Nest locations and search tracks were recorded in Avenza (Avenza Systems Inc., Toronto, Canada). On 23 July 2023, using the same methodology, we also surveyed the two uninhabited, undeveloped islands of Fehigili (0.68 ha; 0.0068 km^2) and Dhehuraa Evvihuraa (0.88 ha; 0.088 km^2) to the east of Kurehdhoo.

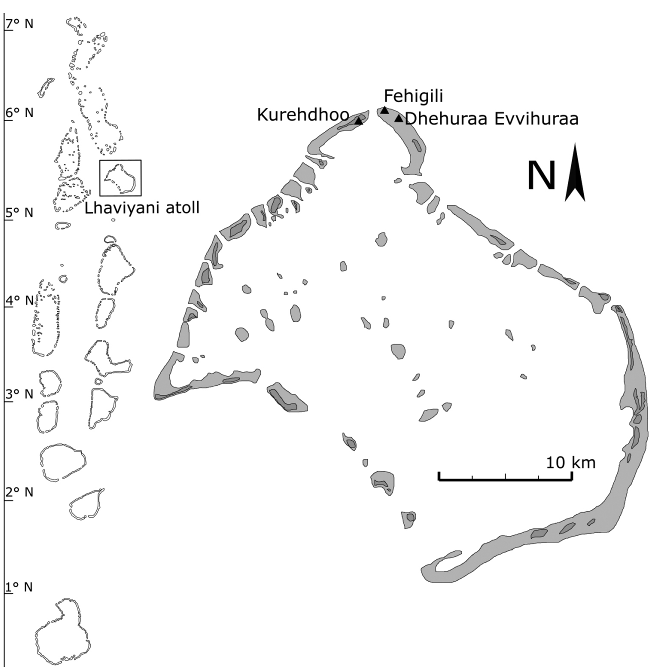

Fig 1. Lhaviyani (Faadhippolhu) Atoll is located in the central Maldives and Kurehdhoo is the northern-most inhabited island in the atoll.

In accord with asynchronous breeding, we did not expect that all resident birds would be present on the colony at any one time, so we corrected our population size estimates for birds absent between breeding periods. To do this, data on the length of breeding stage and cycle were used, and the number of active (egg or chick) nests counted was corrected by the proportion of the population that was instantaneously expected at the colony. However, this assumed that breeding was fully asynchronous across the breeding cycle (i.e., breeding was random with respect to time), resident birds breed every year (i.e., there were no sabbaticals), and there was no nest mortality. Sabbatical birds and nest mortality would both negatively bias the estimate. For White-tailed Tropicbirds, we assumed a total breeding period (incubation and chick raising) of approximately 4 mo (122 d; Lee & Walsh-McGee 2020) and a breeding cycle of about 9 mo (270 d). This method allowed us to estimate a minimum number of adults in the breeding population based only on currently active nests:

$$\hat{N} = 2 \times \text{number of active nests} \times \frac{\text{breeding cycle}}{\text{breeding period}}$$

An alternative estimate based only on nests with eggs and using the mean egg incubation period circumvented negative bias due to nest failures (i.e., chicks that died, for which we might not find evidence). For White-tailed Tropicbirds, we assumed an egg incubation period of 40–42 d (Stonehouse 1962):

$$\hat{N} = 2 \times \text{number of nests with eggs} \times \frac{\text{breeding cycle}}{\text{incubation time}}$$

Our estimate of nest density (total number of nests divided by island area) can also be used to estimate our transect half-width, *w*, by equating nest density to nests detected per kilometre of transect:

$$\frac{\text{nests per hectare}}{10\,000} = \frac{\text{nests per kilometre}}{1000.2w}$$

and solving for *w* = transect half-width.

RESULTS

We counted a total of 128 nests over 16 km of transect in July 2023 and 202 nests over 26 km of transect in January 2024 (Table 1; Fig. 2) across the entirety of Kurehdhoo. In both surveys, about eight nests were detected per kilometre of transect walked; therefore, with its greater survey effort, we used the January 2024 survey for population size estimation. Our estimate of five nests per hectare (0.01 km^2) (total number of nests divided by island area) implies that the transect half-width was, on average, 8 m on either side. Our maximum count of active nests in January 2024 estimates a breeding population size of 783 individuals. Accounting for unobserved nest failure, our maximum count of 63 incubated eggs in January 2024 equates to a slightly higher estimate of 829 individuals. We thus estimate the total breeding population size to be at least 800 adults.

TABLE 1
Number and percentage of White-tailed Tropicbird *Phaethon lepturus* nests on Kurehdhoo (Lhaviyani Atoll), Republic of the Maldives

	Jul 2023		Jan 2024	
	n	%	*n*	%
Number of nests	128	100	202	100
Prospecting	5	4	25	12
Egg	57	44.5	63	31
Downy chick	19	15	40	20
Intermediate chick	19	15	37	18.5
Feathered chick	28	21.5	37	18.5

In both surveys, just over half of the nests were located under screwpine trees, often within the root structure. An additional 9%–15% of nests were among the shielding roots of banyan trees, 19%–20% were located under hibiscus trees, and 12%–13% were located under beach cabbage. A few nests were found under decaying vegetation or in decaying logs, or alongside or inside infrastructure such as decks and pipes. Although we did not survey the relative abundance of vegetation types on the island, it was evident that White-tailed Tropicbirds on Kurehdhoo have a strong preference for nesting under these four plant species, and not the other vegetation types found on the island (e.g., *Cocos*, *Pemphis*, *Suriana*, and other introduced ornamental or agricultural plants). However, we also note that these vegetation types (*Pandanus*, *Ficus*, *Scaevola*, and *Hibiscus*) were the predominant vegetation types on the island at this time, although historically this may not have been the case given that the island's Dhivehi name translates literally to "tongue of *Pemphis*."

We found no White-tailed Tropicbirds on the nearby smaller eastern islands. Both islands were dominated by Shrubby Coral Pemphis *Pemphis acidula* scrub and were evidently over-washed regularly. On Fehigili, we found a Striated Heron *Butorides striata* nest and observed a Grey Heron *Ardea cinerea* in the Shrubby Coral Pemphis. On Dhehuraa Evvihuraa, we found half a dozen old Green Turtle *Chelonia mydas* nests and a dozen Black-naped Terns *Sterna sumatrana* roosting on the sandy beach.

On Kurehdhoo, we also confirmed prospecting of burrows by half a dozen Tropical Shearwaters *Puffinus bailloni* in the western forest in January 2024. This indicates a likely breeding period from January to June, corresponding with the dry season in the Maldives.

On the completion of our survey in January 2024, we ringed the 50 oldest chicks on Kurehdhoo with uniquely numbered aluminium rings (C61501 to 550) provided by the Indian ringing scheme administered by the Bombay Natural History Society, India. During ringing, four chicks regurgitated their most recent feed. Identification of these regurgitates confirmed typical tropicbird prey of squid and flying fish (Exocoetidae) (Le Corre *et al*. 2003).

DISCUSSION

Our two surveys provide a robust population size estimate of White-tailed Tropicbirds on a single island in the Maldives. By

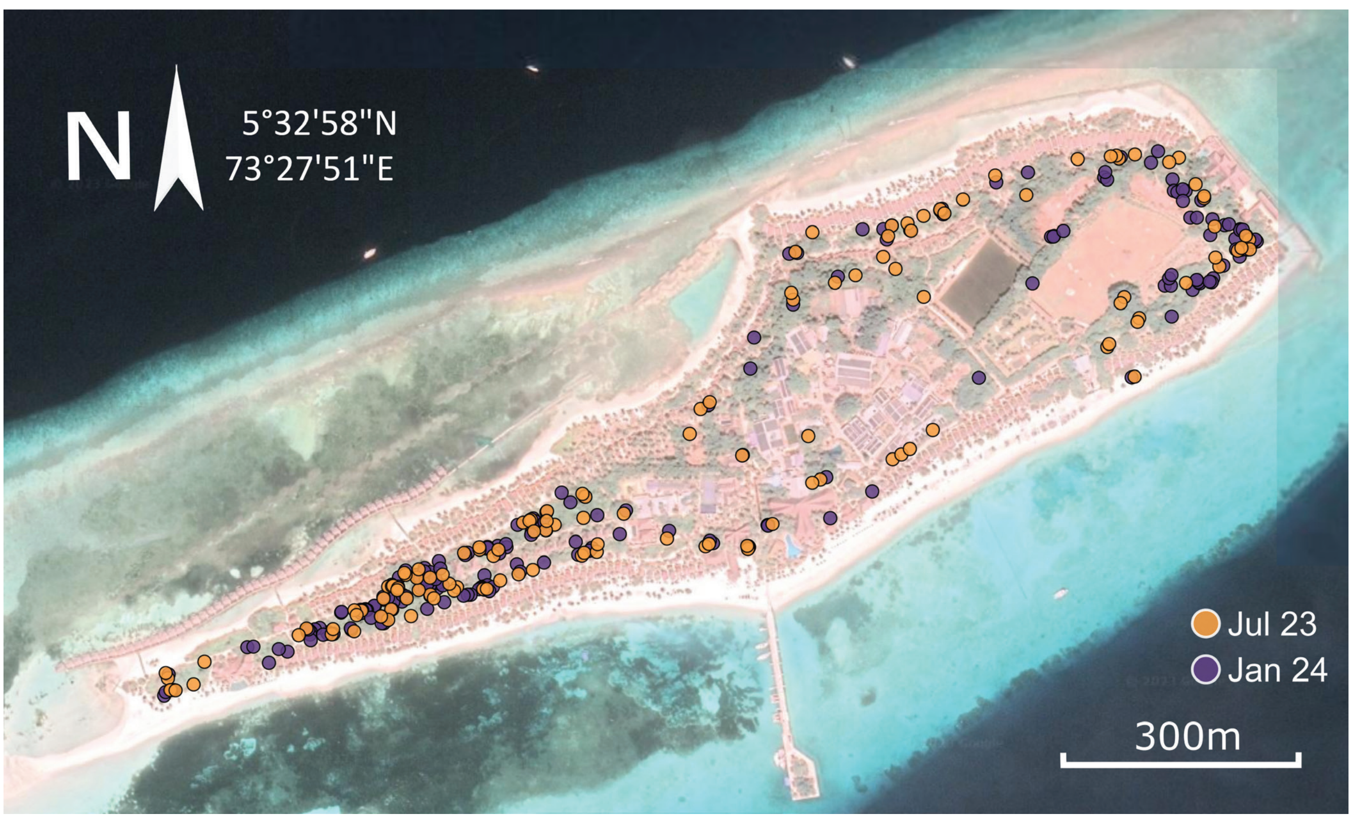

Fig 2. White-tailed Tropicbird *Phaethon lepturus* nests recorded on Kurehdhoo (Lhaviyani Atoll), Republic of the Maldives, in July 2023 and January 2024.

enumerating the entire island on both occasions, we did not need to account for plot sampling extrapolation in our survey methodology (e.g., Russell *et al*. 2017). However, by not accounting for detection probability, our estimate is necessarily a minimum population size with potential negative bias. On the second survey that took place over more days, the additional nests detected were proportional to the additional kilometres walked. Further undercounting remains possible, but we expect any such bias remaining due to imperfect detection to be small. Although we did not inspect within elevated tree trunks where White-tailed Tropicbirds are also known to nest, including in banyan trees on Kurehdhoo, we do not expect the number of these nests was high given the limited number of potential sites.

Breeding appears to be year-round and asynchronous on Kurehdhoo. Therefore, our population size estimates from each survey did require correction because not all resident breeding birds were expected to be present on the colony at once. Our estimates of the minimum number of breeding adults present based on currently active nests with eggs or chicks, and based only on nests with eggs, were in close agreement. This is reassuring, and it also indicates that chick survival is high because accounting for chick deaths did not substantially alter the estimate. However, during our longer second survey, we did observe some nests failing due to both starvation and depredation by either rats or crabs, both of which were observed around nests prior to chicks disappearing. Nonetheless, our estimates are still likely to be conservative due to the presence of both juvenile and sabbatical non-breeders.

White-tailed Tropicbirds lie somewhere between a rat-resilient and rat-vulnerable species (Norbury *et al*. 2015). Adults are generally not depredated by rats, but nests are disturbed and abandoned, and nesting success is greatly diminished by chick predation (Saunier *et al*. 2022). Over time, this leads to a chronic gradual decline and eventual extirpation of the species. This mismatch in threat commencement (in the Maldives, due to rat introduction) and species extirpation can sometimes prevent managers from identifying the threat as the causal mechanism of species decline. However, a substantial reduction of rats, but not necessarily complete eradication, appears to have been sufficient to generate positive population growth. As observed elsewhere, the primary factor limiting White-tailed Tropicbird numbers was the presence of introduced rats (Saunier *et al*. 2022), but where rats are absent or removed, habitat management then played an important role in regulating population size (Catry *et al*. 2009). After invasive predators are removed, seabird colonies are generally capable of recovering despite ongoing marine impacts, including plastic pollution (Borrelle *et al*. 2023).

In the northern Indian Ocean across the Lakshadweep-Maldives-Chagos chain, the White-tailed Tropicbird population on Kurehdhoo now constitutes the largest known colony. White-tailed Tropicbirds are generally absent from the Lakshadweep Archipelago as a nesting species (Pande *et al*. 2007), and < 10 pairs per atoll are present in the Chagos Archipelago (Carr *et al*. 2021). In the eastern Indian Ocean on Cocos-Keeling atoll, the last census documented 45 nesting pairs (Stokes *et al*. 1984). In the western Indian Ocean, large colonies exist on Europa Island (500 to 1000 pairs) and Aldabra atoll (*ca*. 2500 pairs) (Le Corre & Jouventin 1997, Diamond 1975), although more recent estimates on Europa Island have indicated a population crash over a period of 25 y to only 100 pairs due to sustained rat predation (Saunier *et al*. 2022). However, on the larger volcanic and granitic islands in the western Indian Ocean, White-tailed Tropicbird colonies attain sizes of hundreds to a few thousands of pairs (Burt *et al*. 2021, Le Corre *et al*. 2022). Although the Kurehdhoo population size is small in comparison, its density undoubtedly makes it an important population in the Republic of Maldives and probably for the entire Indian Ocean region.

The size of this White-tailed Tropicbird population can be directly attributed to the intensive rat suppression across Kurehdhoo over the past 14 y, functionally extinguishing the impact of rats. Similar strong responses in seabird populations a decade following rat eradication have been noted elsewhere in the Indian Ocean (Le Corre *et al*. 2015). The White-tailed Tropicbird is a typically long-lived (over 15 y) and slow breeding (age at first breeding is typically five years old) seabird species. This means that initial population recovery for this species following instigation of rat management will be slow because, although breeding success will rapidly increase, chicks will not return to the colony to breed for several years. Only from year-five onwards will the population start to grow rapidly. Importantly, population growth will require a surviving source population, at least in the vicinity of the site. White-tailed Tropicbirds have not recolonised rat-free sites that are distant from potential colonists (Le Corre *et al*. 2015). However, when an extant population exists nearby, White-tailed Tropicbirds tend to be rapid prospectors and inspect rat-free sites within months (SS & JCR pers. obs.).

It was evident that the White-tailed Tropicbirds on Kurehdhoo were not significantly disturbed by resort activities given that nesting occurred across the entire island, often in close proximity to human activities such as roads used frequently for walking and driving, and buildings used for resort operations. Indeed, we observed White-tailed Tropicbirds nesting amongst the restaurant dining areas, beside office and accommodation buildings, and by major roads. However, despite the intense development footprint, it has also been important for the White-tailed Tropicbirds that Kuredu Resort kept a substantial fraction of its island vegetated in predominantly native atoll flora forest (*Pandanus*, *Hibiscus*, and *Scaevola*). This shaded native atoll vegetation is where most White-tailed Tropicbird nests were found and is also a key additional contributor to the success of White-tailed Tropicbirds on this island. Although resort development can have negative impacts on coral atoll island biodiversity (Steibl *et al*. 2021), some impacts can be positive. In this case, management of rats as a resort guest nuisance, while also preserving native atoll forest, has had the ancillary benefit of enabling seabird recovery. Furthermore, unlike those seabird species that form noisy and smelly dense colonies, the White-tailed Tropicbird, as well as being resort-resilient, is also a relatively resort-friendly species. We suggest that the terrestrial recovery of seabird biodiversity as an auxiliary benefit of rat management on resort islands is an under-appreciated tourism and marketing opportunity that can supplement protected areas (islands) on atolls in the Maldives, an approach that has already been successfully leveraged elsewhere in the Indian Ocean such as the Seychelles (e.g., Shah 2001).

The presence of this White-tailed Tropicbird population on Kurehdhoo presents opportunities for future research and conservation efforts. With the population of White-tailed Tropicbirds on Kurehdhoo now at a high density, individuals will likely be prospecting other nearby islands for suitable breeding habitat. The most suitable habitat will be on neighbouring rat-managed islands, such as the nearby resort islands of eastern Lhaviyani Atoll, at which intensive rat-management is only now recommencing in association with the opening of new resorts. Indeed, at the same time as our surveys, Kanuhuraa had only a few White-tailed Tropicbird nests (SS & JCR pers. obs.). However, we expect this number of nests to increase over time if rat management is undertaken to a high standard, as similar nesting sites are also available. A long-term individual bird ringing study would provide useful information on population size, the dispersal of White-tailed Tropicbirds among islands, and the relative contribution of internal juvenile *versus* external adult recruitment to recovering populations. This work could be supplemented by at-sea foraging studies (e.g., Ali *et al*. 2023) to determine both the catchment area from which tropicbirds might be drawn to new sites (e.g., Buxton *et al*. 2014), as well as helping define marine protected areas in the Republic of the Maldives (e.g., Le Corre *et al*. 2012).

Tropical Shearwaters are also prospecting on Kurehdhoo following rat suppression, and this species is a more rat-vulnerable and data depauperate species for which more research and monitoring is required. A comprehensive nocturnal survey of breeding locations and the number of burrows of Tropical Shearwaters should be undertaken in a subsequent January during the birds' vocal prospecting phase, followed by monitoring of chick survival and fledging rates. Migratory waders also use the golf course greens and beaches on Kurehdhoo as a stopover site to unknown wintering locations (SS unpubl. data). Therefore, the island is an important site in Lhaviyani Atoll for several bird species that are nationally protected in the Maldives (Steibl & Laforsch 2021). Attaching transmitters to individuals of these species would determine their ultimate destination and, hence, what role the Republic of the Maldives plays in the Indian Ocean flyway.

ACKNOWLEDGEMENTS

Thanks to the resort management and ownership Crown & Champa Resorts, Ray van Eeden from Prodivers Maldives for logistical support, and the Ministry of Environment and Environmental Protection Authority of the Republic of the Maldives for regulatory and permitting support. This work was performed under EPA permit EPA/2024/PSR/01. Thanks to David Ainley, Matthieu Le Corre, and Pete Carr for comments that improved the manuscript, and Rosalyn Johnson for technical editing of the manuscript.

AUTHOR CONTRIBUTIONS

JCR, SS, and GMWS conceptualised the research. JCR and SS undertook the research, and JCR, SS, and GMWS wrote the manuscript.

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