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RESEARCH ARTICLE

Large marine protected areas can encompass movements of diverse megafauna

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Abstract

1. Global calls for greater ocean protection have sparked renewed interest in very large marine protected areas (VLMPAs, >100,000 km^2) to achieve management targets; however, their conservation value is debated.
2. We assessed the suitability of a VLMPA (640,000 km^2) in the Indian Ocean for capturing the movements of resident mobile marine megafauna. We found that 95% of foraging, breeding and/or locally migrating individuals occurred within the VLMPA despite variable habitat use; adult hawksbill turtles (*Eretmochelys imbricata*, $n=22$, 6124 tracking days) foraged on mesophotic banks (>30 m depth), reef manta rays (*Mobula alfredi*, $n=23$, 652 tracking days) used shallow submerged banks, and seabirds (red-footed boobies *Sula sula*, brown boobies *Sula leucogaster*, wedge-tailed shearwaters *Ardenna pacifica*, $n=257$, 1084 tracking days) collectively foraged throughout coastal to pelagic waters.
3. To understand the size of MPA necessary to encompass resident mobile species, we assessed overlap with smaller and larger hypothetical MPAs. An MPA meeting the minimum threshold of a VLMPA (>100,000 km^2) would encompass 97% of manta and 94% of turtle locations, and 59% of all seabird locations because of their more pelagic distribution.
4. *Synthesis and applications*. Our results provide clear evidence for the value of the large scale of the Chagos Archipelago very large marine protected area for protection of taxonomically diverse mobile megafauna. Further, we highlight the value of the VLMPA approach as a strategy towards achieving 30% ocean protection by 2030.

KEYWORDS
biologging, chagos archipelago, manta ray, marine conservation, movement ecology, MPA, seabirds, turtles

1 | INTRODUCTION

Very large marine protected areas (VLMPAs, >100,000 km^2) are often seen as a critical tool for meeting international calls for increased global ocean protection (Toonen et al., 2013), such as the '30×30' target for 30% protection by 2030, which is central to the United Nations Kunming–Montreal Global Biodiversity Agreement. Indeed, the world's 100 largest marine protected areas (MPAs) provide nearly 90% of global marine spatial protection coverage (Pike et al., 2024). However, it could be argued that such a route to conservation planning might miss species-specific resource needs (Belote et al., 2021), and the value of VLMPAs to highly mobile taxa remains ambiguous (Conners et al., 2022). Where animals show basin-wide or global-scale movements, they will not remain continuously within even the world's largest marine protected areas (Beal et al., 2021; Gilmour et al., 2022; Trevail, Nicoll, et al., 2023), which typically extend across 1000 km. In this context, there have been well-justified calls for enhanced protection in other areas that wide-ranging animals move through, including better management of high seas areas beyond national jurisdiction (Harrison et al., 2018; Sala et al., 2021; Sequeira et al., 2019).

Set against this backdrop, VLMPAs can still have benefits for sessile animals and algae, or those that move over shorter distances, for example coral reef-associated fauna (Sala et al., 2021). Importantly, no-take marine reserves provide the most effective tool for biodiversity resilience when ecosystem complexity is restored (Sala & Giakoumi, 2018), including marine megafauna populations (Hammerschlag et al., 2019), which have roles in, for example, nutrient transfer (Graham et al., 2018) and food web stabilisation (Rooney et al., 2006). Furthermore, marine megafauna can be important indicators of ecosystem processes, and therefore, their distributions are useful for establishing marine protected area boundaries (Hooker & Gerber, 2004). Therefore, given the pressing need to protect more of the global oceans with high-quality conservation measures (Pike et al., 2024), and empirically assess existing MPA adequacy (Conners et al., 2022), we aim to address the suitability of a VLMPA to protect a diverse range of mobile megafauna species during breeding, foraging and local migrations.

The Chagos Archipelago fully protected marine protected area was designated in 2010, and remains one of the largest MPAs globally at 640,000 km^2 (Figure 1a). The VLMPA not only supports the world's largest contiguous undamaged reef area (Sheppard et al., 2012), but also surrounding offshore habitats, such as open ocean areas and a network of seamounts that provide foraging grounds for globally important megafauna communities, which are some of the most pristine of their kind (Hays et al., 2020). The protection of such pelagic habitats is considered an important benefit of VLMPAs (Toonen et al., 2013); however, mismatches between the scale of VLMPAs and marine megafauna ranges and/or critical habitats are still a cause for concern (Agardy et al., 2011; Conners et al., 2022). Here, we assess the extent to which the Chagos VMPA encompasses movements and habitats of marine vertebrates with diverse home ranges: Chondrichthyes (reef manta rays) that forage for nearshore and mesopelagic zooplankton (Harris et al., 2023; Peel et al., 2019), Reptilia (sea turtles) that forage on submerged atoll reefs (Hays et al., 2024), and Aves (seabirds) that surface feed in pelagic areas (Trevail et al., 2024; Trevail, Wood, et al., 2023) often in association with sub-surface predators (Jaquemet et al., 2004). We also test how variation in MPA size might benefit different levels of taxonomic diversity, and hence, our study will offer insight into the value of differing sizes of MPAs for global conservation planning.

2 | MATERIALS AND METHODS

2.1 | Tracking at-sea movements

Between 2015 and 2024, 23 reef manta rays (*Mobula alfredi*; 12 adults, eight juveniles, and five of unknown maturity) were tracked with a combination of towed Argos tags (SPOT-253C = 5, SPOT-253G = 8 and SPLASH10-F (Fastloc-GPS) = 10, Wildlife Computers, Seattle, Washington, USA) within their foraging grounds (Figure 1b). Tags were deployed to the upper right dorsal musculature with a titanium anchor attached to a one-metre-long stainless-steel tether with a mid-line swivel, using a modified Hawaiian hand sling while swimming behind the animal. Prior to being tagged, each individual was identified as unique by photographing their distinct ventral spot pattern and their age was determined visually (Stevens, 2017). To estimate the most likely movement paths from manta ray satellite telemetry locations, the hierarchical version of the Bayesian state-space model of the first difference correlated random walk (hDCRW) was fitted to all data to correct errors associated with locations and regularise position estimates to a 5-h time-step. The model was fitted in R 4.3.1 using the *bsam* R package, which implements the model using Markov chains Monte Carlo (MCMC) via JAGS software (Jonsen et al., 2013). Two independent MCMC chains were run using 10,000 adaptive (burn-in) samples, and then, every 50th sample of 5000 was drawn from the posterior distribution to reduce within-chain autocorrelation. Model convergence was assessed using the 'diag_ssm' function in the *bsam* package, which uses Gelman and Rubin's shrink factor (Jonsen et al., 2013).

Central-place foraging movements of breeding adult seabirds were recorded from four colonies within the Chagos Archipelago (Figure 1b). Red-footed boobies (*Sula sula*) were tracked using archival GPS loggers (igotU GT-120, Mobile Action/Axytrek marine,

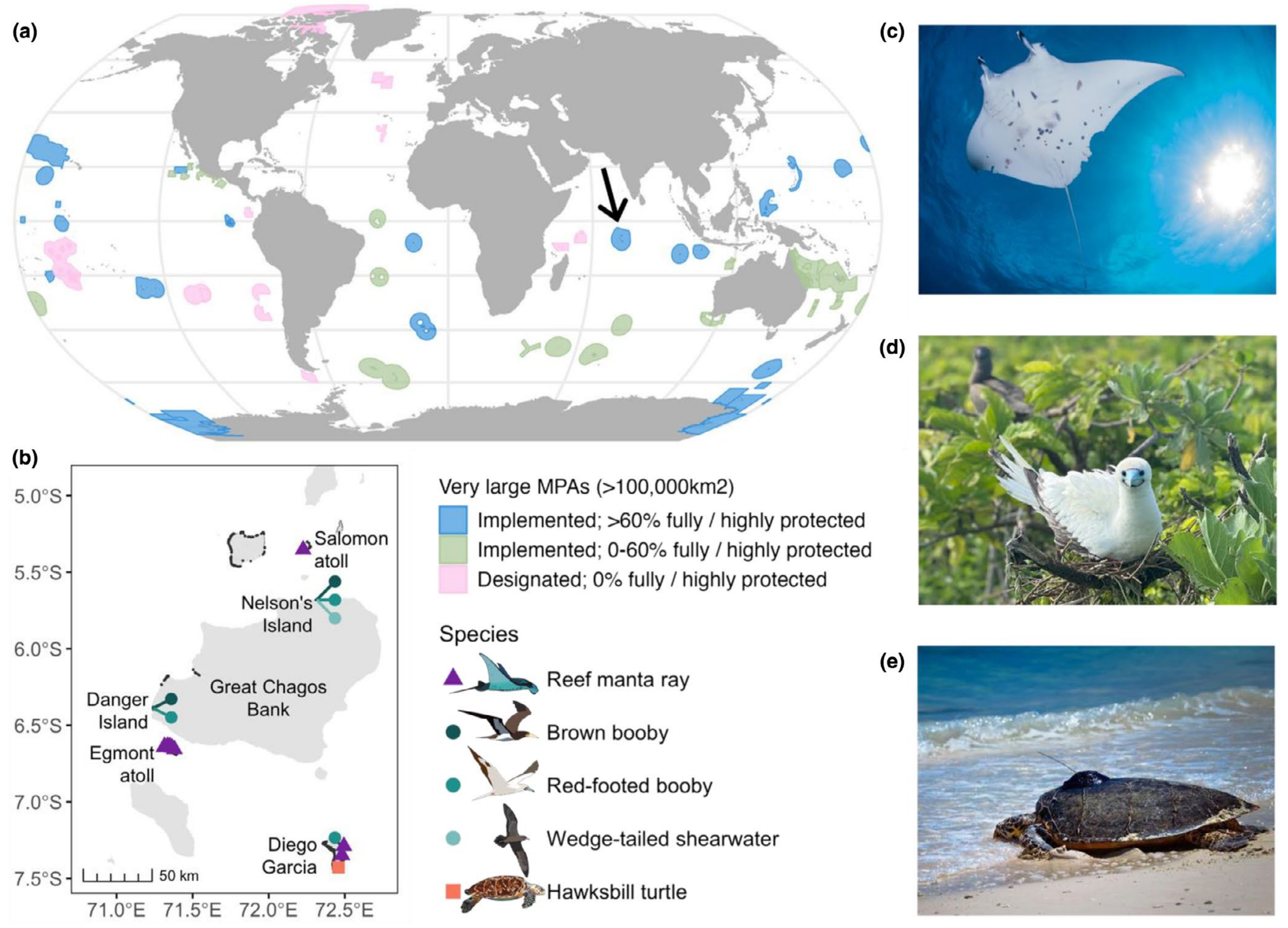

FIGURE 1 Marine megafauna species tracked throughout the Chagos Archipelago marine protected area (MPA), one of a global network of very large MPAs. (a) Global implemented and >60% fully/highly protected, implemented but <60% fully/highly protected, and designated but 0% fully/highly protected, very large marine protected areas (VLMPAs) with the study site indicated by a black arrow (b) tag deployment locations within the Chagos Archipelago MPA. (c) A reef manta ray photographed before tag deployment to determine unique ventral spot patterning (photo: Simon Hilbourne Manta Trust). (d) A breeding red-footed booby with its GPS logger obscured under its tail feathers (photo: authors). (e) A hawksbill turtle equipped with a Fastloc-GPS Argos tag after nesting (photo: authors). In panel (b), point shape varies by class, and where multiple species were tracked at a single site, points are connected to the deployment location by coloured lines. Areas shallower than approximately 100 m are shaded grey, and islands are solid black. Marine protected areas >100,000 km as assessed by Pike et al. (2024) were accessed via the MPA Atlas (https://mpatlas.org/large-mpas/) and downloaded from the World Database on Protected Areas (protectedplanet.net; UNEP-WCMC and IUCN, 2021). We note that <10 newly designated MPAs were unavailable from the WDPA as of January 2025.

Technosmart) at Barton Point (7.23° S, 72.43° E), East Island (7.23° S, 72.42° E); Nelson's Island (5.68° S, 72.32° E); and Danger Island (6.39° S, 71.24° E) during 2016, 2018–2019, and 2022–2023 (Trevail, Wood, et al., 2023). Brown boobies (*Sula leucogaster*) were tracked using archival GPS loggers (igotU GT-120, Mobile Action) at Nelson's Island and Danger Island during 2018–2019 (Trevail et al., 2024). Wedge-tailed shearwaters (*Ardenna pacifica*) were tracked using remote-download GPS loggers (Axytrek remote, Technosmart/nanofix GEO + RF, Pathtrack) during 2023–2024 at Nelson's Island. Loggers were attached to the central 2–4 tail feathers with TESA tape and were set to record a position every 5–15 min. All seabirds were tracked during pre-breeding, incubation, or chick-rearing. Central-place foraging trips were identified using a 1 km threshold from the colony, and fixes at the breeding colony were removed (Trevail et al., 2024).

Adult female hawksbill turtles (*Eretmochelys imbricata*) were equipped with Fastloc-GPS Argos tags (SPLASH10-BF, Wildlife Computers, Seattle, Washington, USA) after they had completed nesting on Diego Garcia during 2018 and 2019 (Hays et al., 2024; Figure 1b). Tags were attached to a cleaned and lightly sandpapered area of the carapace using epoxy, which was then smoothed and covered with anti-fouling paint (Esteban et al., 2017).

All seabird tracking was approved by ethics committees at the Institute of Zoology, Zoological Society London, and the University of Exeter, under licence from the British Trust for Ornithology and through research permit numbers 0001SE18, 007SE18, 0000SE19, 0006SE19, 000SE22 and 0011SE22. All reef manta ray tagging activities were approved by the University of Plymouth Animals in Science Ethics Committee under permit ETHICS-55-2023. Hawksbill turtle tracking work was approved by Swansea University and Deakin University Ethics Committees and through research permit numbers 0009SE18 and 0011SE19.

2.2 | Spatial distributions

To identify class hotspots (i.e. manta, seabird, and turtles), we estimated core (50%) and home range (90%) utilisation distributions across the entire tracking period using fixed bandwidths of 5, 15 and 5 km, respectively, in the R package *eks* (Duong, 2024). These bandwidths reduced the over-fragmentation observed with default or automatic bandwidths and were based on the daily movement ranges of the classes. We calculated utilisation distributions for each species, and then aggregated areas at class level to ensure equal species representation. To map areas where multiple classes overlap, we counted species presence across a hexagonal grid with a cell diameter of 20 km encompassing the MPA and the full extent of the tracks and present the total number of classes present per grid cell, akin to a measure of richness (Trevail, Nicoll, et al., 2023).

To understand habitat types used by each class, we extracted ETOPO 2022 bathymetry from the National Oceanic and Atmospheric Administration (NOAA) via the R package *marmap* (Pante et al., 2023). While there are many environmental variables that can enhance mechanistic understanding of species distributions (e.g. Dunn, Freeman, et al., 2024), here we are interested in whether the Chagos Archipelago MPA captures used habitats at a broad scale, and therefore, we use bathymetry as a proxy for habitat types. Surrounding the Chagos Archipelago, shallow bathymetry values indicate productive shallow and mesophotic reefs (0–100 m) and seagrass meadows (Esteban et al., 2018; Hays et al., 2024). Intermediate depths and steep slopes around submerged banks and seamounts (>50 m deep) cause physical oceanographic processes that enhance accessible productivity to higher trophic levels (Robinson et al., 2023). Deeper waters (>2000 m) comprise pelagic, typically oligotrophic areas, but can include ephemeral processes that cause prey fluctuations. We first calculated the mean bathymetry within each 20 km hexagon grid cell (described above). To represent depth use by each class, we extracted mean bathymetry values from hexagons within core (50%) utilisation distributions. To represent depths encompassed by the MPA, we extracted mean bathymetry values from hexagons within the MPA boundary.

2.3 | Required MPA size

To understand the size of MPA necessary to encompass the distributions of these resident species, we assessed overlap with a set of smaller and larger hypothetical MPAs. We used land above sea level as our minimum hypothetical MPA area and increased the radius by 20 km increments to the edge of the existing MPA at the Chagos Archipelago Exclusive Economic Zone boundary and then further by 20 km increments from the edge of the existing MPA (max 100 km). We calculated the percentage of tracking fixes from each species that fell within each hypothetical MPA and the minimum size MPA required to encompass the entire core (50%) utilisation distribution of each class.

3 | RESULTS

A total of 257 seabirds, 22 hawksbill turtles and 23 reef mantas were tracked, including a total of 7864 days of tracking (1084 for birds, 6124 for turtles and 652 for manta) between 2015 and 2024 (Figure 1). The mean tracking length for individuals of each class was 4.2 ± 0.3 days for seabirds, 278.4 ± 28.3 days for turtles, and 28.5 ± 18.2 days for reef manta rays (Table 1). Across these taxa, 95.3% of the individuals remained entirely within the Chagos Archipelago MPA for 99.1 ± 0.3% of the tracking period; only 5.5% of seabirds ($n = 14$) moved beyond the MPA boundary (<1.1 ± 0.33% of their time, Figure 2a). Core and home range areas of turtles and manta were exclusively within the MPA (Figure 2b), although the

TABLE 1 Sample sizes of manta rays, seabirds and turtles tracked within the Chagos Archipelago marine protected area (MPA).

Class	Species	Years	Individuals	Total tracking days	Mean tracking days per individual ± standard error (range)	References
Manta	Reef manta ray, *Mobula alfredi*	2015–2024	23	656	28.5 ± 3.8 (6–75)	This study
Seabird	ALL	2016–2024	257	1084	4.2 ± 0.3 (1–33)	This study
	Brown booby, *Sula sula*	2018–2019	13	64	4.9 ± 0.4 (3–8)	Trevail et al. (2024)
	Red-footed booby, *Sula leucogaster*	2016–2023	207	640	3.1 ± 0.1 (1–10)	Trevail, Wood, et al. (2023)
	Wedge-tailed shearwater, *Ardenna pacifica*	2023–2024	37	380	10.3 ± 1.7 (1–33)	This study
Turtle	Hawksbill turtle, *Eretmochelys imbricata*	2018–2021	22	6124	278.4 ± 28.3 (38–503)	Hays et al. (2024)

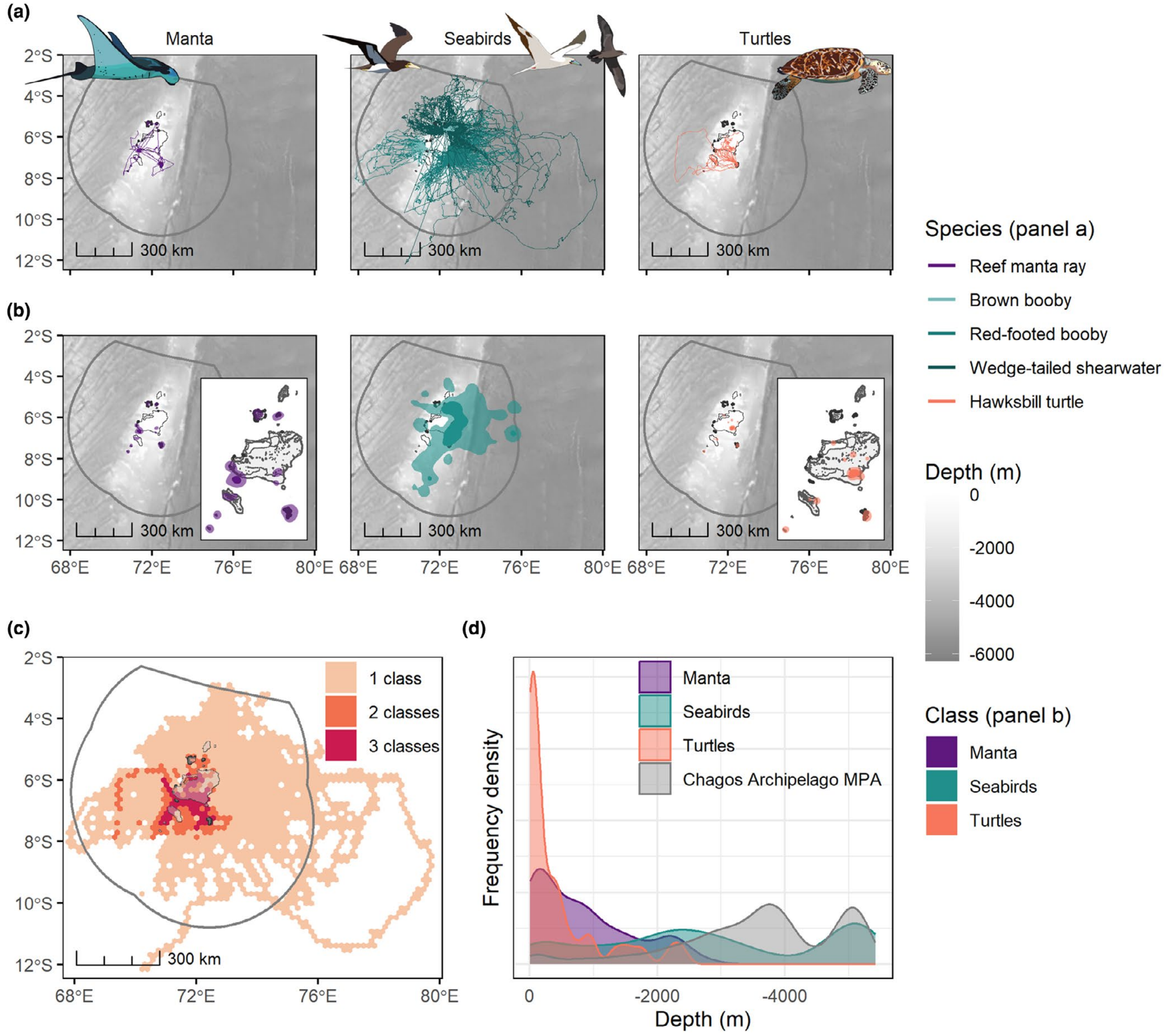

FIGURE 2 The Chagos Archipelago marine protected area (MPA) (grey outline in panels a–c) encompasses >99% of at-sea movements of tracked species. (a) Reef manta rays ($n = 23$, 2015–2024, 100% of individuals remained in MPA), seabirds ($n = 257$, 2016–2024, 94.5% of individuals remained in MPA) and hawksbill turtles ($n = 22$, 2018–2021, 100% remained in MPA). Seabirds and turtles were tracked as adults from their breeding sites, and manta rays were tracked as adults ($n = 12$) and juveniles ($n = 8$) or unknown stages ($n = 5$) from their foraging grounds. (b) Spatial distribution of core areas varied among classes within the MPA (90% and 50% utilisation distributions shown in light and dark-shaded areas, respectively). Notably, seabirds foraged in pelagic areas away from the central Great Chagos Bank, manta rays used the areas between island atolls and submerged banks, and turtles' core areas were restricted to submerged banks. To aid visualisation, inset panels zoom in on the full extent of manta and turtle home ranges. (c) Tracking data from the three classes shows the extent of use throughout the Chagos Archipelago MPA, with areas of high overlap in neritic areas between island atolls. (d) Depths within the core area of each class (coloured relative density curves) range across the extent of bathymetry values within the Chagos Archipelago MPA (grey relative density curve). In panels (a–c), areas shallower than approximately 100 m are outlined in black, and islands are shown in solid black (more detail in Figure 1).

ranges of seabirds extended beyond the MPA boundary, driven by larger ranges of wedge-tailed shearwaters (Figure 2b).

The areas used by the three classes were generally distinctive; red-footed boobies and wedge-tailed shearwaters foraged in open ocean areas, hawksbill turtles foraged on mesophotic (>30 m) submerged banks and reef manta rays and brown boobies foraged in neritic areas, often close to islanded atolls (Figure 2b).

While their high-use areas tended to differ, some areas were commonly used by all classes, particularly areas around the perimeter of the Great Chagos Bank, where all tracked species transited between foraging grounds (Figure 2c). Available habitat within the MPA encompassed recorded bathymetric ranges of all tracked species (Figure 2d). Turtles' core area comprised the shallowest habitats (mean bathymetry ± standard error: 438 ± 107 m,

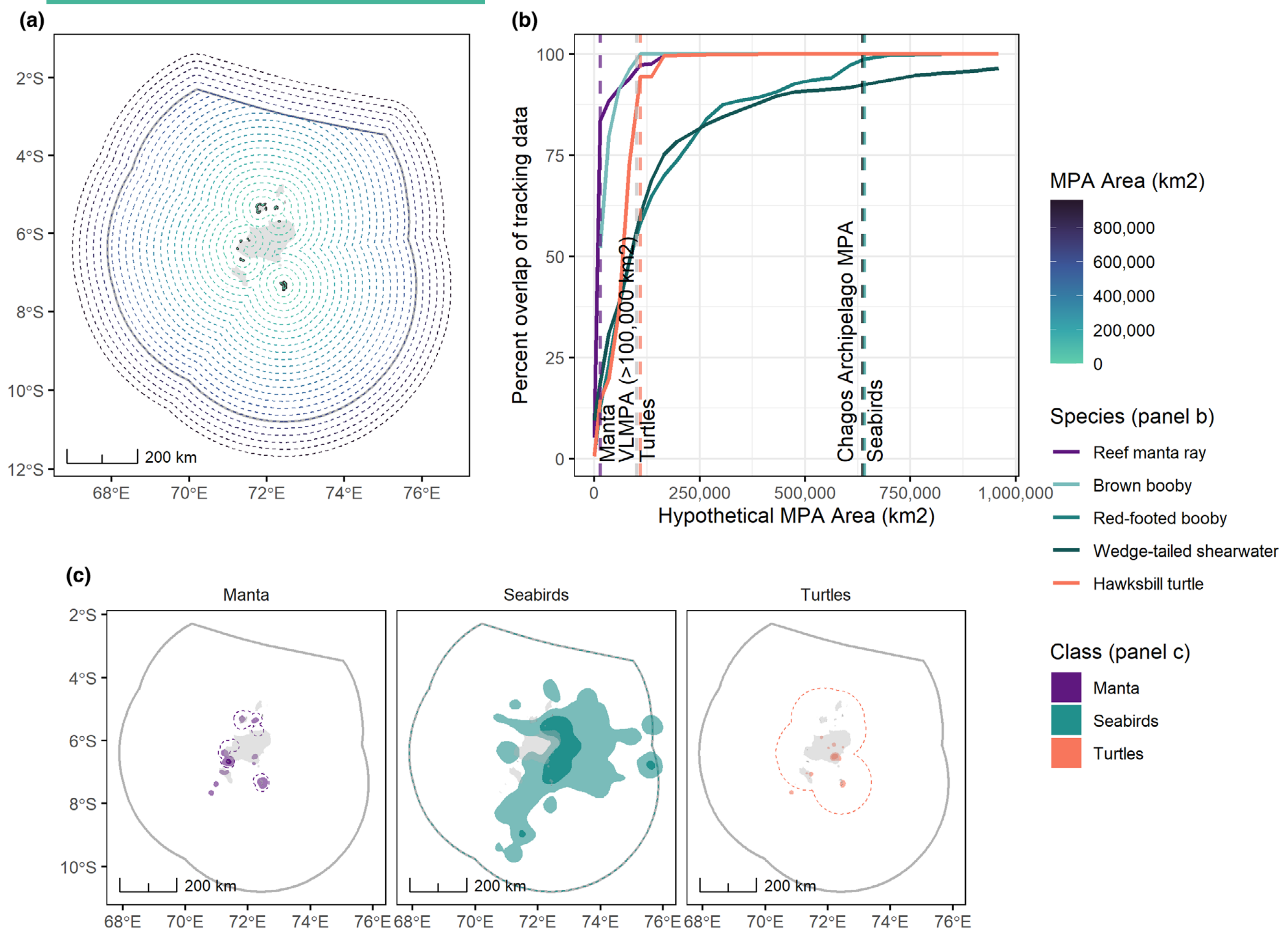

FIGURE 3 The Chagos Archipelago very large marine protected area (VLMPA) encompasses >92% of the tracks of all species, and the minimum VLMPA (>100,000 km^2) would encompass >50%. (a) Hypothetical marine protected areas (MPAs) at 20 km increments from land out to the existing MPA at the extent of the Chagos Archipelago EEZ (exclusive economic zone), and then 20–100 km increments beyond the EEZ boundary. (b) Percentage overlap of tracking data with hypothetical MPAs. Vertical dashed lines illustrate the area of very large MPAs (VLMPA), the Chagos Archipelago VLMPA, and the areas required to encompass the 50% core areas of each Class coloured in accordance with MPA Area in panel (a). (c) minimum MPA sizes to encompass the 50% core areas of each class (coloured dashed lines), including 50% (light) and 90% (dark) core areas as in Figure 2b.

range: 20–2385 m), followed by manta rays (825 ± 99.5 m, 20–2735 m). Seabirds used foraging sites with the widest range of maximum depths (2842 ± 69.2 m, 11.8–5417 m), of which all are available within the MPA (3553 ± 29 m, −9.3–5407 m).

The size of the Chagos Archipelago MPA is necessary for supporting the range of species tracked here, particularly pelagic taxa (Figure 3). The existing VLMPA (640,000 km^2) encompassed 100% of reef manta ray, hawksbill turtle and brown booby tracking locations, 98.9% of red-footed booby tracking locations, and 92.5% of wedge-tailed shearwater tracking locations. The threshold for a very large MPA (>100,000 km^2) would protect 100% of brown booby tracking locations, 97.4% of manta locations, 94.4% of hawksbill turtle locations, 60.3% of wedge-tailed shearwater locations and 58.1% of red-footed booby locations (Figure 3). The minimum MPA size to fully encompass the 50% core use areas of the tracked species would be 13,554 km^2 for manta, 109,007 km^2 for turtles, and 640,846 km^2 for seabirds, because a small portion of the core use area of wedge-tailed shearwaters extends beyond the existing MPA boundary (Figure 3c).

4 | DISCUSSION

We show that the scale of the Chagos Archipelago VLMPA was essential to encompass the distributions and habitats of a diverse range of tracked taxa during their essential breeding and foraging periods. These results provide evidence for the value of VLMPAs in protecting diverse animals and habitats (Sala et al., 2021).

Our results show that VLMPAs may be an effective route to help protect a range of mobile megafauna species towards '30 × 30' conservation targets. VLMPAs have been designated in most marine ecoregions across the globe; however, many lack appropriate conservation regulations and/or do not entirely restrict damaging extractive activities such as fishing (Wilhelm et al., 2014), and as such, MPA quality is lagging behind quantity (Pike et al., 2024). Evidence of the ecosystem value of such areas is therefore essential for appropriate future management in existing VLMPAs (implemented but not fully protected/designated; Figure 1a) or for considering new MPA design. Importantly, we showed that different Classes of marine megafauna used a variety of areas within a VLMPA, but that the scale of the Chagos Archipelago VLMPA was essential to encompass species distributions (Figure 3) and habitat ranges (Figure 2); including submerged banks around islanded and unislanded atolls (hawksbill turtles and manta ray), shelf edges (manta ray and brown boobies) and deep ocean pelagic areas (red-footed boobies and wedge-tailed shearwaters). While the patterns of movements were different among species, they all largely remained within the boundary of the Chagos Archipelago VLMPA. Our results, therefore, argue for the value of VLMPAs in protecting diverse marine megafauna and their key habitats.

Smaller MPAs could still be effective in mitigating some threats, such as protecting species with smaller home ranges (Figure 3c), and are particularly valuable where scales of animal movements align with scales of anthropogenic impact and governance (Lagabrielle et al., 2018). However, global marine ecosystems are affected by cumulative impacts (Halpern et al., 2008), and therefore threats to mobile species also exist across their foraging and migration areas, including targeted capture and bycatch in various fishing gear (Fuentes et al., 2023) during long-distance migrations not captured within this study (Shimada et al., 2020; Trevail, Nicoll, et al., 2023). Hence, MPAs that encompass important life stages such as immaturity, breeding, and foraging will have great value. Larger MPAs around tropical archipelagos will also have the advantage of protecting pelagic species, such as pelagic sharks and tunas that are generally exposed to high fishing pressure (Queiroz et al., 2019) with potential 'spillover' benefits beyond MPA boundaries (Lynham & Villaseñor-Derbez, 2024). The implementation of such conservation measures is particularly timely due to tropical atoll islands increasingly being viewed as conservation priorities because of the high biodiversity that they support (Dunn, Benkwitt, et al., 2024), including an estimated 31.2 million breeding seabirds globally (Steibl et al., 2024).

The Chagos Archipelago supports a diverse range of globally important populations of marine vertebrates (Hays et al., 2020; Koldewey et al., 2010). It is a global bright spot for reef fishes (Cinner et al., 2016) that are vulnerable to fishing pressure in smaller MPAs because of their large home areas (Graham & McClanahan, 2013). Concerning megafauna, the Chagos Archipelago MPA is estimated to support one of the world's largest breeding populations of the critically endangered hawksbill turtle, and an important nesting sanctuary for migratory endangered green turtles, *Chelonia mydas*, both of which have been increasing in number since 1996 in the absence of human exploitation (Mortimer et al., 2020). Furthermore, the Chagos Archipelago supports >280,000 pairs of 18 species of breeding seabirds, of which four, including red-footed boobies, breed in numbers that qualify for globally Important Bird Area designation (Carr et al., 2021). The seabirds tracked here are representative of pelagic seabirds, foraging at similar distances to colonies in other ocean basins (Trevail et al., 2024; Trevail, Wood, et al., 2023), and therefore distributions likely encompass those of species with smaller home ranges such as terns and noddies (Soanes et al., 2015); however, additional local tracking of these species would confirm their key habitats and specific use of the VLMPA. Indeed, while the Chagos Archipelago MPA encompasses a broad range of depths (our proxy for varying habitat types), tropical seabird habitat selection within the region is also driven by a range of more dynamic abiotic factors (Dunn, Freeman, et al., 2024; Trevail, Nicoll, et al., 2023) as well as biotic factors (e.g. facultative and competitive interactions).

Preliminary models based on photographic ID suggest a total population size of >900 reef manta rays (Joanna L. Harris, unpublished data) within the Chagos Archipelago, representing one of the world's largest populations. Like other mobulid species that face unsustainable depletion throughout much of the Indian Ocean (Fernando & Stewart, 2021), the Chagos Archipelago MPA, therefore, provides them essential refuge from fisheries, potentially making the local mobulid populations a stronghold for the species' survival (Harris, Collins, et al., 2024). Though manta ray movements are linked to areas of high primary productivity and prey density, often driven by winds and surface currents (Harris et al., 2020), here we show that their core foraging ranges were close to islanded atolls. Alongside reef manta rays, other large pelagic fish including sharks and tuna show periods of residency within the Chagos Archipelago MPA, habitat selection being driven by temperature and time of day as well as depth (Carlisle et al., 2019; Curnick et al., 2020). While manta rays could be supported by an MPA less than the VLMPA threshold (100,000 km^2; Figure 3c), the larger actual size ensures protection of a greater diversity of taxa (Figure 3), underscoring the value of VLMPAs for mobile megafauna under appropriate enforcement (Collins et al., 2021). Additionally, the impacts of climate change, such as increasingly frequent and extreme El Niño events, can increase dispersive movements of reef shark species (Williamson et al., 2024). Therefore, larger MPAs could capture future climate-driven changes in distributions.

Tracking durations and sample sizes varied among study species according to logistical and technological constraints. Nevertheless, tracking periods include key life stages and, for some taxa, are likely representative over longer durations. For example, hard-shelled turtles have fidelity to both their foraging and breeding sites throughout adulthood (Shimada et al., 2020) and hence adult hawksbills likely spend their entire adult lives within the Chagos Archipelago MPA, their distributions largely being driven by the availability of mesophotic reefs and benthic invertebrates (Hays et al., 2024). Similarly, seabirds in the Chagos Archipelago are highly faithful to their breeding sites, and often forage in the same areas among breeding seasons and years of variable environmental conditions (Trevail, Wood, et al., 2023). Although wedge-tailed shearwaters are migratory (Trevail, Nicoll, et al., 2023), red-footed boobies likely remain within the archipelago year-round, relying on terrestrial overnight roosts (Votier et al., 2024). While reef manta rays are capable of large-scale movements, they display high levels of site fidelity, often remaining resident in, or seasonally returning to, specific locations that provide reliable food resources, cleaning stations, and refuge from predators for multiple decades (Harris, Hosegood, et al., 2024). While our results show the value of large MPAs for these taxa, migratory species, such as some seabirds, post-nesting green turtles and several pelagic shark species, will often travel out of even the largest MPAs (Queiroz et al., 2019; Seminoff et al., 2008; Trevail, Nicoll, et al., 2023). However, these groups or life stages are probably best afforded high seas protection or policy change to reduce threats at ocean basin scales (Beal et al., 2021).

In summary, our results point to the role of VLMPAs in offering protection for diverse, endangered marine megafauna species, adding value to the role of VLMPAs as a useful vehicle to increase the extent of ocean protection and help nations achieve their 30×30 marine conservation goals. Specifically, the Chagos Archipelago MPA offers support to benthic foragers (turtles), pelagic planktivores (manta ray), and oceanic predators (seabirds). These results are particularly pertinent given recent proposed sovereignty changes and ongoing spatial planning discussions in the region. In a world where human disturbance is altering animal movement patterns globally (Doherty et al., 2021), and appropriate strategies for future conservation progress are up for debate (Pike et al., 2024), it is encouraging that large marine reserves can support mobile species and their habitats.

AUTHOR CONTRIBUTIONS

Alice M. Trevail, Ruth E. Dunn, Malcolm A. C. Nicoll, and Graeme Hays conceived and designed this study. Alice M. Trevail, Ruth E. Dunn, Pete Carr, Nicole Esteban, Robin Freeman, Joanna L. Harris, Malcolm A. C. Nicoll, Nia Stephens, Guy M. W. Stevens, Stephen C. Votier, Hannah Wood, and Graeme C. Hays collected and processed tracking data. Alice M. Trevail analysed the data with support from Ruth E. Dunn. Alice M. Trevail, Ruth E. Dunn, Joanna Harris, and Graeme Hays led the writing of the manuscript. All authors contributed to drafts and gave final approval for publication.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare.

DATA AVAILABILITY STATEMENT

Red-footed booby tracking data are accessible via the BirdLife International Seabird Tracking Database (data set IDs 1687-1689, 2098, 2099 and 2100): https://doi.org/10.7910/DVN/XGS5GZ (Nicoll et al., 2025), as are brown booby tracking data (data set IDs 1685 and 1686): https://doi.org/10.7910/DVN/K3SSUS (Nicoll et al., 2024), and wedge-tailed shearwater tracking data (Data set IDs 2385 and 2388): https://doi.org/10.7910/DVN/6BMLLE (Trevail et al., 2025). Turtle tracking data are available via a previous publication: https://doi.org/10.1126/sciadv.adl2838 (Hays et al., 2024). Reef manta ray tracking data are available from the Harvard Dataverse: https://doi.org/10.7910/DVN/MOZTMJ (Harris, 2025). Code is available via Zenodo: https://doi.org/10.5281/zenodo.15789496 (Trevail, 2025).

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