



# Spatial ecology of a newly described oceanic manta ray population in the Atlantic Ocean

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## Abstract

The oceanic manta ray (*Mobula birostris*) is a circumglobally distributed species, but little to no information exists for many parts of their range. The eastern central Atlantic Ocean is a particularly data-deficient area, where manta ray presence has seldom been reported and regional descriptions of the distribution, movement, and connectivity of populations are unavailable. This study makes use of satellite telemetry, coupled with ecological niche modeling, to provide the first description an oceanic manta ray population in the region based on observations from Cabo Verde, and describes the most likely distribution of the species in the region. Repeated surveys between 2015 and 2019 and data from 11 satellite-tracked individuals revealed a reliable and continued presence of manta rays in the archipelago, although the number of sightings was considerably lower than those reported for some of the major aggregation sites for the species and no individual was ever re-sighted. Ecological niche modeling indicates suitable habitat for manta rays exists in Cabo Verde for most of the year, though in considerably higher extent during the summer months. The model furthermore suggests possible seasonal connections between the archipelago and the wider Gulf of Guinea. The role of Cabo Verde in the life-history of oceanic manta rays in the region remains to be elucidated, though the low abundance and re-sighting frequency, coupled with modeling suggesting expanding and contracting suitable habitat, suggests that Cabo Verde might be a key stop-over along a potentially longer movement corridor.

**Keywords** Eastern Central Atlantic · Ecological niche modeling · Satellite tracking · *Mobula birostris* · Macaronesia · Cabo Verde

## Introduction

Manta rays are a group of two planktivorous batoid ray species in the genus *Mobula* (White et al. 2018), with a third putative species having been identified in the western central Atlantic ocean (Hinojosa-Alvarez et al. 2016; Hosegood et al. 2020). The reef manta ray (*Mobula alfredi*) is considered vulnerable to extinction by the IUCN Red List (Marshall et al. 2022b) and the oceanic manta ray (*Mobula*

*birostris*) is considered endangered on a global scale (Marshall et al. 2022a), since their populations have been significantly declining (Ward-Paige et al. 2013) due to direct and accidental fishing, among other factors (Croll et al. 2016; Marshall et al. 2022a, b).

The oceanic manta ray is the largest of the manta rays, and is circumglobally distributed in tropical and temperate waters (Marshall et al. 2022a). Despite a tendency for being more solitary and with a preference for oceanic environments (Armstrong et al. 2020; Marshall et al. 2022a) compared to reef manta rays, oceanic manta rays are also known to frequent coastal habitats (e.g., Medeiros et al. 2015; Andrzejczek et al. 2021), and in some cases display philopatry to certain aggregation sites (Dewar et al. 2008; Stewart et al. 2016). While many important seasonal or stable aggregation sites have been identified for both *M. alfredi* and *M. birostris* (Dewar et al. 2008; Luiz et al. 2009; Kitchen-Wheeler 2010; Deakos et al. 2011; Marshall et al. 2011; Graham et al. 2012; Germanov and Marshall 2014; McCauley et al. 2014; Jaine et al. 2014; Braun et al. 2015),

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little information is available for much of their range. In particular, virtually no information exists on the oceanic manta ray populations of the Eastern Central Atlantic Ocean (ECA). The presence of oceanic manta rays has been listed in published species indexes of Cabo Verde (Freitas et al. 2018) and the Azores (Sobral 2013), and they are sometimes mentioned in bycatch reports of tuna fisheries in the region (Zeeberg et al. 2006; Amandé et al. 2011; Torres-Irineo et al. 2014; Clavareau et al. 2018). No thorough assessment of manta ray presence exists for any country or region of the eastern Atlantic, and no key aggregation sites like the ones described for other parts of their range have been identified and formally described.

The ECA is a highly productive region for marine resources and multiple ecosystems, which sustain high biodiversity (Roberts et al. 2002) as well as productive fisheries (FAO 2018). It is therefore plausible that substantial manta ray populations inhabit this region. Simultaneously, the existence of numerous, highly active industrial and artisanal fishing operations (FAO 2018) is a potential threat to these populations. Manta rays are susceptible to capture in multiple fishery types and fishing gears, but especially in purse seine operations (Croll et al. 2016). In the Atlantic, reports exist on manta rays being accidentally caught in tuna fisheries (Zeeberg et al. 2006; Amandé et al. 2011; Torres-Irineo et al. 2014), though the ECA is one of the regions with the highest proportion of illegal, unregulated, and unreported (IUU) catches (Agnew et al. 2009; Carneiro 2012), suggesting that bycatch frequency might be much higher than official data suggests. Manta rays have extremely conservative life histories with very low fecundity (Dulvy et al. 2014), and are therefore sensitive to even modest increases in mortality (Croll et al. 2016).

In Cabo Verde, sightings of the oceanic manta ray (hereafter referred to only as manta ray. *M. alfredi* will be referred to as reef manta ray) are common among traditional fisher folks and tourism guides, notably in the Eastern islands of Sal, Boavista, and Maio, though no information exists on this population in the scientific literature. Fishermen on the island of Boavista report that manta rays are present around the island year-round, though with potential peaks in abundance in March–April and August–October. Manta rays are also advertised as potential encounters during SCUBA trips by dive shops on the island of Sal, and occasional sightings of the species have also been reported in other islands, including Maio, Santiago, and Sao Vicente (FG, personal observations). Although the presence of manta rays in the archipelago is therefore known, it remains unclear whether they are long-term residents or if Cabo Verde represents a stop in seasonal movements throughout the Eastern Atlantic Ocean.

A better understanding of the manta ray population in the western Atlantic and its distribution in this region, as well as its interactions with fishing activities, is required

to inform regional conservation planning and evaluate the status of manta rays in this part of their range. Here, we present the first description of manta ray presence in the ECA, employ satellite tracking to describe movements of individuals within the country's territorial waters, and use this information to infer, through ensemble ecological niche modeling, the likely wider distribution of manta rays in Cabo Verde and the adjacent region.

## Methods

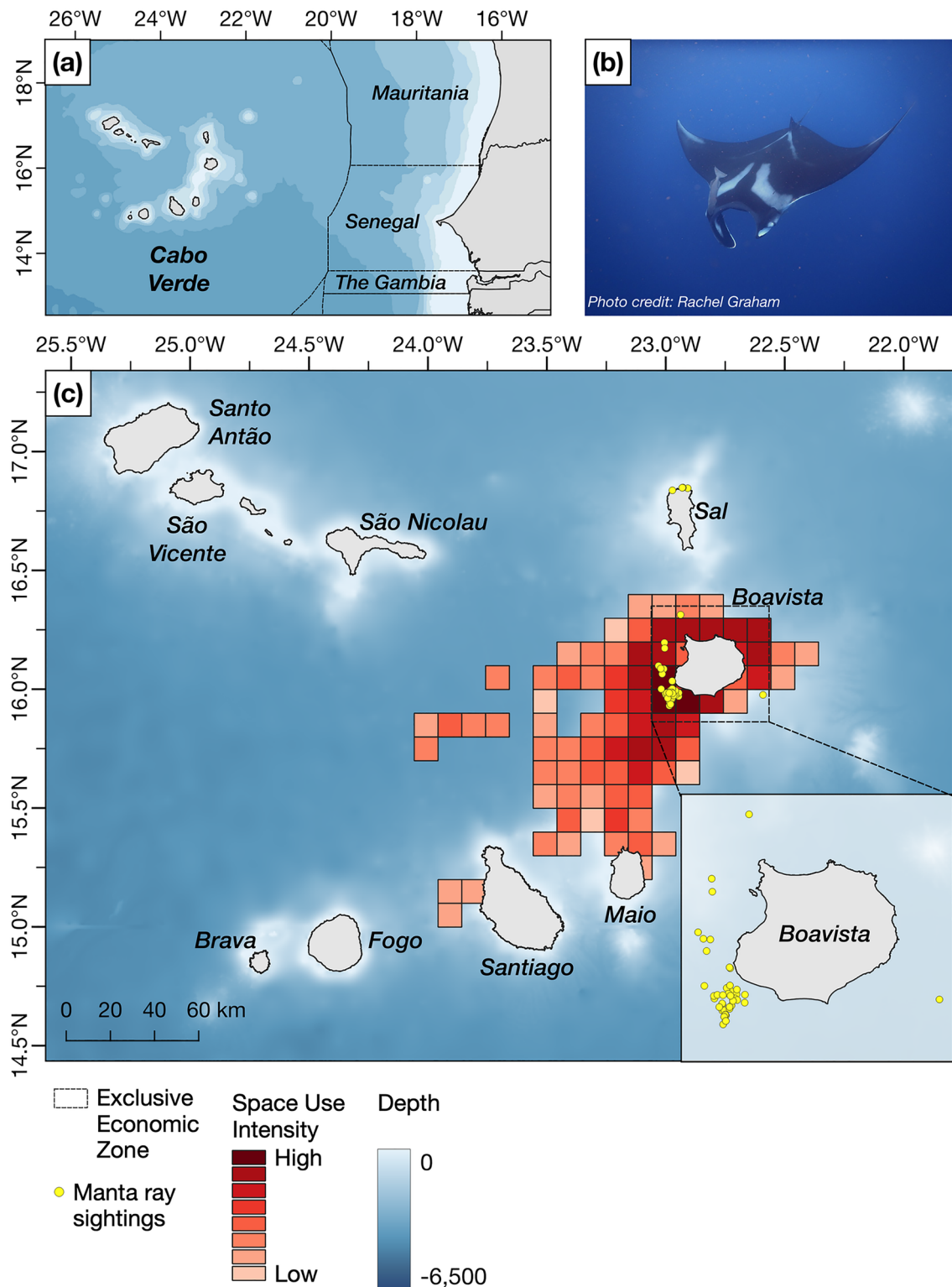
### Visual surveys

Over the course of 4 years (2016–2019), 48 surveys aimed at encountering and identifying megaplanktivores were conducted around the island of Boavista, Cabo Verde (Fig. 1a). Surveys were mostly (80%) conducted during the summer and autumn months (July–October; when sea conditions are most favorable to fieldwork) and were focused on the south-western quadrant of the island, where some of the most productive fishing sites of the island are located and fishermen often reported sightings of manta rays. Several surveys ( $n = 12$ , 27%) were also conducted at other times of the year and/or in other parts of the island, when conditions at sea allowed. Two surveys were also opportunistically conducted in the island of Sal, north of Boavista. Surveys were conducted aboard traditional fishing vessels (6 m-long, open wooden boats), with two to three observers continually scanning the water for sightings. Occasional sightings were also collected opportunistically whenever manta rays were encountered during the course of surveys aimed at other species. Upon sighting of a manta ray, two trained observers would enter the water and obtain pictures of the ventral side of the animals for later photo-identification (Marshall et al. 2011), as well as determine the sex of individuals and estimate their size (size estimation was carried out visually by comparing the animals to an observer of known length or to a 2 m pole spear). Whenever size could be estimated, sexual maturity was then inferred by comparison with published size-at-maturity estimates for the species (Stewart et al. 2018).

Finally, feeding behavior was noted whenever it could be observed. Feeding was indicated in this study by manta ray swimming with open mouth and unfurled cephalic fins. Comparison of photo-identification samples was conducted visually by two trained researchers.

### Satellite tracking

A total of 11 manta rays were fitted with towed satellite transmitting position-only tags (Wildlife Computers SPOT5 and SPOT6; [www.wildlifecomputers.com](http://www.wildlifecomputers.com)), as per methods



**Fig. 1** **a** Location of Cabo Verde within the Eastern Central Atlantic; **b** Example photo of oceanic manta ray (*M. birostris*) encountered in Cabo Verde during surveys; **c** Oceanic manta ray (*M. birostris*) sightings (yellow dots) and space use (red squares) in Cabo Verde, meas-

ured as the total length of track segments intersecting each cell, multiplied by the number of individuals that have been tracked within the cell. Darker shading indicates higher intensity of use of the cell. Only cells used by more than one individual are shown

described in (Graham et al. 2012). Tags were attached while swimming behind and above the animal, using a small percutaneous nylon umbrella dart attached to a 1 m long 1/160 (1.59 mm) nylon cable, inserted into the lower left or lower right quadrant shoulder musculature using a 2 m pole spear. The tags were covered with dark blue antifouling paint to minimize bio-fouling. The tags were programmed to transmit continuously at the sea surface and to record the time each animal spent at pre-established temperature bins within 6-h periods. The tag's position was determined by the Argos System ([www.argos-system.org](http://www.argos-system.org)). Detachment of each tag from the manta ray was estimated based on clear changes in traveling speed, and the number, quality, and time of daily transmissions ((Graham et al. 2012; Hearn et al. 2013); Supplementary Information Appendix 1). All locations received after the estimated detachment time were removed. The remaining Argos data were filtered to only include location classes (LC) 1, 2, 3, A, and B, for which location accuracy is known (Witt et al. 2010). Locations estimated to be on land, or to have required speeds greater than 20 km/h between locations (Graham et al. 2012) were removed.

A hierarchical state-space model (SSM) was applied to the filtered Argos data to regularize positions and improve data retention. The SSM was computed through the R package *bsam* (Jonsen et al. 2005; Jonsen 2016), which estimated locations at 12-h intervals, as the majority (78%) of locations were 12 h apart or less (Lea et al. 2015). A total of 15,000 iterations were run, of which 5,000 assigned to adaptation and burn-in respectively, and were thinned by a factor of 5. The Argos data had some large temporal gaps in transmissions, so periods with no “real” transmissions for 1 week were eliminated, to avoid spurious interpolation.

Since most tagged manta rays undertook long movements between islands, description of a home range through kernel density estimation was deemed inappropriate. Instead, a grid covering the study area with resolution 0.1° was created within the EEZ of Cabo Verde; for each cell, the number of individual manta ray tracks that crossed it was counted, and the length of each segment was measured. Space use of manta rays was then defined as all the cells containing manta ray tracks, while the relative importance of different cells was inferred by the sum of all track segments length within the cell, weighted by the number of individuals present in the cell. The length of tracks was used, instead of the number of locations received within any cells, because it was deemed better suited at capturing manta ray space use, given that most of the time manta rays are found underwater and hence most of their positions are not reflected in satellite transmissions.

## Distribution modeling

Species distribution modeling was used to investigate the broader habitat distribution for manta rays in Cabo Verde, as well as potential seasonal shifts in their distribution. The spatial domain for modeling was fixed to be within latitudes 10° and 22° and from the coast of continental Africa to longitude – 33°. An ensemble approach was used (Garzon et al. 2020), which included general linear models (GLM), general additive models (GAM), boosted regression models (GBM), and Maximum entropy models (MaxEnt) (Araújo and New 2007). In the absence of real absence records (i.e., areas where manta rays have never been recorded despite continuous monitoring), models were trained using data derived from the state-space models as ‘presence’, and an equal number of randomly placed pseudo-absences (Wisz and Guisan 2009; Barbet-Massin et al. 2012; Garzon et al. 2020). To minimize stochastic effects, five pseudo-absence sets were created and used in turn for modeling with the same presence set (See Supplementary Information Appendix 2 for details of the modeling process). Pseudo-absence sets contained an equal number of points as the presence set, each of which was placed randomly within the modeling spatial domain. In order to avoid overfitting of the models, both presence and pseudo-absence points were clustered using K-means clustering with a radius of 4 km to match the resolution of environmental data.

Environmental data to inform models included static and dynamic variables that have been found to relate to presence or increased abundance of manta rays and other mega-planktivores (Panigada et al. 2008; Embling et al. 2010; Freedman and Sen Roy 2012; Jaïne et al. 2012; McKinney et al. 2012; Sequeira et al. 2012; Hacoheñ-Domené et al. 2017; Garzon et al. 2020; Farmer et al. 2022), including bathymetric depth (General Bathymetric Chart of The Ocean; <http://www.gebco.net>), seafloor slope (created from bathymetry data in QGIS), night-time sea surface temperature (NSST, <https://www.oceancolor.gsfc.nasa.gov>), and chlorophyll-a concentration (Chl-a, used as a proxy for plankton abundance; <https://www.oceancolor.gsfc.nasa.gov>). Dynamic variables were sourced as monthly averages (mean) for all years in which manta rays were tracked (2016–2019). All environmental variables were downloaded as spatially referenced gridded layers (from now on referred to as rasters) and re-sampled to match the spatial resolution of the coarsest dataset (Chl-a and NSST, 4 × 4 km<sup>2</sup>) using linear interpolation. Environmental conditions at each presence and pseudo-absence point were extracted from temporally matching rasters (according to the month of the location fix). Correlation between environmental variables was tested using Spearman rank correlation, and only non-correlated variables ( $r < 0.5\%$ ) were kept for modeling.



Ecological niche modeling was carried out using the biomod2 package for the software R (R Core Team 2022); For each pseudo-absence dataset, 10 runs were computed for each model (GLM, GAM, GBM, and MaxEnt) using a 75–25% random split of the data for training and testing, respectively. True Skill Statistic (TSS) scores were computed to evaluate the predictive ability of the models (Allouche et al. 2006). Only models with a  $TSS \geq 0.7$  were used to compute the ensemble model, which was created as their weighted average (weights assigned according to TSS scores).

Predictions of habitat suitability were created for each month of the year in the form of rasters that have the same spatial resolution of the environmental variables used for training, where each cell was given a value ranging from 0 to 1 indicating its relative suitability (RS) for manta rays (0 indicates lowest suitability, 0.5 corresponds to average suitability, and 1 indicates highest suitability). Monthly rasters were turned into binary layers where areas having  $RS \geq 0.5$  (i.e., areas that contained suitable habitat) were assigned the value of 1. These layers were then summed, so that the resulting raster cells contained values ranging from 0 to 12, corresponding to the number of months of the year in which they contained suitable habitat for manta rays.

## Results

Surveys produced 51 manta rays sightings ( $n=7$  in 2015,  $n=29$  in 2016,  $n=3$  in 2017,  $n=6$  in 2018, and  $n=6$  in 2019). Mantas were mostly female ( $n=29$ , though sex could not be determined for 14 individuals) and had an average disk width of  $3.6 \pm 0.6$  m (range 2.8–5.0 m). Of all

sightings for which disk width could be measured ( $n=39$ ), 49% were deemed to be of likely reproductive size. Of all mantas encountered, a ventral photo could be obtained for 24 individuals. Visual inspection of these photographs did not reveal any re-encounter instances. All but two sightings were recorded in the southwest of the island of Boavista (where most tagging events took place, Fig. 1), and the remaining were sighted between the islands of Sal and Boavista. Manta rays were observed feeding on only 5 occasions throughout the study.

All manta rays fitted with satellite tags (Table 1) were encountered and tagged around the island of Boavista. Tagging took place between August and October each year. Satellite tags transmitted positions for an average of 57 days (range 13–99, Table 1) before detaching from the animal or interrupting transmissions, with high variability in the number of transmissions received among individuals (range 27–199, after filtering and regularization). All data were received between August and January, while no data was received between February and July of any year.

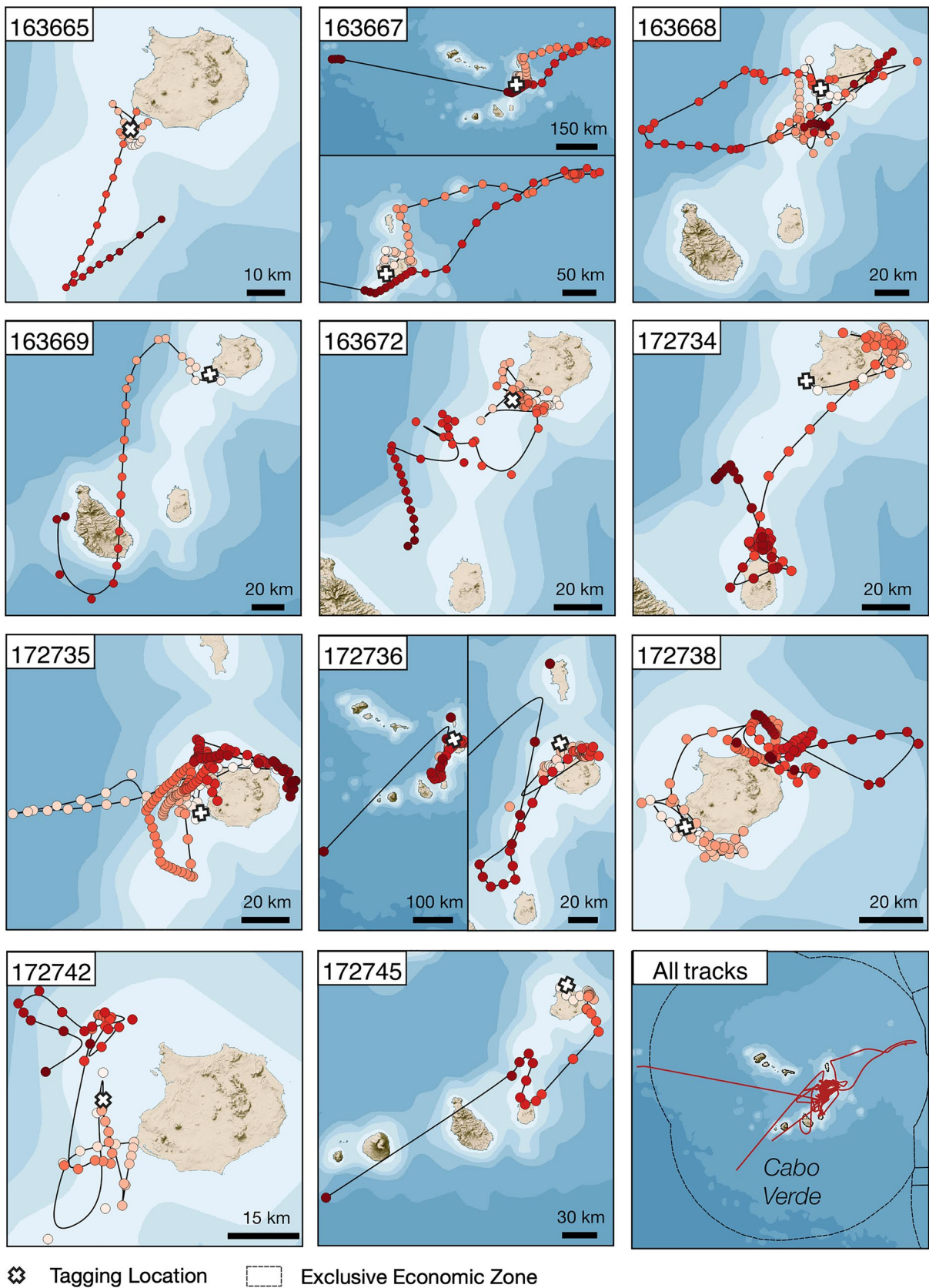
Most manta rays spent all or some time around the island of Boavista following tagging (Fig. 1), with the longest remaining around Boavista for 99 days (PTT 172,735, Fig. 1). Manta rays only moved either slightly further offshore (PTT 163,667, 163,668, and 172,735) before returning to Boavista, or to the southern islands of Maio and Santiago (PTT 163,669, 172,734, 172,736, and 172,745). Two individuals (PTT 163,667 and 172,736) briefly visited the island of Sal, but no locations were received from the northern islands of the archipelago, despite manta ray sightings having been reported there in the past. All tagged manta rays remained within the Cabo Verdean Exclusive Economic Zone (EEZ) for the duration of the tracking (Fig. 1), with

**Table 1** Summary of manta rays tagged with electronic tags

ID	Sex	Disk width (m)	Tagging date	First location	Last location	No. locations	Tracking time (days)	Total distance (km)
163,665	F	3.4	2016-08-10	2016-08-11	2016-08-30	41	20.0	45.0
163,667	U	3.8*	2016-08-27	2016-08-28	2016-11-13	72	77.5	701.2
163,668	F	3.0	2016-09-28	2016-09-29	2016-12-27	109	90.0	113.0
163,669	U	3.8*	2016-08-10	2016-08-11	2016-08-23	27	13.0	156.8
163,672	F	3.5	2016-08-07	2016-08-08	2016-09-13	74	36.5	74.9
172,734	F	3.2	2017-09-25	2017-09-26	2017-11-30	133	66.0	91.1
172,735	F	3.0	2017-09-25	2017-09-26	2018-01-02	199	99.0	83.2
172,736	M	3.6*	2017-10-23	2017-10-24	2017-12-28	70	65.5	436.4
172,738	F	4.0*	2019-08-09	2019-08-10	2019-11-13	134	95.5	81.0
172,742	F	4.4*	2018-10-01	2018-10-01	2018-10-26	52	25.5	30.8
172,745	M	3.5*	2019-08-27	2019-08-28	2019-10-03	32	36.5	283.6

All summary statistics about tracking refer to data processed as described in the methods section (filtered and regularized through state-space modeling)

\*Individuals considered to be likely sexually mature based on measurements listed in Stewart et al. (2018)



**Fig. 2** Filtered and regularized tracks of oceanic manta rays (*M. birostris*) tagged in Cabo Verde between 2016 and 2019. Numbers in the top left of each panel indicate the identification number of each tracker. Color of locations indicates time elapsed from tag deployment, with darker shades corresponding to most recent locations. Bottom-right panel shows estimated tracks for all individuals in relation to Cabo Verde's Exclusive Economic Zone

the exception of manta ray 163,667, whose last transmitted positions placed it just outside the northwest boundary of the EEZ (Fig. 1). Space use of manta rays was concentrated around the island of Boavista, especially in the southeast quadrant of the island (Fig. 2). The shallow corridor linking the islands of Boavista and Maio was also used by 5 individuals, while no other clear movement corridors could be identified.

All 200 ecological niche models (10 runs for 4 algorithms, repeated for 5 pseudo-absence datasets) ran without errors. Since bathymetry was found to be significantly and strongly correlated ( $r > 0.5$ ) with chlorophyll concentration, it was excluded from modeling. Models had generally high TSS scores (mean  $0.81 \pm 0.06$  s.d.). The ensemble model was built using 189 models that had  $TSS \geq 0.7$ . The Ensemble Ecological Niche Model (EENM) indicated that chlorophyll-a concentration was the most important variable in predicting habitat suitability for manta rays (relative importance,  $RI = 0.44$ ), with NSST receiving only slightly less importance ( $RI = 0.42$ ); bathymetric slope was deemed to have the lowest importance in determining habitat suitability ( $RI = 0.14$ ).

The monthly predictions of the model suggest that manta ray presence in the archipelago undergoes considerable seasonal fluctuations, although some suitable habitat for manta rays is present in the EEZ year-round (Fig. 3). The peak of predicted suitable habitat extent and relative suitability was obtained in November, with a significant reduction of habitat extent and relative suitability between February and June. The monthly shift in suitable habitat somewhat follows a northward movement from southern regions of west Africa, passing through Cabo Verde from July to November/December, and then moving offshore—perhaps toward the Western Atlantic. Cabo Verde nonetheless retains suitable habitat for manta rays for at least six months of the year around all of the islands and the two prominent seamounts to the east of the archipelago (in waters shallower than 2000 m, Fig. 4). The only other region that hosts suitable manta ray habitat for over half the year is found in the southeast corner of the study area, in Guinea-Bissau's EEZ and nearby international waters (Fig. 4).

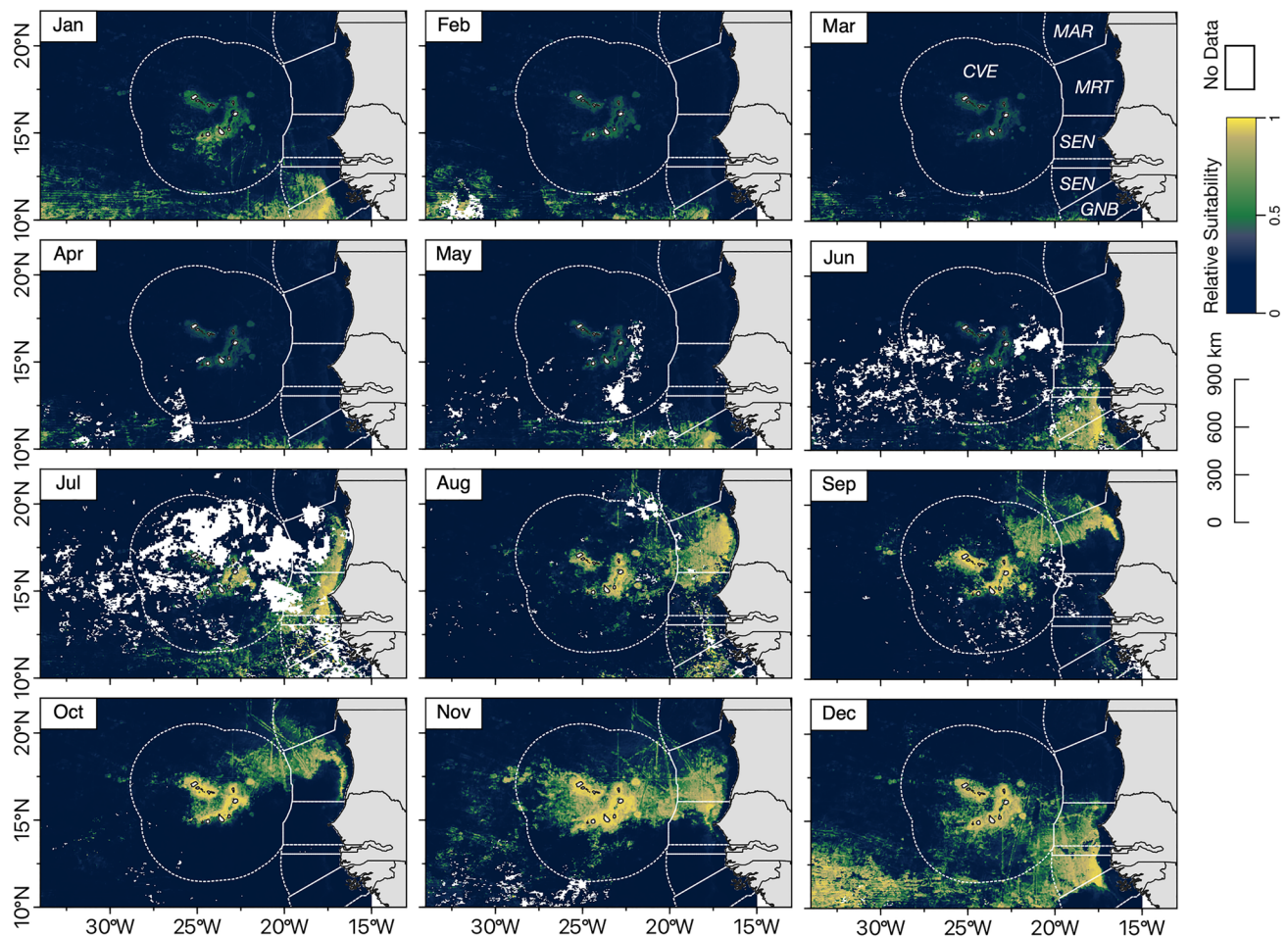
## Discussion

The data presented here suggest a reliable presence of manta rays between July and January in the archipelago of Cabo Verde across at least six years. This is the only documented region in the eastern Central Atlantic where manta rays appear to be regularly encountered, although it is likely that further research in this region will uncover other important locations for the species. Despite the repeated occurrence of manta rays in Cabo Verde, this site is very different to other “aggregation” sites, since manta rays are never sighted in groups bigger than two individuals, their movements are distributed over a relatively large area, and there are no confirmed instances of re-sighting of individuals which would suggest seasonal fidelity to the site. The lack of re-encounters suggests that Cabo Verde could represent a stop along a larger movement route. While the low number of individuals encountered in any year makes it impossible to assess the long-term residency of manta rays from sightings alone, satellite tracking data also suggest that most individuals left the island of Boavista to move to other islands or, in some cases, toward the central Atlantic Ocean, hence supporting the possibility of relatively short residency time within national waters. However, given the relatively low survey effort in relation to manta ray density at this site, it is possible that likelihood of re-sighting was underestimated.

While satellite tracking could elucidate the movements of individuals within Cabo Verdean national waters, it failed to provide long-term insights into the movement of these animals—the longest tag retention time was 99 days. Only one manta was observed leaving Cabo Verde's EEZ in this time, but it appears unlikely that the manta rays tracked in the present study are resident to Cabo Verde year-round. The comparison of identifying features of manta rays in Cabo Verde with those held in other repositories could also further elucidate the long-distance movements of these animals within the Atlantic Ocean.

While it seems that the island of Boavista is a particularly important site for manta rays in Cabo Verde, with all tagged individuals spending time around the island before moving to other islands, it wasn't possible to determine the reason for their stay in this study. The majority of manta rays sighted during the present study had reached a size where maturity was plausible (Table 1, Stewart et al. 2018); yet, no courtship behavior was observed during surveys and individuals were rarely observed feeding, instead usually cruising with rolled-up cephalic fins. The ensemble distribution model suggests a seasonal cycle in manta ray occurrence, and little suitable habitat with overall lower predicted relative suitability scores present from February to June in the country. In the pattern, the model describes concords with reports by fishermen that place the annual peak in manta ray abundance





**Fig. 3** Monthly predictions of habitat suitability for oceanic manta rays (*M. birostris*) in the study area (months are indicated in the top-left corner of each panel). Shading indicates relative suitability from 0 (unsuitable, dark blue) to 1 (extremely suitable, yellow). White cells

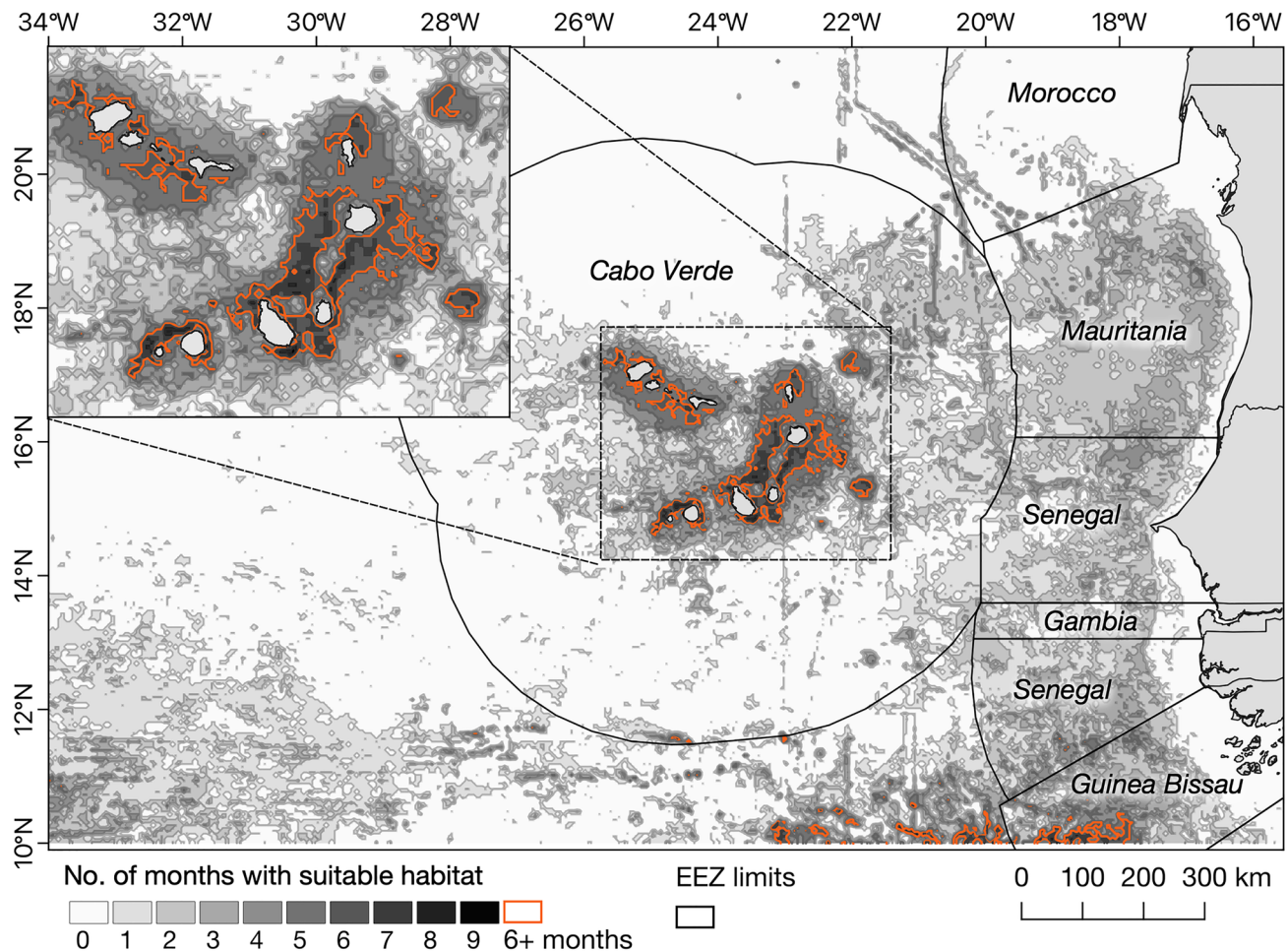
represent areas where environmental data was absent and suitability could not be calculated. Dotted white lines delimit exclusive economic zones (EEZ) of the countries in the study area

between July and October. Sightings of the species are also reported in the winter and spring months (ZS, ZLM, and FG personal observations), when the model largely predicts absence of manta rays, although these records occur irregularly and less frequently than in summer months. It is possible that the lack of data points in the first half of the year in the presence database used to train the model, has led the model to underestimate the breadth of the manta rays ecological niche in Cabo Verde, suggesting that environmental conditions are unsuitable for manta rays when they might in fact be able to tolerate a wider spectrum of temperatures and chlorophyll concentrations. Additional data, obtained either from a more rigorous monthly monitoring system through aerial or in-water surveys, or better telemetry attachment systems that secure longer tag retention times, are required to confirm or refute the seasonality of manta ray presence in Cabo Verde.

At a national level, threats to the survival of manta rays are likely low within Cabo Verde. No directed fishery exists for this species in the country, and given the concentration of suitable habitat nearer the islands, manta rays are most likely to interact with small-scale or semi-industrial fishing vessels, which may be less likely to by-catch, although occasional catches of mobulid species have been observed in the country (FG personal observation). However, large industrial vessels, mainly coming from Europe, Japan, and China, are active within and outside Cabo Verde's EEZ and could also represent a threat to the species. Bycatch of mobulid rays has been reported in the ECA (Zeeberg et al. 2006; Amandé et al. 2011; Torres-Irineo et al. 2014), and though the frequency and overall magnitude of the phenomenon are not clear, mobulid mortality following release from purse seine nets can exceed 50% (Francis and Jones 2017).

This study elucidates the role of coastal and pelagic waters up to 2000 m deep in Cabo Verde in providing





**Fig. 4** Gray shading indicates the number of months of the year in which areas host suitable manta ray habitat. The orange line defines key areas where suitable habitat is encountered for at least half of

the year. Black lines delimit exclusive economic zones (EEZ) of the countries in the study area

favorable conditions and habitat for manta ray habitat for at least half of the year. Similarly, pockets of long-lasting suitable habitat seem to be present further south, off the coast of Guinea-Bissau, suggesting that perhaps a connection could exist between Cabo Verde and the plateau and complex bathymetric region fronting Guinea and Guinea-Bissau. The existence and nature of this connection should be further elucidated, as it could have important consequences for conservation planning for this species in the region. Moving forward, further research to better elucidate the spatial ecology of manta rays in this region of the world is needed. Within Cabo Verde, the cooperation of the fishing community could be enlisted to record sightings of manta rays across the country to obtain a better picture of manta ray space use and residency. Indeed, successful cases of cooperation between conservation organizations and fishermen communities already exists in many islands of the archipelago, highlighting the opportunity for expansion of

the project to other islands and to include new species. The diving community, albeit comparatively smaller in Cabo Verde than other known manta ray aggregations sites, may also offer a source of sighting and photo identification data.

Identifying links between Cabo Verde and other countries, as well as the role that the country plays in the life cycle of manta rays in the region also remains a priority. Strengthening the collection and sharing of individual identifying photos could provide a mean to establish links between regions, while improved satellite telemetry systems could not only reveal movement corridors but also further elucidate the importance of different areas through identification of behaviors.

**Supplementary Information** The online version contains supplementary material available at <https://doi.org/10.1007/s00227-023-04219-y>.

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**Author contributions** RG, ZS, and FG contributed to the study conception and design. All authors participated in data collection. Data analysis was performed by FG. The first draft of the manuscript was written by FG and RG. All authors approved the final manuscript.

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**Data availability** The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Conflict of interest** The authors have no relevant financial or non-financial interests to disclose.

**Ethical approval** The study was conducted under research permits granted by the Cabo Verdean government. No specific ethical approval was necessary for the study, but field operations were conducted according to best-practice methodology in the sector.

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