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Long-term tracking reveals the influence of body size and habitat type on the home range of Antillean manatees (*Trichechus manatus manatus*)

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Abstract

Antillean manatees (*Trichechus manatus manatus*) are endangered coastal, marine, and riverine megaherbivores with high environmental plasticity, constrained by tidal and seasonal water level cycles that affect access to food and fresh water. Accurate quantification of the species' habitat requirements, typically achieved through home range (HR) estimation, is required to implement area-based conservation initiatives. In this study, we used GPS tracking data from 38 wild and captive-rehabilitated released manatees to estimate HR using autocorrelated kernel density estimators (AKDE) and average time speed. We investigated whether body size, habitat type, sex and behavioural group influence home range size due to energy requirements, resources availability, a scramble-competitive polygyny mating system, and adaptation to the wild. Eighteen manatees exhibited range-resident behaviour, with a mean 95% home range of 72.96 km² (± 218.52) and a median of 10.69 km². The mean daily speed was estimated to be 13.47 km/day (± 4.16). Home range and body size were positively correlated, consistent with HR allometry theory. Long-term tracked individuals showed a trend of increasing HR over time. Only four released animals (17.4%) were range-resident, suggesting that they may need additional time to establish a home range.

Individuals using only the marine environment had larger home ranges compared to mixed (marine and estuarine) and estuarine environments, probably due to freshwater availability. Our study contributes to the understanding of the factors driving manatee movement and provides more accurate estimates of area requirements, which can inform the establishment and zoning of marine protected areas.

KEYWORDS

aquatic ecosystems, area requirements, autocorrelated kernel density estimation, connectivity, conservation planning, endangered species, movement ecology, *Sirenia*

1 | INTRODUCTION

Where to move is a fundamental question faced by any mobile organism. Space use behaviour is a key trait influencing ecological processes and affecting individual fitness and population dynamics (Ofstad et al., 2016). In a scenario where most ecosystems are altered by anthropogenic drivers and the increasing degradation of habitats is a norm (Díaz et al., 2019), understanding animal movements have implications for conservation of species (Cattarino et al., 2016). In this context, home range is a characteristic of animal movement that will directly influence the management of endangered species (Schofield et al., 2010), as this life-history component is pivotal in planning protected areas that are effective in maintaining key habitats for foraging and mating.

Recent technological advances are generating massive high-resolution datasets relevant to the ecological context in which animals interact and respond to the environment. They are transforming movement ecology into a data-rich discipline, rapidly expanding scientific frontiers, and offering enhanced opportunities for conservation (Nathan et al., 2008; Nathan et al., 2022). However, high-resolution data generated by tracked animals with GPS devices can have a strong degree of autocorrelation and jeopardize an important assumption of many analytical methods: That data should be independent and identically distributed. To solve this problem, continuous-time movement modelling (CTMM) is rapidly emerging as the best available method to predict space use and estimate autocorrelation-informed home range and time-averaged speed (Alston et al., 2022; Calabrese et al., 2016; Fleming et al., 2015; Silva et al., 2022).

The West Indian or American manatee (*Trichechus manatus*) is an iconic flagship species with significant conservation importance due to its unique ecological roles, charisma, large body size, and cultural value (Barua et al., 2011; Normande et al., 2023). This megaherbivore depends on seagrass meadows, other aquatic plants, and macroalgae banks to feed, moving and behaving differently depending on the environment (Castelblanco-Martínez et al., 2021). However, tidal cycles in coastal systems, seasonal water level cycles in flood-pulse river systems, and seasonal temperature changes in higher latitude regions often constrain the access to feeding resources and freshwater (Deutsch et al., 2022). In Brazil, a subspecies of the West Indian manatee, the Antillean or Greater Caribbean manatee

subspecies (*Trichechus manatus manatus*) is currently classified as Endangered, and subpopulations face various threats such as habitat loss, pollution, and calf stranding (Deutsch et al., 2008; ICMBio, 2018).

The northeast Brazil manatee subpopulation is estimated to contain approximately 1100 individuals (Alves et al., 2016), due to historical and current threats (Anzolin et al., 2012; Attademo et al., 2015; Balensiefer et al., 2017; Borges et al., 2007; Domning, 1982; Lima, 1997; Meirelles, 2008; Meirelles et al., 2022; Parente et al., 2004). This population could benefit from habitat restoration, and the establishment of travel corridors and dedicated protected areas, which are particularly important for successful parturition and neonatal calf survival (Luna et al., 2021). However, these conservation interventions require high quality information on species' characteristics such as traits, behaviour, ecological constraints, and interactions with the environment at the individual and population scales (Allen & Singh, 2016; Nathan et al., 2008; Nathan et al., 2022; Nathan & Giuggioli, 2013).

In this study, we gathered the largest telemetry dataset for the species in the Southern Hemisphere to provide essential information for the understanding of movement ecology and designing of marine protected areas that may facilitate species restoration. We used fine-scale GPS movement data of Antillean manatees to estimate home ranges and mean speeds of individuals. We then tested the hypothesis that body size, habitat type, sex, and behaviour should influence home range size and daily travel due to their energetic requirements, resource availability, polygyny reproductive behaviour, and adaptation to the wild after release. Home range estimates will provide new insights into spatial and territorial requirements, ecological and movement characteristics, and provide the basis for proposing area-based conservation measures.

2 | MATERIALS AND METHODS

2.1 | Study site

The study was carried out in the Northeast Brazilian Marine Ecoregion (NBME), according to the Marine Ecoregions of the World (MEOW) classification, being inserted in the Southwest Tropical Atlantic Marine Province (Spalding et al., 2007)—Figure 1. The Northeast Ecoregion of Brazil is comprised between the municipalities

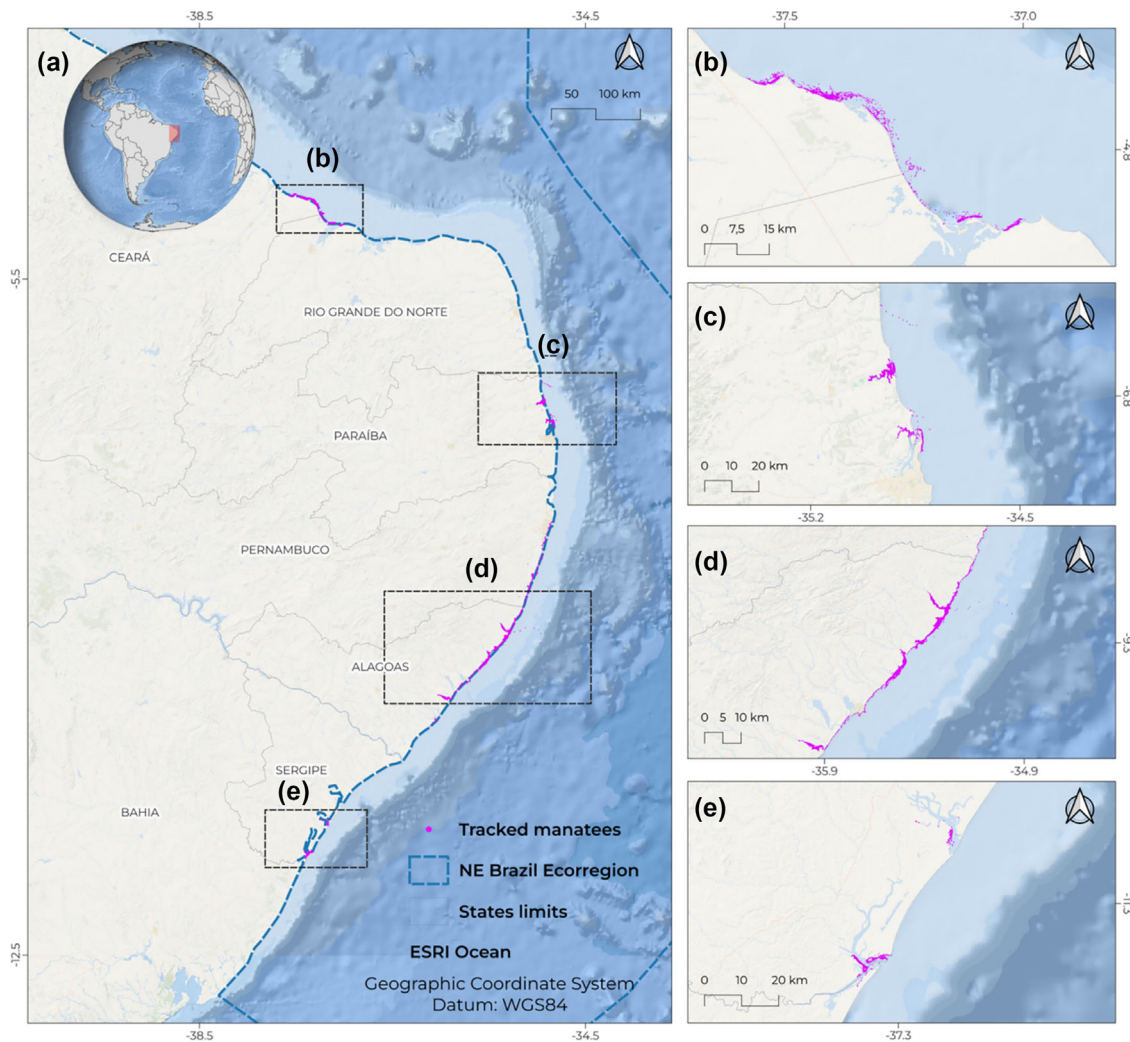


FIGURE 1 (a) Study site in northeast Brazil showing the location data from tagged manatees *Trichechus manatus*, Brazilian States limits, and the four subareas in the Northeast Brazil Marine Ecoregion (NBME): (b) CE/RN, (c) PB, (d) AL/PE, and (e) SE/BA.

of Salvador/BA and Luís Correa/PI and has the geographical coordinates of reference: Latitude -7.04721 and Longitude -37.0512 .

Manatees were tracked in four focal areas, within the NBME: (i) Ceará and Rio Grande do Norte subarea (CE/RN), ranging from Icapuí to Areia Branca and characterized by the presence of seagrass meadows and freshwater springs; (ii) Paraíba subarea (PB), from Rio Tinto to Cabedelo and encompassing two large estuarine systems (Mamanguape and Paraíba rivers), and seagrass and algae banks; (iii) Alagoas and Pernambuco subarea (AL/PE), from Olinda to Coruripe and formed by and extensive coastal coral reef system, seagrass meadows, and several rivers and estuaries; and (iv) Sergipe and Bahia subarea (SE/BA), encompassing from Aracaju to Marau and characterized by and seagrass banks and the presence of two large estuaries formed by Vaza-Barris river and Piauí-Fundo-Real Estuarine complex (Figure 1). One manatee named “Serenó” ventured out of the NBME, travelling through open and deep waters, displaying what seemed to be an erratic movement. Despite this, we chose to confine our analysis to the NBME area, which contains the vast majority of our data.

2.2 | Data collection

Thirty-eight Antillean manatees were tagged in 58 deployments with GPS tags between the years 2011 and 2022 in northeast Brazil. The animals were separated into three groups: (i) wild: captured in the wild using a net deployed from a customized boat and released in the same site; (ii) released: stranded as newborn calves, rehabilitated in captivity, and released into the wild; or (iii) adapted: recaptured and retagged several years after release and successfully adapted to the wild (Figure 2).

The tagging system for manatees is composed of a belt adapted to the caudal peduncle, a tether, and a floating transmitter (Reid et al., 1991). Three models of transmitters were used, two of them produced by Telonics, USA (models TMT-462 and TMT-464-2) using the ARGOS system and the other one produced by Fundação Mamíferos Aquáticos/NORTRONIC using the GLOBALSTAR network (Normande et al., 2016; Santos et al., 2022).

The tags used different sampling intervals. While Telonics tags were programmed to deliver one location every 20, 30, or 60 min,

FMA/Nortronic tags used 15 min ON and 2'45 OFF as the duty cycle. As sampling varied due to several conditions, exact average sample intervals for each deployment are presented in Table 1.

2.3 | Data analysis

2.3.1 | Home range

The home range estimation was performed using the *ctmm* package (Fleming & Calabrese, 2023) in the R Studio environment (R Core Team, 2024) and applied a CTMM approach, as proposed by Fleming et al. (2015). Initially, relocation data was plotted in maps (QGIS v3.30) and scatterplots to identify outliers and coarse aspects of the movement. Then, empirical variograms and periodograms were plotted and revealed features of the movement behaviour, showing the appropriateness of the different models for the data. Models identified as suitable were fitted to the data using maximum likelihood estimation and subsequently compared using AICc, with the best-fit model selected based on the lowest AICc values. Autocorrelated kernel density estimation (AKDE) of 95% home ranges in square kilometres were subsequently generated for those animals that showed range-residency behaviour (Calabrese et al., 2016). Range-residency was defined when each individual deployment met all three of the following criteria: (i) asymptote of the semivariogram's curve, (ii) stationary movement behaviour by visual inspection of the track plotted using the function *colour* in the *ctmm* package, and (iii) effect sample size greater than 10 (N) after movement modelling, meaning that at least 10 independent and identically distributed point were used in the analysis. (Calabrese et al., 2016; Silva et al., 2022). As a

threshold, deployments shorter than 21 days were excluded from the home range estimation as they were considered to be a short period of time. Autocorrelated home ranges were estimated for all individual deployments ($n = 58$). All deployments were considered as independent samples once they encompass long time intervals between them.

For mean home range estimation between multiple deployments, we applied the *mean* function in the *ctmm* package (Silva et al., 2022) for all deployments with range-resident behaviour for the same individual manatee. Two individuals (Lua and Tuca) showed a bimodal pattern of habitat use. For those individuals, tracks were segmented, and the home range was estimated also using the *ctmm::mean* function. We also calculated the overlap between 95% home range (function *ctmm::overlap*) and performed a cluster analysis (function *ctmm::cluster*) of the four animals tracked simultaneously in CE/RN subarea from 2012 and 2013. This function clusters and classifies individual movement models and related estimates, including AKDE home range areas, while considering estimation uncertainty. The AICc formula is approximated via the Gaussian relation (Silva et al., 2022). Additionally, we generated an animated video of the same animals through the Moveapps interface using the *moveVis* app (Kölzsch, 2023).

To ensure accurate predictions of manatee space use, we combined shapefile delineations of various aquatic features, encompassing freshwater bodies, mangrove forests, and coastal features derived from Magris et al. (2021). Additionally, we produced a coastal shapefile detailing bathymetric depths up to 10 m out to sea, which is the maximum depth manatees in this region have been recorded to go (Alves et al., 2013; Meirelles et al., 2022; Normande et al., 2016). The depth shapefile was generated via Satellite-derived

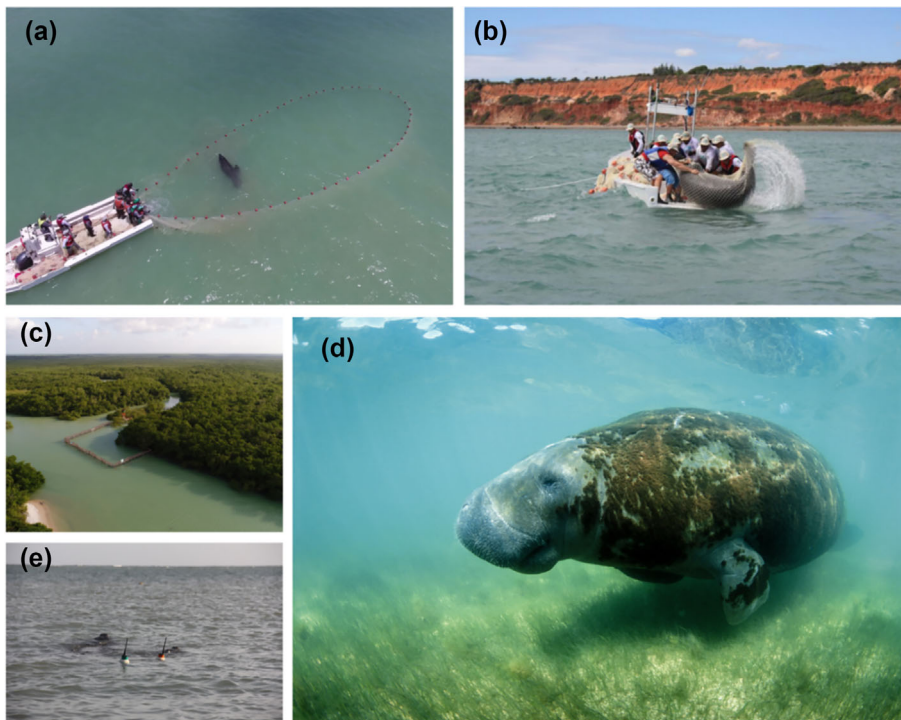


FIGURE 2 (a) Boat-based capture of wild Antillean manatees *Trichechus manatus manatus* in Costa dos Corais, AL, in 2016 and (b) Picos, Ceará, 2012; (c) soft-release enclosure in Barra do Rio Mamanguape, PB; (d) adapted female “Lua” 9 years after release in the wild in a seagrass meadow in Costa dos Corais (2005), and (e) Lua and her calf “Romulo” being tracked with GPS tags in AL/PE site in 2016.

bathymetry (SDB) calculated from an automated shallow water bathymetry method (Li et al., 2021) within the Google Earth Engine cloud environment (Gorelick et al., 2017). Integrating the coastal bathymetric shapefile with the detailed spatial outline of the synthesized coastal features created a spatial boundary that included the desired fine-scale information for our analysis to be run over. Through this, we were able to constrain our analysis to within this boundary, enabling us to predict manatee spatial utilization more accurately, grounded in realistic ecological premises.

2.3.2 | Average time speed

The average daily movement speed (in km/day) was estimated for all deployments ($n = 58$) using the function *speed* in *ctmm* package (Fleming & Calabrese, 2023) in R Studio (R Core Team, 2024) and used the continuous-time speed and distance (CTSD) estimation (Noonan, Fleming, et al., 2019). The time-averaged speed in kilometres per day is proportional to the distance travelled daily and was estimated for each individual deployment by simulating multiple realizations of the individual's trajectory (Noonan, Fleming, et al., 2019).

2.3.3 | Multiple linear regression models and generalized linear models

We examined the impact of body size, sex, group, and habitat type on home range and average speed using two distinct methods: multiple linear regression models (LM) when normality and homoscedasticity criteria were met, and generalized linear models (GLM) when they were not. For the LM, the log-transformed home range area (measured in km^2) served as the response variable, with total body length (cm), sex, group (wild, release and adapted), and habitat classification (marine, mixed, or estuarine) as explanatory variables. In the GLM, the only difference was the use of average-time speed as the response variable. In both models, significance was considered when the p value was ≤ 0.05 . Additionally, the best models were chosen based on the optimal AICc value and model weight using the MuMIn package (Bartoń, 2023). Potential multicollinearity was assessed using the generalized variance inflation factor (gvif) in the *glmtoolbox* package (Vanegas et al., 2024), and model adequacy was checked using the *testDispersion* function in the DHARMA package (Hartig, 2022). The coefficient of determination (R^2) for the individual explanatory variables was estimated using the total variance and variance explained by each variable in the case of LM, and deviance in the case of GLM.

3 | RESULTS

After data cleaning, the tracking effort resulted in 5363.15 days and 91,688 location points. On average, the effort was 3.04 (± 2.51) months and 1608 (± 1610) location points per deployment. Summary

results regarding all 58 deployments from the 38 individuals are presented in [Supporting Information](#).

From the 38 manatees tracked, 18 (28 deployments) showed a range-resident movement behaviour (Table S1). Of the 28 deployments with range-residency, 17 were from adapted, seven were from wild and four were from released manatees. The mean 95% home range (HR) was estimated in 72.96 km^2 (± 218.52) per individual ($n = 18$), and the median was calculated in 10.69 km^2 . The smallest HR estimated was 0.35 km^2 for the released female named "Clara" tracked in the AL/PE study site, and the largest was 1066.16 km^2 for the wild male named "Adão" tracked in the CE/RN site.

Average 95% HR was estimated in 123.80 km^2 (± 331.82) for males, 73.16 km^2 (± 6.72) for females with calves, and 26.71 km^2 (± 31.80) for females. Adult manatees presented an average home range of 93.12 km^2 (± 252.54) and juveniles of 15.84 km^2 (± 26.79), while according to group, the mean 95% HR was, respectively, 220.13 km^2 (± 415.62) for wild, 23.60 km^2 (± 26.94) for adapted, and 1.71 km^2 (± 1.93) for released manatees.

The best LM model ($\log\text{Lik} = -101.06$, $\text{AICc} = 2016.03$, $\text{delta} = 0$, $\text{weight} = 0.4$, to more details on model selection results, see [Supporting Information](#)) analysis revealed a positive correlation (Figure 3) between log home range size and total length ($p = 0.0194$, t value = 2.57, Std. error = 0.01), marine ($p = 0.00027$, t value = 4.51, Std. error = 4.51), and mixed environments ($p = 0.00678$, t value = 3.058, Std. error = 0.56) ($R^2 = 0.59$, $df = 18$).

The overlap analyses of the 95% home ranges of all four simultaneously tracked animals in the CE/RN site (Figure 4, Table 1, and animated tracks in the [Supporting Information](#)) revealed higher overlap between females "Eva" and "Icapuí" and an overlap between these females and the female with calf "Redonda." The overlap between the male "Adão" and the three females was 31%, 25%, and 14% for "Icapuí," "Eva," and "Redonda," respectively. Additionally, the cluster analysis revealed two groups, where the first one was formed by the male and the second one by the three females.

The mean average speed of the tracked individuals was estimated in 13.47 km/day (± 4.16), after removing the outliers. Fourteen deployments resulted in fractal movement, making it not feasible to estimate speed. The naive released male "Raimundo" tracked in the AL/PE study site exhibited the highest average daily speed (27.13 km/day), while the released male "Guga," tracked in the AL site, showed the lowest average daily speed (5.95 km/day). The mean average speed was 13.71 km/day (± 5.03 , $n = 14$) for males and 13.50 km/day (± 3.47 , $n = 17$) for females. No significant relation was found between total length, sex, and environment regarding the average-time speed in our GLM.

Five individuals had more than one deployment with range-resident movement pattern: Astro ($n = 2$), Puã ($n = 4$), Zelinha ($n = 3$), Mel ($n = 4$), and Tupã ($n = 2$) (Figure 5). In four of these individuals, home range became larger over time. The manatee named "Mel" showed very small home range for several years after released in 2009 in Barra do Mamanguape Environmental Protected Area. Then, 10 years later, she migrated to another estuarine area

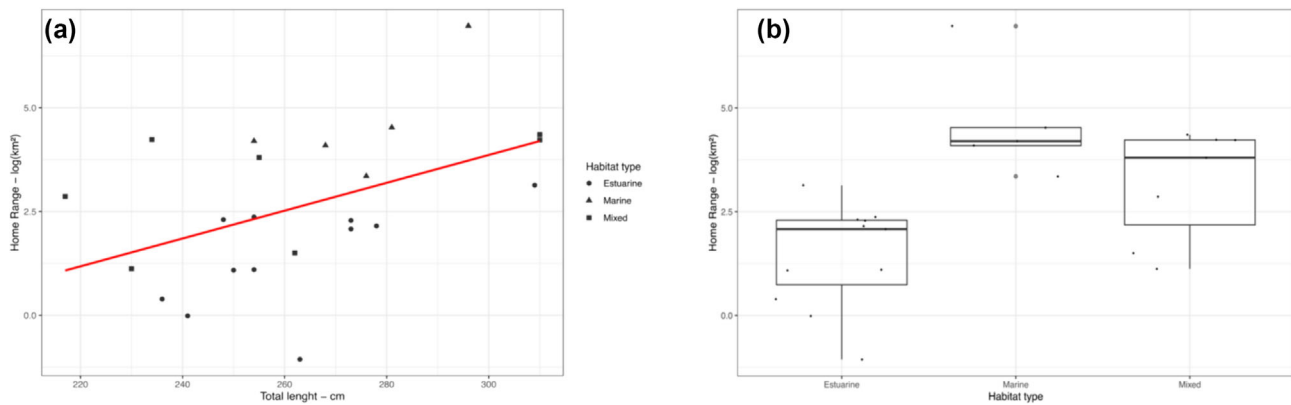


FIGURE 3 Scatterplots (a) evidencing the effects of total length (cm) on home range size ($\log \text{km}^2$) by habitat type, and (b) boxplot showing the effects of environment on home range size ($\log \text{km}^2$) of Antillean manatees (*Trichechus manatus manatus*) in Northeastern Brazil.

(Cabedelo, PB) and established herself in the new site, presenting a much larger home range area.

4 | DISCUSSION

We used the largest telemetry dataset available for the West Indian manatee in the Southern Hemisphere to estimate home range and movement patterns of wild and released Antillean manatees in northeast Brazil. Not only is this the first time that wild manatees have been tracked in Brazil, but it is also the first autocorrelated-informed home range estimation. This is important because conventional home range estimators assume that the data are independent and identically distributed, often generating underestimated area estimations (Noonan, Tucker, et al., 2019). Our unbiased estimates that encompass both wild and previously captive individuals thus provide robust space use results for making conservation planning decisions about the most southerly population of this iconic species.

4.1 | Home range size and daily travel rates

The mean home range estimated in this study was higher than those observed by other studies with released and adapted Antillean manatees in Brazil (Normande et al., 2016; Santos et al., 2022), even after applying the coastal features shapefile as hard boundaries to exclude unsuitable habitats. Tracked individuals showed dichotomous patterns, either remaining sedentary in small home ranges or dispersing longer distances along the coast. In the same region, a long-term tracking study of six individuals found a very similar mean home range of 13.17 km^2 (ranging from 2.56 to 42.02 km^2) (Santos et al., 2022). This dichotomous pattern was also observed in 16 wild Antillean manatees tracked in Mexico and Belize. When individuals were sedentary, they were restricted to a small home range in the bay or lagoon in which they were captured. On the other hand, some were wide ranging, with large home ranges that encompassed lagoons, rivers, and coasts of both countries (Castelblanco-Martínez

et al., 2013). The authors argued that some of this wide variation could be explained due to the large spread in tracking durations among individuals. Additionally, there is an argument to see evidence for a sex difference, with males ranging more widely than females (Castelblanco-Martínez et al., 2013).

Our study revealed an enormously wide variation in range size, from 0.35 to 1066.16 km^2 . This is likely to be an artefact caused by some individuals being recently released from captivity. For example, the smallest home range was observed for the naive released female “Clara.” It is important to highlight that this estimate pertains to her second deployment, following a rescue due to a long-distance travel and an unsuccessful adaptation to the wild. Unfortunately, “Clara” died shortly afterwards, indicating another failure to adapt to natural conditions and resulting in an unrealistic home range estimate. Interestingly, only four released manatees exhibited range-residency behaviour (17.4%), whereas 18 adapted and seven wild individuals demonstrated this behaviour. These findings suggest that captive-raised individuals may require additional time after release to settle and establish a home range with regular use.

In contrast, the wild adult male “Adão” showed the largest home range among all range-resident individuals. This male was tracked continuously for 11.62 months and presented a bimodal pattern of range use, making sequential travels on average every 8.43 days (ranging from 1 to 43) to Areia Branca/RN and then returning to Icapuí/CE (approximately 50 km in straight line). The wild females ($n = 3$) tracked simultaneously at the same site showed a much smaller home range and did not engage in sequential long travels during the tracking period. In the same direction, the HRs overlapped more between females than between females and the male. Initially, a search for oestrous females could possibly help us to understand the pattern, but the short time between successive travels and the maintenance of the behaviour for the entire year suggests other factors may be involved.

Additionally, factors such as individual personality, or temperament, also play a role in animal movement behaviour, as the boldness of an individual may determine how quickly it explores new habitats (Nilsson et al., 2014). Boldness-shyness traits was recorded in

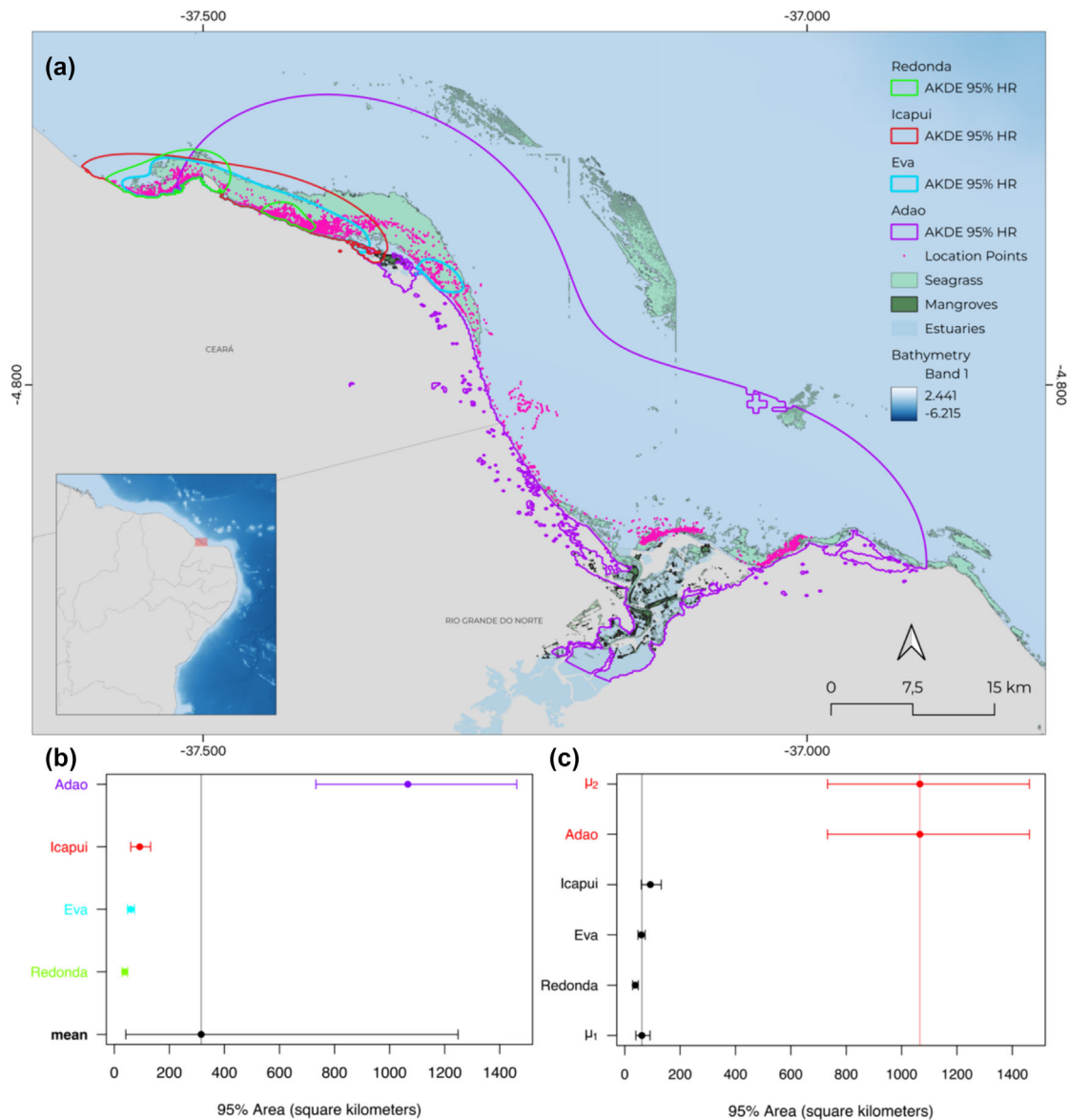


FIGURE 4 Overlap between 95% home ranges for all four resident animals “Adão,” “Icapuí,” “Eva,” and “Redonda” tracked in CE subarea from May 2012 to April 2013. (a) The map presents the AKDE 95% HR and its relations to environmental features such as seagrass meadows, mangrove and estuaries; (b) HR sizes in square kilometres with 95% confidence intervals. The mean home range for all CE/RN individuals is represented in black in the chart; and (c) a cluster analysis reveals two groups, where the first one (red) is formed by the male and the second (black) by the three females.

TABLE 1 Amount of overlap (from 0 to 1) among resident animals “Adão,” “Icapuí,” “Eva,” and “Redonda” tracked in CE subarea from May 2012 to April 2013.

	Adao	Eva	Icapui	Redonda
Adao	1.0000000	0.2528359	0.3106552	0.1370430
Eva	0.2528359	1.0000000	0.9112588	0.5152212
Icapui	0.3106552	0.9112588	1.0000000	0.6239847
Redonda	0.1370430	0.5152212	0.6239847	1.0000000

captive Antillean manatees and individuals characterized as bolder displayed more and longer approach and more contact towards stimuli (Charles et al., 2022; Lucchini et al., 2023). In our study,

distinct exploration behaviours were observed among individuals, with some bold and rapid movements (e.g., Sereno), while others (e.g., Telinha) displayed more cautious behaviour, taking longer to venture beyond the acclimation area. Notably, our findings also revealed that captive-rehabilitated manatees demonstrate exploratory behaviour immediately after release ($n = 19, 82.6\%$) and may take time to establish a stable home range. These insights are essential for informing monitoring methodologies in rehabilitation and release protocols, ensuring successful reintegration into their natural habitat.

In a recent review, Deutsch et al. (2022) explored small-scale movements of sirenians worldwide and revealed dynamic patterns related to the aquatic environment. Relatively small home ranges have been found in studies with Amazonian manatees (95% fixed kernel) in

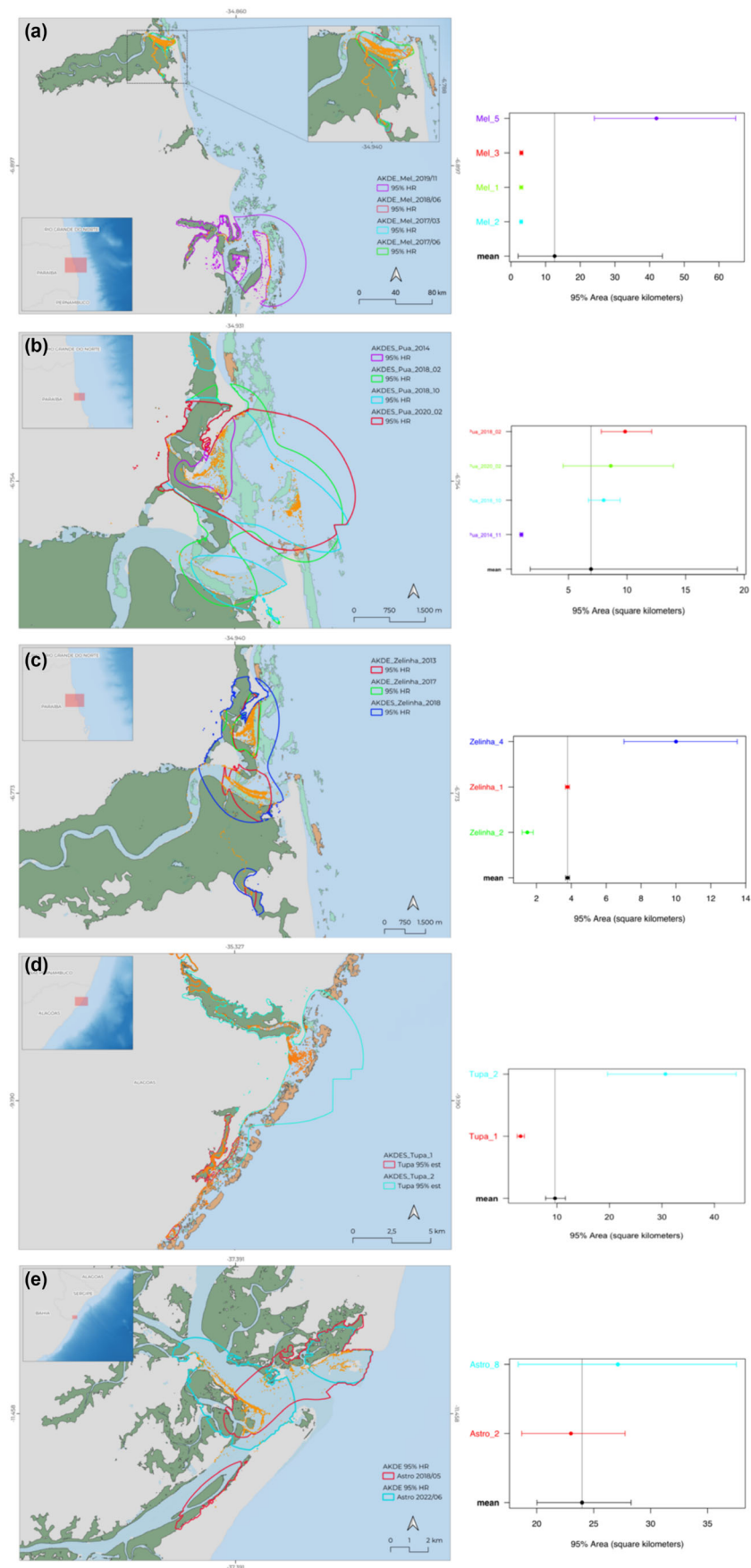


FIGURE 5 The changes in the 95% home ranges of five individual manatees (*Trichechus manatus manatus*) were studied over time through multiple deployments. Each deployment was assigned a specific colour, which corresponded to the colour used in the charts. The charts displayed the area of the home ranges in square kilometres and included the 95% confidence interval for each deployment and the mean home range for each individual is displayed in black. The following individuals were tracked: (a) “Mel,” (b) “Puã,” and (c) “Zelinha” in PB subarea; (d) “Tupã” in the Costa dos Corais EPA, AL/PE subarea; (e) “Astro” in the SE/BA subarea.

the floodplain lakes during the high-water season (mean = 6.3, min-max = 2.5–12.9 km², $n = 6$) and combined seasons of falling water and low water (mean = 14.6, min-max = 5.2–26.6 km², $n = 7$) (Arraut et al., 2010) and African manatee (100% minimum convex polygon, excluding land) between seasons: wet season, mean = 10.9 km² (min-max = 8.0–15.7 km², $n = 6$) versus dry season, 4.8 km² (3.7–6.5 km², $n = 6$) (Kouadio, 2004). With dugongs, in general, the 95% KDE home range has averaged between approximately 30 and 80 km² ($n = 50$) across the majority of the regions (Sheppard et al., 2006). Still, a large variation between regions and studies with different tracking duration was found: in the region of Western Australia, the average home-range area of only 10.3 km² ($n = 6$, tracked from 0.6–1.6 months) (Deutsch et al., 2022); in the Gulf of Carpentaria in Northern Australia, there was an average home-range area of 280.3 km² ($n = 5$, tracked for 3.7–6.5 months) and a high variation among individuals (Sheppard et al., 2006); in Torres Strait between Australia and Papua New Guinea, the 95% KDE area averaged 925 km² ($n = 6$) (Gredzens et al., 2014).

The average daily movement rates in our study were a marginally higher than others—1.7 to 7.3 km/day (Normande et al., 2016) and 8.36 ± 2.21 km/day for females and 10.82 ± 3.4 km/day for males (Santos et al., 2022). The different analytical methods used in the analysis make it difficult to compare the results, but a trend can be seen towards males moving more on a daily basis.

Analysis employing kernel density estimators (KDEs) is commonly used but tends to underestimate home-range areas due to autocorrelation and nonstationarity, and sensitivity to bandwidth optimization methods and sample sizes (Fleming et al., 2015; Noonan et al., 2020) may lead to ineffective strategies (Gaston et al., 2008). The autocorrelated kernel density estimation (AKDE) family addresses these challenges, designed to handle autocorrelation, small sample sizes, and appropriate bandwidth estimation, ensuring statistical efficiency (Silva et al., 2022). Despite AKDE's efforts to mitigate bias, our study revealed fragmented home ranges in certain areas, emphasizing the need to consider movement corridors between core use areas for effective conservation planning (Silva et al., 2022).

4.2 | Effects of body size, sex, and environment on home range and speed

We found a positive correlation between home range and body size, consistent with the metabolic theory of ecology (West et al., 1997), which suggests that body mass represents a super trait governing several ecological processes. One significant aspect is the relationship between body mass and home range size, an allometric pattern that has been integral to ecological theory for more than five decades (Jetz et al., 2004; McNab, 1963).

The scaling relationship between body size and home range has been studied over the past decades on a wide range of taxa including terrestrial and aquatic mammals, reef fishes, turtles, and lizards on both interspecific and intraspecific levels (Hanson et al., 2015; Jetz

et al., 2004; McNab, 1963; Nash et al., 2015; Noonan et al., 2020; Perry & Garland, 2002; Slavenko et al., 2016; Tucker et al., 2014), but no studies could be found on sirenians. Energy requirements and ecological niche play a crucial role in determining home range size. The high degree of home range overlap in large mammals suggests that population density and other behavioural ecological phenomena, such as group living, mate finding, disease transmission, and predator-prey encounters are also vital to explain this correlation (Jetz et al., 2004; McNab, 1963). Accordingly, in the marine environment, diet and body size influence home range patterns but have different relative contributions, showing that colonization of this environment has resulted in the expansion of home range size (Tucker et al., 2014).

On an intraspecific level, the relation between home range and body size can be found in different species like estuarine crocodiles (*Crocodylus porosus*) and large terrestrial herbivores such as the moose (*Alces alces*) (Hanson et al., 2015; Van Beest et al., 2011). Conversely, small marsupials <100 g in body mass tend to have a negative relation, possibly because of the energetic cost related to thermoregulation (Vieira et al., 2019).

Our individual-scale temporal analyses demonstrated a trend of increasing home range size over time. These findings support the scaling theory, indicating that energy requirements escalate as individuals grow, necessitating larger areas to meet their needs. Additionally, mate finding appears to be a significant factor, as evidenced by home range shifts and long-distance travels observed shortly before parturition in long-term tracked released manatees (Attademo et al., 2022; Lima, 2008; Normande et al., 2015).

Despite the differences in mean home range size between males, females with calves, and females, our results showed no significant relation between home range and sex or between average-time speed and sex, in contradiction with other studies on the species (Deutsch et al., 2022; Flamm et al., 2005; Santos et al., 2022), which may be due to the inclusion of animals from four different areas with different environmental conditions. It is clearly documented with tracked Florida and Antillean manatees that males move more in an hourly or daily basis and travel over wider distances than females during the seasonal breeding period. This aligns with a male's reproductive strategy of actively seeking and mating with oestrous females. In contrast, females experience distinct reproductive events such as oestrous and mating that can lead to heightened movement or parturition leading to reduced movement for several weeks (Deutsch et al., 2022).

In contrast, while few or no differences in large-scale movement behaviours like migration and dispersal have been documented between the sexes or across female reproductive states throughout its range (Deutsch et al., 2022), there is an indication that in Mexico and Belize, male Antillean manatees are more likely to make long-distance movements (Castelblanco-Martínez et al., 2013; Deutsch et al., 2022). Similarly, male-biased dispersal or breeding movements have been noticed in Antillean manatees in Puerto Rico, in riverine populations of Antillean and Amazonian manatees in South America, and in dugongs in Queensland (Deutsch et al., 2022).

Additionally, a recent study found significant differences in *T. manatus* body types according to sex, following the commonly

observed pattern that sexual dimorphism is biased towards a larger body size in females (Castelblanco-Martínez et al., 2021). The same study suggests two ecotypes according to the environment they use—coastal marine or riverine. This bias towards larger females can possibly generate some variability in our analyses, even though no correlation was detected regarding both variables, making it more difficult to isolate the effects of sex and body size in area use and movement patterns, requiring further analysis with bigger samples to accurately answer this question.

4.3 | Implications to coastal marine ecosystems conservation

Our study revealed a significant connection between the size of a manatee's home range and the type of environment it inhabits. In certain regions, like CE/RN study site, manatees primarily depend on natural springs within coastal marine environments to access freshwater sources. In these areas, the region climate is influenced by the Brazilian dry forest called caatinga and the input of freshwater is limited in the river basis, resulting in elevated salinity (Favero et al., 2020). Conversely, in the other study sites (PB, AL/PE and SE/BA), which are influenced by Brazilian Atlantic Rain Forest, manatees typically rely on rivers for its freshwater needs. This difference in resource access might explain why manatees that do not venture into rivers tend to have larger home ranges, as these individuals may need to travel greater distances to obtain freshwater. On the contrary, manatees that exclusively inhabit estuarine areas may find all essential resources (Santos et al., 2023)—food, freshwater, and potential mating partners—within a smaller range.

To effectively safeguard manatee populations and their habitats, conservation initiatives based on area, such as the creation of MPAs and zoning plans, should encompass sufficiently large regions that incorporate all critical resources vital to the species. These resources include food and freshwater sources, as well as sheltered areas, which must be integral components of MPA design. This approach allows manatees safe access to these essential resources and addresses their needs. Given the significant variation in home range (HR) sizes observed in this study and the substantial variability in HR size among individual manatees, a strategy involving a mosaic of protected areas should be considered. Core usage areas can be designated for higher levels of protection, while movement corridors connecting these areas can be designated as multiple-use protected zones, each with specific regulations targeting the primary threats to the species.

AUTHOR CONTRIBUTIONS

Iran C. Normande designed the study, collected the data, performed the analysis, raised funds, and wrote the manuscript. João Carlos G. Borges, Fernanda L. N. Attademo, Sebastião S. dos Santos, and Cristine P. Negrão collected the data and reviewed the manuscript. Emma Deeks performed analysis and reviewed the manuscript. Fabia O. Luna raised funds and reviewed the manuscript. Nuno Queiroz and Robson G. Santos designed the study, raised funds, and reviewed the

manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no know competing financial or personal relationship that could have appeared to influence work reported in this paper.

DATA AVAILABILITY STATEMENT

All data used in this study are available in the Movebank data repository (www.movebank.org) under the study “*Trichechus manatus* Sirenia NE Brazil” movebank ID 1936932457 and are available to predefined collaborators due to the embargo policy of the institutions collecting the data. The dataset can be made available upon reasonable request.

RESEARCH PERMIT STATEMENT

Research permits and authorizations were obtained for the research (SISBIO 43406; 45568; 25597; 25473; 24767; 41337; 74626; 81090) and the research protocols were approved by the CEUA UFAL Animal Ethics Committee under number 18/2023.

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REFERENCES

- Allen, A.M. & Singh, N.J. (2016). Linking movement ecology with wildlife management and conservation. In: *Frontiers in ecology and evolution*, vol. 3. Frontiers Media S. A. <https://doi.org/10.3389/fevo.2015.00155>
- Alston, J.M., Fleming, C.H., Kays, R., Streicher, J.P., Downs, C.T., Ramesh, T. et al. (2022). Mitigating pseudoreplication and bias in resource selection functions with autocorrelation-informed weighting. *Methods in Ecology and Evolution*, 14(2), 643–654. <https://doi.org/10.1111/2041-210X.14025>
- Alves, M.D., Kinas, P.G., Marmontel, M., Borges, J.C.G., Costa, A.F., Schiel, N. et al. (2016). First abundance estimate of the Antillean manatee (*Trichechus manatus manatus*) in Brazil by aerial survey. *Journal of the Marine Biological Association of the United Kingdom*, 96(4), 955–966. <https://doi.org/10.1017/S0025315415000855>
- Alves, M.D., Schwamborn, R., Borges, J.C., Marmontel, M., Costa, A.F., Schettini, C.A. et al. (2013). Aerial survey of manatees, dolphins and sea turtles off northeastern Brazil: correlations with coastal features and human activities. *Biological Conservation*, 161, 91–100. <https://doi.org/10.1016/j.biocon.2013.02.015>

- Anzolin, D.G., Sarkis, J.E.S., Diaz, E., Soares, D.G., Serrano, I.L., Borges, J.C.G. et al. (2012). Contaminant concentrations, biochemical and hematological biomarkers in blood of West Indian manatees *Trichechus manatus* from Brazil. *Marine Pollution Bulletin*, 64(7), 1402–1408. <https://doi.org/10.1016/j.marpolbul.2012.04.018>
- Arraut, E.M., Marmontel, M., Mantovani, J.E., Novo, E.M.L.M., Macdonald, D.W. & Kenward, R.E. (2010). The lesser of two evils: seasonal migrations of Amazonian manatees in the Western Amazon. *Journal of Zoology*, 280(3), 247–256. <https://doi.org/10.1111/j.1469-7998.2009.00655.x>
- Attademo, F.L.N., Balensiefer, D.C., da Bôaviagem Freire, A.C., de Sousa, G.P., da Cunha, F.A. & de Oliveira Luna, F. (2015). Debris ingestion by the Antillean manatee (*Trichechus manatus manatus*). *Marine Pollution Bulletin*, 101(1), 284–287. <https://doi.org/10.1016/j.marpolbul.2015.09.040>
- Attademo, F.L.N., Normande, I.C., Sousa, G.P., Costa, A.F., Borges, J.C.G., De Alencar, A.E.B. et al. (2022). Reproductive success of Antillean manatees released in Brazil: implications for conservation. *Journal of the Marine Biological Association of the United Kingdom*, 102(3–4), 252–259. <https://doi.org/10.1017/S0025315422000443>
- Balensiefer, D.C., Attademo, F.L.N., Sousa, G.P., Freire, A.C., da Cunha, F.A., Alencar, A.E. et al. (2017). Three decades of Antillean manatee (*Trichechus manatus manatus*) stranding along the Brazilian coast. *Tropical Conservation Science*, 10, 1–9. <https://doi.org/10.1177/1940082917728375>
- Bartoň, K. (2023). *_MuMIn: Multi-Model Inference*. R package version 1.47.5 <https://CRAN.R-project.org/package=MuMIn>
- Barua, M., Root-Bernstein, M., Ladle, R.J. & Jepson, P. (2011). Defining flagship uses is critical for flagship selection: A critique of the IUCN climate change flagship fleet. *Ambio*, 40(4), 431–435. <https://doi.org/10.1007/s13280-010-0116-2>
- Borges, J.C.G., Vergara-Parente, J.E., Alvite, C.M.C., Marcondes, M.C.C. & Lima, R.P. (2007). Embarcações motorizadas: uma ameaça aos peixes-boi marinhos (*Trichechus manatus*) no Brasil. 7(3). <http://www.biotaneotropica.org.br/v7n3/pt/abstract?article=bn03607032007>
- Calabrese, J.M., Fleming, C.H. & Gurarie, E. (2016). ctmm: an R package for analyzing animal relocation data as a continuous-time stochastic process. *Methods in Ecology and Evolution*, 7(9), 1124–1132. <https://doi.org/10.1111/2041-210X.12559>
- Castelblanco-Martínez, D.N., Padilla-Saldívar, J., Hernández-Arana, H.A., Slone, D.H., Reid, J.P. & Morales-Vela, B. (2013). Movement patterns of Antillean manatees in Chetumal Bay (Mexico) and coastal Belize: a challenge for regional conservation. *Marine Mammal Science*, 29(2), E166–E182. <https://doi.org/10.1111/j.1748-7692.2012.00602.x>
- Castelblanco-Martínez, D.N., Slone, D.H., Landeo-Yauri, S.S., Ramos, E.A., Alvarez-Alemán, A., Attademo, F.L.N. et al. (2021). Analysis of body condition indices reveals different ecotypes of the Antillean manatee. *Scientific Reports*, 11(1), 19451. <https://doi.org/10.1038/s41598-021-98890-0>
- Cattarino, L., Mcalpine, C.A. & Rhodes, J.R. (2016). Spatial scale and movement behaviour traits control the impacts of habitat fragmentation on individual fitness. *Journal of Animal Ecology*, 85(1), 168–177. <https://doi.org/10.1111/1365-2656.12427>
- Charles, A., Henaut, Y., Saint Jalme, M., Mulot, B., Lecu, A. & Delfour, F. (2022). Studying Antillean manatees' (*Trichechus manatus manatus*) temperament in zoological parks: exploration of boldness, sociality and reactivity to humans. *Applied Animal Behaviour Science*, 246, 105512. <https://doi.org/10.1016/j.applanim.2021.105512>
- Deutsch, C.J., Castelblanco-Martínez, D.N., Cleguer, C. & Groom, R. (2022). Movement behavior of manatees and dugongs: II. Small-scale movements reflect adaptations to dynamic aquatic environments. Cham: Springer International Publishing, pp. 233–298. https://doi.org/10.1007/978-3-030-90742-6_6
- Deutsch, C.J., Self-Sullivan, C. & Mignucci-Giannoni, A. (2008). *Trichechus manatus*, West Indian Manatee THE IUCN RED LIST OF THREATENED SPECIE. The IUCN Red List of Threatened Species. <https://doi.org/10.2305/IUCN.UK.2008.RLTS.T22103A9356917.en>
- Díaz, S., Settele, J., Brondizio, E.S., Ngo, H.T., Agard, J., Arneeth, A. et al. (2019). Pervasive human-driven decline of life on Earth points to the need for transformative change. *Science*, 366(1327), 1–10. <https://doi.org/10.1126/science.aaw3100>
- Domning, D.P. (1982). Commercial exploitation of manatees *Trichechus* in Brazil c. 1785–1973. *Biological Conservation*, 22(2), 101–126. [https://doi.org/10.1016/0006-3207\(82\)90009-X](https://doi.org/10.1016/0006-3207(82)90009-X)
- Favero, I.T., Favero, G.E., Choi-Lima, K.F., dos Santos, H.F., Souza-Alves, J.P., de Souza e Silva, J. et al. (2020). Effects of freshwater limitation on distribution patterns and habitat use of the West Indian manatee, *Trichechus manatus*, in the northern Brazilian coast. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 30(8), 1665–1673. <https://doi.org/10.1002/aqc.3363>
- Flamm, R.O., Weigle, B.L., Wright, I.E., Ross, M. & Aglietti, S. (2005). Estimation of manatee (*Trichechus manatus latirostris*) places and movement corridors using telemetry data. *Ecological Applications*, 15(4), 1415–1426. <https://doi.org/10.1890/04-1096>
- Fleming, C.H. & Calabrese, J.M. (2023). ctmm: Continuous-Time Movement Modeling. R package version 1.2.1. <https://groups.google.com/g/ctmm-user>
- Fleming, C.H., Fagan, W.F., Mueller, T., Olson, K.A., Leimgruber, P., Calabrese, J.M. et al. (2015). Rigorous home range estimation with movement data: A new autocorrelated kernel density estimator. *Ecology*, 96(5), 1182–1188. <https://doi.org/10.1890/14-2010.1>
- Gaston, K., Jackson, S., Cantú-Salazar, L. & Cruz-Piñón, G. (2008). The ecological performance of protected areas. *Annual Review of Ecology, Evolution, and Systematics*, 39, 93–113.
- Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D. & Moore, R. (2017). Google Earth Engine: planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*, 202, 18–27. <https://doi.org/10.1016/j.rse.2017.06.031>
- Gredzens, C., Marsh, H., Fuentes, M.M.P.B., Limpus, C.J., Shimada, T. & Hamann, M. (2014). Satellite tracking of sympatric marine megafauna can inform the biological basis for species co-management. *PLoS ONE*, 9(6), e98944. <https://doi.org/10.1371/journal.pone.0098944>
- Hanson, J.O., Salisbury, S.W., Campbell, H.A., Dwyer, R.G., Jardine, T.D. & Franklin, C.E. (2015). Feeding across the food web: the interaction between diet, movement and body size in estuarine crocodiles (*Crocodylus porosus*). *Austral Ecology*, 40(3), 275–286. <https://doi.org/10.1111/aec.12212>
- Hartig, F. (2022). DHARMA: residual diagnostics for hierarchical (multi-level/mixed) regression Models_. R package version 0.4.6. <https://CRAN.R-project.org/package=DHARMA>
- ICMBio. (2018). *Livro Vermelho da Fauna Brasileira Ameaçada de Extinção*, 1st edition, Vol. II: ICMBio/MMA.
- Jetz, W., Carbone, C., Fulford, J. & Brown, J.H. (2004). The scaling of animal space use. *Science*, 306(5694), 266–268. <https://doi.org/10.1126/science.1102138>
- Kölsch, A. (2023). Animated Map (moveVis). version v3.5 (7). MoveApps. <https://github.com/movestore/animation-moveVis.git>
- Kouadio, A. (2004). *Fishers and the West African manatee in the Fresco lagoon complex, Cote D'Ivoire: common property, conflict and conservation*, UK: University of Kent.
- Li, J., Knapp, D.E., Lyons, M., Roelfsema, C., Phinn, S., Schill, S.R. et al. (2021). Automated global shallow water bathymetry mapping using Google Earth Engine. *Remote Sensing*, 13(8), 1469. <https://doi.org/10.3390/rs13081469>
- Lima, R.P. (1997). Peixe-boi marinho (*Trichechus manatus*): distribuição, status de conservação e aspectos tradicionais ao longo do litoral nordeste do Brasil.

- Lima, R.P. (2008). PEIXES-BOIS (*Trichechus manatus*) REINTRODUZIDOS NO LITORAL NORDESTINO E AVALIAÇÃO DA PRIMEIRA DÉCADA (1994-2004) DO PROGRAMA DE REINTRODUÇÃO. 178.
- Lucchini, K., do Val, H.G., Umeed, R., de Azevedo, C.S., Attademo, F.L., Melo, L.I. et al. (2023). Personality traits in captive Antillean manatees (*Trichechus manatus manatus*) in Brazil and perspectives for the release of individuals. *Applied Animal Behaviour Science*, 266, 106031. <https://doi.org/10.1016/j.applanim.2023.106031>
- Luna, F.D., Beaver, C.E., Nourisson, C., Bonde, R.K., Attademo, F.L., Miranda, A.V. et al. (2021). Genetic connectivity of the West Indian manatee in the southern range and limited evidence of hybridization with Amazonian manatees. *Frontiers in Marine Science*, 7, 574455. <https://doi.org/10.3389/fmars.2020.574455>
- Magris, R.A., Costa, M.D.P., Ferreira, C.E.L., Vilar, C.C., Joyeux, J.C., Creed, J.C. et al. (2021). A blueprint for securing Brazil's marine biodiversity and supporting the achievement of global conservation goals. *Diversity and Distributions*, 27(2), 198–215. <https://doi.org/10.1111/ddi.13183>
- McNab, B.K. (1963). Bioenergetics and the determination of home range size. *The American Naturalist*, 97(894), 133–140. <https://doi.org/10.1086/282264>
- Meirelles, A.C.O. (2008). Mortality of the Antillean manatee, *Trichechus manatus manatus*, in Ceará State, north-eastern Brazil. *Journal of the Marine Biological Association of the United Kingdom*, 88(6), 1133–1137. <https://doi.org/10.1017/S0025315408000817>
- Meirelles, A.C., dos Santos Lima, D., de Oliveira Alves, M.D., Borges, J.C., Marmontel, M., Carvalho, V.L. et al. (2022). Don't let me down: West Indian manatee, *Trichechus manatus*, is still critically endangered in Brazil. *Journal for Nature Conservation*, 67, 126169. <https://doi.org/10.1016/j.jnc.2022.126169>
- Nash, K.L., Welsh, J.Q., Graham, N.A.J. & Bellwood, D.R. (2015). Home-range allometry in coral reef fishes: comparison to other vertebrates, methodological issues and management implications. *Oecologia*, 177(1), 73–83. <https://doi.org/10.1007/s00442-014-3152-y>
- Nathan, R., Getz, W.M., Revilla, E., Holyoak, M., Kadmon, R., Saltz, D. et al. (2008). A movement ecology paradigm for unifying organismal movement research. *Proceedings of the National Academy of Sciences*, 105(49), 19052–19059. <https://doi.org/10.1073/pnas.0800375105>
- Nathan, R. & Giuggioli, L. (2013). A milestone for movement ecology research. *Movement Ecology*, 1(1), 1–3. <https://doi.org/10.1186/2051-3933-1-1>
- Nathan, R., Monk, C.T., Arlinghaus, R., Adam, T., Alós, J., Assaf, M. et al. (2022). Big-data approaches lead to an increased understanding of the ecology of animal movement. *Science*, 375(6582), eabg1780. <https://doi.org/10.1126/science.abg1780>
- Nilsson, J.-Å., Brönmark, C., Hansson, L.-A. & Chapman, B.B. (2014). Individuality in movement: the role of animal personality. In: *Animal movement across scales*, Oxford: Oxford University Press, pp. 90–109. <https://doi.org/10.1093/acprof:oso/9780199677184.003.0006>
- Noonan, M.J., Fleming, C.H., Akre, T.S., Drescher-Lehman, J., Gurarie, E., Harrison, A.L. et al. (2019). Scale-insensitive estimation of speed and distance traveled from animal tracking data. *Movement Ecology*, 7(1), 1–15. <https://doi.org/10.1186/s40462-019-0177-1>
- Noonan, M.J., Fleming, C.H., Tucker, M.A., Kays, R., Harrison, A.L., Crofoot, M.C. et al. (2020). Effects of body size on estimation of mammalian area requirements. *Conservation Biology*, 34(4), 1017–1028. <https://doi.org/10.1111/cobi.13495>
- Noonan, M.J., Tucker, M.A., Fleming, C.H., Akre, T.S., Alberts, S.C., Ali, A.H. et al. (2019). A comprehensive analysis of autocorrelation and bias in home range estimation. *Ecological Monographs*, 89(2), e01344. <https://doi.org/10.1002/ecm.1344>
- Normande, I.C., Costa, A.F., Coelho-Jr, C., dos Santos, J.U. & Ladle, R.J. (2023). Flagship species: manatees as tools for mangrove conservation in northeast Brazil. In: *Brazilian mangroves and salt marshes*, Cham: Springer International Publishing, pp. 281–295. https://doi.org/10.1007/978-3-031-13486-9_13
- Normande, I.C., Luna, F.D.O., Malhado, A.C.M., Borges, J.C.G., Viana Junior, P.C., Attademo, F.L.N. et al. (2015). Eighteen years of Antillean manatee *Trichechus manatus manatus* releases in Brazil: lessons learnt. *Oryx*, 49(2), 338–344. <https://doi.org/10.1017/S0030605313000896>
- Normande, I.C., Malhado, A.C.M., Reid, J., Viana, P.C., Savaget, P.V.S., Correia, R.A. et al. (2016). Post-release monitoring of Antillean manatees: an assessment of the Brazilian rehabilitation and release programme. *Animal Conservation*, 19(3), 235–246. <https://doi.org/10.1111/acv.12236>
- Ofstad, E.G., Herfindal, I., Solberg, E.J. & Sæther, B.E. (2016). Home ranges, habitat and body mass: simple correlates of home range size in ungulates. *Proceedings of the Royal Society B: Biological Sciences*, 283(1845), 20161234. <https://doi.org/10.1098/rspb.2016.1234>
- Parente, C.L., Vergara-Parente, J.E. & Lima, R.P. (2004). Strandings of Antillean manatees, *Trichechus manatus manatus*, in northeastern Brazil. *Lajam*, 3(1), 69–75. <https://doi.org/10.5597/lajam00050>
- Perry, G. & Garland, T. (2002). Lizard home ranges revisited: effects of sex, body size, diet, habitat, and phylogeny. *Ecology*, 83(7), 1870–1885. <https://doi.org/10.2307/3071771>
- R Core Team (2024). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
- Reid, J.P., Rathbun, G.B. & Wilcox, J.R. (1991). Distribution patterns of individually identifiable West Indian manatees (*Trichechus manatus*) in Florida. *Marine Mammal Science*, 7(2), 180–190. <https://doi.org/10.1111/j.1748-7692.1991.tb00564.x>
- Santos, S.S., Medeiros, I.D.S., Rebelo, V.A., Carvalho, A.O.B., Dubut, J.P., Mantovani, J.E. et al. (2022). Home ranges of released West Indian manatees *Trichechus manatus* in Brazil. *Oryx*, 56(6), 939–946. <https://doi.org/10.1017/S003060532100079X>
- Santos, S.S., Medeiros, I.S., de Almeida, I.C., Rebelo, V.A., Carvalho, A.O.B., Menezes, R. et al. (2023). Environmental characterization of home range of Antillean manatees (*Trichechus manatus*) released in northeastern Brazil. *Anais da Academia Brasileira de Ciências*, 95(suppl 1), e20220574. <https://doi.org/10.1590/0001-3765202320220574>
- Schofield, G., Hobson, V.J., Lilley, M.K.S., Katselidis, K.A., Bishop, C.M., Brown, P. et al. (2010). Inter-annual variability in the home range of breeding turtles: implications for current and future conservation management. *Biological Conservation*, 143(3), 722–730. <https://doi.org/10.1016/j.biocon.2009.12.011>
- Sheppard, J.K., Preen, A.R., Marsh, H., Lawler, I.R., Whiting, S.D. & Jones, R.E. (2006). Movement heterogeneity of dugongs, *Dugong dugon* (Müller), over large spatial scales. *Journal of Experimental Marine Biology and Ecology*, 334(1), 64–83. <https://doi.org/10.1016/j.jembe.2006.01.011>
- Silva, I., Fleming, C.H., Noonan, M.J., Alston, J., Folta, C., Fagan, W.F. et al. (2022). Autocorrelation-informed home range estimation: a review and practical guide. *Methods in Ecology and Evolution*, 13(3), 534–544. <https://doi.org/10.1111/2041-210X.13786>
- Slavenko, A., Itescu, Y., Ihlw, F. & Meiri, S. (2016). Home is where the shell is: predicting turtle home range sizes. *Journal of Animal Ecology*, 85(1), 106–114. <https://doi.org/10.1111/1365-2656.12446>
- Spalding, M.D., Fox, H.E., Allen, G.R., Davidson, N., Ferdaña, Z.A., Finlayson, M. et al. (2007). Marine ecoregions of the world: a bioregionalization of coastal and shelf areas. *Bioscience*, 57(7), 573–583. <https://doi.org/10.1641/B570707>
- Tucker, M.A., Ord, T.J. & Rogers, T.L. (2014). Evolutionary predictors of mammalian home range size: body mass, diet and the environment. *Global Ecology and Biogeography*, 23(10), 1105–1114. <https://doi.org/10.1111/geb.12194>
- Van Beest, F.M., Rivrud, I.M., Loe, L.E., Milner, J.M. & Myrseter, A. (2011). What determines variation in home range size across spatiotemporal

- scales in a large browsing herbivore? *Journal of Animal Ecology*, 80(4), 771–785. <https://doi.org/10.1111/j.1365-2656.2011.01829.x>
- Vanegas, L., Rondón, L. & Paula, G. (2024). glmtoolbox: Set of Tools to Data Analysis using Generalized Linear Models. R package version 0.1.10. <https://CRAN.R-project.org/package=glmtoolbox>
- Vieira, M.V., Loretto, D. & Papi, B. (2019). Scaling of movements with body mass in a small opossum: evidence for an optimal body size in mammals. *Journal of Mammalogy*, 100(6), 1765–1773. <https://doi.org/10.1093/jmammal/gyz166>
- West, G.B., Brown, J.H. & Enquist, B.J. (1997). A general model for the origin of allometric scaling laws in biology. *Science*, 276(5309), 122–126. <https://doi.org/10.1126/science.276.5309.122>

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.