Latin American Journal of Aquatic Mammals

ISSN: 2236-1057 | Vol. 19 No. 1, April 2024

Density and abundance estimation of West Indian manatee, *Trichechus manatus*, between the states of Ceará and Piauí, Northeast Brazil, using active acoustics

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Abstract

The West Indian manatee is one of the most threatened species in Brazil. The species has currently a patchy distribution from the state of Alagoas to the state of Amapá. The difficulty of observing manatees, especially in estuarine waters, is a challenge for conservation. Therefore, it is necessary to use new methodologies and technologies to solve manatee detection problems in their natural habitats. The goal of this study was to use an active acoustic method of detection to estimate manatee density and abundance in the estuarine complex of the Timonha and Ubatuba rivers, between the states of Ceará and Piauí, northeast Brazil. Data collection was conducted from a wooden boat with an outboard motor using a side-scan sonar. Sonar images were collected along line transects in three regions within the study area. Manatee abundance was calculated using distance sampling (Distance 6.0 software). There were 1,396 transection lines that totaled 863.6 km traveled in the study area. The observed general encounter rate was 0.089 group detected per kilometer traveled. The best detection model was the hazard-rate with no adjustment terms, resulting in a detection probability of 33.7%, and an estimated density for the entire study area of 9.19 manatees per km^2. Abundance of manatees in the estuary was estimated to be 37 animals (CV% = 30.2, 95% CI = 21 - 66). The methodology using side-scan sonar proposed here was successful in the detection of manatees in the study area and in defining parameters for its use to estimate the population size using the distance sampling method. This study provides an estimate of manatee density and abundance in a key estuarine system along the northeast coast of Brazil, which can serve as a baseline for future studies and aid in the development of conservation strategies for the species. This is the first time this methodological approach has been used for manatee detection and abundance estimation in Brazil. We recommend the use of side-scan sonar in future West Indian manatee research.

Keywords:
bioacoustics, conservation, distance sampling, population ecology, side-scan sonar, Sirenia

ARTICLE INFO

Manuscript type: Article

Article History
Received: 31 August 2023
Received in revised form: 17 April 2024
Accepted: 17 April 2024
Available online: 29 April 2024

Handling Editor: Nataly Castelblanco-Martínez

Citation:
Choi-Lima, K. F., Abessa, D. M. S., Wedekin, L. L., Gonzalez-Socoloske, D., Sousa-Lima, R., Meirelles, A. C. O., & Silva, C. P. N. (2024). Density and abundance estimation of West Indian manatee, *Trichechus manatus*, between the states of Ceará and Piauí, Northeast Brazil, using active acoustics. *Latin American Journal of Aquatic Mammals, 19*(1), 112-119. https://doi.org/10.5597/lajam00333

Introduction

The population size of endangered species is considered an essential variable to guide conservation actions. Thus, one of the main questions regarding the vulnerable West Indian manatee conservation is: how many individuals are there in a particular place? Studies on sirenian abundance estimation usually employ aerial surveys (Reynolds et al., 2012; Bauduin et al., 2013). However, this technique has certain limitations, such as the visibility through the water allied to the perception bias of the observer on the sightings (Pollock et al., 2006; Martin et al., 2012). High levels of turbidity and tannins of the coastal and inland waters and probability that manatees may be submerged while the aircraft passes can result in availability bias that can cause underestimation of true abundance. In addition, aerial surveys are logistically difficult and expensive, requiring reliable aircraft, qualified pilots, and trained observers (Reynolds et al., 2012).

In Brazil, for a long period, population estimates from the 1990s based on interviews (Luna et al., 2008; Lima et al., 2011) was the best data available on the abundance of animals in the country. This estimate suggested that there were approximately 500 West Indian manatees along the northern and northeastern coast. Additionally, in its 2008 edition, the IUCN Red List of Threatened Species presented a minimum population estimate for the species in Brazil of around 200 individuals, but without methodological details (Self-Sullivan & Mignucci-Giannoni, 2008). Both estimates, though addressing the lack of population information on the species, did not use robust methodological and statistical techniques that consider imperfect detection.

A recognized and robust method to estimate abundance was first performed in 2010, when Alves et al. (2015) estimated 1,104 individuals (CI 95% = 485 - 2,221) between the states of Piauí and Alagoas through aerial surveys. The authors highlighted the uncertain estimate, indicating surveys were limited to coastal marine waters, where detection of manatees was possible. Thus, bays and inner estuaries were not sampled. Later, in a smaller area (Potiguar Basin), also through aerial surveys, Petrobras (2014) reported an estimate of 193 manatees (CV = 35%; 95% CI = 98-378), but as in Alves et al. (2015), efforts were concentrated in marine coastal areas and the authors recommended sectorized efforts to obtain more accurate estimates.

While inner estuaries and bays were excluded from previous studies, it is well-established that manatees predominantly inhabit these habitats, characterized by generally turbid and tannin-stained waters. Additionally, the low density of individuals and the cryptic behavior exhibited by manatees during breathing, momentarily exposing only the tip of the rostrum without emitting an audible exhale, render them extremely challenging to monitor and study in the field. Consequently, accurately counting individual manatees in these habitats using traditional methods proves to be a formidable task. This underscores the necessity for new approaches and technologies to overcome these challenges, emphasizing the critical need for innovative methods in order to achieve precise and reliable estimates of manatee abundance in these environments. Some studies have suggested that passive (Sousa-Lima et al., 2008; Castro et al., 2016) or active acoustics (Gonzalez-Socoloske et al., 2009; Guzman & Condit, 2017) are potential tools that can address challenges in abundance estimation of manatees in these habitats. Abundance estimation using acoustics appears as a promising alternative, since it is not necessary to visualize the animals, but rather to detect sounds and/or images produced by ensonified manatees. The use of side scan sonar has proven to be a useful tool to detect manatees in such environments (Gonzalez-Socoloske et al., 2009; Gonzalez-Socoloske & Olivera-Gómez, 2012, 2023; Arévalo-González, et al., 2014; Brice, 2014; Castelblanco-Martínez & Arévalo-González, 2015; Guzman & Condit, 2017; Serrano et al., 2017), and as the detection rates in the wild varied from 81 to 93% in clear and turbid waters, Gonzalez-Socoloske et al. (2009) concluded that side-scan sonars are sensitive enough to accurately detect the presence of manatees in their natural environment and can be an effective and accessible tool to study the species throughout its distribution.

Data obtained with the side-scan sonar can be applied to estimate the population size by using distance sampling methods, because it allows obtaining accurate data with a low margin of error. There are three main assumptions for the application of the distance sampling method: (1) all individuals in the line are detected, *i.e.*, animals at or near the zero line of the transection line will be detected ($g_{(0)} = 1$); (2) individuals are detected before responding to the presence of the observer, with evasive movements, for example, or absence of responsive movements; and (3) distances are measured or estimated accurately. The perpendicular distance from the line transect is an essential variable for distance sampling method. Aerial and boat surveys usually get this information through the angle reading of a clinometer and then calculate the perpendicular distance. But the angle reading is prone to measurement error, even for trained researchers, and thus may result in further errors that may violate one of the assumptions of the method. The correct and precise measurement of perpendicular distance is crucial for reliable estimates and is one of the advantages of using the sonar.

In this context, the present study estimated the density and abundance of the West Indian manatee in the estuarine complex of the Timonha and Ubatuba rivers, Northeastern Brazil, using a side-scan sonar.

Material and Methods

Study area

The study area is located in the Federal Environmental Protection Area (APA) Delta do Parnaíba, Northeastern Brazil, in the eastern portion of the estuarine system formed by the rivers Timonha and Ubatuba (02º57'56" S, 41º15'48" W). The Timonha-Ubatuba estuarine system covers the municipalities of Cajueiro da Praia in the state of Piauí, and Chaval and Barroquinha in the state of Ceará (Fig. 1). The sampled area was based on previous knowledge about the presence of the West Indian manatee in the region (Choi et al., 2009). The study area was stratified into three sampling zones – Route I (Barra), Route II (Ubatuba River), and Route III (Carpina River). Each zone was traversed with an outboard motorboat, in linear transects (Fig. 1) based on the method proposed by Buckland et al. (2008) and Thomas et al. (2009) for complex study areas.

Side-scan Sonar

The technique consisted of the use of side-scan sonar (Humminbird® 998c SI Combo), referred simply as 'sonar' elsewhere in the manuscript, to detect and count manatees. This type of sonar has been used to detect manatees in various environmental conditions and habitat types (Gonzalez-Socoloske et al., 2009, Guzman et al., 2017; Factheu et al., 2023; Gonzalez-Socoloske & Olivera-Gómez, 2023).

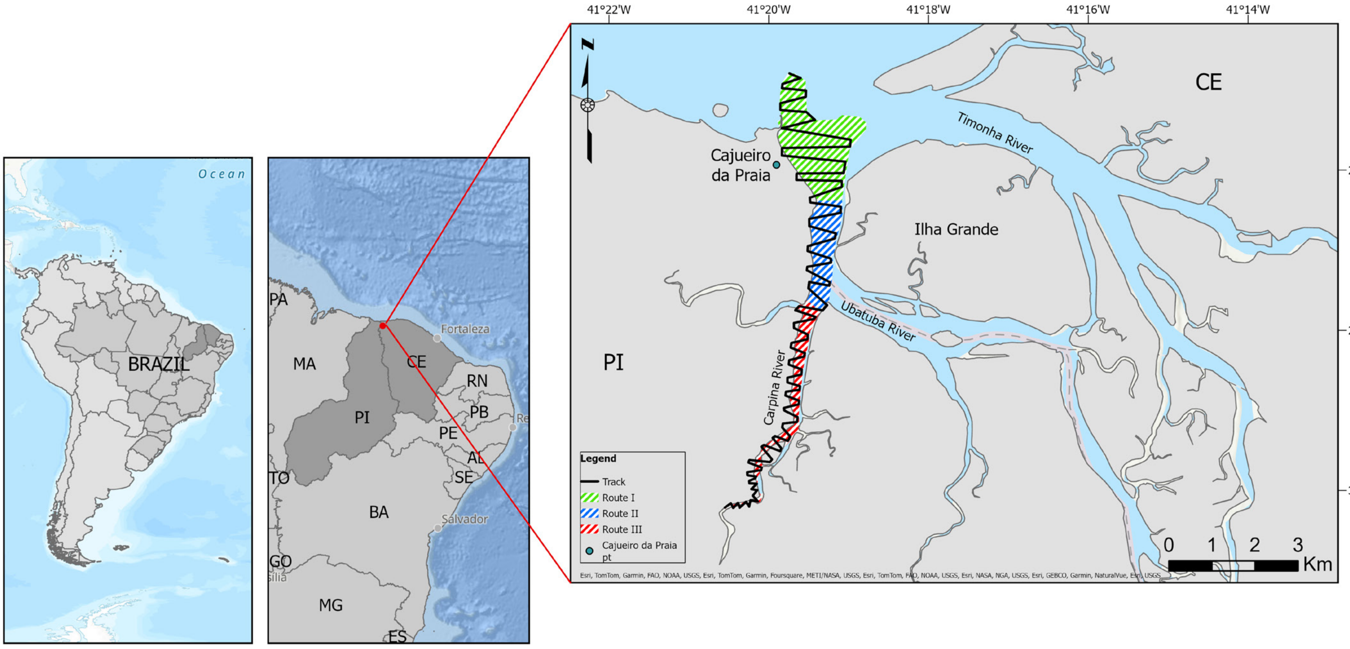

Figure 1. Study area in the low region of the Timonha-Ubatuba Estuarine System, Northeastern Brazil, showing the line transects and zones of sampling.

Data collection

Boat surveys were carried out during five consecutive days, twice a month, from March to June 2013, and January to June 2014, totaling 18 field trips and 75 daily surveys. The first half of the year was chosen due to previous information (Aquasis, 2008; Choi et al., 2009) that manatees were present in the estuarine complex only in this period (rainy season).

The transects were systematically placed and the width was standardized according to the quality of the background of the side-scan sonar image, set at 30 m on each side (right and left), totaling 60 m wide. The total length of the transects varied in each region: Route I - 6.12 km; Route II - 5.78 km; and Route III - 5.19 km. The speed of the boat varied from 0.1 km/h to 9.4 km/h, remaining on average 5.0 km/h.

The path of each region was completely covered with the sonar and two researchers took turns hourly in the visualization of the images generated by the sonar. Every five minutes an image was saved (screen shot) and when a potential manatee or something undefined was detected on the sonar, a screen shot was recorded for further analysis of the perpendicular distance in which the animal was detected. Manatees were identified following Gonzalez-Socoloske et al. (2009) and Gonzalez-Socoloske and Olivera-Gómez (2012), with additional consideration for the effect of the object density and position of the object shadows.

Data analysis

The inclusion criteria for manatee detection were conservative and provided a minimum count, which depended on the orientation of the manatee in the water column. All observations were documented in a spreadsheet along with the following parameters: region, depth, boat speed, perpendicular distance from the boat, geographical position, date, and time.

The Humminbird PC software was used to view data recorded by the sonar and the images saved by the sonar were viewed in the IrfanView® program. Each image was analyzed and categorized by four researchers independently, according to the following classification (Choi-Lima, 2017): A - sure it is a manatee (one or more - if more, say the quantity); B - most likely a manatee, but not 100% sure; C - doubt if it is a manatee; and D - sure it is not manatees. All objects that produced acoustic responses or demonstrated manatee morphology, including the paddle-shaped tail, peanut body shape, small head, or fins were evaluated. If the acoustic response exhibited approximate manatee-like morphology and length, produced a shadow, and fit one of the manatee model images established by Gonzalez-Socoloske and Olivera-Gómez (2012), it was included as a manatee observation.

A total of 3,489 images were captured and saved for further analysis during the effort. Of the 3,489 images recorded, 569 contained usable data and were carefully reviewed in image editors by the researchers. Of the 569 images, 77 were confirmed manatee detections (category A – Fig. 2) and the remaining 492 images were not confirmed as manatees, as they did not have a peanut shape body, shade or other characteristics of manatees as seen from the sonar (described above), or it was not confirmed in category A by at least three researchers.

Density and abundance estimation

The method used to estimate the density and abundance of the manatee in the study area was the standard line transects distance sampling (Buckland et al., 2001; Thomas et al., 2002). This method consists of counting individuals or groups (clusters) along sample units (line transects) positioned in the study area. The next step is to quantify the probability of detection of each individual or clusters, and it is possible to infer about present but undetected individuals (Thompson, 2009). The distance sampling method consists of registering the distance perpendicular to the line transect for each detected individual or cluster. The sonar allows obtaining this information in a simple, direct, and precise way, this being one of the main advantages of its use.

For the analysis of the distance sampling data, the software DISTANCE 6.0 (Thomas et al., 2009) was used. The software is based on the Fourier probability series for the density function of f(x), which is the function of probability of detection at a range of distances (x). The densities were estimated using the equation:

$$D = \frac{n \times f(0)}{2 \times L}$$

where D = estimated population density, n = number of animals detected in the transect, $f_{(0)}$ = density function and L = transect length.

The detection function was constructed using a key function with or without adjustment terms, which can improve the fit of the function to the data. Among the mathematical functions considered were the uniform, half-normal, and hazard-rate. The considered series adjustments were the cosine, simple polynomial, and Hermite polynomial. Thus, different detection models were considered for the data. Along with the detection function, the detection probability was obtained, which corrects the animals that are no longer detected because of the distance.

The best model among the set of considered models was chosen based on the lowest AIC value (Akaike's Information Criterion - see Burnham & Anderson, 2002). The validation of the best model was done by means of goodness-of-fit plots and statistical tests (Kolmogorov-Smirnov test, Cramér-von-Mises test, and the quantile-quantile Q-Q plot) (Buckland et al., 2001; Thomas et al., 2009). If the test results show that they are not significant, the null hypothesis of non-significant differences between what the model predicts and the data cannot be rejected. So, we can consider that the data fit the model well.

Table 1. Sampling effort and numbers of West Indian manatee (*Trichechus manatus*) detections in different zones of the study area. n = number of detections, K = number of transect lines, L = kilometers of effort traveled in transect lines, n/L = encounter rate.

Zone	n	K	L	n/L
Route I	11	366	447.1	0.025
Route II	2	325	200.6	0.009
Route III	64	705	215.9	0.296
TOTAL	**77**	**1396**	**863.6**	**0.089**

Results

A total of 1,396 transect lines were considered, totaling 863.6 km traveled in the study area (Table 1). There were 77 manatee detections, solitary or in groups, of up to seven individuals (mean = 1.8, SD = 0.12, mode = 1). The overall encounter rate observed was 0.089 group detected per kilometer (CV% = 24.08, 95% CI = 0.055 - 0.142), but the manatee encounter rate varied between sample regions (Table 1).

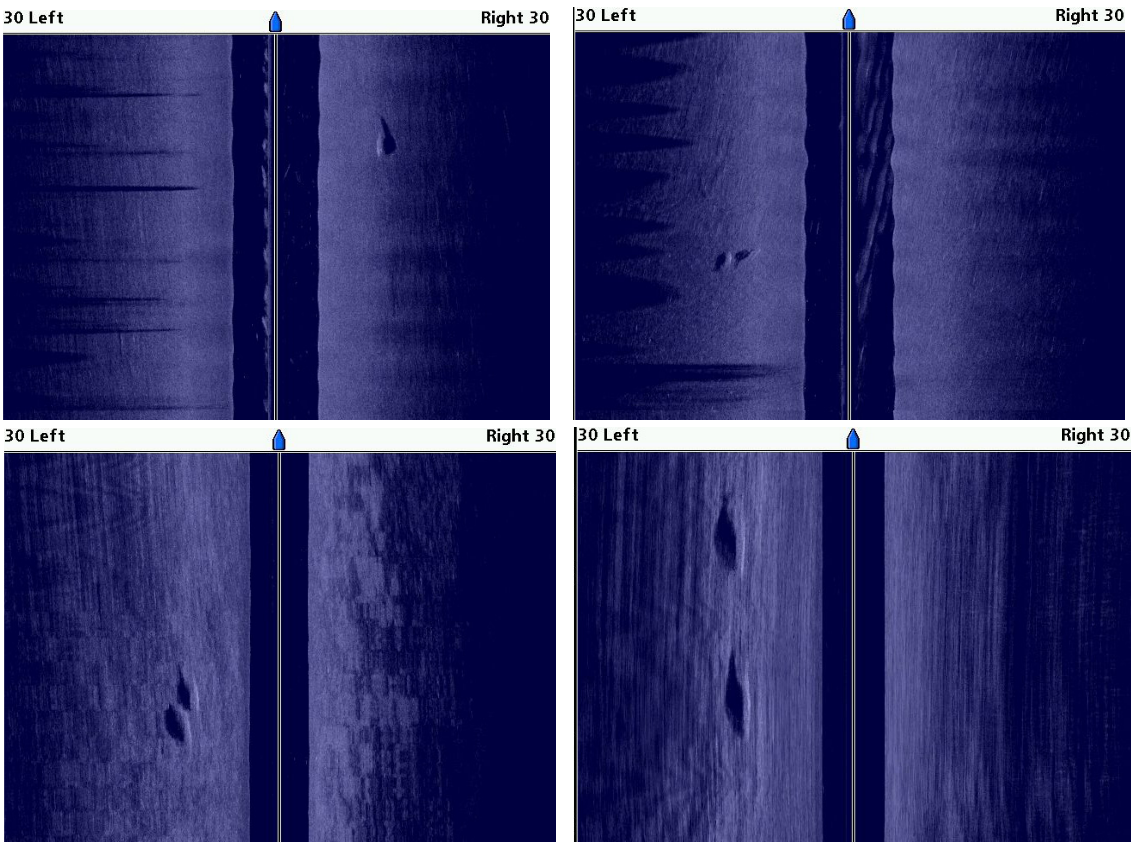

Figure 2. Images of West Indian manatees (*Trichechus manatus*) considered as detections, classified by researchers in category A (100% sure it is a manatee) in Timonha-Ubatuba Estuarine System, Northeastern Brazil.

Table 2. Detection models for manatees as a function of the distance from the transect lines. K = number of parameters.

Detection model (adjustment series)	K	AIC	Delta AIC
Hazard-rate	2	438.95	0.00
Half-normal (cosine)	2	440.53	1.58
Hazard-rate (polynomial)	2	441.07	2.12
Hazard-rate (cosine)	2	441.09	2.14
Half-normal	2	443.03	4.08
Half-normal (polynomial Hermite)	2	445.10	6.15
Uniform (cosine)	1	446.67	7.72
Uniform	1	492.59	53.64

Eight detection models were compared (Table 2). The best model, indicated by the lower AIC value, was the one described by the hazard-rate curve without any adjustment series. The half-normal curve with cosine adjustment was also a plausible model (Delta AIC < 2). As the density estimations of the two models were similar, we chose to use for inference the model that best fitted the data (hazard-rate).

Plotting the detection curve, we saw that the model fitted well to the observations (Fig. 3). As expected, the probability of detection of manatees by sonar at the transect line was 100% ($g_{(0)}$ = 1), and this probability decreased the further away from the transect line. At a distance of approximately seven meters from the transect line, the detection probability fell to 50%. The effectively sampled width was estimated at 8.27 m (SD = 1.48; CV% = 17.9) and the detection probability of groups of manatees during the study was estimated at 33.7%.

All function adjustment diagnostics of the model to the data indicated that the hazard-rate detection curve fitted well to the data. The Q-Q plot showed a satisfactory fit, as did the Kolmogorov-Smirnov test (D = 0.091, p = 0.547) and the chi-square test of goodness-of-fit (x^2 = 7.013, p = 0.724). The best detection model resulted in an estimated density for the study area of 9.19 manatees per km^2 (CV% = 30.2, 95% CI = 5.14 - 16.43). The estimated density resulted in a total abundance for the study area of 37 manatees (CV% = 30.2, 95% CI = 21 - 66). Density and abundance varied among sampled zone (Table 3). Route III (Carpina River) had the highest abundance of manatees within the study area, with 33 animals estimated. Zones Route I and II (Barra and Ubatuba River, respectively) showed the lowest abundances, of only four manatees in the two areas. Estimates of these areas were imprecise due to the high variability of encounter rates, especially the large proportion of transect lines with no detections (more than 90% for these areas).

Discussion

Here we provided the first density and abundance estimation of West Indian manatees using a side-scan sonar and distance sampling technique in Brazil. The tool associated with the method proved to be efficient to these parameters' estimation, reducing the uncertainty related to the perpendicular distance measurement.

Table 3. Density and abundance estimates of manatee (*Trichechus manatus*) in the estuarine complex of Timonha and Ubatuba rivers. N = abundance; CI = confidence interval; CV = coefficient of variation; D = density (individuals per km^2).

Zone	N	CI 95%	CV%	D	CI 95%
Route I	3	1 – 12	77.5	2.01	0.52 – 7.75
Route II	1	0 – 3	72.8	0.60	0.17 – 2.17
Route III	33	18 – 60	31.8	32.84	17.85 – 60.45
TOTAL	**37**	**21 – 66**	**30.2**	**9.19**	**5.14 – 16.43**

There are several reasons that explain the notable difference between presumptive (569) and confirmed (77) manatee detections. The Humminbird® unit that displays the probe's acoustic response has a 12.5 cm x 7.5 cm screen. This screen is small and has limited resolution unless zoom is used (Humminbird 998c SI Manual). However, using the zoom in the field is impractical, as to access it you lose the screen in real time and may miss some manatee detection while viewing the zoom. In addition to having a limited size and resolution, the glare from the sun on clear days makes it difficult to view images on the screen. Difficulties in detecting manatees in the field using sonar included swell (only works in estuarine environments with low ripple), limited display time (10 seconds) and resolution, small screen size, sun brightness, and the observer's perception due to fatigue (too much time in the sun, with head down looking at a screen). Given these issues with manatee detection during sonar field research, the ability to analyze and evaluate image recordings using an image viewer and editor was essential. On the computer, with an image editor it is possible to view images with higher resolution and details on a much larger screen and without sun reflection, allowing a slow and detailed review, in addition to being possible for other experienced people to evaluate the images. In the field, sun glare was minimized by using dark cloths, forming a covering on the sonar screen. Finally, regarding the observer's perception due to fatigue, two technicians took turns viewing the sonar images every hour.

The detection probability of groups of manatees during the study was estimated at 33.7%, which can be considered

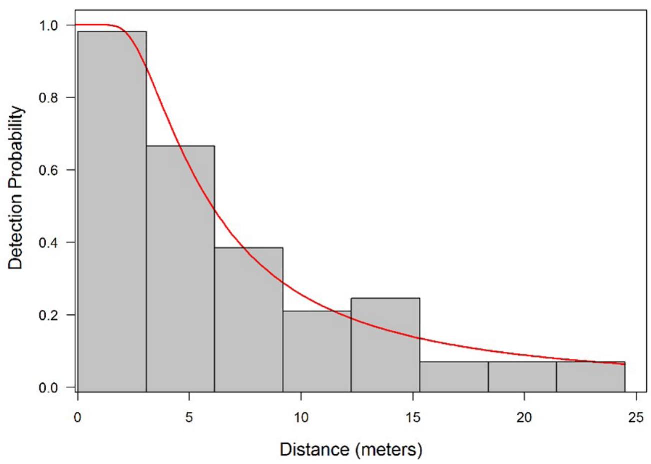

Figure 3. Detection curve of West Indian manatees (*Trichechus manatus*) in the Timonha-Ubatuba Estuarine System, Northeastern Brazil, given by the hazard-rate model (red line). The columns show the relative frequency of manatee detections in the study.

reasonable, since it is a shy species that has a patchy distribution in the study area. The low density of manatees in Routes I and II, and consequently the low detection probability, influenced the detection probability for the whole study area, pulling it down. We found no information about the detection probability of West Indian manatees using side-scan sonar. However, aerial survey studies in relatively clear waters reported detection probability higher than 50% [*e.g.,* Potiguar Basin, Brazil (Petrobras, 2014); Tampa Bay, USA (Edwards et al., 2007)]. In dark waters, Souza et al. (2021) reported an Amazonian manatee (*T. inunguis*) detection probability of 50% combining boat surveys and indirect evidence of presence (feeding trails, feces presence, and manatee sound emissions); and Narváez Ruano et al. (2021) reported similar values using side-scan sonar to detect Amazonian manatee.

Based on the ideal value for the coefficient of variation of less than 20% (Hines et al., 2005; Marsh et al., 2005), the value of 30.2% suggests a moderate level of uncertainty in the abundance estimation of the manatee in this study. However, above-ideal values are commonly recorded in aerial surveys for estimates of sirenians, mainly related to studies in turbid water habitats, such as Chetumal Bay, Mexico, with 21 to 70.3% (Morales-Vela et al., 2000) and 34.4 to 65.5% (Olivera-Gómez & Mellink, 2002); Andaman region, Thailand, with 33.4% (Hines et al., 2005); Puerto Rico with 55.8% (Powell et al., 1981); and Ceará and Rio Grande do Norte, Brazil, with 35% (Petrobras, 2014). Thus, the coefficient of variation obtained in the present study is within that observed for manatees and dugongs in other areas.

There were no previous density and abundance estimates for the study area, making these results the first of this kind for the region, emphasizing the importance of the information. According to Olivera-Gómez and Mellink (2005) and Lima et al. (2011), estuaries are environments highly favorable to the occurrence of the species, for feeding, reproduction, and resting. The estuarine complex of the Timonha/Ubatuba rivers, and the adjacent coastal zone, is considered an important region for the species, with seagrass beds, freshwater sources, and adequate places for parental care (Choi et al., 2009; Favero et al., 2020). Therefore, the high density of this species found in the study area may be directly related to the environmental characteristics of the estuary with areas preserved by the Marine Protected Area APA Delta do Parnaíba.

Densities reported in other regions ranged from 0.075 to 0.240 individual/km^2 (Preen et al., 1997). In Australia, high densities of dugongs (7.25 individuals/km^2) were recorded in specific feeding areas, with several individuals sharing limited space (Lanyon, 2003). The density of manatees found by Alves et al. (2015) was 0.05 individual/km^2 in Brazil, being higher in the state of Piauí (0.02 individual/km^2). Using side-scan sonar, reported densities range from 0.23 animal/km^2 in Alvarado Lagoon System, Mexico (Serrano et al., 2017); 6.13 animals/km^2 in the San San Pond Sak wetland, Panamá (Guzman et al., 2017); to 21.7 manatees per km^2 in the San Pedro River system, Mexico (Puc-Carrasco et al., 2017). Most of the estimated densities, were lower than that estimated in the present study of 9.19 manatees/km^2. However, Alves et al. (2015) performed only one aerial survey and focused the sampling effort in a large area, making it difficult to compare the studies.

The results obtained here correspond to a minimum abundance estimate which highlights the conservative nature of the information, and which may represent a baseline for future studies of the distribution and population trends of the species (Ackerman, 1995; Lefebvre et al., 1995; Miller et al., 1998; Olivera-Gómez & Mellink, 2002; Katsanevakis et al., 2012). The data highlight the need for more efforts in the same area sampled, if possible, on a larger geographic scale. Additionally, it is useful for the evaluation of the regional population status of the West Indian manatee in an area with increasing threats.

The occurrence of the species in the study area reinforces the importance of protected marine areas for the conservation of the West Indian manatee, since in these areas the important ecological aspects of the species can be preserved. This information is also important to discuss conservation strategies, such as the creation of other marine protected areas in the region or even the zoning of the existing marine protected area (Delta do Parnaíba).

As the APA Delta do Parnaíba is already a Sustainable Use Protected Area, it is important to establish zoning compatible with the protection of the manatee in places of greatest occurrence, such as the Carpina River (Route III), in addition to creating rules and agreements to avoid impacts on animals, especially during periods when they are present in the estuary. We suggest that the planning of use in the region be provided for in the Management Plan of the APA Delta do Parnaíba, with the objective of protecting areas of intensive use by manatees and that have the necessary niches for the occurrence and maintenance of the species, restricting the use by motorized vessels that can lead to animals being run over and driven away.

Acknowledgments

This research (authorized by ICMBio, under SISBIO license number 14104-3) was conducted by AQUASIS and LABOMAR – UFC, and was sponsored by Fundação Grupo Boticário de Proteção à Natureza (0943_20121), Rufford Small Grants for Nature Conservation (RSG 12411-2), and Idea Wild. KFCL was granted a Fundação Cearense de Apoio a Pesquisa (Funcap) PhD scholarship. Important cooperation has been established with the APA Delta do Parnaíba/ICMBio, Comissão Ilha Ativa (CIA), Instituto de Desenvolvimento Sustentável Mamirauá (IDSM), and Serviço Social do Comércio - SESC/CE.

References

Ackerman, B. B. (1995). Aerial surveys of manatees: a summary and progress report. In T. J. O'Shea, B. B. Ackerman & H. F. Percival (Eds.), *Population biology of the Florida manatee* (pp. 223-258). National Biological Service, Information and Technical Report 1.

Alves, M. D. O., Kinas, P. G., Marmontel, M., Borges, J. C. G., Costa, A. F., Schiel, N., & Araújo, M. E. (2015). 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

Aquasis (2008). *Refúgio de Vida Silvestre Peixe-Boi-Marinho: estudos socioambientais complementares e consolidação da proposta de criação de Unidade de Conservação.* Relatório técnico final do projeto "Refúgio de Vida Silvestre Peixe-boi-marinho" - SOS Mata Atlântica/Fundação Avina/ FMA.

Arévalo-González, G. K., Castelblanco-Martínez, D. N., Sanchez-Palomino, P., López-Arévalo, H. F., & Marmontel, M. (2014) Complementary methods to estimate population size of Antillean manatees (Sirenia:Trichechidae) at Ciénagas de Paredes, Santander, Colombia. *Journal of Threatened Taxa, 6*(6), 5830–5837. https://doi.org/10.11609/JoTT.o3156.5830-7

Bauduin, S., Martin, J., Edwards, H. H., Gimenez, O., Koslovsky, S. M., & Fagan, D. E. (2013). An index of risk of cooccurrence between marine mammals and watercraft: Example of the Florida manatee. *Biological Conservation, 159*, 127–136. https://doi.org/10.1016/j.biocon.2012.10.031

Brice, C. E. (2014). *The detection of Amazonian manatees (*Trichechus inunguis*) using side-scan sonar and the effect of oil activities on their habitats in eastern Ecuador* [Master's thesis, Nova Southeastern University]. NSUWorks. https://nsuworks.nova.edu/occ_stuetd/8/

Buckland, T., Anderson, D. R., Burnham, K. P., & Laake, J. L. (2008). *Advanced Distance Sampling: Estimating Abundance of Biological Populations.* Oxford University Press.

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L., & Thomas, L. (2001). *Introduction to distance sampling: estimating abundance of biological populations.* Oxford University Press.

Burnham, K. P., & Anderson, D. R. (2002) *Model Selection and Inference: A Practical Information-Theoretic Approach* (2nd ed.), Springer-Verlag. https://doi.org/10.1007/b97636

Castelblanco-Martínez, N., & Arévalo-González, K. (2015). *Status of manatee research in Colombia during the last 25 years: a review* [Paper presentation]. Seventh International Sirenian Symposium, San Francisco, CA.

Castro, J. M., Rivera, M., & Camacho, A. (2016). Automatic manatee count using passive acoustics. *Proceedings of Meetings on Acoustics, 23*(1), 010001. https://doi.org/10.1121/2.0000148

Choi, K. F., Campos, T. M., Meirelles, A. C. O., Campos, A. A., & Fernandes, M. B. (2009). Desenho da área de um refúgio de vida silvestre para a conservação do peixe-boi-marinho. *Natureza & Conservação, 7*(2), 82–89.

Choi-Lima, K. F. (2017). *Estimativa de abundância e impactos antrópicos sobre o peixe-boi marinho (*Trichechus manatus*) no estuário dos Rios Timonha e Ubatuba, divisa dos estados do CE e PI*. [Doctoral dissertation, Universidade Federal do Ceara].

Edwards, H. H., Pollock, K. H., Ackerman, B. B., Reynolds, J. E., & Powell, J. A. (2007). Estimation of detection probability in manatee aerial surveys at a winter aggregation site. *Journal of Wildlife Management, 71*, 2052–2060. https://doi.org/10.2193/2005-645

Factheu, C., Rycyk, A. M., Kekeunou, S., Keith-Diagne, L. W., Ramos, E. A., Kikuchi, M., & Takoukam Kamla, A. (2023). Acoustic methods improve the detection of the endangered African manatee. *Frontiers in Marine Science, 9*, 1032464. https://doi.org/10.3389/fmars.2022.1032464

Favero, I. T., Favero, G. E., Choi-Lima, K. F., dos Santos, H. F., Souza-Alves, J. P., de Souza e Silva, J., & Feitosa, J. L. L. (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

Gonzalez-Socoloske, D., & Olivera-Gómez, L. D. (2023). Seeing in the dark: A review of the use of side-scan sonar to detect and study manatees, with an emphasis on Latin America. *Latin American Journal of Aquatic Mammals, 18*(1), 114–124. https://doi.org/10.5597/lajam00301

Gonzalez-Socoloske, D., & Olivera-Gómez, L. D. (2012). Gentle giants in dark waters: Using side-scan sonar for manatee research. *Open Remote Sensing Journal, 5*, 1–14. https://doi.org/10.2174/1875413901205010001

Gonzalez-Socoloske, D., Olivera-Gómez, L. D., & Ford, R. E. (2009). Detection of free ranging West Indian manatees *Trichechus manatus* using side-scan sonar. *Endangered Species Research, 8*, 249–257. https://doi.org/10.3354/esr00232

Guzman, H. M., & Condit, R. (2017). Abundance of manatees in Panama estimated from side-scan sonar. *Wildlife Society Bulletin, 41*(3), 556–565. https://doi.org/10.1002/wsb.793

Hines, E. M., Ulyanukosol, K., & Duffus, D. A. (2005). Dugong (*Dugong dugon*) abundance along the Andaman coast of Thailand. *Marine Mammal Science, 21*(3), 536–549. https://doi.org/10.1111/j.1748-7692.2005.tb01247.x

Katsanevakis, S., Weber, A., Pipitone, C., Leopold, M., Cronin, M., Scheidat, M., Doyle, T. K., Buhl-Mortensen, L., Buhl-Mortensen, P., D'anna, G., De Boois, I., Dalpadado, P., Damalas, D., Fiorentino, F., Garofalo, G., Giacalone, V. M., Hawley, K. L., Issaris, Y., Jansen, J., . . . Vöge, S. (2012). Monitoring marine populations and communities: methods dealing with imperfect detectability. *Aquatic Biology, 16*, 31–52. https://doi.org/10.3354/ab00426

Lanyon, J. M. (2003). Distribution and abundance of dugongs in Moreton Bay, Queensland, Australia. *Wildlife Research, 30*, 397–409. https://doi.org/10.1071/WR98082

Lefebvre, L. W., Ackerman, B. B., Portier, K. M., & Pollock, K. H. (1995). Aerial survey as a technique for estimating trends in manatee population size – problems and prospects. In T. J. O'Shea, B. B. Ackerman & H. F. Percival (Eds.), *Population Biology of the Florida Manatee* (pp. 63–74.). National Biological Service Information and Technology Report 1.

Lima, R. P., Paludo, D., Soavinski, R. J., Silva, K. G., & Oliveira, E. M. A. (2011). Levantamento da distribuição, ocorrência e status de conservação do peixe-boi marinho (*Trichechus manatus*, Linnaeus, 1758) no litoral nordeste do Brasil. *Natural Resources, 1*, 41–57. https://doi.org/10.6008/ESS2237-9290.2011.002.0006

Luna, F. O., Lima, R. P., Araújo, J. P., & Passavante, J. Z. O. (2008). Status de conservação do peixe-boi-marinho (*Trichechus manatus manatus* Linnaeus, 1758) no Brasil. *Revista Brasileira de Zoociências, 10*, 145–153.

Marsh, H., Ath, G., Gribble, N., & Lane, B. (2005). Historical marine population estimates: triggers or targets for conservation? The dugong case study. *Ecological Applications, 15*, 481–492. https://doi.org/10.1890/04-0673

Martin, J., Edwards, H. H., Burgess, M. A., Percival, H. F., Fagan, D. E., Gardner, B. E., Ortega-Ortiz, J. G., Ifju, P. G., Evers, B. S., & Rambo, T. J. (2012). Estimating distribution of hidden objects with drones: from tennis balls to manatees. *PloS One, 7*, e38882. https://doi.org/10.1371/journal.pone.0038882

Miller, K. E., Ackerman, B. B., Lefebvre, L. W., & Clifton, K. B. (1998). An evaluation of strip transect aerial survey methods for monitoring manatee populations in Florida. *Wildlife Society Bulletin, 26,* 561–570. https://www.jstor.org/stable/3783769

Morales-Vela, B., Olivera-Goméz, D., Reynolds, J. E., & Rathbun, G. B. (2000). Distribution and habitat use by manatees (*Trichechus manatus manatus*) in Belize and Chetumal Bay, Mexico. *Biological Conservation, 95*, 67–75. https://doi.org/10.1016/S0006-3207(00)00009-4

Olivera-Gómez, L. D., & Mellink, E. (2002). Spatial and temporal variation in counts of the Antillean manatee (*Trichechus manatus manatus*) during distribution surveys at Bahia de Chetumal, Mexico. *Aquatic Mammals, 28*(3), 285–293.

Olivera-Gómez, L. D., & Mellink, E. (2005). Distribution of the Antillean manatee (*Trichechus manatus manatus*) as a function of habitat characteristics, in Bahia de Chetumal, Mexico. *Biological Conservation, 121*(1), 127–133. https://doi.org/10.1016/j.biocon.2004.02.023

Petrobras (2014). *Subprojeto de monitoramento de Sirênios: Monitoramento remoto por telemetria satelital e censo populacional por meio de sobrevôo.* Relatórios dos Programas e Projetos Ambientais.

Pollock, K., Marsh, H., Lawler, I. R., & Alldredge, M. W. (2006). Estimating animal abundance in heterogenous environments: an application to aerial surveys for dugongs. *Journal of Wildlife Management, 70*, 255–262. https://doi.org/10.2193/0022-541X(2006)70[255:EAAIHE]2.0.CO;2

Powell, J. A., Belitsky, D. W., & Rathbun, G. B. (1981). Status of West Indian manatee (*Trichechus manatus*) in Puerto Rico. *Journal of Mammalogy, 62*, 642–646. https://doi.org/10.2307/1380417

Preen, A. R., Marsh, H., Lawler, I. R., Prince, R. I. T., & Shepherd, R. (1997). Distribution and abundance of dugongs, turtles, dolphins and other megafauna in Shark Bay, Ningaloo Reef and Exmouth Gulf, Western Australia. *Wildlife Research, 24,* 185–208. https://doi.org/10.1071/WR95078

Puc-Carrasco, G., Morales-Vela, B., Olivera-Gómez, L. D., & González-Solís, D. (2017). First field-based estimate of Antillean manatee abundance in the San Pedro River system suggests large errors in current estimates for Mexico. *Ciencias Marinas, 43*(4), 285–299. https://doi.org/10.7773/cm.v43i4.2704

Reynolds III, J. E., Morales-Vela, B., Lawler, I., & Edwards, H. (2012). Utility and design of aerial surveys for sirenians. In E. Hines, J. E. Reynolds III, A. A. Mignucci-Giannoni, L. V. Aragones & M. Marmontel (Eds.), *Sirenian Conservation: Issues and Strategies in Developing Countries* (pp. 186-195). University Press of Florida. https://doi.org/10.2307/j.ctvx079z0

Narváez Ruano, V., Utreras B., V., & Zapata-Ríos, G. (2021). Occupancy and population density estimates of the Amazonian manatee in eastern Ecuador. *Endangered Species Research, 44*, 105–112. https://doi.org/10.3354/esr01094

Self-Sullivan, C., & Mignucci-Giannoni, A. A. (2008). *Trichechus manatus* spp. *manatus. IUCN Red List of Threatened Species 2008*, e.T22105A9359161. https://doi.org/10.2305/IUCN.UK.2008.RLTS.T22105A9359161.en

Serrano, A., Daniel-Rentería, I. D. C., Hernández-Cabrera, T., Sánchez-Rojas, G., Cuervo-López, L., & Basáñez-Muñoz, A. (2017). Is the West Indian manatee (*Trichechus manatus*) at the brink of extinction in the State of Veracruz, Mexico? *Aquatic Mammals, 43*(2), 201–207. https://doi.org/10.1578/AM.43.2.2017.201

Sousa-Lima, R. S., Paglia, A. P., & da Fonseca, G. A. B. (2008). Gender, age and identity in isolation calls of Antillean manatees (*Trichechus manatus manatus*). *Aquatic Mammals, 34*(1), 109–122. https://doi.org/10.1578/AM.34.1.2008.109

Souza, D. A., Gonçalves, A. L. S., Von Muhlen, E. M., & da Silva, V. M. F. (2021). Estimating occupancy and detection probability of the Amazonian manatee (*Trichechus inunguis*), in Central Amazon, Brazil. *Perspectives in Ecology and Conservation. 19*(3), 354–361. https://doi.org/10.1016/j.pecon.2021.03.009

Thomas, L., Buckland, S. T., Burnham, K. P., Anderson, D. R., Laake, J. L., Borchers, D. L., & Strindberg, S. (2002). Distance Sampling. In A. H. El-Shaarawi & W. W. Piegorsch (Eds.), *Encyclopedia of Environmetrics* (Vol. 1, pp. 544–552). John Wiley & Sons, Ltd.

Thomas, L., Laake, J. L., Rexstad, E., Strindberg, S., Marques, F. F. C., Buckland, S. T., Borchers, D. L., Anderson, D. R., Burnham, K. P., Burt, M. L., Hedley, S. L., Pollard, J. H., Bishop, J. R. B., & Marques, T. A. (2009). *Distance 6.0. Release 2*. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. https://distancesampling.org/

Thompson, W. (2009). Toward reliable bird surveys: accounting for individuals present but not detected. *Auk, 119*(1), 18–25. https://doi.org/10.1093/auk/119.1.18