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Where there's smoke, there's fire: Hypotheses for the high incidence of West Indian manatee calf strandings on the Brazilian semi-arid coast

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The West Indian manatee is a threatened species, classified as 'Vulnerable' by the International Union for the Conservation of Nature's (IUCN) Red List of Threatened Species (Deutsch et al., 2008). In Brazil, the species faced intensive hunting in the past (Domning, 1982) and, presently, it is intentionally captured for human consumption and medicinal purposes (Barbosa, 2013; Luna et al., 2018). Additionally, various human activities negatively impact manatees in the country, including habitat loss, incidental capture in fishing nets, collision with boats, and pollution (see Meirelles et al., 2022 for a review).

In northeastern Brazil, an unusually high incidence of calf strandings has been documented since the 1990's, particularly along a 400 km stretch between the states of Ceará and Rio Grande do Norte (Potiguar Basin), situated within a region known as the semi-arid coast (Parente et al., 2004; Meirelles, 2008; Silva, 2010; Balensiefer et al., 2017). Distinguished by its arid coastline, the semi-arid region harbors semi-deciduous forests, savannas, grasslands, and smaller mangrove systems linked to the shallow-water estuaries (Moro et al., 2015, 2016). This stretch of the coast is nearly straight and experiences significant wave energy. Its defining features include sandy beaches, sand dunes, and sandstone cliffs (Schaeffer-Novelli et al., 1990). In this region, most river systems are temporary, featuring hypersaline mangroves and meadows known as "apicuns" (Soares et al., 2021). Thus, mangroves are underdeveloped along this coastline due to insufficient freshwater runoff and extended periods of drought (Schaeffer-Novelli et al., 1990). An interesting characteristic of this region is the presence of submarine groundwater discharges in coastal waters (Meireles & dos Santos, 2012), where manatees go to drink freshwater (Alves, 2007)

In this region, 84% of stranded manatees are calves, especially newborns, resulting in an 'inverted J-shape' age-specific mortality curve [Fig. 1, with data from Meirelles (2008), Silva (2010), Lima (2019), SIMBA (2021), SIMMAM (Cabral & Barreto, 2022), and Aquasis (unpublished)], while in the state of Paraíba, for example, 50% of stranded manatees were calves (Parente et al., 2004). Before 2013, manatee calves stranded on the semi-arid coast were sent to a rehabilitation facility in the state of Pernambuco

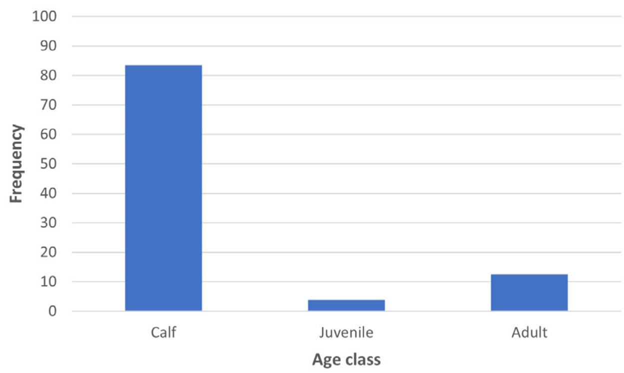

Figure 1. Frequency distribution of West Indian manatee (*Trichechus manatus*) stranding records in the semi-arid coast of Brazil, from 1991 to 2023, for each age class.

Keywords:
Brazil, mortality, newborn, Sirenia, threats *Trichechus manatus*

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(Balensiefer et al., 2017), 1,000 km away, and released back into the wild in the waters of the states of Alagoas and Paraíba (Normande et al., 2015). After 2013, rescued manatees in this region have been rehabilitated in the Marine Mammal Rehabilitation Center (CRMM/Aquasis), in Iparana, state of Ceará, and in the Marine Animal Rehabilitation Center (UERN), in Areia Branca, state of Rio Grande do Norte. Only in 2021 these animals started being released in their site of origin (Viana-Junior et al., 2022).

The pattern of mortality with age in long-lived mammals is commonly characterized by a high rate in the juvenile phase, followed by a low mortality rate in the post-juvenile phase, which then increases with age at a nearly constant rate (Caughley, 1966; Spinage, 1972; Siler, 1979). This 'U-shape' mortality pattern has been reported for marine mammals, including bottlenose dolphins, *Tursiops truncatus* (*e.g.*, Stolen & Barlow, 2003), and West Indian manatees (*e.g.*, Mignucci-Giannoni et al., 2000; Galves et al., 2023).

However, other studies with sirenians reported distinct results. In Florida, a higher mortality rate was observed in subadult manatees (41%) compared to calves (27%) and adults (33%) (Ackerman et al., 1995). This suggests that distinct human-related mortality causes can result in different mortality curves. Moreover, a recent summary revealed that in 2021, 10% of dead manatees rescued in that state were attributed to perinatal causes (Florida Fish and Wildlife Conservation Commission, 2021). Along Johor and Singapore Straits, a highly urbanized coastal area, a high incidence of dugong (*Dugong dugon*) calf strandings (45%) was also reported, potentially caused by habitat destruction (Ng et al., 2022). Similarly, an unexplained increase in dugong calf strandings has been observed in many parts of Southeast Asia and the Arabian Gulf (Ponnampalam et al., 2022).

Understanding the reasons behind the high incidence of newborn manatee strandings in the study region is crucial for formulating conservation actions to this nationally 'Critically Endangered' marine mammal (Meirelles et al., 2022). Thus, here we discuss some hypotheses that can explain this unusual high incidence, along with future steps and recommendations.

Numerous publications in Brazil consistently attribute calf strandings in the semi-arid coast to habitat loss. This hypothesis was first proposed by Lima (1997), who suggested that pregnant females no longer venture into the calm waters of estuaries for birthing. The avoidance would be primarily because these areas have become excessively shallow due to siltation resulting from mangrove deforestation. The pregnant females' inability to access estuaries, leading to an increased use of coastal areas, could potentially result in more calf strandings. This is because the strong coastal currents and occasional swell waves (Claudino-Sales et al., 2018) could separate mother-calf pairs (Lima, 1997). Notably, several calves rescued in the study area stranded near the Jaguaribe River mouth, an area dominated by wave action and high energy levels (De Paula et al., 2009). In one instance, an adult manatee was observed close to the stranding location, an area where manatees are not commonly sighted. Following a careful evaluation, the calf was released back into the water near the adult, leading to their reunion and movement towards the east (Choi et al., 2009; Carvalho & Borges, 2016).

A Traditional Ecological Knowledge study conducted in the area confirmed the historical use of estuaries by manatees but revealed a contemporary absence of this use (Choi et al., 2017). Furthermore, an independent study involving the capture, marking, and release of five wild manatees within the region reported a similar pattern: these manatees have not entered estuaries (Petrobras, 2014), thereby strengthening the hypothesis that manatees are likely exclusively found in coastal marine waters within this region.

While mangrove forests in other estuaries of northeastern Brazil where manatees occur have also been deforested, the incidence of calf stranding in other areas is different from the one observed in the semi-arid coast (Parente et al., 2004). This higher frequency can be explained by the fact that on the semi-arid coast most of the rivers are temporary and were dammed, generating sediment deposition in the riverbed and mouth, resulting in semi-enclosed estuaries (Morais & Pinheiro, 2011).

Additionally, the removal of mangroves, particularly for the establishment of salt and shrimp farms (Queiroz et al., 2013; Ferreira & Lacerda, 2016), has accelerated the sedimentation in the estuaries. This siltation was amplified by diminished river flow stemming from damming and reduced rainfall. Consequently, there has been an expansion in the area of estuarine islands (Godoy & Lacerda, 2014), leading to the loss of habitat for manatees. Although siltation processes can also be observed in other rivers in northeastern Brazil (*e.g.,* Medeiros et al., 2021), it is not as pronounced as on the semi-arid coast (Soares et al., 2021). Thus, data on manatee historical and current presence in estuaries of the region, added to mangrove deforestation and estuary siltation, support the hypothesis of habitat loss and degradation as explanation for the high incidence of calf strandings in the study region.

With habitat fragmentation, manatees probably have to explore new areas to find suitable habitats (Castelblanco-Martínez et al. 2013). As the social transmission of knowledge (vertical and horizontal) plays an important role in manatee learning skills (Henaut et al., 2022), it is importantly related to the animals' ability of finding adequate places to forage, drink freshwater and calving, and consequently influencing their home range. This adaptability becomes particularly challenging for these animals when faced with changing environments. While there is evidence of philopatry in West Indian manatees (Deutsch et al., 2003, 2022; O'Shea et al., 2022), indicating a tendency to persist in or return to the areas they inhabited as dependent calves, the need to explore beyond their home range for new suitable habitats implies that they are likely to navigate based on environmental cues. This navigation probably continues until they encounter unfavorable environmental features or discover suitable areas (Flamm et al., 2005). Thus, we believe that it is plausible to believe that in the study area, due to the changing environment and habitat loss, some of the females in labour still do not know new proper areas to give birth. In their attempts to locate these areas, they may be unsuccessful, ultimately giving birth in unsuitable regions, potentially leading to calf stranding.

Systematically monitoring this manatee population, especially through boat surveys, can help to identify calving areas and environmental characteristics related to calving and nursing success. Unfortunately, reversing habitat loss for manatees in this region poses a significant challenge. To restore these estuaries, it would be essential to reforest mangroves, removing all villages, summer houses, and shrimp and salt farms that were built in areas formerly occupied by these forests. Additionally, removing dams from the rivers would be crucial to reestablish proper freshwater discharge into the estuaries, reducing sediment deposition in river mouths.

Another plausible explanation for the high calf stranding incidence on the semi-arid coast is the density-dependent change of vital rates in response to the low manatee density observed in the study area, which is only 0.03 individual/ km^2 (Petrobras, 2014). Predictions from life-history theory indicate that in reduced mammal populations below the carrying capacity, a decrease in the mean age at first birth is expected (see Fowler, 1987 for a review), *i.e.,* the recruitment of young females that lack experience in mothering.

Although there is no published information on manatees regarding this matter, typically, for mammals, young primiparous females have a reduced probability of successfully raising their offspring because they must allocate resources between growth and reproduction (Schino & Troisi, 2005; Zedrosser et al., 2009). In Antarctic fur seals (*Arctocephalus gazella*), for example, it was reported that young primiparous females were less likely to be observed in subsequent years than older ones, indicating a potential cost, in terms of survival, for those seals that give birth for the first time at a premature age (Lunn et al., 1994). Additionally, in Northern elephant seals (*Mirounga angustirostris*), it was observed that young females lose more weight after birth than older ones, and that these females' pups gain less mass than those of older females (Deutsch et al., 1994).

The recruitment of young nulliparous females has also been hypothesized as one of the causes of the high manatee perinatal death rate in Florida, as these inexperienced females might abandon their calves (Bossart, 1999). To investigate this hypothesis, we recommend the investigation of the mean age at first birth (AFB) of this population. Age estimation can be obtained by counting annual growth layer groups in the tympanoperiotic complex of their earbones (Marmontel et al., 1996), along with assessing the reproductive tracts of dead animals. Additionally, comparing the obtained AFB with information from other populations, preferably in higher densities, would provide valuable insights. Reducing the species mortality and protecting its habitat in the study area, especially seagrass meadows and freshwater springs, might allow the population to grow and increase the AFB in the future.

An additional potential explanation for the observed high newborn stranding rate is a high level of inbreeding in this population. It is known that the manatee population in Brazil, between the states of Ceará and Alagoas, has a low genetic diversity (Garcia-Rodriguez et al., 1998; Vianna et al., 2006; Luna et al., 2012). This can be explained by the intensive hunting of manatees in the region, resulting in a small population and a

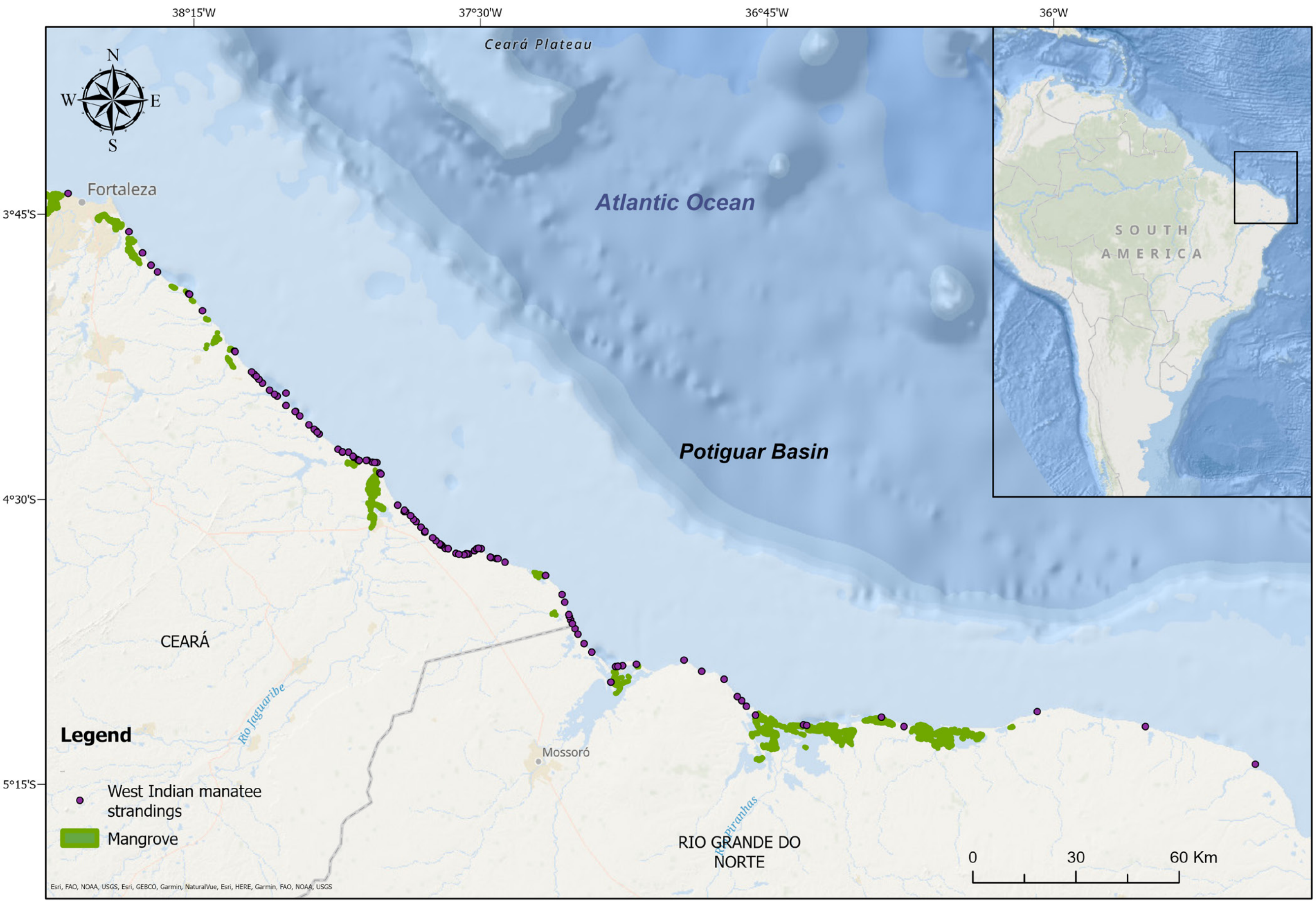

Figure 2. West Indian manatee (*Trichechus manatus*) strandings in the study area (according to Parente et al. (2004), Meirelles (2008), Lima (2019), SIMBA (2021), and SIMMAM (Cabral & Barreto, 2022)).

Figure 3. Stranded newborn manatees (*Trichechus manatus*) in the Praia das Agulhas beach, Fortim. Photo: Aquasis

bottleneck effect, or a founder-effect (Garcia-Rodriguez et al., 1998). Nevertheless, populations that have undergone one of these processes are expected to present high intra-populational relatedness (Hunter et al., 2010). In fact, evidence of inbreeding in the manatee population inhabiting the study area was already reported (Moreira et al., 2022). Additionally, samples from 37 manatees stranded in the study area indicated that 34% of the pairs had some level of genetic kinship (Moreira, 2015). Moreover, several animals stranded in the study area but in rehabilitation or permanent captivity in the Aquatic Mammal Center (CMA), state of Pernambuco, were reported to be related, including a pair of full siblings (Luna, 2012).

It is well known that, in mammals, inbreeding can affect reproductive success (Margulis, 1996, 1998), leading to reduced fertility, smaller litters, lower newborn weight, and diminished survival (*e.g.,* Greenwood, et al. 1978; Ralls & Ballou, 1982; Ralls et al., 1988; Keane, 1990; Coltman et al., 1998; Ryan et al., 2003). However, it is not entirely clear whether the high calf mortality in these studied populations was caused by the lack of maternal care, the low health conditions of the newborns, or a combination of both. In Brazil, Luna (2012) reported relatedness between almost all captive manatees in CMA, including a hybrid between a West Indian and an Amazonian manatee, both wild rescued animals, and manatees born in captivity. Fifty percent of the manatees born at this facility were stillborn or died shortly after birth, potentially due to the observed high degree of inbreeding, as discussed by Luna (2012).

While in the study area most of the calves stranded in apparent good health condition (Fig. 2), two manatee calves with cerebral and cardiac congenital malformations were recorded in this region (Carvalho et al., 2019). Additionally, two other animals exhibited disorders of the locomotor system, such as spinal fusion in the lumbar region, permanent folding of the caudal fin and scapular-humeral arthropathy (Carvalho & Silva, 2016; Meirelles et al., 2018). Thus, genetic evidence and malformation in some stranded calves support the inbreeding hypothesis as one of the potential causes for the high calf stranding incidence in the study area.

The translocation of manatees from other areas within the same Evolutionary Significant Management Unit (ESU) (Lima et al., 2021) might help to reduce inbreeding in this population (Vergeer et al., 2008). Nevertheless, it seems crucial to further investigate the inbreeding level in this population and how it affects the health of newborn and subsequent stranding events.

Although we lack support for the following hypothesis, we believe it is worth mentioning it, to guide future research on the theme in the study area. For several mammals, populations under nutritional stress triggered by food limitation often experience unusually high calf mortality (Lee & Moss, 1986; Trillmich & Dellinger, 1991; Ward et al., 2009). Additionally, when resources are limited, females may choose to abandon their pups in favour of their own survival, as nursing and maternal care involves a high energetic investment (DeLong & Antonelis, 1991; Soto, 2004; Davis, 2014).

Considering this, we believe that it would be important to investigate the carrying capacity of the area for West Indian manatees and how the availability of food items changes seasonally, especially because manatees are specialist feeders in the study area, consuming almost exclusively shoal grass, *Halodule wrightii* (Ciotti, 2012; Vasconcelos, 2013; Carvalho, 2019). Seagrass meadows in the study region are probably being negatively impacted by several human actions, such as bottom shrimp trawling (Santos et al., 2006), the illegal placement of hundreds of thousands of artificial reefs made of toxic metal barrels (*marambaias*) to capture lobsters (Brasil, 2013), and oil spills (Magalhães et al., 2021). Additionally, fluctuation in seagrass biomass associated with climate events can also be causing seasonal nutritional stress in pregnant females, resulting in high calf mortality, as reported for dugongs by Marsh et al. (2018).

Investigating seagrass biomass in the region and human and environmental factors related to meadows loss would help to clarify this hypothesis as a possible cause of the observed high calf stranding incidence. Additionally, assessing the body condition of manatees using drone based photogrammetry (Ramos et al., 2022) would be valuable to identify the population health status. Moreover, protected seagrass meadows in the study area, by monitoring and preventing regulated activities such as bottom trawling and artificial reefs placement, would help this manatee population to thrive.

Last but certainly not least, calves can be stranding because human activities are killing their mothers or separating the mother-calf pair. While strandings of adult manatees in the study area are uncommon, there have been at least four adult females accidentally captured in shrimp trawling nets and gillnets in the region (Meirelles, 2008; Silva, 2010). Additionally, one lactating female died following a boat collision in the region during a regatta race. Although some of the carcasses were not necropsied, evidence of recent labour and lactation was found only in the last case. Even though the available data do not strongly support this hypothesis, continuous efforts to identify manatee death cause in the region are necessary. With increasing human activity, certain impacts may escalate, such as boat collisions and accidental captures, while others may emerge, like the construction and operation of offshore wind farms (Hernandez et al., 2021).

Overall, there are several potential causes for the high incidence of manatee calf strandings on the Brazilian semi-arid coast that can be acting simultaneously and synergistically. While most calves strand alive, and are subsequently rescued, rehabilitated, and released back into their original habitats (Carvalho & Borges, 2016; Choi-Lima et al., 2022), this process is lengthy and costly. Investigating the causes of these strandings and finding ways to reduce non-natural causes should be considered a priority action for the species conservation in northeastern Brazil. This would enable more efforts to be dedicated to *in situ* conservation. Additionally, awareness efforts to reduce and mitigate the impact of strandings should continue (Meirelles, 2016; Meirelles et al., 2016), involving local communities and stakeholders.

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