Occurrence of cetacean strandings on the coast of São Paulo, Brazil: a spatio-temporal assessment from 2017 to 2021

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Abstract

This study is part of the Projeto de Monitoramento de Praia–Bacia de Santos - (PMP-BS, Santos Basin Beach Monitoring Project) and is based on data from stranded cetaceans collected during beach monitoring in the state of São Paulo, between 2017 and 2021. Our aim was to assess the temporal and spatial patterns of strandings, including the main recorded species, stranding locations, and their distribution throughout the year. The analysis covered 258 beaches along the coast of São Paulo, which was divided into three mesoregions: South Coast (LSP), Central Coast (LCP), and North Coast (LNP). We calculated the number of regularly monitored beach kilometers and the number of cetacean records for each of these mesoregions. These records were termed 'Strandings per Unit of Sampling Effort' (EPUE). The total regular daily monitoring covered 430,596.36 kilometers along the beaches, with a record of 2,055 stranded individuals belonging to 18 cetacean species. On average, there were 411 ± 38 stranded individuals per year, ranging from 387 in 2019 to 470 in 2021. The species most frequently encountered were Franciscana dolphin (*Pontoporia blainvillei*), Guiana dolphin (*Sotalia guianensis*), humpback whale (*Megaptera novaeangliae*), and Atlantic spotted dolphin (*Stenella frontalis*). The Franciscana and Guiana dolphins accounted for 86% of records. Forty-three percent of strandings (877) was located in LSP, 33% (670) in LCP, and 25% (508) in LNP. These results were expected and supported by previous studies, as LSP encompasses important priority conservation areas with a diversity of ecosystems and the presence of endemic and endangered species.

Introduction

The Cetacea Order includes animals commonly known as whales, porpoises, and dolphins. There are 89 cetacean species worldwide, distributed between the Mysticeti (14 species) and Odontoceti (75 species) suborders (Figueiredo et al., 2019). These animals live exclusively in aquatic environments; some species display coastal marine habits, while others are entirely oceanic (Di Beneditto et al., 2001a).

Mysticetes are also known as whales due to the presence of a row of baleen plates in their upper jaw. On average, they are the largest marine mammals. Some species may reach up to 33.6 meters and weigh up to 160 tons. Mysticetes primarily feed on zooplankton and small fish species. They undertake seasonal migrations of thousands of kilometers, both for feeding and for reproduction in warmer areas. Therefore, whales remain in feeding areas during summer and migrate to breeding grounds in the fall, where they stay during winter before returning to their feeding areas (Di Beneditto et al., 2001a).

Odontocetes, known as porpoises and dolphins, are cetaceans with teeth and generally range from small to medium-sized.

They have diverse diets that vary among species (Di Beneditto et al., 2001a). Prey items include fish, squids, octopuses, and crustaceans. Among large odontocetes, orcas stand out, as they prey on a variety of species, including other cetaceans, pinnipeds, otters, and bony fish, among other taxa (Lodi & Borobia, 2013). The Odontoceti suborder comprises several species, such as dolphins, porpoises, and beaked whales. However, unlike mysticetes, odontocetes do not undertake large regular migrations. Their movements may vary seasonally depending on sea surface temperature and food availability, with a closer relationship to coastal proximity (Lodi & Borobia, 2013). Odontocetes form groups that are restricted to particular regions within their distribution range (Di Beneditto et al., 2001a).

The Brazilian coastline extends for about 9,500 km, and it is a distribution area of 40 cetacean species recorded so far, which represents almost 50% of the known species worldwide. The most common and studied odontocetes in the coastal region of the Southeast Continental Shelf are the Franciscana dolphin (*Pontoporia blainvillei*) and the Guiana dolphin (*Sotalia guianensis*), both residents of the region and found only on the east coast of Latin America. Resident populations live in the estuaries of Paranaguá (state of Paraná) and Cananéia (state of São Paulo) (Santos & Rosso, 2007; Santos et al., 2009). Other studies indicate that species such as the Atlantic spotted dolphin (*Stenella frontalis*) and the bottlenose dolphin (*Tursiops truncatus*) may be annual residents, based on stranding records throughout the year (Figueiredo, 2017).

Worldwide, cetaceans have faced various anthropogenic threats over the years, including pollution, incidental capture, vessel traffic, collisions with ships, hunting, and dam construction, as reviewed in more than 100 articles published over a 30-year period (1986 - 2016). Most of these studies were conducted on stranded animals (Marega-Imamura et al., 2020), enhancing the importance of this kind of events.

Several anthropogenic threats primarily occur due to the intensification of human activities in coastal areas in recent decades, leading to changes in the structure and function of coastal ecosystems, resulting in a vulnerability increase of different coastal cetaceans (Di Beneditto & Rosas, 2008; Filla et al., 2008; Zappes et al., 2009; Ross et al., 2011; Gusso-Choueri, 2015). One method for identifying species occurring along the coast and their potential vulnerability involves the analysis of stranded animals (Pinedo et al., 2001; Peltier et al., 2012).

The importance of strandings in understanding species biology and the effects of human actions led to the establishment of the Projeto de Monitoramento de Praias – Bacia de Santos (PMP-BS, Santos Basin Beach Monitoring Project) (Petrobras, 2023) in August 2015. This project is a requirement for the Federal Environmental Licensing of Petrobras' oil and natural gas production and distribution activities in the Santos Basin, supervised by IBAMA (Brazilian Institute of Environment and Renewable Natural Resources). The project aims to assess the impact of activities related to gas and oil exploitation on birds, turtles, and marine mammals through beach monitoring, veterinary care for live animals, and necropsies on dead animals.

Methodology

The study area is situated in the state of São Paulo, southeastern Brazil, which has approximately 880 km of coastline with 16 municipalities and a total area of 7,759 km². The analyzed area comprehends the coast from Ubatuba (23°26′04″ S, 45°05′5″ W) in the north to Cananéia (25°00′38″ S, 47°55′47″ W) in the south (Fig. 1). A significant portion of the study area is covered by different marine protected areas.

To analyze cetacean stranding occurrence patterns on the 258 beaches of São Paulo, we divided the study area into three regions composed by municipalities with similarities in social, economic or natural framework, known as "mesoregions" (IBGE, 2017), named South Coast (LSP), Central Coast (LCP), and North Coast (LNP), according to the geographic boundaries defined by the Brazilian Institute of Geography and Statistics (IBGE, 2022). According to decree No. 90,347, dated 23 October, 1984, LSP is mostly a protected area (Brasil, 1984).

Data on cetacean occurrence on the coast of São Paulo are sourced from the PMP-BS (Petrobras, 2023) throughout the study area. To standardize data collection, beach monitoring was carried out through three main strategies: (i) land-based active monitoring - performed daily or exceptionally on a weekly basis in areas with restricted access, using cars, quadricycles, motorcycles, bicycles, or on foot; (ii) boat-based active monitoring - conducted weekly on beaches with difficult or no terrestrial access, such as rocky cliffs and islands. In bays in LNP, water surface areas are monitored to detect animals drifting near the coast or islands; (iii) public report (passive monitoring) - response to public authorities and general public reports through direct communication or phone calls.

The study was conducted from 1 January, 2017 to 31 December, 2021. To quantitatively analyze the spatial patterns of cetacean occurrences and provide a more accurate reflection of environmental processes, records obtained through active monitoring (both land-based and boat-based) were considered. Using data from active monitoring efforts, we calculated the quantity of regularly monitored beach kilometers and the number of cetacean records for each location. Since the size of the monitored beaches is not uniform, monitored distances varied. Additionally, there may be differences in the number of times beaches are monitored each month due to logistical or environmental factors. Thus, it was necessary to account for these differences in the sampling effort. Therefore, we calculated the monthly rates of records per actively monitored kilometer, distinguishing between beaches monitored daily and those monitored weekly. The values of cetacean records per kilometer of monitored beaches were termed 'Strandings per Unit of Sampling Effort' (EPUE), where 'effort' refers to the distance effectively monitored during a specific period (month).

Results

Monitoring Effort
Between 2017 and 2021, a total of 310,458 regular daily monitoring efforts were conducted along the entire coastline of the state of São Paulo, encompassing the three mesoregions,
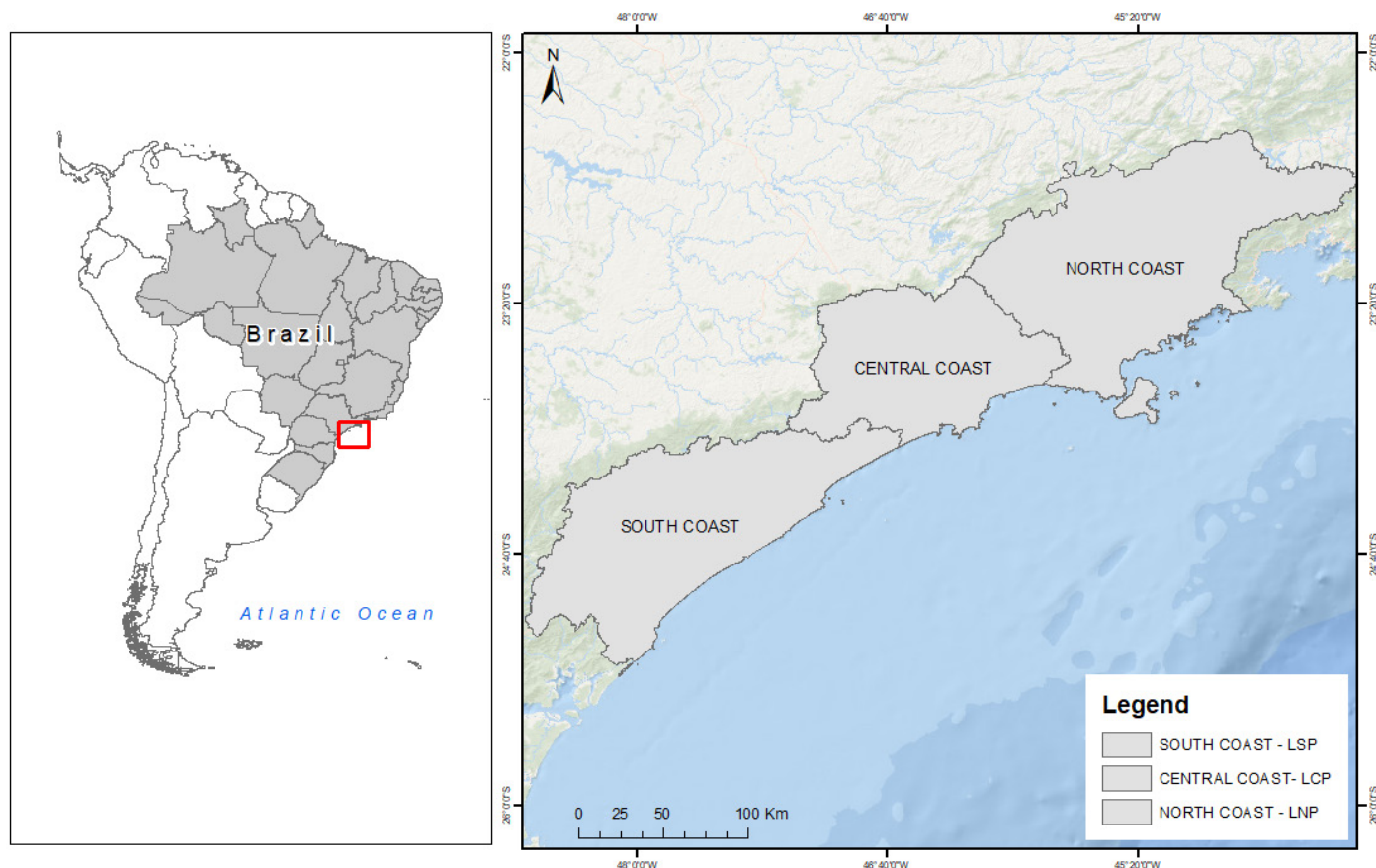
Figure 1. Map of study area, indicating the coast of the state of São Paulo, subdivided into three mesoregions (in gray): South Coast (LSP), Central Coast (LCP) and North Coast (LNP), according to IBGE's image bank.

covering a total of 430,596.36 kilometers of beaches (Table 1). In only 2.52% (7,841) of daily efforts, the total planned distance could not be completed, whether due to operational reasons (vehicle breakdown) or environmental reasons (such as high tide). These were considered incomplete monitoring efforts and excluded from the analyses of spatial distribution to ensure equal effort for species occurrence mapping (SIMBA, 2022). In addition to daily efforts, weekly beach monitoring in regions with difficult access or isolated areas were also conducted (Table 2).

Species Occurrence

Over the five-year period of beach monitoring on the coast of São Paulo, we recorded the stranding of 2,055 individuals belonging to 18 cetacean species and non-identified to its taxonomic level of 'species', displaying a heterogeneous distribution along the coast. Out of these, 93,18% (1,915) were odontocetes, 3,79% (78) mysticetes and 3,01% (62) unidentified (Table 3). The five species with the highest stranding occurrences were four odontocetes: Franciscana dolphin Guiana dolphin, common bottlenose dolphin, Atlantic spotted dolphin, and one mysticete, the humpback whale. A summary of species richness recorded in the three mesoregions is shown in Table 3, indicating a heterogeneous distribution along the coast.

Strandings per Unit of Sampling Effort *(EPUE)*

Based on records from beaches daily monitored by land and

grouped by mesoregions, the total EPUE values remained similar over the years for the LSP and LCP, while the values for LNP were lower (Fig. 4). The observed EPUE values were different on beaches with weekly land-based monitoring; in some cases, they were even higher than those observed on beaches with daily monitoring within the same mesoregion (Fig. 5).

Seasonal and Temporal Distribution

The occurrence peaks of strandings took place in the second semester of each year, extending into the beginning of the following year for Franciscana dolphin throughout the study period (Fig. 6). Guiana dolphin had a higher peak of occurrence in 2017, with smaller peaks in the following years, while humpback whale had an increase in occurrences in the second half of 2021. The other two species had more homogeneous records throughout the year (Fig. 6).

Between 2017 and 2021, there was an average of 411 ± 38 strandings per year, totaling 2,055 records. The year of 2020 presented the lowest number of strandings (387), while 2021 had the highest (470) (Table 4). The relative frequencies of stranding occurrences distributed over the five years remained similar in each region, as seen in Figure 7.

Overall, the fluctuation in the frequencies of stranding occurrences over the five years in the study site were 137± 27.20. However, occurrences in LSP were more frequent throughout the studied years. Results indicate a stranding dominance by Franciscana dolphin from 2017 to 2021 and an increase of
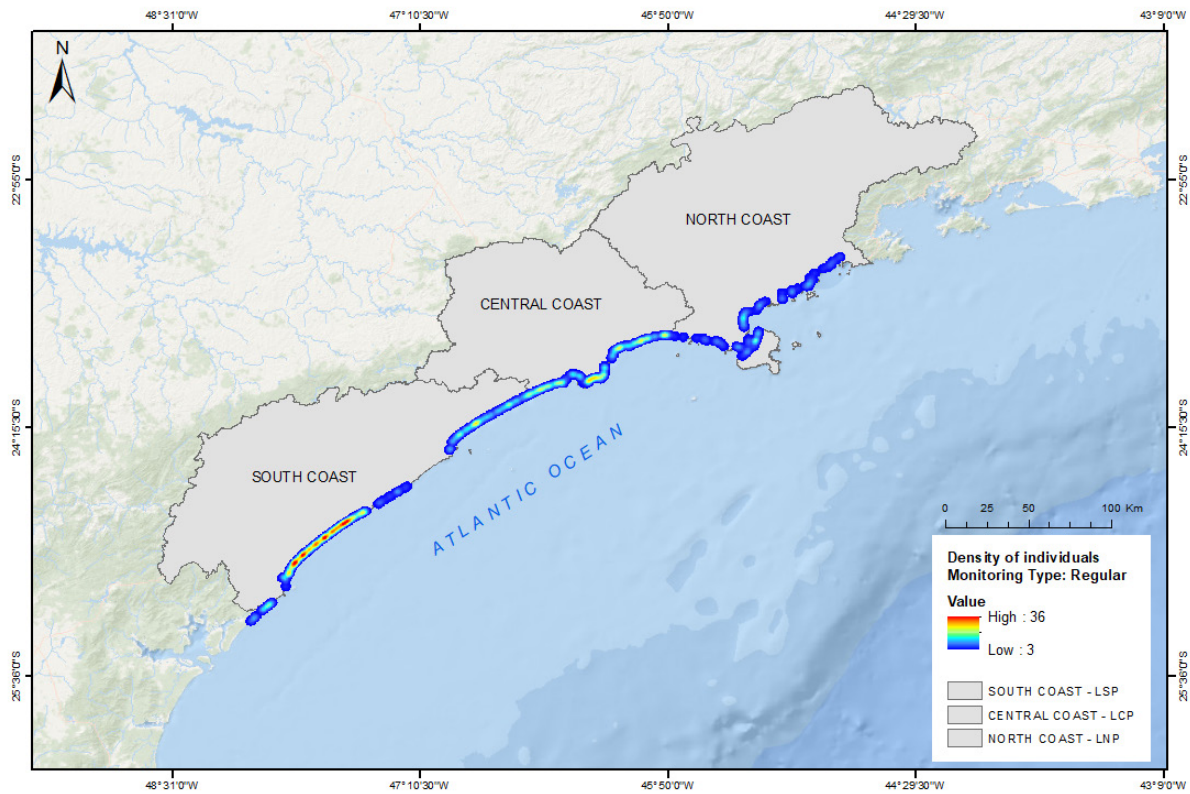
Figure 2. Map of study area, subdivided into three mesoregions (in gray): South Coast (LSP), Central Coast (LCP) and North Coast (LNP), indicating cetacean stranding records on regular monitoring on the coast of São Paulo from 2017 to 2021.
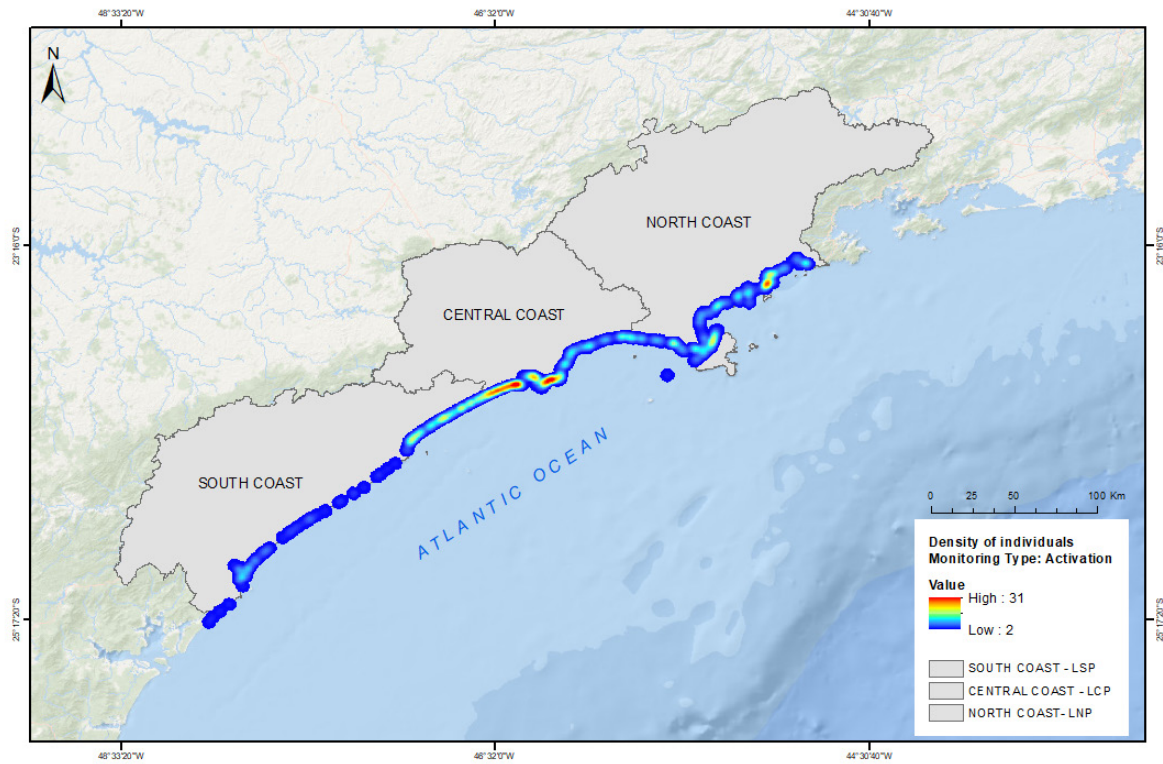

Figure 3. Map of study area, subdivided into three mesoregions (in gray): South Coast (LSP), Central Coast (LCP) and North Coast (LNP), indicating cetacean stranding registered via public reports on the coast of São Paulo from 2017 to 2021.
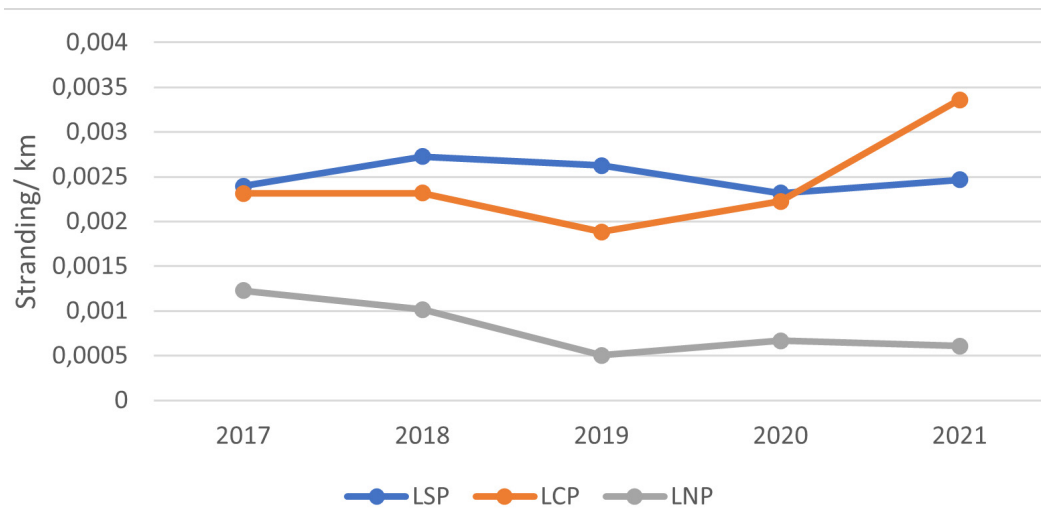
Figure 4. Result of cetacean strandings per Unit of Sampling Effort (EPUE) in daily terrestrial monitoring in mesoregions LSP, LCP and LNP of state of São Paulo from 2017 to 2021.
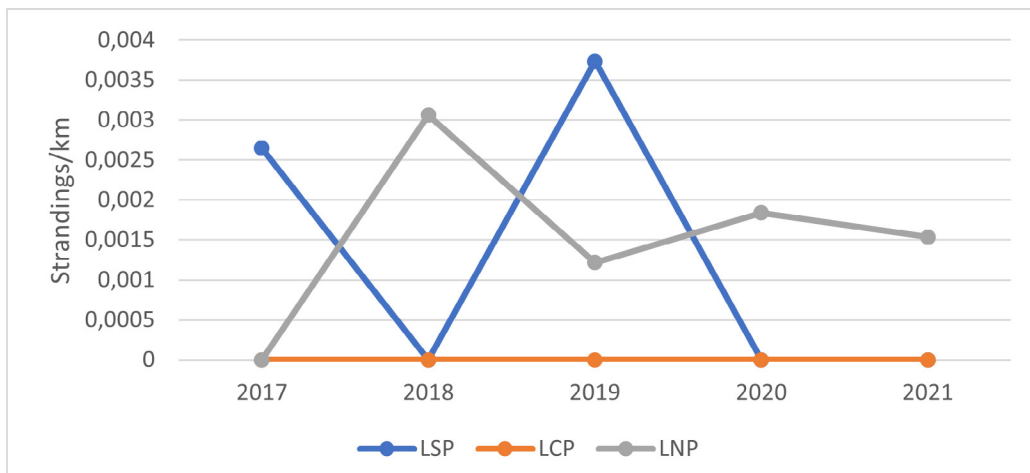
Figure 5. Result of cetacean strandings per Unit of Sampling Effort (EPUE) in weekly terrestrial monitoring in mesoregions LSP, LCP and LNP of the state of São Paulo from 2017 to 2021.

Figure 6. Seasonal distribution of cetacean species with higher stranding indexes recorded monthly from 2017 to 2021 on the coast of São Paulo.

Figure 7. Distribution of cetacean strandings in mesoregions LSP, LCP and LNP of the state of São Paulo from 2017 to 2021.

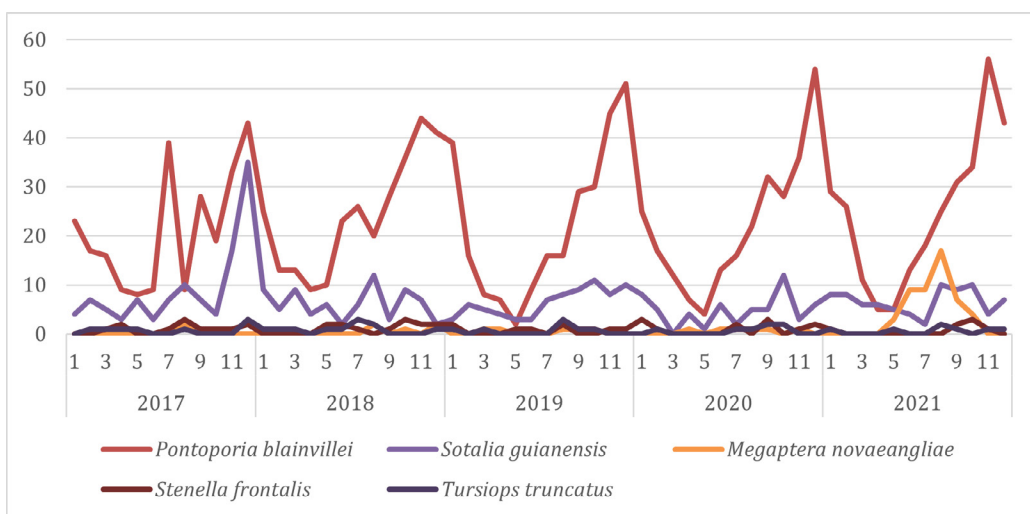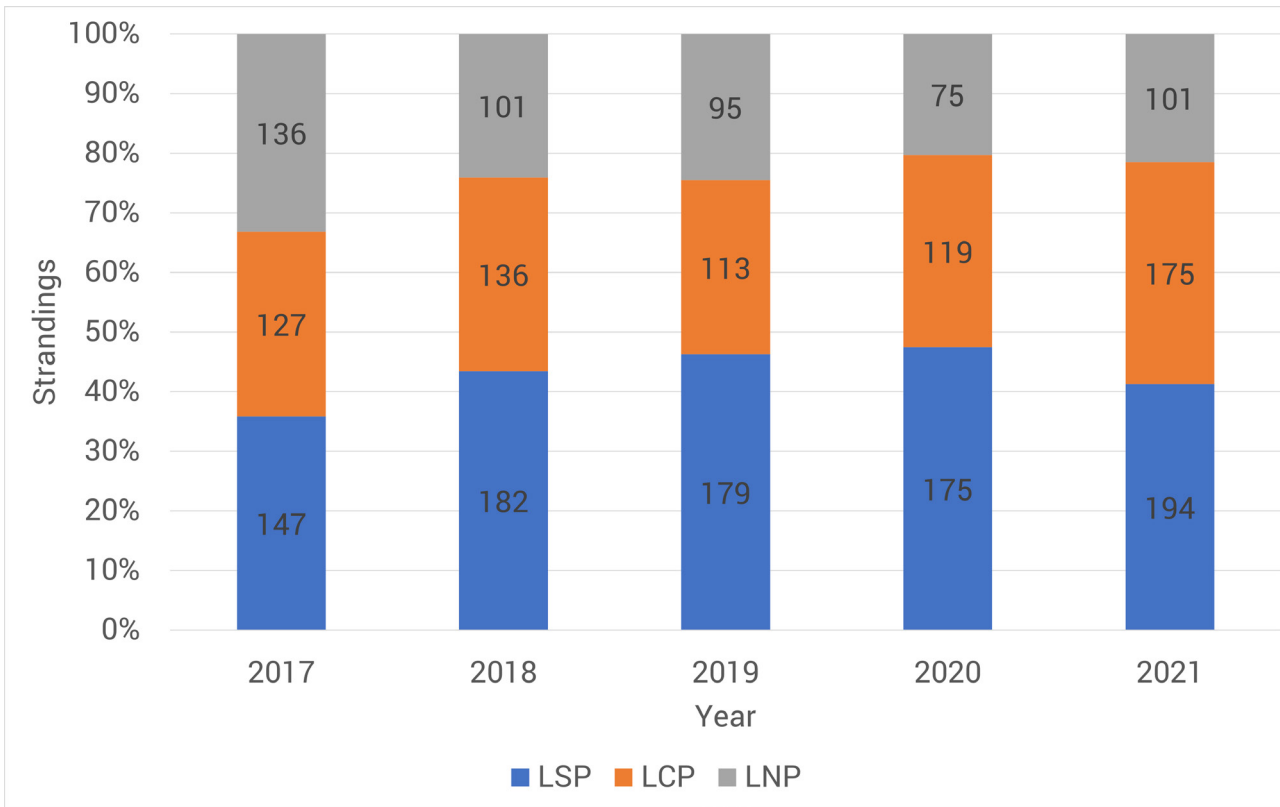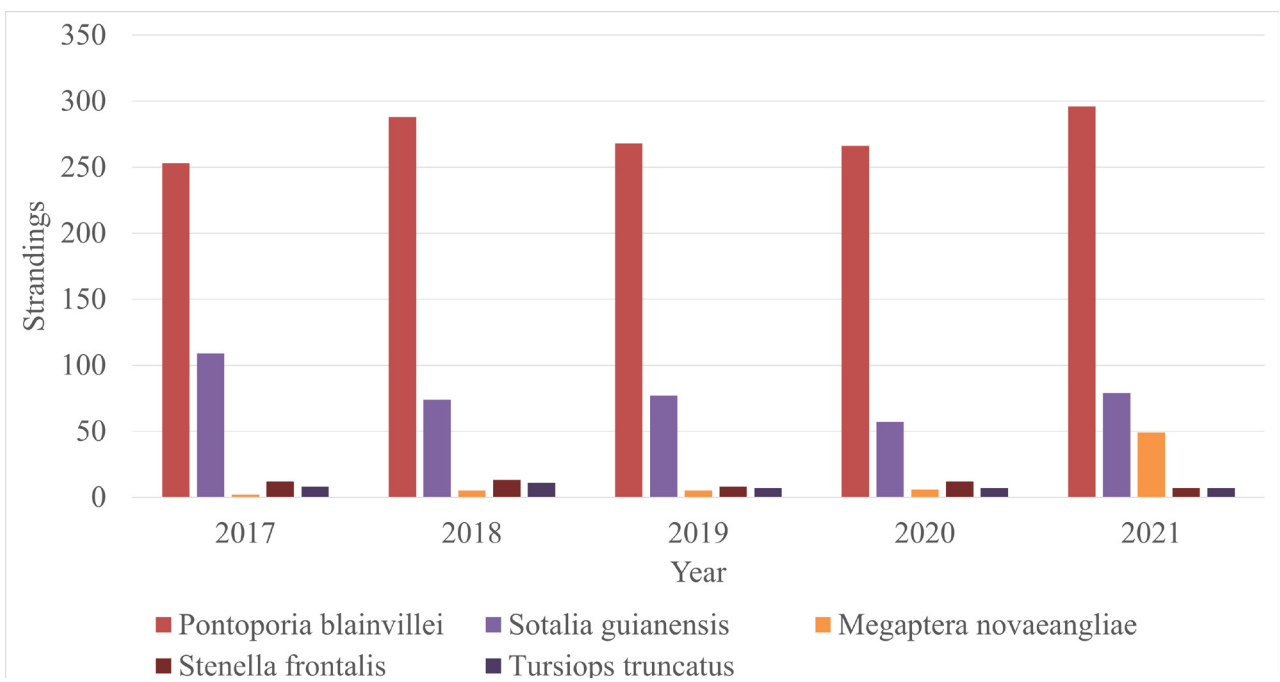**Figure 8.** Distribution of most abundant cetacean species occurrence on the coast of São Paulo from 2017 to 2021.

Table 1. Summary of daily beach monitoring efforts, conducted on the coast of São Paulo, per mesoregion. The number of incomplete sampling efforts is shown in parenthesis.

Mesoregions	Daily monitoring sampling effort	Distance covered (km)
North Coast (LNP)	239,828 (3,093)	23,856.94 (3,231.81)
Central Coast (LCP)	44,062 (2,817)	141,409.78 (10,799.39)
South Coast (LSP)	26,568 (1,931)	265,329.64 (45,235.98)
TOTAL	310,458 (7,841)	430,596.36 (59,567.18)

Table 2. Summary of weekly beach monitoring efforts, conducted on the coast of São Paulo, per mesoregion.

Mesoregion	Weekly monitoring sampling effort	Distance covered (km)
North Coast (LNP)	4,049	3,513
Central Coast (LCP)	416	67.87
South Coast (LSP)	771	2,403.7
TOTAL	5,236	5,984.57

occurrences of humpback whales in 2021 (Table 3).

The Franciscana dolphin was the most commonly stranded species between 2017 and 2021, with over 200 strandings recorded in 2018 during beach monitoring. The second most abundant species was the Guiana dolphin, followed by the humpback whale, the only Mysticete that frequently strands on the coast of São Paulo.

Spatial Distribution

During the sampling period, LSP had the highest number of strandings, accounting for 43% (877) of the total while LCP accounted for 33% (670) of the records, and LNP 25% (508), totaling 2,055 strandings.

Regarding the spatial distribution of cetacean strandings along the coastline of São Paulo, a higher concentration of records is noticed in LSP (Fig. 2), whereas during the sampling period, we observed that the highest number of cetacean stranding records received through the public report strategy took place in LCP, as indicated by Figure 3.

Discussion

Between 2017 and 2021, the monitoring conducted by PMP-BS in the State of São Paulo recorded 18 cetacean species, totaling 2,055 stranding records. This result corroborates the diversity found by Mayorga et al. (2020), who reported 20 species in Espírito Santo, (Southeast) Brazil, registered from 1975 to 2015 and the 15 species of cetaceans recorded by Freitas et al. (2021) between 2003 and 2016 in Santa Catarina, (South) Brazil. Di Tullio (2016) conducted a study aboard an oceanographic vessel along the South and Southeast of Brazil continental shelf and slope, from 2009 to 2014, and reported 21 cetacean species, which also corroborates to our findings. Table 3 highlights the heterogeneous distribution of stranded species in different mesoregions of state of São Paulo, also reported by other studies.

Out of the total of species in this study, nine represent 99% of the richness in strandings found on the coast of São Paulo, with Franciscana and Guiana dolphins accounting for 86% of the records. In the state of Espírito Santo, six species represented the majority (94.7%) of stranding events (Mayorga et al., 2020), which is consistent with our findings. Similarly, according to Mayorga et al. (2020), Franciscana and Guiana dolphins were also the most frequent species in Espírito Santo, with the latter distributed along the entire coast. According to spatiotemporal data from PMP-BS (2015-2020) (Prado et al., 2023) the three most common cetaceans are Franciscana dolphin (1,738), Guiana dolphin (621), and common bottlenose dolphin (182), which corroborates the data of this study. Another study in Santa

Table 3. Richness of cetaceans registered during beach monitoring on the coast of São Paulo, in South Coast (LSP), Central Coast (LCP), and North Coast (LNP), 2017 - 2021.

Species	2017	2018	2019	2020	2021
Odontoceti					
Delphinus delphis (common dolphin)	5		1		2
Feresa attenuata (pygmy killer whale)		1			
Globicephala macrorhynchus (short-finned pilot whale)			1		
Kogia breviceps (pygmy sperm whale)	2	1	1	3	
Kogia sima (dwarf sperm whale)	1		2		
Lagenodelphis hosei (Fraser's dolphin)					8
Pontoporia blainvillei (Franciscana dolphin)	253	288	268	266	296
Pseudorca crassidens (false killer whale)	1		0		
Sotalia guianensis (Guina dolphin)	109	74	77	57	79
Stenella frontalis (Atlantic spotted dolphin)	12	13	8	12	7
Stenella longirostris (spinner dolphin)		1			
Steno bredanensis (rough-toothed dolphin)	7	6	8	2	2
Tursiops truncatus (common bottlenose dolphin)	8	11	7	7	7
Mysticeti					
Balaenoptera acutorostrata (minke whale)	1	3			1
Balaenoptera borealis (sei whale)					1
Balaenoptera brydei (Bryde's whale)				2	1
Eubalaena australis (Southern right whale)	1	1			
Megaptera novaeangliae (humpback whale)	2	5	5	6	49
Non-identified (NI)	8	14	9	14	17
Total	**410**	**419**	**387**	**369**	**470**

Table 4. Number of strandings registered during beach monitoring in mesoregions South Coast (LSP), Central Coast (LCP), and North Coast (LNP), from 2017 to 2021.

Year	LNP	LCP	LSP	Total
2017	136	127	147	410
2018	101	136	182	419
2019	95	113	179	387
2020	75	119	175	369
2021	101	175	194	470

Catarina reports that from 2003 to 2016 Franciscana dolphin and common bottlenose dolphin were the most frequently reported stranded species (De Freitas et al., 2021).

The abundance of Franciscana and Guiana dolphins was expected over the studied period, as these two species are frequently sighted in the study area and, due to their strictly coastal habits, are directly impacted by anthropogenic threats, leading to a higher number of deaths and, consequently, strandings (Hetzel & Lodi, 1993; Di Beneditto & Rosas, 2008; Filla et al., 2008; Bertozzi, 2009; Montealegre-Quijano & Ferreira, 2010; Desvaux, 2013; Godoy et al., 2015; Zappes et al., 2018; Marega-Imamura et al., 2020; Secchi et al., 2022). As a result of these threats, both species are listed as endangered by the Ministry of Environment and Climate Change (MMA), classified as Critically Endangered and Endangered, respectively (MMA, 2022).

However, in order to compare the number of strandings of different species and in different locations we must consider various factors from the animal's death at the sea to its arrival on land. Among the different existing factors, such as carcass sinking, two are widely known to influence floating carcasses, making them reach the shore: the season of the year and how far from the coast the animal died, as a carcass can drift for kilometers after the animal's death (Lugon et al., 2019; Tavares, 2021). As a result, the chances of a carcass that belonged to a coastal species reaching the shore are higher than those of a carcass of an oceanic species. In most cases, these animals arrive at the beach in an advanced stage of decomposition, making it impossible to identify them to species level. Consequently, due to the drift and decomposition of carcasses, 859 cetacean strandings recorded in the state of São Paulo were in such an advanced stage of decomposition that it was impossible to identify the species affected.

Among the beaches monitored daily by land, in 2021 LCP presented relevant increase of EPUE (48%) in this mesoregion. Although LNP had the second highest number of monitored kilometers among the mesoregions, it showed the lowest EPUE values throughout the entire time series, with an average of 33 occurrences over the years (75% lower compared to LSP). These values reflect the occurrence data by mesoregion, indicating that LSP has the highest stranding occurrences through the entire study period. On the beaches monitored weekly by land in LNP, the annual EPUE values were higher than those from daily monitoring. Daily annual values were higher on the beaches in LSP and LCP (Table 4).

This pattern of strandings possibly occurs due to the accumulation of animals on the beaches monitored following the strategy of daily monitoring and the way EPUE is calculated. A factor that may be affecting this pattern is the relatively smaller extension of the beaches monitored weekly, leading to higher EPUE values when animals are found there. A second factor is the accumulation of individuals, likely to be more relevant in large specimens, such as mysticetes, as remains of their carcasses can be found on the beach even after several days. However, it is important to note that the occurrence of cetacean species in the weekly strategy is considered low compared to daily monitoring. Therefore, a few specimens can generate high EPUE values, while the absence of occurrences generates constant zero values, as is the case for consecutive years in LSP and LCP.

Although the EPUE values between these two strategies are not directly compared, the information they provided is essential to understand different processes or phenomena, as well as the possibility of occurrence of species of greater conservation interest and rare events. Mayorga et al. (2020) also observed that the seasonal distribution of strandings peaked during the second semester of the year, which could be related to migration of species, influence of oceanographic factors, or greater spatial distribution in search of resources (Daura-Jorge et al., 2004; Prado et al., 2023).

Over the years, LSP was responsible for the highest relative frequency of strandings compared to the other mesoregions The fact that LSP is mostly legally protected area makes it a refuge for marine life, primarily due to the abundance of food resources. This abundance may be responsible for higher occurrence of standings. The coastal species Franciscana and Guiana dolphins occur frequently along the entire coast, with a resident population of Guiana dolphins in LSP and southern

Rio de Janeiro, that borders LNP (Monteiro-Filho, 1991; Lodi, 2003; Havukainen et al., 2011; Godoy et al., 2015).The increase in humpback whale strandings along the coast may be related to the population increase over the past years, which led to their removal from the Brazilian list of endangered species, being reclassified as Near Threatened, combined with their occurrence in highly anthropized areas (Julião, 2013; Bortolotto et al., 2016). As observed here, previous studies showed that the highest occurrences of strandings on the coast of São Paulo were from Franciscana and Guiana dolphins, with fewer records of humpback whale (Santos et al., 2002, 2010; Vicente et al., 2021).

However, the number of strandings in previous studies is relatively low compared to this study due to the geographic coverage and sampling effort of daily regular monitoring, while in previous studies data came from public reports or from those that were not surveyed as frequently as the Projeto de Monitoramento de Praias does (Di Beneditto et al., 2001b; Desvaux, 2013; Mayorga et al., 2020; Dudhat et al., 2022).

The LCP and LNP mesoregions had a greater number of reported stranding incidents when compared to LSP. This may be related to a higher flow of people on the beaches in these two areas, increasing the chances of people finding stranded animals and reporting them.

The study of stranding patterns of marine mammals contributes to the conservation of different species by providing new information, especially to management authorities of protected areas in these locations. Thus, the strategy of regular daily monitoring of beaches along the coast has been essential for recording strandings and collecting standardized and systematic information. This allows the creation of a historical data series of great relevance for biodiversity research and management.

It is important to note that although this study covers a period of five years, it represents only a small-time fraction due to these species' population dynamics and long-life cycles. Therefore, it is extremely important to continue collecting data to contribute to the identification of larger stranding patterns and provide data for different population dynamics parameters, such as mortality rate.

The record of 18 cetacean species in the study area, including endangered species, corroborates the importance of the study area for ecosystem diversity conservation and as refuge of endemic species of South Atlantic Ocean, such as Franciscana dolphin and other endangered species. Information gathered by studies like this should be a useful tool for their management improvement.

Acknowledgments

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